# ANNUAL TECHNICAL REPORT

PN-AAG-847

Annual Technical Report
IMPROVING IRRIGATION WATER MANAGEMENT ON FARMS
April 1, 1978 to March 31, 1979

Submitted to
The U.S. Agency for International Development
Contract AID/ta-C-1411

June 30, 1979

Water Management Research Project
Colorado State University
Fort Collins, Colorado 80523

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A. Annual Report Summary Sheet

Project Title: Improving Irrigation Water Management on Farms

Contract Number: AID/ta-C-1411

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Contractor: Colorado State University

Contractor's Address: Water Management Research Project
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Colorado State University
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Contract Period: April 1, 1977 to March 31, 1980

Reporting Period: April 1, 1978 to March 31, 1979

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|---|---|
| Total Expenditures and Obligations Through Previous Contract | $1,008,992<br>April 1, 1978 to March 31, 1979 |
| Total Expenditures and Obligations for Current Contract Year | $950,000<br>April 1, 1979 to March 31, 1980 |

Narrative Summary

Among the most significant accomplishments during this report year are: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project (MREP), including results of the watercourse cleaning and maintenance research program, which could be implemented throughout the country; (2) completion of watercourse surveys, including physical and socio-economic aspects; (3) participation with the USAID Mission to Pakistan and the Soil Conservation Service in implementing the On-Farm Water Management Pilot Project; (4) evaluation of the On-Farm Water Management Pilot Project by a joint team of Pakistanis and Americans; (5) development of cooperative efforts with the Department of Agriculture in the three provinces of Punjab, Sind and North West Frontier in order to implement the On-Farm Water Management Pilot Project; (6) conduct phase I field studies in cooperation with the University of Agriculture, Faisalabad (UAF) regarding alternatives for organizing farmers, as well as conducting seminars in each of the four provinces plus the Federal Capital on establishing a legal framework for organizing farmers in order to improve on-farm water management practices; (7) preliminary development of training materials, initial training of trainers, and training of second class of Water Management Extension Officers for pilot project; (8) development of research proposal, "Water Management Research and Training Programme for Rural Development" with UAF using an area of 37 villages to provide field research experiences for faculty and more meaningful field experiences for trainees; (9) completion of a reconnaissance survey for identifying on-farm water management constraints encountered by farmers in Baluchistan; (10) successful development of concrete nakka lids in the Punjab, with this technology to be transferred to the other provinces for use in the provincial On-Farm Water Management Development Projects; (11) development of bullock-drawn furrower and tractor-drawn bed shaper for bed and furrow irrigation of summer crops; (12) cooperative efforts with the major agricultural research centers in Pakistan on significant research pertaining to wheat, rice, cotton and maize; and (13) the transfer process being developed for use in other countries has evolved into three major manuals, namely, problem identification, development of solutions, and project implementation, along with an overview report, all of which will be completed during the final contract year.

Annual Technical Report
IMPROVING IRRIGATION WATER MANAGEMENT ON FARMS

## B. Background

### 1. General

Inadequate water is the primary constraint on agricultural production in a large portion of the developing countries. The technology for using available water supplies most efficiently is either lacking or not adapted to the available resources, in many of these countries.

Recognizing that these water management problems were common to many countries, it was apparent that solutions gained in one country should be, to some degree, transferable to others. Consequently, it was decided that a coordinated effort should be made to build up a fund of transferable water management technology. A consortium of universities was formed to develop this fund of water management information and gain experience in the factors limiting or accelerating its adaptation in new countries. CSU was initially assigned the Near East-South Asia, with Pakistan and Vietnam as the study areas in which on-farm water management principles and concepts would be developed and adapted to resources similar to those available in many other developing countries. The present contract focuses upon: (a) continuing the on-farm water management research program in Pakistan; (b) developing the transfer process that can be utilized by other countries for improving their on-farm irrigation water management practices; and (c) providing limited technical assistance to AID Missions for initiating on-farm water management programs.

### 2. Pakistan

The irrigation system of Pakistan represents one of the largest modern conveyance systems in the world and is a marvel of engineering skill and technology. The hydraulic features, dams, barrages, canals, distributaries, structures, and appurtenances have been fully described in other publications. There is however a paucity of information and, indeed, a lack of understanding of that portion of the irrigation system with which the farmer deals. This refers to the system from the canal outlet (mogha) through the irrigated field. The farmer operates and manages this water with little or no governmental assistance. The procedures, rules, resources and constraints at his disposal determine his on-farm water management practices, which in turn determine the crop production per unit of irrigation water.

A modern irrigation conveyance system was constructed by the British in the late 1800's and it is one of the largest in the world. There are about 40,000 miles of canals which command a gross area of over 33 million acres of fertile soils. About 25 million acres actually receive surface water. The system is not only large with a vast potential but it is unique in several other aspects. One disappointing feature, however, is the present low production in light of the apparent highly suitable soil, water and climatic resources. These factors suggest a production potential many times greater than presently achieved. The "green" revolution increased production appreciably, but even this appears to be far below potential and in many respects this so-called revolution today is stalled.

Many experts agree that the farming practices, including irrigation water management, must be modernized in order to achieve higher production. There are important reasons for the low crop yields and lack of agricultural production, including insufficient water supply, lack of proper land leveling, lack of irrigation water control, lack of salinity control, lack of water management extension services, use of ancient cropping systems with ancient tools, or, in other words, there is a need for a much improved on-farm management system. The potential for increasing production through improved water management is great.

C. Project Objectives

1. General Objective

The general objective of this research is to develop, design and implement guidelines for improving irrigation water use efficiency and effectiveness on farms.

2. Specific Work Plan

a. General Activities

Any technological improvement must be acceptable to those who will provide for, utilize, and manage it. It is therefore essential that the research on this project take into account the special needs of the farmer including the interrelationships among technology, institutions and the prevailing economic, social and cultural factors. Therefore, the laboratory for the research will be primarily the farmer operated and managed sub-irrigation system. This includes the water transport system among farms and on farms, the crop fields, and the institutional and procedural arrangements involved in managing the water supply.

Previous work on this project has identified several acceptable technologies for improvement. Under this contract the contractor will test and evaluate these separately and in combination under farmer conditions. Most research will be conducted on watercourse areas being pilot tested under the

USAID/Pakistan On-Farm Water Management Project No. 391-4130, hereafter referred to as the "pilot project." This large-scale "pilot project" will require considerable technical assistance effort from the contractor to develop training materials and trainers, for the variety of functions required in the integrated package of improvements. An important aspect of this program will involve organizing farmers on watercourses to effectively implement the management program, as well as insure the continued usefulness of the improvements through effective operation and maintenance procedures in succeeding years.

The contractor will conduct a two pronged research program involving: (1) the study of problems, constraints, procedures, training, institutional, technical and economic requirements associated with implementing, managing, and maintaining the improvements, and; (2) the articulation of results (especially the investigative and procedural requirements for technology selection and implementation) clearly and concisely and in a format readily usable in other socio-economic environments.

The technologies to be tested and evaluated by the contractor include: (a) watercourse improvement, (b) improved structures for water control, (c) land shaping and farm field layout, (d) augmentation of water supply with wells and on-farm storage, and (e) optimal utilization of increased water supplies. The contractor will provide technical services to ensure that these technologies are installed on at least ten (10) watercourse areas. These areas will preferably be a part of the "pilot project." However, in case that project is unduly delayed or fails, the contractor will provide the same services to install the improvements on ten areas through the research project agreements between USAID and WAPDA and/or USAID and the Punjab Department of Agriculture under which the contractor-Colorado State University is presently working. These watercourse areas will become the principal laboratory areas for the research. Since the contractor will address the technical, training, institutional, and economic aspects of implementation and management of the improvements, data collection on these areas will be necessary throughout the implementation, management, and maintenance process.

b. Specific Activities

(1) Technical Activities

The contractor will give technical guidance on the watercourse rehabilitation and land leveling aspects of the "pilot project" being especially careful that these components are technically correct on all watercourse areas comprising the laboratory for this research. A series of watercourses will be reconstructed with concrete and masonry control devices at every major junction and outlet. Existing ditch banks will be removed and the watercourse will be reconstructed to proper channel size and elevation, compacting the earth in the banks. The labor will be provided by the farmers. These reconstructed watercourses will be designed on the basis of a complete topographic map of the area, measurements of the flow to be handled, the number and position of structures and culverts needed and basic principles of open channel flow. As each watercourse is completed and evaluated, utilizing benchmark data compared with improved conditions, the lessons will be used to refine guidelines for future watercourse improvement projects.

The contractor will also test an "essential improvements program." This will involve minimum engineering and capital outlay. Losses at degraded junctions will be reduced by filling borrowed areas and bringing watercourse banks to proper cross sections. Observable leakage through banks will be stopped by simple core compaction techniques. Degradation and subsequent leakage due to animal traffic will be minimized by designing and constructing compacted earth watering and bathing stations and sediment will be controlled with earthen sediment traps. One or two major junctions will be improved with concrete control structures when the farmers have finished their earthen improvements and they will be given cost information. The farmers may then decide to invest in more of these structures. The professional services will be provided primarily by extension agents who will have had special short course training provided by the contractor.

The contractor will determine the maintenance and educational requirements of precision land leveling to ensure that properly designed and constructed fields remain in good order.

The research will include an analysis of crop water needs and cropping patterns to efficiently utilize water. Obviously, it is not possible to include all crops and related variables in such a program. Therefore, a synthesis of cropping recommendations and related cultural practices appropriate to the increased water supplies will be field tested with farmer cooperators. The approach will be to use water requirements as a focal point. Climatic records will be examined and water needs for various crops as a function of time computed for normal and dry years. Cropping mix, planting dates, or irrigation practices will be shifted to best match the available water supply to the needs of the crop. Such programs will be tested in farmer cooperators' fields. The research component will consist of documenting the performance of the improved cropping system as compared to previous or unimproved systems.

Field evaluations of tubewells and pumping devices will be made to develop guidelines for designing and operating skimming wells such that water of satisfactory quality (salinity) can be safely extracted.

(2) Training Activities

The contractor will provide personnel assistance (for the "pilot project") in design of a training program. This will include development of materials and methodologies for implementation and evaluation. Major inputs will be organization, development of training methods and materials, and training and evaluating trainers and trainees. Evaluation and refinement of the program will be major activities during both the classroom and on-the-job training periods.

The entire training project experience will be analyzed and developed into a manual which describes and recommends minimum training requirements for various aspects of the water management improvement process. The evaluation will include selection of trainees, methods for training, and content of material to be taught. Throughout the training exercise, the contractor will assay the possibility and feasibility of developing a worldwide or regional training center in the field of water management development. In this effort, linkages with other agencies (IRRI, SEARCA, East West Center for example) will be examined.

(3) Institutional Activities

In order that improved farmer operated irrigation systems can be maintained and managed properly, the farmers must be organized in some manner. The contractor will develop evaluative tools to measure the effectiveness of farmer organization and with these tools evaluate a representative number of farmer organizations formed under the "pilot project." The interrelationships between these organizations and the individual farmer and the relevant government institutions will be identified and evaluated.

(4) Economic Activities

A major focus over the contract period will be given to several types of economic analyses to determine the cost/benefit ratios of alternative technologies and methods for watercourse improvements, increasing cropping intensities, and improving irrigation and cropping practices. These economic studies are of critical importance for policy makers in planning both short and long term research and development programs on a country wide basis.

Water management alternatives will be analyzed using cost-benefit methods to determine the relative value of various combinations of technologies for varying water supply situations over various time periods.

Specific economic studies will focus on the following areas: (1) Economic benchmark studies of ten pilot experimental watercourse areas to document the economic benefit-cost ratios resulting from specific technologies. These studies will document the costs of labor and materials and determine the increases in cropping intensities, crop yields, and net farm income resulting from adaptation of technologies; (2) Farm management studies to ascertain alternative changes in cropping intensities and crop mixes to increase net farm income resulting from the increased water supplies due to reduction of water losses and improved field application practices. Special focus will be given to small and medium sized farms. (3) Costs of production of water from private (both diesel and electric) tubewells will be analyzed. The relationship between degree of utilization and availability and dependability of canal water supplies will also be studied. Data on the productive life of different tubewell and pump components as well as actual pumping rates will be collected and analyzed; (4) An intensive socioeconomic benchmark evaluation will be made on a sample of the 1500 watercourse areas under the "pilot project." The methodologies and socioeconomic analyses will be specified and documented such that replication of the process with site specific data can be accomplished expeditiously.

(5) Utilization and Extension Activities

The results of the research efforts in Pakistan under this and previous contracts will be presented in a set of manuals which can be utilized in other LDCs to identify farmer irrigation water management problems and to select and implement solutions in a manner consistent with their own social, economic, and physical constraints.

A manual of first importance is a description of the methodology or systematic process (herein called the transfer model) which has evolved from the research experience in Pakistan. This process of problem identification, development of appropriate solutions, and demonstrations on farmers fields preceding full-scale implementation will be defined in sufficient detail that others could utilize it in developing and implementing on-farm water management programs. The development of the transfer model will begin immediately since it involves the synthesis and articulation of all aspects of the project into a model which can be utilized by others in other places. A preliminary description will be presented to AID where it will be extensively reviewed in TAB, Regional Bureaus, and selected Missions. The model will be finalized as the research and development phases are concluded and the technological components of the management improvement processes are formalized. The process (model) description will be developed by all disciplines involved in the project with assistance from AID/W and the Mission in Pakistan as representatives of the donor agency.

A by-product of the transfer model is a set of technologies which have proved to be successful in Pakistan in improving irrigation water management. Each of these will be presented in manual form. The material will be presented such that another LDC can utilize the manual to make a determination as to whether the particular technology is socially, economically, and technically acceptable in its environment. If it is found to be acceptable, the manual will also contain detailed instructions on how to implement and manage it. Specific subject matters to be covered in these technological manuals will include:

a) watercourse improvement,
b) land shaping and field arrangement for efficient use,
c) crops and cropping patterns for efficent utilization,
d) institutional and organizational needs,
e) system maintenance
f) augmentation of supply by wells and farm storage

One of the most important aspects of the water management research experience in Pakistan is determining the degree of transferability of the research results. Although there is considerable confidence that much of the research findings have value in other LDCs, this must be documented by and in other LDCs. Contractor professionals and in some cases their Pakistani counterparts will provide limited technical assistance to AID for irrigation water management project planning and evaluation. Approximately the equivalent of one full-time professional will be allotted from project funds for this purpose. Specific Mission requests will be reviewed by TAB and the Contractor to determine relevance and availability of suitable technicians. Two purposes will be served by this activity. The Missions will receive needed technical assistance for project development and/or evaluation and Colorado State will gain experience and data valuable in refining the transfer process and determining the transferability of the Pakistan water management project. It will also serve to acquaint project personnel with AID's project development process.

## D. Continued Relevance of the Objectives

Our research findings, surveys in Pakistan, and consultation with experienced water management personnel from USAID, FAO, the World Bank and several developing countries indicate that accomplishment of the original objectives will benefit the developing countries and contribute substantially to the fund of transferable water management technology. In fact, there is a growing awareness among international donors of the importance of on-farm irrigation water management for LDC's.

## E. Accomplishments During the Reporting Year (April 1, 1978 to March 31, 1979)

### 1. Summary

Among the most significant accomplishments during this report year are: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project (MREP), including results of the watercourse cleaning and maintenance research program, which could be implemented throughout the country; (2) completion of watercourse surveys, including physcial and socio-economic aspects; (3) participation with the USAID Mission to Pakistan and the Soil Conservation Service in implementing the On-Farm Water Management Pilot Project; (4) evaluation of the On-Farm Water Management Pilot Project by a joint team of Pakistanis and Americans; (5) development of cooperative efforts with the Department of Agriculture in the three provinces of Punjab, Sind and North West Frontier in order to implement the On-Farm Water Management Pilot Project; (6) conduct Phase I field studies in cooperation with the University of Agriculture, Faisalabad (UAF) regarding alternatives for organizing farmers, as well as conducting seminars in each of the four provinces plus the Federal Capital on establishing a legal framework for organizing farmers in order to improve on-farm water management practices; (7) preliminary development of training materials and training of the second class of Water Management Extension Officers for Pilot Project; (8) development of research proposal, "Water Management Research and Training Programme for Rural Development" with UAF using an area of 37 villages to provide field research experiences for faculty and more meaningful experiences for trainees; (9) completion of a reconnaissance survey for identifying on-farm water management constraints being faced by farmers in Baluchistan; (10) successful development of concrete nakka lids in the Punjab, with this technology to be transferred to the other provinces for use in the provincial On-Farm Water Management Development Projects; and (11) development of a bullock-drawn furrower and a tractor-drawn bed shaper for bed and furrow irrigation of summer crops.

Besides the research programs with WAPDA and the provincial departments of agriculture, the CSU Field Party is working with the major agricultural research centers in Pakistan on significant research pertaining to wheat, rice, cotton and maize. In addition, the CSU Field Party has joint efforts with the University of Agriculture at Faisalabad, Quaid-i-Azam University (formerly the University of Islamabad), Sind Agricultural University and University of Peshawar.

The transfer process being developed for use in other countries has evolved into three major phases; namely, problem identification, development of solutions, and project implementation. A report has been prepared describing the transfer process. A second draft of the problem identification manual is completed, while a first draft of the project implementation manual has been completed.

The following four personnel have served with the CSU Field Party in Pakistan during this entire report period: Dr. John O. Reuss (Agronomist) who is Chief-of-Party; Dr. Helmer Holje (Agricultural Economist); Dr. Dwayne Westfall (Extension Agronomist); and Mr. Norman Illsley (Agricultural Engineer, Equipment). Mr. Douglas J. Merrey (Social Anthropologist) arrived in April 1978. The field staff was completed in September 1978 with the arrival of Mr. Dwayne E. Konrad (Agricultural Engineer, Irrigation Extension). Mr. Tom Trout (Agricultural Engineer, Irrigation) returned to campus in September 1978 to write up his research results and to complete his graduate program. In November 1978, Dr. Sidney A. Bowers (Soil Scientist) left the field staff to assume a position with USAID in Pakistan. The present Field Party faculty personnel are John Reuss, Helmer Holje, Norman Illsley, Dwayne Konrad, Douglas Merrey and Dwayne Westfall.

2. Water, Soil and Crop Management

a. Moisture Stress and Fertilizer Response

Several sets of experiments concerned with the interaction of moisture stress and fertilizer response have been conducted through the years. Recently, results have been analyzed from a three-year experiment on sugarcane. These results were consistent with those previously reported in that the effect of interaction between nitrogen and water on cane yield was small, indicating that nitrogen response was not much affected by water stress. Highest yields were generally obtained with a total of 55 inches or more of water applied, but 80 to 85% of maximum yields were obtained with only 30 inches of water providing that adequate nitrogen was used. Optimun N and water levels depend on the cost of water, but in general, N levels near 200 lbs N per acre are most economical, even under conditions of water stress.

Analysis of one set of cotton trials conducted in 1978 suggested a somewhat different pattern where, in this case, there was a strong interaction between water stress and fertilizer. Irrigation levels either above or below optimum markedly depressed nitrogen response. It is not yet clear whether this is a general pattern that must be expected for cotton or whether it was related to an unusual rainfall and temperature pattern.

Even though a strong interaction between water and nitrogen has been encountered for cotton, the general pattern of little or no interaction has been encountered for several years at numerous locations for wheat and sugarcane. This general pattern strengthens our previous conclusion that if uncropped land is available, additional water available as a result of improved water conveyance is best used to increase cropped acreage, even though moderate water stress may result at some point in the growing season. These conclusions are consistent with results from linear programming models that gnerally indicate optimum cropping patterns are those that use irrigation levels below full irrigation requirement as long as land availability is not limiting. Only when land availability constrains increasing cropped area should crops be grown at full irrigation requirement, unless high water tables or uses of saline groundwaters render the land especially vulnerable to salt accumulation.

b. Crop Stands

Over the years CSU has been concerned with the problem of inadequate crop stands that is so commonly encountered in Pakistan, particularly during the kharif season. Past results have indicated that stands and yields could be improved by methods such as bed and furrow planting, crust control by mechanical methods or irrigation water timing, field drainage, and land leveling to avoid loss of crops due to flooding of low areas of the fields.

While the potential of bed and furrow planting of such crops as cotton and maize for stand improvement has been recognized, we have lacked adequate bedding and planting equipment for even planting good demonstrations, let alone for encouragement of farmers to adopt such practices. Such equipment is not available in Pakistan, and imported equipment is not well adapted. Therefore, new bedding and planting equipment that appears to be better adapted to local conditions has been designed and several units fabricated for use in demonstration trials during the coming seasons. This equipment is presently tractor mounted, but modifications for bullock-drawn equipment for use by small farmers is being planned.

Another related approach is to provide surface drainage through an integrated water delivery and surface drainage system. Such a system has been designed for one of the improved watercourses under construction.

c. Optimum Management

Research cum demonstration trials over several years have provided insight into those problems that appear to be the most serious in limiting production, as well as the effectiveness of practices intended to alleviate these problems. Along with fertility and crop stands discussed above, weed control consistently emerges as one of the most important factors affecting production.

Hand weed control has been consistently shown to be highly effective in increasing crop yields in our field trials. Even in a labor intensive economy, it is often impossible to attain the needed level of control by this method. Chemical control is in its infancy in Pakistan, but some effective chemicals are available. Weed control trials on maize and wheat have recently demonstrated that at least one effective and easily used chemical method is available for each of these crops. Unfortunately, there are also materials available that are either ineffective or likely to result in crop damage. Serious efforts are required to provide more widespread testing, make available those materials that are safe and effective, and to remove inappropriate materials from the market.

d. Water Quality

The dissertation of Mr. Ghulam Hussain (MREP) on water quality criteria was completed in May 1978. The final conclusion reached is that the Residual Sodium Carbonate criteria does not contribute much to the prediction of water quality problems and should be dropped. The investigations indicated that the practice of using combined analysis of Ca and Mg, in areas such as Pakistan where high Mg waters are common, should be discontinued. Analytical methods accurately separating these ions should be used.

3. Watercourse Improvement

Increased knowledge concerning the improvement of farm water distribution system was gained from the following studies.

a. Determination of Minimum Cost Cross Sections for Lined Channels

Recognizing that some watercourse sections will often require lining and the choice of materials is often limited, a technique was developed to minimize lining costs for given material costs through selection of optimum cross sectional shapes. Cost minimization theory from economics and open channel hydraulics equations (Manning's equation) were combined to develop cost minimization solutions presented in both equation and easy-to-use nomograph form.

b. Infiltration into Soils as a Function of Soil Water Content at Time of Compaction

Compaction of soil at water contents near field capacity by compaction loads feasible in the field was found to decrease infiltration rates in medium textured soils to less than 0.01 cm per hour. Even in loamy sand soils, sufficient decrease in infiltration was attained by compaction at field capacity to bring watercourse losses down to tolerable levels. This study identified the water contents to which soils should be brought when watercourse banks are to be constructed and compacted to achieve minimum loss of water from the watercourses.

Soils with appreciable sodium on the exchange complex had high aggregate strength when they were moist. This property enabled clods and aggregates to resist compaction loads equivalent to human traffic, resulting in large pores and high rates of permeability through such soils. This factor probably plays a major role in the piping and failure of earthen banks made of such materials. Most earthen dams which have failed have been constructed of sodic soils. Compaction loads greater than one kilogram/cm$^2$ were not resisted by such soils and their subsequent resulting permeabilities were low.

c. Training and Equipment Needed by Village Level Workers to Help Farmers Achieve Essential Improvements

The cleaning and maintenance and essential improvement programs reported last year indicate that farmers, when shown their potential for improvement will put forth the effort to help themselves. The numbers of watercourses needing improvement requires training a large number of technicians and equipping them to help the farmers. A program has been designed to give extension field assistants the training and equipment that will enable them to provide this help to farmers. This program is currently being tested in the field.

d. Structures for Lifting Canal, Drainage and Tail Water in Watercourses

High volume, low lift jet pumps designed and tested in the hydraulics laboratory at CSU were constructed and installed in two locations in Pakistan, where they are using excess gravitational energy available from high level tubewell water to lift canal water up to levels needed in the field. Local fabricators have been able to utilize locally available materials and bring the materials cost of these installations down to the range of Rs. 1000 to Rs. 3000 (about $100 to $300). Reception of these jet pump structures by farmers and engineers in Pakistan has been enthusiastic. Further tests and refinements to optimize the efficiency of these pumps are underway at the CSU hydraulics laboratory.

e. Factors Affecting Loss in Pakistan Watercourses

Extensive water conveyance loss data were collected by both inflow-outflow and ponding methods and analyzed with statistical techniques to determine functional relationships between several watercourse design parameters and water losses. The study concluded that:

(1) Losses are very sensitive to and exponentially related to water depth fluctuations in a channel.

(2) Flow rate changes affect depth and consequently losses.

(3) Cleaning of channels reduces wetted perimeter, roughness and thus flow depths and water losses.

(4) Water losses are higher from larger channels which carry larger flows.

(5) The more of a channel section is full of water, the lower are its loss rates.

(6) Sarkari khal channels have lower loss rates than farmers branches.

These derived functional relationships were then combined into a watercourse model which can predict changes in conveyance losses resulting from changes in the design parameters. The model was then applied to several practical watercourse design alternatives to indicate its usefulness in saving irrigation water.

f. Potentials for Improving Watercourse Delivery Efficiencies in Baluchistan

Losses were measured on watercourses in representative areas of Baluchistan. While the average watercourse losses were only about 24%, compared to 45% in the Punjab, many specific sections were identified where high loss rates were occurring and benefits from improvements would exceed their cost several fold. Irrigation applications exceeded crop water requirements on the average field by almost 100%. The installation of flow measurement structures, along with simple guidelines for applying the proper amount of water to croplands, would have benefit/cost ratios. A primary reason for the potentially high benefit/cost ratio is the high value of water in Baluchistan, which exceeds Rs. 1000/acre ft in areas where high value fruit, nut and vegetable crops are grown.

Particular potentials for improvement, recognized in this survey and agreed to by Irrigation and Agricultural Department officials as locally critical were:

(1) guidelines for construction of diversions and bunds to take water out of flash flood stream beds and guide it to usable locations;

(2) guidelines and engineering for construction of bunds around cropped areas fed by hill torrent waters which will increase their probabilities of remaining intact;

(3) methods for storing on the surface, or piping and valving underground karez channels, so that these precious waters can be retained in the aquifer rather than being dissipated when they are not needed for crop use;

(4) instrumentation and technicians to help these farmers measure their rates of flow and losses so they will know how to improve their system to save the extremely valuable water which they are losing;

(5) guidelines for applying the proper amount of water to croplands; and

(6) water management advisors trained and equipped to work with farmers to help them identify and attain their potentials for water management improvement.

4. Economics of Watercourse Improvements

Several approaches have been used to evaluate costs and returns from watercourse improvements. Costs are normally compared on an annual basis. However, annual costs are highly sensitive to assumptions of life and interest rates. We lack sufficient experience with many of the improvement alternatives to accurately evaluate life and maintenance costs. Even so, sufficient data are emerging to give a general pattern of costs. Fully lined channels have cost up to Rs. 60 per linear foot for five cusec channels, but it appears that well constructed 9-inch section brick and mortar channels can be constructed for two cusec channels at an initial cost of Rs. 35 to 40 per foot or an annual cost of Rs. 3.9 per foot assuming 25-year life and 10% interest charge.

Lower cost construction of several types, including the methods presently used in India and systems presently being tested at MREP, may allow us to achieve lining for 1.5-2 cusec channels at a cost of Rs. 20 per foot or an annual cost of about Rs. 2.2 per foot.

Earthen improvement with concrete control structures and lining in stress areas can probably be achieved for an overall cost of less than Rs. 3 per foot and an annual cost in the range of Rs. 1 to 1.5 per foot depending on the assumptions of life and maintenance for the earthwork and structure components. Heavy cleaning and maintenance on unimproved watercourses could be carried out annually at a cost of about Rs. 4 per foot.

The value of the returns is more difficult to estimate. Much of the water lost from watercourses enters the water table and can be recovered by tubewells. Thus, the cost of tubewell water delivered to the root zone could be used as a basis of comparison. These costs are usually estimated at Rs. 80-120 per acre foot at present, but most analyses probably do not adequately take into account losses occurring between the tubewell and field delivery so perhaps the higher figure is more appropriate.

In the areas where groundwater is saline, we do not have the option of tubewell recovery of water lost to the groundwater table, so other methods are required to evaluate benefits. One method is to set up linear programming models using appropriate cropping patterns, costs, prices, and irrigation frequencies with their appropriate yields. Irrigation water value is then evaluated using the shadow prices associated with the optimal solutions. These exercises generally reveal a logical pattern of water value decreasing as availability increases. This effect results in water saved by watercourse improvement being highly valuable during some seasons of the year and having little or no value at other times. The annual average value of increased supplies generally varies from Rs. 400 per acre foot, or more, if water is extremely limiting, to about Rs. 70 per acre foot if supplies are generally more plentiful. Considering the increased net income that results after watercourse improvement, one could assign substantially higher values.

Faced with this bewildering array of returns, evaluating net returns or benefits is difficult. Most of our analyses have used values of water saved in the range of Rs. 100 to Rs. 200 per acre foot. Such analyses tend to give benefit/cost ratios of 5 or more for heavy cleaning and maintenance, about 3 for earthen improvement with permanent control structures and 0.8 - 1.5 for complete lining of the sarkari khal.

While benefit/cost ratios are useful they do not tell the whole story. The total net returns per watercourse are typically of the same order of magnitude for lining and earthen improvement, and substantially higher than for cleaning and maintenance. The higher cost systems require much more capital inputs, so decisions concerning alternate strategies are heavily dependent on the availability of capital and whether the cost of the capital is adequately covered in the calculation of annual cost.

The above calcuations assume that a single improvement strategy is applied to an entire watercourse. Recently, considerable effort has gone into quantitative analysis of the alternative of mixing improvement strategies on the same watercourse. These analyses reveal that is is practical to apply much higher cost improvements to the head reaches of watercourses, that are in use perhaps 4 to 7 days per week, than to the tail reaches that only operate a few hours each week. Thus, net returns are often maximized by mixed strategies involving lining the head reaches and earthen improvement or even heavy cleaning and maintenance at the tail. An important aspect of these mixed strategies is that while the lining is physically placed adjacent to the property of the generally more affluent farmers along the head reaches, the benefits of this lining in the form of increased deliveries accrue much more heavily to the farmers served by the tail reaches.

5. Training Water Management Extension Officers

Saving water in watercourses is not productive unless the water is used effectively to increase crop production. CSU has been asked to work with the University of Agriculture, Faisalabad (UAF), in developing a training program which will prepare one Water Management Extension Officer for each water management development field team under the On-Farm Water Management Pilot Project. His responsibility will be to help farmers improve their production through better management of his expanded water supply, leveled land and other essential inputs (seed, fertilizer and weed and pest control). Dr. Early, Dr. Lowdermilk and Dr. Johnson developed an outline for this training which has served as the basis for an agreement between the Punjab Government and the University of Agriculture, Faisalabad. In addition, the Sind, North West Frontier and Baluchistan provincial governments developed similar agreements with the University of Agriculture, Faisalabad. CSU will help develop training materials that can be used by all four provinces, and will assist to the extent of available personnel and as requested by the respective provincial governments.

The first course was given June 10-October 20, 1977 and had 16 participants (8 from the Punjab, 4 from the Sind, and 2 each from the North West Frontier and Baluchistan). Additional training materials were developed afterwards in preparation for the second training course, which began on April 19, 1978 and was completed August 30 with 10 graduates. The third course began in March 1979. Eight faculty trainers have been involved along with two CSU advisors.

6. Water Users Associations

The first pilot watercourse improvement project was carefully selected on the basis of leadership and organization being inherent in the farmers group which would allow them to complete the improvement successfully. However, studies by Mirza and Freeman and by Lowdermilk indicate that water users on most watercourses are divided by long standing disputes, caste differences, and other factors, to the extent that the degree of cooperation and organization is a primary factor limiting watercourse cleaning, maintenance and improvement projects. Radosevich has studied and outlined the types of water users organizations effective in managing water in the primary irrigated areas of the world and has suggested organization guidelines, rules and policies which appear to be adapted to Pakistan's physical and cultural characteristics. It is probable that implementation of some of these guidelines, rules and policies may provide the foundations of cooperative organizations, which have had a profitable experience in watercourse improvement and maintenance, and will have sufficient credibility and prestige to help the farmers cooperate in ownership of equipment, tractors, tubewells and other activities, thereby allowing these farmers with small acreages to participate in the new technologies previously available only to those with larger holdings.

At the request of USAID/Islamabad, Colorado State University agreed to develop a research project to test and identify the organizations that might help farmers more efficiently use their water. Professor Ashfaq Mirza at the University of Agriculture, Faisalabad (UAF) and Mr. Douglas Merrey, who joined the Field Party in April 1978 and is stationed in Faisalabad, have been working cooperatively in these studies. They published an interim report in November 1978. Their Phase I studies will be completed in late 1979.

7. Water Management Research and Training Program for Rural Development

The University of Agriculture at Faisalabad was asked by the Punjab Agriculture Department, and later by the Sind, NWFP and Baluchistan Agriculture Departments, to provide training to their personnel who would work as Water Management Extension Officers (Agricultural Officers) in their On-Farm Water Management Development Projects. The University of Agriculture at Faisalabad agreed to provide the necessary training in the classroom and field aspects of water management utilizing existing information, facilities and the experience of its faculty. As the materials were assembled and the presentations developed for these classes, it became apparent that this course could be an important factor in bringing the faculty closer to the problems of the farmers. Since most of the problems do not presently have satisfactory solutions and the farmer is still largely an unpredictable factor in water management, this research program will allow the faculty an opportunity to identify problems and test alternative solutions. Thus, it became apparent that a primary need for the trainees would be to identify farmers' problems in the fields, observe well-planned demonstrations of how to motivate farmers to adopt improved practices, followed by opportunities to work directly with the farmers and practice the demonstrated techniques.

The major objectives of the proposed research project include the following:

a. To provide research results which will prove useful to policy makers in the future implementation of the On-Farm Water Management Development Projects of the provinces.

b. To strengthen the University research and training curricula in water management and increase faculty involvement in the solution of farmers' problems.

c. To develop appropriate water management technologies through research and demonstration of farmers' fields, which are suitable to the harsh environment of the mid-doab, that will provide a long-term balance between the use of surface and ground water in order to alleviate waterlogging and salinity problems while increasing crop production.

d. To provide technology and guidelines to be used by Watercourse Engineers and Irrigation Engineers to facilitate their doing a better job of motivating farmers and implementing technological change.

e. To directly support the training course for the Water Management Extension Officers by providing planned educational field experiences in technical aspects of water management and essential interaction with farmers to motivate them to adopt new technologies.

f. To provide technology and guidelines to be used by the Water Management Extension Officers, including the development of an effective package of extension materials for watercourse improvement, improved agronomic and irrigation practices, farm management planning, and organizing and motivating farmers to improve their water management practices.

g. To train Agricultural Officers/Assistants of the Provincial Agricultural Extension Service in watercourse cleaning and maintenance techniques and water management aspects of improved agronomic techniques. To train the In-Service Training Institute Staff of the Agricultural Extension Service in all phases of watercourse improvement, cleaning and maintenance, and water management aspects of improved agronomic techniques so they can integrate these into their training programs at the Training Institute.

8. <u>Joint U.S.A.-Pakistan Evaluation of On-Farm Water Management</u>

During April and May of 1978, a team of Pakistanis and Americans undertook an evaluation of the On-Farm Water Management Pilot Project, which is referred to as the On-Farm Water

Management Development Project in each of the provinces. This evaluation included the role of CSU research and training activities supporting the Pilot Project. The material below has been excerpted from the Summary and Recommendations of their report.

> While it is too early to fully judge the success or viability of the Pilot On-Farm Water Management (OFWM) program during the first phase of implementation, it is evident sound procedures have been established for assisting small farmers to improve their watercourses and to level land for more efficient irrigation. The initial goals were optimistic. The start up time was under estimated and the project is about one year behind schedule in achieving planned targets.
>
> As would be expected, the major problems occur in administrative management rather than technical areas of the project. Recruitment of qualified personnel, training time and once trained, retaining them on the teams has been difficult. The provinces are experiencing difficulty in regularizing the positions. Staff recruitment and retention is particularly acute in the Sind where only 12 percent of the positions have been regularized. It appears that morale and productive work of field team members is low because they are uncertain of their future.
>
> The technology for improvement of watercourses and precision land leveling is appropriate for small farmers and has been adequately tested and demonstrated to be effective in reducing water losses and increasing crop production. Colorado State University has been doing research in this area since 1972 and the Soil Conservation Service assisted in a pilot land leveling project in the Punjab and Sind in late 1973.
>
> Water User Associations are <u>ad</u> <u>hoc</u> groupings along a watercourse, organized for the purpose of providing labor for improvements of the watercourse and for later operation and maintenance. These associations do not have legal nor permanent status. Colorado State University in cooperation with the University of Agriculture, Faisalabad is conducting research in this area. Establishment of permanent Water User Associations is very important and is the key to long-term, sustained improvement in irrigation efficiency and increased crop production.

The following recommendations were made regarding institutions:

a. A permanent institutional arrangement needs to be established in order to implement the OFWM Project and to continue to provide similar services after this project terminates. In addition to the usual government agency, consideration should be given to establishing a semi-autonomous corporate entity.

b. Legal status for the Water User Associations (WUA) is very important to their establishment as permanent institutions for the operation and maintenance of the watercourses and possibly for taking on other responsibilities.

c. Responsibilities for extension and related farmer services with the WUA needs to be assigned to a new dynamic agency(s) designed to help members with organizational and agricultural problems.

9. Specific Studies Reported in Appendix

A short summary of each appendix report is presented below. Each summary is reported in the same sequence as the listing of appendix reports (e.g., summary e below corresponds with Appendix 5).

a. A Small Farmer's Cotton Experiment in the Mona Project Area

During the 1977 kharif season, Larry Nelson, a Colorado State University Agronomy student, carried out a cotton experiment in the Mona Project Area. On seven acres of land in Chak 11 ML, District Sargodha, he conducted experiments to determine the feasibility of planting cotton on beds, application of recommended rates of fertilizer and insecticides combined with controlled irrigation. Mr. Nelson was not entirely satisfied with the results of his experiment but remained convinced that the basic approach is appropriate for this area. Therefore, before he left Pakistan, he asked Sardar Mohammad Langah of village Khizar, a local farmer, if he would be willing to grow cotton following Mr. Nelson's instructions. Mr. Sardar Mohammad had been an interested observer of Mr. Nelson's project, and readily agreed. Mr. Douglas Merrey agreed to act as the communicator and go-between.

Mr. Nelson provided one container each of the insecticides Nuvacron-40 and Nogos, a hand-operated sprayer, money for fertilizer and seeds, a rain gauge, and detailed instructions. Mr. Merrey had the instructions translated into Urdu and helped Sardar to understand them and monitored the progress of the work. Mr. Sardar Mohammad owns only about 1-1/4 acres of land, and cultivates about three more acres on a sharecropping basis. He was able to spare only one quarter acre of his own land for planting cotton. He and his brother did all of the labor. The beds and furrows were made by hand, they used a borrowed hand-seeder for sowing and did all of the weeding, spraying, irrigating, etc. themselves. His family harvested the crop. Since his watercourse had been improved with Mona Project aid the previous year, he had sufficient water even though his land was towards the tail of the watercourse. He maintained detailed records of all inputs and rainfall. This report is based on those records plus discussion between the two authors. The experiment was carried out in the 1978 kharif season.

Mr. Sardar Mohammad is impressed with the usefulness of beds and furrows, especially since his soil tends to crust after irrigation. He also recognizes the advantages of beds and furrows in reducing damage to young plants when there is too much rain and in saving irrigation water. He plans to plant his next sugar cane crop on beds. Further, though he had abandoned growing cotton some years ago, he plans to plant cotton next year using beds and furrows and modifying the cultivation practices as discussed above. The input of insecticides and perhaps fertilizer will probably have to be decreased for economic reasons.

Other farmers in Khizar were impressed by his crop but were intimidated by all the spraying and labor required. Furthermore, they would be unlikely to invest very much money in insecticides and the like--especially considering the high risks involved and the fact that the returns from spraying are not clear. If a bed shaper were available to them at a minimum cost, however, some farmers would probably adopt a simplified version of the above method of cultivating cotton.

b. Rice Production Guidelines

The primary purpose of this production guideline is to provide the Agriculture Officer with the basic knowledge required to advise farmers in the latest rice production practices. It is meant to be brief, factual and easy to read and use. For this reason referencing to scientific publications has not been [illegible]e although the majority of the material presented here was [illegible]ained from such publications.

Rice is grown on about 4 million acres in Pakistan. [illegible]t 50% of this area is in the Punjab with a production of [illegible] million tons. Some high yielding varieties have been im[illegible]rted from the International Rice Research Institute (IRRI) in the Philippines and production technology is being improved in Pakistan. Pakistan has not only become self-sufficient in rice but also exports large quantities of high quality rice. This export results in a good source of foreign exchange. So far export has been to the Middle East, Far East and some African countries. However, there is a big market over the entire globe for the world famous high quality Basmati varieties and the demand continues to exceed the supply available for export.

c. The Response of Sugarcane to Water Stress and Nitrogen Fertilizer

This report gives the results of three years research on the relationship between the response to water and nitrogen in sugarcane, conducted at the Mona Reclamation Experimental Project. A detailed economic analysis is included using production surfaces determined by regression techniques.

Nitrogen responses were only slightly decreased by water stress and substantial rates of nitrogen were profitable even on stressed treatments in all years. The optimum water application is, of course, dependent on the cost of water, whether it is the actual cost to him or the opportunity cost of using it for another crop or increasing his cropping intensity. The optimum levels of water application varied among the three years, but in two of the three years applications of less than 50-inches were more profitable than 60-inch applications when water costs exceed Rs. 10 per acre-inch.

Finally it should be recognized that these results consider only bulk cane yields and not sucrose content. While farmers in Pakistan are presently paid on the basis of bulk yield, it is well known that high rates of nitrogen often depress sucrose levels. Therefore, in order to assess the true value of the output it will be necessary to include sucrose measurements in work of this type.

d. An Agronomic and Economic Evaluation of the Effect of Irrigation and Nitrogen on Cotton Yields in Multan District

Cotton is one of the most important agricultural crops in Pakistan. Acreage varies from 4.5 to 5.0 million acres each year. It supports the local textile industry which is of major economic importance to the country and except in years of low production exports are a significant source of foreign exchange. The average cotton yield presently is about 1200 kg/ha. Yields in Pakistan are only 50% of Egypt's despite the fact that both countries grow cotton under irrigated conditions. In Arizona, where climatic conditions are similar to Pakistan's, a high state of irrigation technology, balanced fertility program and a scientific pest control program have brought average yields to more than three times those of Pakistan. Cotton yields of 2500 kg/ha can be achieved in Pakistan under proper irrigation, fertilizer and pest control management.

Field experiments were conducted to determine the interaction of nitrogen (N) fertility and irrigation intensity of the economics of cotton production. A regression analyses using a yield model was used to evaluate the yield results and economic returns. The yield response to N was linear over the N rates tested (55-140 Kg/ha). The theoretical optimum numbers of irrigations was 4.2 and yields decreased substantially as over or under irrigation occurred. The marginal product of N (Kg Cotton/Kg N) was 11.03 at the theoretical optimum number of irrigations and decreased to 2.32 and 4.36 at 3 and 6 irrigations, respectively. The return on investment in N was relatively insensitive to cotton price and very sensitive to number of irrigations.

Farmers generally apply more than five irrigations. Based on these results the number of irrigations should be decreased. Four or five irrigations are optimum for cotton production and over irrigation will decrease their net income to a point where return on investment makes cotton production uneconomical.

e. <u>The Effect of Herbicides and Mechanical Weed Control on Maize Yields (1978)</u>

The practice of using herbicides to control weeds in crops is in its infancy in Pakistan. The Government has approved only a few herbicides for use by the farmers and very few farmers have accepted this new technology as part of their production program. A considerable amount of effort must be undertaken in order to inform the farmers of the benefits herbicides have on crop yields. Also, additional field performance data are needed on herbicide efficacy and selectivity.

A weed control demonstration experiment was conducted on maize at Mona using three chemical and three hand control methods. Maize yields were doubled when Primextra herbicide was used to control weeds as compared to no weed control. The Primextra treatment yielded significantly more than the best hand weed control of three hoeings. Return on investment in herbicides to control weeds was greater than the return on investment in hand labor. These results show that the use of herbicides to control weeds in maize is economical under farmer conditions.

f. <u>Yield Trends and Adoption of Improved Agricultural Practices in Mona Project Area 1964-65 to 1973-74.</u>

Crop cutting surveys have been conducted on wheat, rice, sugarcane and cotton fields on the Mona Reclamation Experimental Project area during the period 1965-74. This period has a special significance due to the introduction of improved practices such as chemical fertilizers and high yielding varieties (HYV's) of wheat and rice. The project mean cropped area during this period was about 123,000 acres, of which 73% were in the perennial canal command area. During this period, mean wheat yields on the perennial command area increased approximately from 20 to 30 mds per acre. Percentage of HYV's increased from 3% to 96%. Wheat fields fertilized with commercial nitrogen increased from 13% to 55% of the total and average N, applied over all fields increased from 1.5 to about 41 lbs/acre. Wheat yield increased about 15 lbs for each 1 lb N applied. Of the 10 md/acre increase about 6 can be assigned to the use of HYV's and 4 to fertilizer use.

Mean rice yields on the perennial area varied from about 19 to 28 md/A but there was no clear cut trend over time. Average fertilizer use increased from 0 to 11 lbs N/acre. Fertilizer increased rice yields about 11 lbs for each 1 lb of N. Sugarcane yields in the perennial area averaged 522 md/A at the first three years and 435 the final three years and the declining yield trend was significant ($P > .95$). N use increased from an average of <1 to 39 lbs/A over the period and yield increases due to fertilizer averaged about 63 lbs fresh cane per lb of N.

No trend of increasing or decreasing cotton yields was detected. Average overall use of N at the end of the period was about 14 lbs/A with roughly 30% of the fields fertilized. Increased yields amounted to about 5 lbs cotton per lb of N.

g. A Note on the Fertilizer Ratio Concept

The concept of plant nutrient ratios has long been utilized by agronomists and appears to be particularly prevalent in Pakistan. Production experts often express concern that the nutrient ratios utilized by the farmers are not optimum for a particular crop. These concerns are reflected in the press and are considered by those charged with planning production and imports. Agronomists interested in plant nutrients may thus find themselves designing experiments to determine the optimum ratios of plant nutrients for different crops grown under different conditions. This discussion is limited to two nutrients, nitrogen and phosphorus and the resulting N/P ratios. This is appropriate because these fertilizer elements are the most widely used in Pakistan and crops often respond to their use. However, combinations involving other nutrients or crop inputs are subject to the same principles.

Although this paper cannot cover all aspects of the supplying power of the soils for plant nutrients, but should be sufficient to illustrate some of the technical and economic limitations of the ratio concept. Raising an alarm over the Pakistan farmers' improper fertilizer ratio not only serves no useful purpose, but also illustrates a lack of knowledge of the technical-economic relationships involved. A blanket recommendation for the whole country such as a N/P ratio of 2/1 will not be valid for all areas or farmers.

Farmers in different stages of adoption of improved practices will be applying widely different fertilizer rates.

There is no sound basis for assuming that ratios should be the same for different doses. Actually most fertilizer experiments would have to be drastically redesigned in order to adequately test the ratios concept, even for fixed cost/price relationships.

h. Improving Field Corn Stands in Crusting Soils

Practical solutions to the problems of stand establishment of field corn in Pakistan were investigated in a field trial conducted at the Colorado State University Agronomy Research Center, Fort Collins, Colorado. Objectives of the study were to determine the effects of; (1) bedding practices; (2) initial seed moisture content at sowing; and (3) soil mulching on stand establishment and yield when soil crusting occurred during the emergence period.

Harvest stands of crust and crust-thin treatments were 6 and 11% lower than comparable stands of optimal treatments. Plant populations of these treatments were reduced by the development of a soil crust on the 5th day after sowing. Soil crusting extended the emergence period by an additional 5 to 7 days. The extended period of emergence was caused by low seedbed temperatures and the development of a soil crust.

Final stands of ridge furrow and broadbed treatments were 9 and 12% lower than those observed in basin treatments. The improved stands in basin treatments resulted from a more shallow seeding depth which exposed the seed to a more favorable heat flux and reduced the emergence distance.

i. Irrigation Influence on Nitrogen Use Efficiency and Yield of Paddy Rice.

Rice yields improve under continuous flooded conditions and are reduced when the fields are allowed to dry well past the field capacity. This is especially true at critical growth stages such as tillering and blooming. Because of limited irrigation resources, farmers in Pakistan, in general, follow alternate flooding and drying cycles. Canal closures and other causes of periodic drying are common in Pakistan. Because of these fluctuating moisture contents, the oxidation and reduction (redox) status of the soil becomes more conductive to higher nitrogen losses.

There is a recent hypothesis that most of the nitrogen losses occur in the critical redox range of 12-15. Elevated temperatures coupled with frequency and time of exposure of fields to such critical redox levels as imposed by alternate flooding and drying irrigation regimes, generally lead to high nitrogen losses and very low nitrogen use efficiencies in paddy rice. As a result, production usually falls considerably short of the potential production capabilities. The present investigation was directed to explore the response of paddy rice to various irrigation treatments in terms of nitrogen use efficiency and yield.

j. Effect of Soil Temperature and Moisture on Cotton Germination Under Arid and Semi-Arid Conditions

A major problem faced by cotton producers in the arid and semi-arid regions is the establishment of a good stand early in the season, which can be insured only by a high and fast rate of germination. Stand uniformity (or lack of it) greatly affects production and the management of the crop during the crop year. The physical properties of the soil surrounding the seed, primarily high temperature, low moisture content and a physical impedence above the seed have been recognized as the most common physical factors restricting successful cottonseed germination and stand in those regions.

The purpose of this study was to analyze the effect of high soil temperatures and different soil moisture content on the rate and percent of emergence of cottonseed at the laboratory and greenhouse. Since soil temperature fluctuates through a daily cycle, the experiments were conducted to evaluate the combination of different daily soil temperatures and several moisture regimes representing field conditions.

k. Effect of Tillage Practices on Moisture and Nitrogen Status of Soil in Dryland Wheat Production

Minimum tillage practices for row crops have gained much ground during recent years because of increasing tillage costs and the need to reduce energy consumption. Nitrogen availablility, moisture conservation and management practices are major factors influencing growth and yield of crops.

The dryland agriculture in Pakistan is characterized by cultural practices which lead to excessive loss of moisture and nitrogen in the field, the conservation of which could appreciably increase the yield of wheat per acre.

The pivotal problem of dryland agriculture in Pakistan is the conservation of soil moisture, which is the single most important factor in increasing the yields from the present very low levels. The present study, which is aimed at investigating tillage and moisture conservation practices, would help a great deal in solving the problem of dryland agriculture in Pakistan.

Minimum tillage and moisture conservation practices being tested appear to be more effective in conserving moisture in soil than those used by the farmers in the dryland areas of Pakistan. This data may provide evidence to recommend reduction in the amount of plowing currently done during the fallow period, and to adopt other moisture conservation practices such as controlling of weeds and keeping of some straw in the field, etc. The adoption of minimum tillage practices could lead to continuous economization of fossil fuel as there is an increasing trend to tractor cultivation in Pakistan.

## 1. Bullock-Drawn Groundnut Harvester

Pakistan has approximately 40,000 ha annually planted in groundnuts, producing 56,000 manuds of nuts. Virtually all of this crop is harvested by hand. The harvest season extends from mid-November to the end of December. As is typical of many crops in Pakistan, there is a shortage of labor during the harvest season. This labor shoratge works a hardship on the farmers in two ways; first, it artifically inflates wages for harvest labor and second it extends the harvest time into the season when the farmers should be preparing the fields for the following crop, thereby jeopardizing the quality of that crop. An improvement in the harvesting methods of nuts would be of real value to the farmers concerned. If the plants can be loosened from the ground mechanically, thus elimiating the kussi (shovel) work, and then stored for later removal of the nuts, this will free the land for immediate cultivation and also delay the nut removal operation until a more slack labor season.

Harvesting machines should be developed for both tractor power and for bullock power. Machines do exist in other parts of the world, but for various reasons, none of these designs have been successful in Pakistan. At least three versions of animal drawn groundnut harvesters, based on designs borrowed from other countries, have been tried but not adopted. Their faults include being too heavy, too narrow, too difficult to control, fouling with trash, and requiring too much draft.

The field testing looked at three factors. First, would the harvester lift the groundnut plants and leave them sufficiently loose in the soil that they could be hand lifted as easily as by the traditional kussi method? Second, was the draft requirement low enough that a team of bullocks could pull it for a reasonable length of time without tiring, and thirdly, would the farmers recognize any advantages in using the harvester?

The final version of the harvester, while operating at a depth of 10 cm lifted the soil about 5 cm and simply allowed it to fall off the back of the blade for breakup. In the process; the soil was moved forward with the harvester about 15 cm. With one model in the field, and being used for perhaps half of one season, no conclusive statement can be made about the farmer acceptance of the machine. However, when that model was sought for testing, the farmers who were using it made it very clear that they did not wish to give it up until their harvest was completed. Instead of using this model for the draft tests, an additional model similar to it was made and tested. It is expected that after these farmers have operated the harvester for this initial season, they will have suggestions that will contribute in making a more refined machine.

m. <u>A Report on the Precision Land Leveling and Water Management Project in the NWFP</u>

While some farmers have apparently become sufficiently enthused about land leveling in the North West Frontier Province (NWFP) to participate in this program, there is little evidence that farmers who have participated in a watercourse improvement program have the enthusiasm to motivate their neighbors to do likewise. Apparently, their major problems lay in inadequate diversions from the river and over use of water between the diversion and their watercourse by farmers in the upper reaches of this channel. These are long standing basic problems which were not addressed by the improvement program.

The following general approach is recommended which will bring together the personnel and resources to help farmers identify their potentials for improvement and develop programs for attaining those potentials.

(1) A research team should be inaugurated immediately to support the On-Farm Water Management Project in the NWFP. This team should be drawn from personnel in the

(a) NWFP, OFWM office (as assigned by the Director)

(b) National OFWMP office

(c) U.S. Soil Conservation Service

(d) Colorado State University Field Party

(e) Master Planning Unit, Survey and Research Division, WAPDA

(2) Research would include farmer cooperation in the problem identification, planning, execution and evaluation stages.

(3) Farmer inputs of labor and capital will be invited for improvements involved in the research. Items authorized for reimbursement by the OFWM project would be paid for from that budget. Minor items would be handled through the CSU operations budget.

(4) Rodmen, beldars and other assistance that may be needed would be provided on request by the NWFP, OFWMP.

(5) A series of meetings should be held with groups of farmers to determine their water

management problems. These meetings should include on-site inspection and discussion of the problems.

(6) Where substantial potentials for improvement exist, the farmer(s) will be encouraged to consider one or more approaches which appear to have promise for achieving those potentials. These considerations will include benefit and cost estimates.

(7) Based on the economic considerations and the experience and knowledge of the farmer and the technicians, one or more approaches for achieving the potentials for improvement will be implemented and evaluated.

(8) If the results are positive and the farmers are pleased and enthused, field days will be arranged to allow them to tell their story.

(9) If these same potentials for improvement are widely present in the NWFP and can be addressed within the framework of the current OFWMP, personnel will be trained in the methods found to be most effective in helping farmers achieve those potentials.

(10) Stress should be placed on developing programs which feature the farmer, show him his potentials for improvement, and motivate him to invest his own labor and other resources in the improvement. Insofar as possible he should be given insight, broader options and technical guidance in place of physical materials.

n. Water Delivery Efficiencies on MN-140: An Uncommanded Watercourse.

The average delivery efficiency only a complete irrigation turn (warabundi) for MN-140, an uncommanded watercourse, was 51.6 percent. Of 32.8 ac ft discharged into the watercourse, 16.9 ac ft were delivered to 50.6 acres, with the average irrigation depth being 4.04 inches. During conveyance to the fields 48.4 percent of the water was lost. Operational losses accounted for 15.2 percent (2.4 ac ft) of the total water lost. Of the 3.7 ac ft required to fill the channels, 67 percent was recovered as channel drainage.

The average infiltration loss rate from inlet to fields was 0.53 cusecs/1000 ft. Ponding infiltration measurements from five selected small channel sections averaged 0.37 cusecs/1000 ft over a one-hour period with water at full supply level. Water loss from the ponded section was due only to seepage and evaporation. Infiltration rates during channel filling were 1 1/2 - 4 times greater than the full supply infiltration rate. Seepage is a major component of the loss due to the prevailing soil texture. Such high seepage loss probably preclude the earthen watercourse improvement techniques and elsewhere.

Very little leakage or seepage through the channel banks was observed. Rodent holes averaged 3.81 holes/1000 ft. of channel. This was 1/8 to 1/3 the rate of holes found on three other watercourses.

o. Determining Minimum Cost Cross Sections for Lined Channels

Reducing channel lining costs involves not only utilization of low cost materials, but also optimally using these materials to convey the required flow. A mathematical treatment is presented for determining the minimum cost cross sectional shape and dimension which will fulfill the hydraulic requirements, according to Manning's equation, for various bed and side wall material costs. A practical example of lined watercourse design is given to explain the utilization of the results. Nomographs are presented to simplify the minimum cost design process.

p. Roughness Coefficients for Watercourse Design

The Manning's roughness coefficient was evaluated on 16 Pakistan watercourses in various stages of vegetative growth and maintenance. The derived values tended to be somewhat higher than those listed in the Western literature, perhaps because of the small size of the watercourses and the tropical vegetation involved; however, a wide variability of the coefficient, depending on the channel conditions, was found.

Utilizing the results of ponding loss measurement studies, which indicate that watercourse losses are strongly related to the depth of flow relative to the usual flow depth, a theoretical analysis of loss rates as a function of roughness coefficients was made. A graphical depiction of the results points out that moderate vegetative growth in earthen channels can increase the roughness coefficient from 0.03 to 0.45, which would increase the depth of flow by about 4-8 cm and losses by 2 to 3 times.

The study concludes that only cleaning and maintaining earthen watercourses, such that the roughness is reduced, can cut conveyance losses in half. Also, a roughness coefficient value of 0.04 is recommended for watercourse design.

q. Low Cost Farm Irrigation Control Structures for Pakistan

The control structures presently existing on nearly all of Pakistan's 2 million kilometers of watercourses in 78,000 command areas are temporary ones constructed from earth. In order to divert the water from one channel into another, the irrigator cuts a hole through the bank and then attempts to stop the flow in the original direction by building an earthen dam across the channel.

The effects of this practice are everywhere evident. Watercourse banks are weak, porous, and irregular from the many cuts. Adjoining crops are sometimes poor due to excessive water leakage. Junctions are often very much enlarged as a result of borrowing soil from inside the channel to build the dams, or crops are spoiled from the borrow pits outside the banks. Banks are thin and weak in the junction area, and water is often trickling into side branches through the porous dams which will quickly wash out.

On the basis of the practical experience of developing, installing and testing of different low cost irrigation control structures, the following recommendations are made:

(1) Precast reinforced concrete is a recommended material for fabricating nuccas. It has many advantages including cost, life, and availability. Recommended installation materials will depend upon the local conditions.

(2) Circular orifice panel nuccas with a curved sealing surface, are easy to fabricate, simple to use, and allow less leakage than other tested materials.

(3) Additional work must be done to develop easy to use larger size check structures where leakage is small.

(4) Small drops in watercourse levels can be accomplished by judiciously sized and located check structures.

r. Evaluation of Pucca Nuccas in Watercourse Improvement

An integral part of the On-Farm Water Management (OFWM) watercourse improvement program is the installation of concrete checks and outlet structures (pucca nuccas). The type presently being installed are precast concrete panel orifices and lids installed in a brick masonry structure. The latest design has evolved during three years of experimentation. This particular nucca is being produced by New Hassnain RCC Products, Sargodha. About 4,000 of these structures have been installed in Pakistan.

The precast orifice nuccas, when in good condition, had practically no leakage. Average losses were about 1 percent of the mogha inflow after one year of field use. Breakage of nuccas is still a problem and the quality of the structures must be improved. A nucca replacement rate of 10-20 percent per year might be expected with the present nuccas. Water and/or labor savings will repay the cost of pucca nuccas. Extra benefits are improved water control, more irrigation time and farmer pride.

s. Aids and Suggestions for the Successful Manufacture of Concrete Nuccas

Control of irrigation water on Pakistani farms has been the subject of a series of studies and reports. Through this resesearch a successful concrete control structure for small stream flows (under 5 cusecs) has been developed.

The design and fabrication of this structure is relatively simple, but quality control is essential to achieve satisfactory results. This paper describes some of the techniques used in making quality concrete, and in particular, describes a simple machine specially designed for finishing the control structures.

t. Trapezoidal Plates with Circular Orifices for Measuring Flow Rates and Water Loss in Watercourse

A set of three trapezoidal plates with 4", 6" and 8" diameter orifices was fabricated. The plates were cut from 1/4" thick sheet plastic. If this sheet is clear or translucent, it allows the reader to see the level of water on the front side of the plate when viewing from the back side and thereby facilitates and increases the accuracy of the head loss measurement.

Orifice plates can generally be made at less cost than other flow measuring devices. They are also easy to transport in passenger vehicles and easy to carry to the field. Although they are simple, they can be an accurate tool for measuring water flow rates and rates of loss in watercourses.

u. Tubewell Junction Jet Pump

A common problem for irrigation farmers in the Mona Project area is that their full authorized discharge is not provided at the outlet (mogha) to their watercourse. The moghas are either modular (flume type) or non-modular (pipe orifice). The modular moghas are designed to discharge the full supply at an unsubmerged condition. Because of flat watercourse gradients, along with silt deposits, vegetative growth, and elevated fields, the water is usually backed over the mogha.

Where tubewells exist near the mogha, it is possible to use excess water horsepower or energy at the tubewell to raise the level of the water in the watercourse. This was done successfully in two locations in the Mona Project area. The first jet pump utilized a long discharge pipe from the tubewell to the watercourse and from there a horizontal steel jet pipe and nozzle. The other jet pump involved bringing the watercourse to the tubewell to save piping cost. The existing concrete discharge box was heightened to allow full use of the relatively high discharge elevation of the tubewell. In both cases, the previously submerged mogha was freed to allow full supply flow. Also, the jet pump allows the complete mixing of the canal water with the more saline groundwater.

The increased water supply caused by the installation of the junction jet pumps caused farmers on both watercourses to begin further watercourse improvement programs. The Mona Project staff briefed them on the fact that they would need an improved and enlarged watercourse to make use of the full supply that they hadn't seen in 13 years. The jet pumps at MN-60 and MN-62 were provided from Mona Project Research funds and the farmers were willing to put in many man-hours of earth work in expectation of the results. None were disappointed when the job was completed.

v. Post-Improvement Study on the Watercourse at Chak-2J.B. Ram Devali

A brief description is provided of the pre- and post-improvement situation on a single watercourse. The short report provides valuable insight regarding the problems continually being faced by villagers and irrigators. The impact of tubewells on cropping intensity and changing cropping patterns is discussed, as well as changes in irrigation practices. The problems of water theft are also discussed.

w. Tree Removal and Watercourse Improvement: A Preliminary Survey

Preliminary results are reported on the tree removal requirement under the watercourse improvement program being carried on in Pakistan. In order to proceed with the improvement work on a particular watercourse, the farmers are required to remove all of the trees on the sarkari khal (main watercourse in the command area) before any technical or monetary assistance is provided. At present, there are very little data available on the number and value of the trees removed, or farmer's attitudes and perceptions toward removing their trees as part of the watercourse improvement program. Two surveys were carried out. One was conducted on five watercourses that had been improved and the other on four watercourses that were to be improved in the immediate future.

The general c

(1) Trees, without question, are a valuable resource to the farmers. They are used for many purposes, such as; implements, building materials, furniture, fuel, fodder, shade, boundary lines, wind breakers and have great aesthetic value. They also serve many farmers as a source of income for emergency and other purposes.

(2) Unfortunately, trees can also be a serious detriment to the farmer's operations, particularly when they are located in improper places. Those located on the sarkari khal or farmer's branches often impede the full flow of water and provide opportunities for trash to accumulate, which further restricts the flow of water. Likewise, the trees located on the banks of the watercourse makes them porous and enables rodents and insects to greatly increase the seepage losses. The trees themselves also consume large quantities of water which otherwise could be used for crop production. Also, many of the trees are an ideal haven for destructive birds.

(3) It was estimated that 26,612 trees were removed from the sarkari khal on the nine watercourses included in this survey. Almost all of these were removed by the farmers and represents a lot of hard work. In most cases, no definite plans have been made to replace these trees. Obviously, most of them were not planted, but are a result of natural propogation. It would be desirable to develop a tree replacement policy. Desirable species could be selected and planted in strategic locations, thereby maintaining the free flow of water in the watercourses and as time goes on in the farmer's branches as well.

(4) Almost all of the farmers believe that the trees on the sarkari khal belong to the farmers whose land it borders. This is a legal question that hasn't been resolved in the courts, but the government thus far has adopted a lenient policy regarding their removal and will probably do so in the future. The general feeling being that the tree removal program is essential to the watercourse improvement work, which in turn is most beneficial to increasing agricultural production.

(5) Over 95% of the farmers interviewed feel that the tree removal requirement is desirable and that the increased water supplies more than offset the loss suffered from the removal of the trees.

(6) Finally, it seems apparent from this brief survey that a much more intensive study of this matter is warranted. It appears that if the proper programs and policies are developed that the removal of the trees would not only enhance the water supply, but with a well designed tree planting program the benefits from the trees themselves could be increased, too.

x. A Study into the Marketing Problems of Citrus Growers in the Mona Project

This is a study of the citrus industry in Pakistan with special reference to Tehsil Bhalwal, which is one of the major citrus producing areas in Pakistan and the general location of the Mona Reclamation Experimental Project. A random sample of citrus growers was selected for study and stratified in terms of small, medium and large sized growers. Interviews were also conducted with the citrus contractors and other middlemen involved in the marketing of citrus.

Citrus has become a very important crop in Pakistan and a very significant increase in production and consumption has occurred in the last few years. Unfortuantely, there have developed a number of problems in the citrus industry which need to be resolved if it is to become a viable industry. In view of this, growers, contractors and various middlemen were contacted to analyze these problem areas and to determine solutions for the betterment of the citrus industry. Generally speaking, the growers are greatly handicapped in marketing their citrus because of ignorance, lack of capital and the inability to organize an effective marketing system. The contractors are confronted by high risks in production, prices, transportation and spoilage.

Most of these problems could be eliminated or minimized by a concerted effort on the part of the GOP with cooperation from the growers and private contractors. There is a great potential for further development of the citrus industry if the proper policy steps are taken. This will enable the domestic consumer to secure this highly desirable food product, provide foreign exchange for Pakistan and provide the growers and contractors a reasonable return on their investments.

y. Impact of Mona Reclamation Experimental Project on the Farm Economy of the Project Area

This study is an economic appraisal of the Mona Experimental Reclamation Project. A benchmark study of this area was made in 1965-66 which was followed by an economic appraisal study in 1970-71. This study concentrates primarily on the changes that have taken place since 1970-71. The Mona Project was initiated in 1965 with a view of finding out ways and means of overcoming the factors limiting agricultural development in the immediate area and using these findings throughout the whole of Pakistan to increase their production of food and fiber.

The project is concerned with research activities in most areas of agricultural production, the dissemination of these findings to the farmers through the Extension Division and lastly, with problems related to public tubewell performance and maintenance.

The methodology used in the analysis is commonly referred to as a "with" and "without" comparison. The "with" area consists of those lands that are supplied by public tubewell water through the SCARP Program and the "without" area are those lands in which no public tubewells have been installed. In each of these areas, three classifications were made in terms of their water supply. These are: 1) perennial, 2) non-perennial, and 3) uncommanded. A representative sample of farms was selected in each for both the with and without situation.

Current prices were used in this study to present a more meaningful picture of the present day situation. As is well known, farmers are very responsive to price changes, and when able to do so, change their cropping patterns and intensities to maximize their returns. The primary limiting resource in almost all of Pakistan is the limited and unstable water supply.

Though a well developed and sophisticated system of surface water supply was established many years ago, it is found that under present day standards that this water supply is inadequate to provide the agricultural output to make Pakistan self-sufficient in its food supplies. With the advent of the public tubewell (SCARP) development and followed soon by many private tubewell installations, the water supply has been increased substantially, as well as providing a more stable supply. This study is an attempt to determine the effect of these increased water supplies and discover what research and extension activities should be implemented to further enhance agricultural production throughout Pakistan.

Many changes have occurred in land use, cropping patterns, cropping intensities, mechanization and the use of modern inputs. Many of the farmers are producing cash crops for sale in the markets. Agriculture in Pakistan is moving in the direction of a market oriented economy. An excellent example of this is the citrus industry. A large increase in the production of this crop was noted. This was made possible because of the increased water supply and its dependability.

From an economic point of view, the Project Area has provided handsome dividends. It was found that the annual costs of the project were Rs. 5.4 million, whereas the annual benefits were Rs. 17.6 million. This means, of course, that the cost-benefit ratio was 1:3.26; thereby, indicating that the project has been very successful. However, with increasing emphasis on research and extension activities, it is possible to improve the present situation much further.

z. Simulating Cropping Pattern and Water Management Alternatives in the Punjab, Pakistan - Model Development

A watercourse command area simulation model is planned as one of the current tasks within the USAID sponsored work of Colorado State University. The objectives outlined for the model are as follows:

(1) To establish the overall water balance on a watercourse command area as affected by canal diversions, tubewell pumping, watercourse condition, cropping patterns, and climatic variables; and

(2) To examine the viability of various cropping patterns systems and intensities in terms of water availability for planting and in-season water stress.

In order to accomplish these objectives, the model is initially being set up on a Hewlett-Packard HP 9825A computer.

Any model of this scale can generate very valuable information to the irrigation planner and thus should be verified for one or more case studies. If squares along one or more watercourses could be studied intensively as a system, the validity of the model could be demonstrated and the results could yield beneficial information for model improvements.

aa. A Survey of the Graduates of the First On-Farm Water Management Agricultural Officer Training Course

The University of Agriculture (Faisalabad) is responsible for training the Agricultural Officers (AO) for the field teams of the On-Farm Water Management Pilot Project of all the four provinces of Pakistan. Colorado State University provides advisory assistance to this training program. The first course was completed on October 20, 1977. From October to November 1978 a survey was conducted of all but two of the 16 graduates of this course. We assumed that during the year since graduation these AO's would have had sufficient experience to help us in improving the effectiveness of the training course.

In terms of the first objective, to learn whether the graduates are doing what they were trained for and what sorts of problems they face on the job, we discovered that the respondents feel the training was adequate and did prepare them for their jobs. They do not seem to have any major on-the-job problems or grievances.

Our second objective was to elicit their opinions on the effectiveness of the training and ways to improve it. Most were basically satisfied with the training. Some of the problems and suggestions they mentioned have been dealt with in the second and currently in the third training courses. Their suggestions that the agronomy and extension components need strengthening are well-taken in view of their performance on the technical knowledge questions.

The third objective was to test the graduates' basic knowledge of the subjects taught in the course as a test of the effectiveness of the training. The performance on questions regarding irrigation methods and extension methods was not satisfactory, which suggests that these components need strengthening.

Based on this survey, the following recommendations are suggested:

(1) More emphasis needs to be given to the Agricultural Extension and Agronomy Components of the training program. Special emphasis should be placed upon establishment of result demonstration using irrigation and agronomic inputs. Every trainee should be required to help establish a demonstration in the field.

(2) A watercourse cleaning and maintenance operation should be physically accomplished during the training course. This should include the physical process from initial farmer contact through the cleaning and maintenance operation

(3) In order to encourage the trainees to study more diligently and to raise the standards of the course, examiantions need to be given on a regularly scheduled basis. Passing marks and acceptable class room attendance should be required for graduation.

(4) Since getting the farmers to cooperate with them is perceived as a major problem by the AO's, more attention needs to be given to teaching human interaction skills and building up their confidence in their ability to work with farmers.

(5) Greater attention to the importance of increasing agricultural production as the real goal is needed, both in the training course and in the policies of the OFWM Project.

(6) Refresher courses need to be given regularly at the provincial level in order to raise the level of expertise in areas where the AO's are weak and to keep the AO's informed of the latest recommendations.

(7) The difficulties the respondents faced both in understanding our questions and in giving acceptable answers raises questions about the efficiency of English medium training: Consideration should be given to using Urdu at least to supplement English - language presentations.

In conclusion, many of the above recommendations have been at least partially included in the third training course which began in March 1979.

bb. Training Agriculture Officers for the On-Farm Water Management Development Project

The second Agricultural Officer training program was conducted at the University of Agriculture at Faisalabad from April 19 to August 30, 1978. This interdisciplinary program included subject matter training in irrigation engineering, agronomy, agricultural extension, rural sociology, soil science, farm management and farm machinery. The main objectives of the training program were to teach these very important members of the On-Farm Water Management Field Team how to work with farmers to improve agronomic practices and to keep their watercourses cleaned and maintained. A considerable amount of time was spent on engineering skills such as watercourse design, surveying, etc. This is necessary because every field team member has to be cross trained in all skills.

The major benefit of the OFWMDP will be obtained when farmers use their additional supply of water to increase agricultural production. Every facet of the training curriculum should be oriented toward teaching skills that will result in the achievement of this benefit. When the Agriculture Officer is able to show farmers how to use their increased water supply to increase agricultural production, Pakistan will reap the ultimate benefit of the On-Farm Water Management Development Project.

cc. <u>The On-Farm Water Management Training Program at the University of Agriculture at Faisalabad</u>

The interdisciplinary OFWM training at the UAF is designed to teach the practical skills that are needed in working with farmers. There are two courses taught, a 4-1/2 month course containing highly technical subjects and a less technical six-week course. The Agricultural Officers of OFWMDP and instructors of the In-Service Training Institute of the Agricultural Extension Service attend the 4-1/2 month course while the Agricultural Officers/Assistants of the Agricultural Extension Service attend the six-week course.

A research project at the UAF has been developed to increase the effectiveness of the training programs by providing the faculty with funds to conduct field research projects related to OFWM. These research programs cover the major areas of training and will serve as a nucleus of expertise in OFWM techniques at the University.

dd. <u>The Water User Association Research Project - An Interim Report</u>

The OFWM Pilot Project is specifically directed toward helping small farmers. Because of the small land holdings, a relatively large number of farmers share each watercourse. A critical problem has been that of effectively organizing farmers, especially for maintenance of watercourses after improvement. Frequent and regular maintenance is essential if the farmers are to reap the benefits of watercourse improvement. The University of Agriculture, Faisalabad, was therefore asked to do a study on the possibilities of organizing water users associations on each watercourse.

This study is based on research completed on four watercourses exhibiting a variety of sociological characteristics. The research methods have combined the use of formal questionnaires with more informal techniques in order to achieve a deeper understanding of key social processes. Among the tentative conclusions suggested by the data are:

(1) Maintenance of watercourses after improvement is a major problem that must be solved.

(2) The social organization of watercourses is a major determinant of the likelihood of a successful improvement and maintenance program. It appears that the best maintained watercourses are those with at least some of the following characteristics:

(a) a single sarkari khal branch;

(b) a high percentage of small but economically viable land holdings (5 to 25 acres);

(c) relative equality among farmers of power and influence and especially, a high percentage of farmers being recognized as influential and a low percentage of farmers with no or little influence;

(d) equality of influence of all sections of the watercourse, or concentration of influence at the middle and tail sections;

(e) a low level of pre-existing conflict and hostility;

(f) a previous history of cooperation on community projects;

(g) nonfragmentation into separate competing biradaris none of which are dominant; and

(h) a high level of "progressiveness" as measured by educational level, exposure to mass media, and the like.

(3) Most farmers interviewed favor establishing legally constituted water user associations. Given the lack of effective social mechanisms to ensure cooperation among watercourse shareholders, such legally constituted organizations are essential to maximize the impact of the On-Farm Water Management Pilot Project on water management in Pakistan.

(4) A previous knowledge of the social relations on a watercourse, training in the use of this knowledge and the attitude of the Government personnel towards their clients, are important for choosing watercourses on which to work, and in order to plan the work so as to anticipate, and reduce the effect of, conflict.

ee. <u>Irrigation and Honor: Cultural Impediments to the Improvement of Local Level Water Management in Punjab, Pakistan</u>

Inadequate organization of irrigation water users is now recognized as the major constraint for improving on-farm water management in Pakistan. Previous studies carried out by Colorado State University and Pakistani sociologist have identified characteristics of local social organization that either inhibit or facilitate the introduction of programs for watercourse reconstruction and maintenance. This study includes observations of a watercourse reconstruction project and supplements previous studies by describing a major theme in Punjabi culture, the concept of izzat ("honor", "reputation"). Much of Punabi behavior, and especially the difficulty of organizing local-level cooperative projects, can be understood in terms of the concept of izzat. The concern for preserving or increasing one's izzat, or reducing others' izzat, generates conflict and competition among people and discourages cooperation. The implications of the concept of izzat for organizing farmers to construct their watercourses and manage their irrigation water is discussed, and some general recommendations are presented.

ff. Optimization of Lengths of Alternative Watercourse Improvement Programs in Pakistan

Over the past several years, a substantial amount of information has been collected concerning watercourse losses in Pakistan. Due to the high water losses encountered, improvement programs have been designed and undertaken. To date, these are largely either experimental programs or pilot operational programs, but serious consideration is being given to more substantial operational programs.

Several studies contain information on costs and returns from earthen improvement either with or without permanent control structures and/or improvements involving brick or concrete linings of various types. These studies have assumed that the complete main channel or official watercourse would be improved by either one method or the other, but studies have not considered the alternative of lining the heavily used portions and using lower cost improvements on the less used tail reaches. This paper undertakes the development of a theoretical basis for determining the optimum amount of any contemplated improvement, or the optimum point on the watercourse at which a high cost program would switch to a lower cost alternative.

There are many practical considerations to watercourse improvement that are relevant, in addition to the more theoretical approach given here. At present information is being assembled from various watercourses that have been studied in some detail so that the application of these theoretical approaches to field situations can be properly examined. However, various organizations and agencies are presently involved in analyzing water management alternatives for new or revised programs. It therefore seems appropriate to issue a progress report on the theoretical aspects at this time. While some important conclusions are fairly obvious from the material presented here, comprehensive recommendations must await the more complete analysis.

The technical analyses helped to establish a sound theoretical basis for evaluating watercourse improvement alternatives. On the basis of these principles, we must give serious consideration to mixing high and low-cost improvement programs on the same watercourse. Admittedly, some of the detailed analyses require many simplifying assumptions that may lack reality when applied to a particular field situation. However, the important lesson to be learned here is that analyses of improvement alternatives, based on the assumption that one method will be used throughout, may give a distorted picture of the economic viability of the method when applied to certain sections of the watercourse. Specifically, relatively high cost linings should seriously be considered for high water use sections of the watercourses, even though they would not be economically feasible if used throughout.

In terms of optimization, we have presented a relevant method for analyses using both linear and non-linear water loss assumptions. The non-linear assumption results in optimum solutions at shorter lengths of improvement than does the linear, but it also predicts higher benefits. At this time, we prefer the linear assumption for general use. While there are many possible reasons for higher water losses at the head of the watercourse, which would be consistent with the non-linear assumption, there are some counterbalancing factors that tend to increase losses near the tail. In the first place, we have considered largely the steady state losses from a flowing watercourse. In fact, significant non-steady state losses such as channel wetting occur. The channel wetting loss tends to assume greater importance near the tail when the watercourses are dry much of the time. These alternately used channels also tend to develop more porous banks below the normal water level due to rodent and insect activity than do the more heavily used channels.

## F. Dissemination and Utilization of Research Results

Throughout the year in keeping with program objectives, special efforts have been made which have resulted in wide dissemination and utilization of research results. As credibility with the Government of Pakistan has been increased as a result of a wide range of project activities, interest in Pakistan from farmers to government officials has accelerated. The major results of project efforts described in more detail below are: 1) continued implementation of the comprehensive On-Farm Water Management Pilot Project; 2) the training of a large number of host country personnel for research and development activities; 3) the institutionalization of water management research activities in research stations and with other organizations; 4) the assistance to WAPDA Master Planning, the University of Agriculture, Faisalabad (UAF), and other institutions in action oriented research and development activities; 5) focus on the need to improve water laws and codes and the provision of incentives for farmers to organize for improving their farm irrigation systems; (6) increase linkages with international organizations active in Pakistan and elsewhere with a concern and focus for on-farm irrigation problems; and 7) utilization of project personnel for reconnaissance surveys to irrigated projects in other low income nations.

In May of 1976, USAID Washington approved an AID Mission to Pakistan proposal for a loan of over $10 million to help Pakistan launch a comprehensive On-Farm Water Management Pilot Project (referred to by the provincial governments as the "On-Farm Water Management Development Project"). This five-year project will cover 1500 watercourse command areas totaling about 600,000 acres of land and involving about 60,000 farmers. The major components of this Pilot Project (costing an estimated $40 million) include watercourse rehabilitation, precision land leveling, and water management advisory services. The research data of the CSU program, and the particular vehicles by which these were transferred to farmer and official audiences, convinced both the GOP and the USAID Mission that such a pilot project was both needed and feasible. This program has been actively underway during the past two report years with the first watercourses being completed in September 1977. Now, the World Bank and the governments of Canada and the United Kingdom have developed watercourse improvement projects to be implemented soon in Pakistan.

A training program has evolved for farm level extension personnel as a result of both the Pilot Project and the concern of provincial agriclutural departments. It has been realized that saving water through reducing conveyance losses is only half the job; the farmer must also receive help to utilize his water more effectively for increased crop production possibilities. The first training course for Water Management Extension Officers was given June 10-October 20, 1977. The graduating class consisted of 16 participants representing all four provinces. The second course was conducted April-August 1978, while the third course was initiated in March 1979.

As improved models of the panel water control structures have been designed, they have been immediately adopted by the On-Farm Water Management Development Project in the Punjab, where this program is moving ahead rapidly. Several sources indicate that the successful performance of these control structures is a major factor in motivation of farmers to enter into the watercourse improvement program. This technology will be transferred to the other provinces in the very near future.

The finding that good cleaning and maintenance of watercourses increases delivery of water to the fields by about 50% is being incorporated into the training materials for the Water Management Extension Officer Training Program at UAF so that the

Agricultural Extension Officers training under this program will have the faith and visual aids necessary to convince the farmers to take this apparently mundane step which can provide them with such substantial benefits at such low cost. A common host country request is that we focus more attention on how to give existing organizations a mission and requisite capabilities, rather than conceiving new organizations. The cleaning and maintenance research which has been carried out primarily by Field Assistants (with training comparable to that of Field Assistants in the Department of Agriculture of the various provinces) indicates a real potential for carrying this message and the necessary technology to the farmers via the existing extension program. The watercourse improvement program involved in the On-Farm Water Management Pilot Project will improve only about 2% of Pakistan's watercourses and even the most ambitious proposals would require a decade or more to improve all the watercourses in Pakistan. However, programs for giving field training to extension Field Assistants, which would allow them to lead the farmers in watercourse cleaning and maintenance projects, could be developed within a year and the training and maintenance and cleaning programs could be achieved within two or three years. Current observations indicate an alarming tendency of farmers on some of the improved watercourses to not maintain their watercourses. It is probable that both the watercourse improvement program and the proposed cleaning and maintenance program could be benefited by requiring a good cleaning and maintenance program as a prerequisite for participating in the improvement program which provides the farmers with the concrete control structures.

The findings of the cleaning and maintenance program and the low operational level design trial provide a real opportunity for reducing the water losses by about 25% of what they were prior to the improvement program. The improvement program underway in the On-Farm Water Management Pilot Project and the improved watercourses at Mona reduce losses to about 50% of what was occurring before the improvement was undertaken. However, this improvement does not persist if the watercourses are not cleaned and maintained regularly and losses tend to creep back up to 60, 70 or even 80% of their original values. Within a year or two, development of good visual aids and sound arguments to help the farmers understand the potential for increasing their water delivery to the field by cleaning, maintaining and redesigning their watercourses should play a major role in giving further emphasis to the on-farm water management programs existing in Pakistan and those which may be developed in other countries of the world.

A series of seminars on "Water Users Associations for Improving Irrigated Agriculture" was held in each of the four provinces of Pakistan and the Federal Capital in June 1978. Dr. George Radosevich spent one-month TDY for this purpose to assist Prof. Ashfaq Mirza and Mr. Douglas Merrey. There was unanimous approval at the provincial seminars of the need to legally constitute some form of association. For this reason, a proposed draft of an Irrigation Association Act or Order was prepared that was consistent with the seminar recommendations. The proceedings of these seminars were published by the Ministry of Food and Agriculture, Government of Pakistan, Islamabad.

As the pilot watercourse improvement program has evolved at Mona, a steady stream of at least 1000 visitors annually from the provincial and federal government, USAID, FAO, the World Bank and several other countries have visited the projects, talked to the farmers and seen the improvements. This on-site inspection has been reported as a major factor helping bring about the acceptance of the water management program by various agencies in the Government of Pakistan.

The results concerning conveyance efficiency in watercourses have had a major impact on Pakistan's future planning and on programs presently being developed. Previously, plans for water related projects assumed 90% of the water delivered to canal outlets or by public tubewells was delivered to the fields. Presently, the Federal Planning Commission is assuming that 60% is delivered. Our measurements suggest this value is still about 7% high, but it is certainly much more realistic than previous assumptions. New SCARP programs on the drawing boards are including plans for rebuilding of watercourses as part of the SCARP program. International funding agencies such as IBRD (World Bank), SIDA, and Canadian Aid are interested in funding water management related programs. Agencies such as the Punjab Agriculture Department and the WAPDA Master Planning and Survey Division are using our results in the planning process as a basis for new programs.

A team of five Canadians visited campus personnel in January 1979 and then traveled to Pakistan to determine the feasibility of the Canadian government providing assistance for a facility in the Sind that would be comparable to Mona. In addition, they recommended that such a research program include faculty at the Sind Agricultural University at Tandojam.

The undergirding philosophy of the CSU Water Management Research Project from its inception has been the clean objective of building up host country capabilities in the water management related fields. All research and other program activities involve host country personnel--ranging from extension workers, engineers, agronomists, social scientists, as well as officials in applied field training. The program identification surveys in the Punjab and Sind Provinces alone resulted in field training of a group of about 30 individuals from disciplines including agronomy, economics, extension and engineering. This state of the art study was done in cooperation with the WAPDA Master Planning group and all trained personnel have been employed by WAPDA for an intensive survey of 60 command areas (UNDP and World Bank funding), which is now nearing completion. This same trained staff will be used in the near future for the "Monitoring and Evaluation of the On-Farm Water Management Pilot Project."

Formal graduate training at the CSU campus was continued during this report year by Mr. Barkat Ali (Agricultural Economics), Mr. M. Hanif (Agronomy), and Mr. M. A. R. Farooqi (Agronomy). Mr. Mohsin Wahla (Agricultural Extension) and Mr. Mohammad Akram (Agricultural Engineering) completed their campus training December 1978 and will complete their field research programs during this final contract year. Mr. Zahid Khan (Agricultural Engineering) began his campus training in September 1978. An important innovation in this formal training is the requirement that after successful completion of course work, the candidate for a degree will return to Pakistan and conduct his thesis research on a relevant problem area in his representative field. The field research, data analysis, writing of the thesis, and final examination are all completed in-country under the guidance of the CSU Field Party. Mr. Ghulam Hussain successfully completed his Ph.D. in Agronomy in the summer of 1978 and is presently active in research at Mona. The field research program was conducted at Mona and resulted in findings that advanced technical procedures for evaluating salinity of irrigation water supplies. Mr. Nur Din Ahmad, who is a senior official of the Land and Water Reclamation Directorate in Lahore, has completed his M.Sc. in Agronomy and course work for a Ph.D. and is presently doing his research. Mr. Khalid Gill has completed course work at the Ph.D. level in Agronomy and returned to Punjab Agricultural Research Institute (PARI). He will complete the requirements for the Ph.D. degree in soils under CSU staff guidance during the final contract year.

Realizing the worldwide demand for expertise in on-farm irrigation related fields, the project has provided an opportunity for two state-side graduates to conduct field research in Pakistan. Mr. Tom Trout is a Ph.D. candidate in Agricultural Engineering and his research will result in a comprehensive technical design manual for improvement of farm water conveyance systems. Mr. Larry Nelson, who returned to campus in December 1977, conducted his research at MREP related to the problem of kharif (summer) season, including his soil temperatures, crusting of soil, and the germination and emergence of maize and cotton. He is presently conducting field research on soil crusting in western Colorado using soils similar to those found in much of Pakistan. Both candidates received much orientation at CSU prior to their research tour in Pakistan. Trout will complete his work in 1979, while Nelson will complete the writing of his dissertation in 1980.

While not directly related to or sponsored by the CSU project, Field Party members have helped arrange research sites and provided guidance for two social anthropologists from the University of Pennsylvania and one economist from the University of Wisconsin during the first contract year. These three Ph.D. candidates conducted their research on subjects relevant to Pakistan's irrigation problems. One of the social anthropologists became a member of the CSU Field Party in April 1978.

Beginning in June 1977, Mr. Ramchand Oad, a Ph.D. student in Agricultural Engineering at Cornell University, received special training at CSU in irrigation engineering and the interdisciplinary aspects of on-farm water management. He returned to Cornell University in September 1978 and then undertook his dissertation work in Indonesia in early 1979 as part of an AID funded irrigation research program in Asia. Later, Mr. Oad will return as a faculty member in the Mehran University of Engineering and Technology located in the Sind at Nawabashah.

Expertise developed in the research and surveys conducted in Pakistan is providing a substantial springboard for the water management project in Egypt where aspects of the problem identification surveys found effective in Pakistan are proceeding at an accelerated pace in Egypt because they have been able to avoid some of our mistakes and because Pakistan Field Party members who have returned to campus are available to give support and on-the-spot guidance to the Egyptian Program.

The relative success of the farm water management research in Pakistan in helping develop a viable national water management improvement program has led to a continuing stream of requests for information concerning how the research programs were conducted and the available findings. A slide show titled "Investments in Water Management" has been developed to tell these experiences. A half hour movie on "Watercourse Improvement" is also available for this purpose. However, one of the primary means of transferring this information to other programs is for project members to consult with individuals involved in water management in other countries and international programs. These consultants have involved TDY trips of Kemper to Sri Lanka and Reuss to Thailand. The World Bank has shown interest in the program and has at various times asked for consultations with Clyma, Kemper, Lowdermilk, Radosevich, Freeman and Skogerboe. The Food and Agriculture Organization of the United Nations has also shown a strong interest in the program asking for a paper on the history of the project and asking Kemper to spend three weeks with them writing a position paper on how water management research should be organized and coordinated with development programs in developing countries.

Four of the CSU Field Party have visited Ludhiana University and the watercourse lining program in India, including John Reuss, Tom Trout, Norman Illsley and Dwayne Konrad. The experiences in India are being given serious consideration in Pakistan.

Dr. Doral Kemper participated in the development of a project paper in Sri Lanka during October 1978. The role of Dr. Kemper was to look at investments in improved water management that would result in increased food production for Sri Lanka.

G. Involvement of Minority Personnel and Women

A project was developed jointly with CSU and USAID to determine the effective role of rural womin in deciding priorities in investment, especially for agricultural and water improvement projects. Dr. Sam Johnson previously was in charge of coordinating this project with Mrs. Emily Datta, a graduate student from the University of California, Berkeley, to do the actual field work. This project was funded by USAID/Islamabad with the end result to be a report to USAID describing the role of rural women in decision making and recommending steps to be taken to better reach this segment of the population. The project gathered data in the villages in the Mona and Faisalabad areas. The final report is presently being written.

H. List of Publications

1. Water Management Technical Reports

a. Farm Irrigation Constraints and Farmer's Responses: Comprehensive Field Survey in Pakistan by Max Lowdermilk, Alan Early and David Freeman. Water Management Technical Report No. 48 (six volumes). September 1978.

Abstract

Volume I summarizes the findings of the six volume study, "Farm Irrigation Constraints and Farmer's Responses: Comprehensive Field Survey in Pakistan". The purpose of the study was to answer a major question, "What are the significant farm level constraints confronting farmers in their irrigation systems which are presently responsible for low crop yields and crop production?" As a problem identification field survey, the goal is to describe how farmers respond to selected constraints as they manage irrigation water for their crop production systems.

The findings are based upon a sample more fully described in Volume VI, Appendix I, Part A. Data was collected during 1975 and the winter-spring months of 1976 on a sample of 387 farmers located in 16 villages and 40 watercourses stratified by head, middle and tail location. The research sites were selected so as to represent the major agro-climatic zones of the Pakistan Punjab and Sind, but because of USAID's emphasis on the small farmer, the sample includes a disproportionately large sample of villages characterized by small farmer owner-operator majorities.

Chapter 1 sets forth major findings related to the irrigation system: delivery to the farm, field application efficiency and irrigation efficiency; agronomic factors: crop yield per acre, cropping patterns, intensities; and farmers' perceived constraints with regard to economics, knowledge of agricultural practices, water codes and regulations, and farmer organization. Each of the findings is followed by one or more policy implications.

Employing base-line knowledge gained from the survey, Chapter 2 describes possible criteria--physical, economic and social--to be considered in the selection of watercourse commands for comprehensive improvement of water management in Pakistan.

Chapter 3 discusses implications of subsequent projects, surveys and/or implement improvement programs, in terms of delivery efficiencies and application efficiencies.

Appended to the text of this volume are glossaries which include photographs taken in Pakistan during the survey, English and Urdu/Punjabi terms.

Overall the structure of the report which follows in the subsequent volumes is:

Volume II: States research objectives and describes major features of the irrigation system being studied--rivers, canals, moghas, watercourses, tubewells, and the organization of village social networks.

Volume III: Establishes the consequences of the existing irrigation system, a major one being low agricultural productivity in a part of the world which has potential to be one of the most productive regions on this planet.

Volume IV: Examines major constraints confronting farmers within the existing system which are associated with the low productivity discussed in Volume III.

Volume V: Presents farmers responses to the constraints detailed in Volume IV.

Volume VI: Contains supplementary appendix materials relating to methodology, data summaries, watercourse profiles and maps.

2. Field Party Reports

a. Optimization of Lengths of Alternative Watercourse Improvement Programs in Pakistan, by John Reuss. Progress Report No. 11.

b. Operational Irrigation Evaluations of Three Watercourse Systems by Ch. Rahmat Ali, Mohammad Ashraf, Tom Trout, Waryam Ali Mohsin, Mahmood Ahmad, Nazir Ahmad Anwar, and Mohammad Umar Khan. WAPDA Publication No. 1. August 1978.

c. Abstracts of Reports and Publications by Colorado State University, Water Management Research Project in Pakistan. December 1978.

3. Theses

a. Irrigation Water Quality Evaluation Under Pakistan Conditions, by Ghulam Hussain. Ph.D. thesis, Summer 1978.

Abstract

A study on irrigation water quality utilized results from three related investigations; a lysimeter study, a field study and theoretical investigations on residual sodium carbonate (RSC). The purpose was to determine water quality effects on soils and crops in order to recommend appropriate changes in the water quality guidelines in Pakistan.

In the lysimeter study, 29 waters of desired total dissolved solids (TDS), sodium adsorption ratio (SAR) and RSC combinations were synthesized and used for irrigation. Three soil types: sandy loam, loam and clay loam were used. Crop rotation of berseem, maize, and wheat was used. Irrigation with mixed tubewell and canal water was done under farmer's management conditions. The theoretical basis of RSC and determination of whether RSC is a useful index in predicting the effects of irrigation water on soils was investigated along with total alkalinity, RSC and residual sodium carbonate (calcium only), (RSCC) indexes.

Results indicated that RSC is not a valid criteria in determining its effects on soils and crops since its effect is confounded with that of the Ca/Mg ratio. The SAR of water was found to be more closely related to the final electrical conductivity of the saturation extract (ECe) and SAR of soil than was the EC of the water. Change in the SAR of the soil, as predicted by chemical equilibrium due to change in $CO_2$ partial pressure, was relatively small for waters containing significant Mg. However, changes due to leaching fractions were substantial. Among the various alkalinity index investigated, RSCC was the most effective in predicting the Ca content of equilibrium soil solution followed by RSC and total alkalinity. If waters are generally low in Mg, RSCC and RSC are essentially the same, but with high Mg waters they are not.

Based on the results and subsequent discussions, it is recommended in the future that under any water quality

evaluation program, the following conclusions should be followed:

1. The RSC criteria for water quality evaluation should be discarded. If alkalinity is to be considered, the RSCC criteria should be used instead of RSC since it is a better index for predicting final Ca concentration of the equilibrium soil solution.

2. The analytical procedure followed for determination of total (Ca + Mg) should be replaced by methods which will accurately determine both Ca and Mg in the soil saturation extract, because many of the ground waters in Pakistan are high in Mg. There is a possibility that Mg saturated soils might develop. Further high Mg content of water may be a source of Mg toxicity or induce nutrient deficiencies in plants.

b. Computer Evaluation of Surface Irrigation Systems, by Kenneth Litwiller. M.S. thesis, Summer 1978.

Abstract

An evaluation procedure was developed for analyzing the performance and effective water use of farm surface irrigation systems. This procedure included data sheets, data forms, and a digital computer program.

For purposes of evaluation, the subsystems of water-conveyance, water-application and water-allocation were considered separately and evaluation parameters were defined for each. The purpose of the procedure was to determine values for these parameters by using field data.

The flexibility and utility of the evaluation procedure was demonstrated by using real and sample data. Values of the evaluation parameters were calculated and tabulated for a farm for a growing season.

4. Journal Articles

a. Improving Irrigation Water Management in the Indus Basin by Sam Johnson, III, W. Doral Kemper, and Max K. Lowdermilk. Water Resources Bulletin, Vol. 15, No. 2. April 1978.

Abstract

Over half of the water delivered from the canal system to the watercourses managed by the farmers is not made available to the farmers' crops in Pakistan. Most of this water loss is due to loss of water through the banks of the watercourses. Lack of maintaining these banks and lack of cleaning the watercourse is a result of inadequate organization

of the 10 to 150 farmers who use the watercourse, and a deficiency of knowledge concerning the amount of their water which is being lost.

Various methods of watercourse improvement have been evaluated including concrete and masonry linings and simple earthen improvements of the ditches with concrete control structures, junctions and turnouts. With the cost of labor low in Pakistan, the earthen improvements with concrete structures appears to be the best investment.

Farm water management improvement programs have been implemented in most of the provinces which include this type of watercourse improvement, land leveling and advice to the farmers on how and when to irrigate his crops to optimize his production.

The rate at which personnel can be trained to help the farmers implement these improved water management practices is limiting the rate of implementation.

b. Land Leveling and Watercourse Improvements for Pakistan by Muhammad Shafique, Wayne Clyma and Sidney Bowers. Presented at the 1978 summer meetings of American Society of Agricultural Engineers, June 1978. ASAE Technical Paper No. 78-2021.

Abstract

A watercourse area was selected for evaluation of channel improvement and land leveling in Pakistan. Application efficiencies averaged 46 percent on unleveled fields. Delivery efficiency increased from 71 percent to 88 percent after improvement. Benefit cost ratios for channel improvements ranged from 2.2 to 11.5.

c. Farm Water Management Constraints to Indus Basin Crop Production by Alan Early, Max Lowdermilk, and David Freeman. Presented at the 1978 summer meetings of American Society of Agricultural Engineers, June 1978. ASAE Technical Paper No. 78-2023.

Abstract

An interdisciplinary problem identification field survey in irrigated districts of Pakistan provided insights into the four major water management constraints experienced by farmers. The physical and irrigation constraints emphasized water supply, farm location, field levelness, and watercourse (tertiary) condition for conveyance. The agronomic and economic constraints dealt with input and credit availability and utilization of improved technologies and high yielding varieties plus

their requisite practices. The knowledge and information constraints ranged from the cropping decision basis, irrigation scheduling basis, recognition of water losses and field levelness, to knowledge of improved practices, institutional services and information sources. The organizational and institutional services emphasized the lack of incentives for group activities as well as services received by farmers, kinship cooperation boundedness, social conflict related to water and the importance of power and influence on village watercourse maintenance activities.

d. Physical and Socio-Economic Dynamics of Irrigation in Pakistan by Max Lowdermilk, Wayne Clyma and Alan C. Early. Proceedings of the ASCE Speciality Conference on Legal, Institutional and Social Aspects of Irrigation and Drainage and Water Resources Planning and Management, June 1978.

Abstract

There is a growing awareness today (1978) that an important aspect of irrigation has been neglected. Water management on-farm must be improved to meet the present and growing demands for increased food production. Levels of living must be enhanced in rural areas. Improvement of on-farm water management directly meets both needs and provides local employment to a large number of the rural underemployed.

This paper describes a procedure for the identification of priority problems in water management. The procedure is applied as a case study of an outlet command area in Pakistan. Problem identification involves an interdisciplinary approach with farmer participation to achieve an understanding of the farm water management system operation. The result is an objective, quantitative definition of priority problems.

A systematic approach to improving water management as a research-development process includes problem identification, a search for solutions, assessment of solutions and implementation of a program that provides the solutions to all farmers (Clyma, Lowdermilk and Corey, 1977). This approach has been tested in Pakistan and is being tested in Egypt.

Irrigation began in Pakistan with the Mohanjandaro civilization more than 3500 years ago. Modern irrigation was begun by the British in the late 1800s. Major emphasis on irrigation development and improvement increased in the early 1960s. Corey and Clyma (1974) and Clyma and Corey (1975) have summarized these developments and discussed their implications. Basically irrigation in Pakistan is characterized by continued waterlogging and salinity, a shortage of water such that an average of only half the available irrigated land is cultivated during any year, and low crop yields relative to the potential.

The great emphasis on irrigation development during the 1960s neglected water management because on-farm use of water was assumed to be very efficient (Clyma and Corey, 1975).

e. Use of Gypsum Stones to Lower the Sodium Absorption Ratio of Irrigation Water, by Bashir Ahmad, W. D. Kemper, Ghulam Haider and M. A. Niaza. Accepted for publication by the Soil Science Society of American Proceedings.

Abstract

Many sources of irrigation water have sufficiently high $Na^{+}/Ca^{++}$ ratios to be harmful to soils and crops. When the salt contents of the waters are reasonably low, the primary method of lowering this ratio is to apply extra $Ca^{++}$ on the fields or in the water. Gypsum is generally the most reasonably priced source of $Ca^{++}$. A major portion of its current cost is associated with grinding the stones to a powder and application of this powder to the fields.

This study shows that gypsum stones 5 to 20 kg in size are a usable source of the $Ca^{++}$ needed to bring down the SAR in sodic irrigation waters. The dissolution rate of the gypsum stones is proportional to the square root of the velocity of flow through the bed. Since the time of residence of solution in the bed is inversely proportional to its velocity through the bed, the increase in concentration of $Ca^{++}$ in solution as it passes through the whole bed is inversely proportional to the square root of the velocity of flow. Solution concentration is also inversely proportional to the square root of the size of the stones in the bed.

Equations were developed to facilitate design of channels with the proper cross section and length to supply the needed amounts of $Ca^{++}$ to the water when the average size of the stones, the flow rate of the water, and the initial ionic concentration of the water are known.

f. Infiltration of Soils as Affected by the Pressure and Water Content at the Time of Compaction by Mohd. Akram and W. D. Kemper. Accepted for publication by the Soil Science Society of America Proceedings.

Abstract

Infiltration rates, volume reduction and bulk densities of soils were determined on soils as a function of compacting pressures and water content at the time of compaction.

Maximum compaction generally occurred when the soils were packed at water contents near field capacity.

When compacting loads were less than 1 $kgm/cm^2$ the minimum bulk densities occurred when soils had water contents of about one half field capacity, indicating that surface tension of water films in the soils plays a major role in cohesiveness and stabilization against compaction under these conditions.

Compacting loads of 3.46 $kgm/cm^2$, at field capacity on sandy loams and finer textured soils, reduced infiltration rates to less than 0.1% of values obtained after these soils had been compacted when they were air dry. In a loamy sand soil this reduction was to about 1%.

The low infiltration rates following compaction were increased by wetting and drying although several cycles of wetting and drying did not raise the infiltration rate to the level observed before packing.

Freezing and thawing cycles also increased the infiltration rates of previously compacted soils. Most of the change took place in the first freezing and thawing cycle.

The large changes in infiltration rates using achievable levels of compaction at the "optimum" water contents indicate that compaction can play a major role in the management of water in ditches, reservoirs, furrows and watersheds.

5. <u>Movies and Slide shows</u>

   a. Investments in Water Management by W. Doral Kemper and Richard L. Aust.

   b. Watercourse Improvement by W. Doral Kemper and Dan Lattimore.

6. <u>Brochures</u>

   a. Improving Agricultural Production Through On-Farm Water Management, Dan Lattimore, editor; Jim Mealler, illustrator; and Dale Rosenbach, designer.

# APPENDIX 1

## A SMALL FARMER'S COTTON EXPERIMENT IN THE MONA PROJECT AREA

Douglas J. Merrey and Sardar Mohammad Langah1/

During the 1977 Kharif season, Larry Nelson, a Colorado State University Agronomy student, carried out a cotton experiment in the Mona Project Area. On seven acres of land in Chak 11 ML, District Sargodha, he conducted experiments to determine the feasibility of planting cotton on beds, application of recommended rates of fertilizer and insecticides combined with controlled irrigation. Mr. Nelson was not entirely satisfied with the results of his experiment but remained convinced that the basic approach is appropriate for this area. Therefore, before he left Pakistan, he asked Sardar Mohammad Langah of village Khizar, a local farmer, if he would be willing to grow cotton following Mr. Nelson's instructions. Mr. Sardar Mohammad had been an interested observer of Mr. Nelson's project, and readily agreed. Mr. Douglas Merrey agreed to act as the communicator and go-between.

Mr. Nelson provided one container each of the insecticides Nuvacron-40 and Nogos, a hand-operated sprayer, money for fertilizer and seeds, a rain gauge, and detailed instructions (See Appendix II). Mr. Merrey had the instructions translated into Urdu and helped Sardar to understand them and monitored the progress of the work. Mr. Sardar Mohammad owns only about 1¼ acres of land, and cultivates about three more acres on a sharecropping basis. He was able to spare only one quarter acre of his own land for planting cotton. He and his brother did all of the labor. The beds and furrows were made by hand, they used a borrowed hand-seeder for sowing and did all of the weeding, spraying, irrigating, etc. themselves. His family harvested the crop. Since his watercourse had been improved with Mona Project aid the previous year, he had sufficient water even though his land was towards the tail of the watercourse. He maintained detailed records of all inputs and rainfall. This report is based on those records plus discussion between the two authors.

### The Experiment

The experiment was carried out in the 1978 Kharif season. This section provides a month by month record of the cultivation progress with comments on problems faced.2/

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1/Respectively, Assistant Professor, Social Anthropology, Colorado State University, and small progressive farmer of village Khizar, District Gujrat, Pakistan.

2/See Appendix I for totals of major inputs.

May

| Day | Activity | Quantity | Quantity per acre |
| --- | --- | --- | --- |
| 05 | rouni irrigation (No. 1) | 3" to 4"<br>27 lbs. DAP | 1<br>108 lbs. DAP |
| 08 | broadcast fertilizer<br>4-plowings (tractor) and<br>4-plankings | 6 lbs. urea<br>4<br>2 | 6 lbs. urea |
| 9-10 | made beds (40" wide) by hand | | |
| 11 | sowed seeds with hand planter | 6.6 lbs. | 26.4 lbs. |
| 12 | irrigation until furrows filled to 3/4 height of the beds (No. 2 ) | | |
| 19 | Hand resowing of seeds where germination was thin and irrigation (No. 3) | 2.2 lbs. seed | 8.8 lbs. |
| 23 | broadcast Malathion mixed with wood ash on plants because insects (locally called toka) were eating plants | 1 lb. | 4 lbs. |
| 29-31 | first hoeing and weeding | | |

The sowing was done about one month later than Mr. Nelson had recommended because of Mr. Merrey's late arrival in Pakistan and the consequent delay in Mr. Sardar Mohammad's getting the seeds and instructions. Since acid was not available the seeds were soaked in water for 36 hours before sowing. By mixing the seeds with dust and ashes they were fully cleaned an hour before sowing. Mr. Sardar Mohammad felt emergence was poor because the germination of the seed was low. The seed was a mixture of about 75 percent Delta Pine-25, and about 25 percent desi and AC-134.

Malathion mixed with wood ash was used instead of the recommended insecticide because the sprayer had not arrived from the USA when the need arose. The Malathion-ash mixture was very effective in controlling toka.

## June

| Day | Activity | Quantity | Quantity per acre |
|---|---|---|---|
| 01 | first spray: Nuvacron-40 | 2 Chattank (4 ounces) | 1 lb. |
| 02 | irrigation (No. 4) | | |
| 04-06 | hoeing, weeding and thinning | 3-4" spacing between plants. | |
| 09 | spray No. 2 Nuvacron | 4 oz. | 1 lb. |
| 13 | rainfall | 13 mm | |
| 14 | rainfall | 10 mm | |
| 22 | spray No. 3: Nuvacron<br>Nogos | 6 oz.<br>4 oz. | 1½ lbs.<br>1 lb. |
| 26 | fertilizer: urea<br>irrigation (No. 5) | 26 lbs. | 104 lbs. |

The irrigation on the second of June was necessary because the plants were wilting from the severe heat. No thermometer was available to Mr. Sardar Mohammad but there was a record heat wave this month; the temperature in nearby Sargodha reportedly reached 52°C.

On the 26th too much fertilizer was mistakenly applied; the amount should have been fourteen lbs. not twenty-six.

## July

| Day | Activity | Quantity | Quantity per acre |
|---|---|---|---|
| 01 | rainfall | 2 mm | |
| 03 | rainfall | 29 mm | |
| 06 | rainfall | 12 mm | |
| 09 | rainfall | 60 mm | |
| 11 | spray No. 4: Nuvacron<br>Nogos | 6 oz.<br>4 oz. | 1½ lbs.<br>1 lb. |
| 14 | rainfall | 12 mm | |
| 17 | rainfall | 25 mm | |

| | | | | |
|---|---|---|---|---|
| 21-26 | rainfall every day; total: 117 mm | | | |
| 28 | spray No. 5 | Nuvacron<br>Nogos | 6 oz<br>3 oz. | 1½ lbs.<br>3/4 lb. |
| 29 | rainfall | | 10 mm | |

The fourth spraying containing Nogos caused leaf burn; consequently the amount of Nogos was reduced twenty-five percent for the fourth spraying3/. The number of sprayings during July was less than Mr. Nelson had recommended because of the frequent rains.

August

| Day | Activity | | Quantity | Quantity per acre |
|---|---|---|---|---|
| 01 | spray No. 6: | Nuvacron<br>Nogos | 4 oz.<br>2 oz. | 1 lb.<br>½ lb. |
| 02 | rainfall | | 11 mm | |
| 05 | rainfall | | 5 mm | |
| 12 | spray No. 7: | Nuvacron<br>Nogos | 6 oz.<br>3 oz. | 1½ lbs.<br>3/4 lb. |
| 19 | fertilizer:<br>(broadcast)<br>rainfall | urea | <br>10.5 kg<br>46 mm | |
| 21 | Spray No. 8: | Nuvacron<br>Nogos | 6 oz.<br>3 oz. | 1½ lbs.<br>3/4 lb. |
| 25 | rainfall | | 25 mm | |
| 26 | spray No. 9: | Nuvacron<br>Nogos | 6 oz.<br>3 oz. | 1½ lbs.<br>3/4 lb. |
| 28 | rainfall | | 46 mm | |

By the end of August the plants were six to eight feet tall and so thick that it was impossible to get among the plants to spray properly. Mr. Nelson's guidelines call for the first picking this month but because of the month's delay in sowing, the growth was about one month behind schedule.

3/The sprayer was never calibrated properly, which may have been a factor in the leaf burn.

## September

| Day | Activity | | Quantity | Quantity per acre |
|---|---|---|---|---|
| 03 | rainfall | | 5 mm | |
| 07 | spray No. 10: | Nuvacron<br>Nogos | 6 oz.<br>4 oz. | 1½ lbs.<br>1 lb. |
| 15 | rainfall | | 5 mm | |
| 17 | spray No. 11 | Nuvacron<br>Nogos | 6 oz.<br>4 oz. | 1½ lbs.<br>1 lb. |
| 18 | irrigation (filled furows) No. 6 | | | |
| 23-24 | first picking of cotton | | 16 seers[4/] (32.8 lbs.) | 131.2 lbs. |
| 27 | spray No. 12: | Malathion | 1 lb. | 4 lbs. |

In early September the cotton balls started drying before ripening, and dropping. Mr. Sardar Mohammad realized that the bolls were being attached by insects (bollworms) and felt the spray being used was not strong enough to solve the problem; this is why he used Malathion on the 27th.[5/]

The ladies of the household in Punjab traditionally pick the cotton; in this case the ladies were very unhappy because the cotton plants were so large and the growth so thick that it was difficult for them to harvest.

## October

| Day | Activity | | Quantity | Quantity per acre |
|---|---|---|---|---|
| 09 | second picking of cotton | | 32 seers (65.6 lbs.) | 262.4 lbs. |
| 12 | spray No. 13: | Malathion<br>Nuvacron | 1 lb<br>8 oz. | 4 lbs.<br>2 lbs. |

4/40 seers=1 maund=82 pounds. 1 seer=2.05 lbs.

5/Dr. Westfall, CSU Agronomist, later suggested it was already too late to solve the problem. It seems likely the heavy growth reduced the effectiveness of spraying when the cotton was flowering. Bolls around the edges of the field were not as affected as those deeper inside. The late sowing may also have been a factor.

| Day | Activity | | Quantity | Quantity per acre |
|---|---|---|---|---|
| 16 | irrigation (No. 7) | | | |
| 28 | third picking | | 40 seers (1 md) (82 lbs.) | 328 lbs. |
| 29 | spray No. 14: | Nuvacron<br>Nogos | 8 oz.<br>8 oz. | 2 lbs.<br>2 lbs. |

Mr. Sardar Mohammad applied Malathion again and increased the dosages of Nuvacron and Nogos, trying in vain to save his crop.

November

| Day | Activity | | Quantity | Quantity per acre |
|---|---|---|---|---|
| 06 | spray No. 15: | Nuvacron<br>Nogos | 6 oz.<br>4 oz. | 1½ lbs.<br>1 lb. |
| 10 | fourth picking of cotton | | 20 seers (41 lbs.) | 164 lbs. |
| 15 | spray No. 16: | Nuvacron<br>Nogos | 6 oz.<br>4 oz. | 1½ lbs.<br>1 lb. |

December

| Day | Activity | Quantity | Quantity per acre |
|---|---|---|---|
| 10 | fifth picking of cotton | 10 seers (20.5 lbs.) | 82 lbs. |
| 18 | irrigation (No. 7) | | |
| 28 | sixth and final picking | 10 seers (20.5 lbs.) | 82 lbs. |

January

06 cutting of the stalks for firewood

Up to September we had high hopes for a good crop, but this was not to be. The total production was three maunds and 8 seers (262.4 lbs.) which would be 12.8 maunds (1049.6 lbs.) on a per acre basis. This is two or three times the normal cotton production in Khizar, but considering the volume of inputs and the expectations, the production was disappointing.

## Costs and Income

Most of the inputs were supplied to Mr. Sardar by Mr. Nelson. The Mona Project supplied the seed. Therefore, Mr. Sardar's actual income from the project did exceed his own costs. However, if one includes the value of Sardar's own labor as a cost the total costs of production exceeded the value of the cotton produced.

Table 1 gives an estimate of the value of Mr. Sardar's labor input in terms of what it would have cost him if he had

Table 1. Estimated Labor Costs if Hired Labor Had Been Used

| Activity | | Rupee Cost | Cost per acre |
|---|---|---|---|
| preparation of beds (by hand) | 2 men x 3 days* at Rs. 15/day- | 90.00 | 360.00 |
| sowing | 2 men x 1 day (total of 2 sowings) | 30.00 | 120.00 |
| irrigation | Rs. 5 per irrigation x 7 times irrigated | 35.00 | 140.00 |
| spraying | 1 man x ½ day x 16 sprayings | 120.00 | 480.00 |
| thinning | 1 woman x ½ day at Rs. 10/day* | 5.00 | 20.00 |
| hoeing and weeding | 2 women x 2 days per hoeing x 2 hoeings; and | 80.00 | 320.00 |
| | 1 man x 3 days | 45.00 | 180.00 |
| picking | 3 women x 6 pickings rate is 5% of harvest total # | 25.50 | 102.00 |
| cutting stalks | 1 man x 2 days | 30.00 | 120.00 |
| | Total Labor Costs | 460.50 | 1842.00 |

*Mens' labor at Rs. 15 per day, including food; womens' labor at Rs. 10 per day including food. These are the prevailing rates in this area, and whole day rates are often paid even if the work is less than a full day but is laborious.
#Five percent of the cotton harvested is the traditional remuneration in this area; this is regarded as womens' work.

used locally hired labor. It is a fair representation of his labor cost only in the sense that if he had not participated in this experiment he would have used his time to produce another crop on the same piece of land. He did not actually use hired labor and would not have hired himself out for this time if he had not participated in the experiment. Table 1 shows the value of his labor input at Rs. 460.50.

Table 2 shows the other costs of inputs into this quarter acre of cotton. The high cost of the insecticides, particularly the Nuvacron 40 and Nogos, is especially notable. It is unlikely that such expensive insecticides would be used by small farmers. When added to the estimated labor cost, the total cost of production was Rs. 826.26, or Rs. 3155.08 on a per acre basis.

Table 2. Costs of Production of the Cotton

| Activity | Quantity | Rate Rupees | Total Cost Rupees | Cost per acre |
|---|---|---|---|---|
| plowing (tractor) | 4 cultivations<br>1 planking | 20/acre | 25.00 | 100.00 |
| fertilizer* | DAP 12.5 kg. | 72/50 kg. bag | 18.00 | 72.00 |
| | urea | 68/50 kg. bag | 34.00 | 136.00 |
| seeds* | 4 kg. | 3.50/kg. | 14.00 | 56.00 |
| Insecticides | | | | |
| Malathion* | 1½ kg. | 20/kg. | 30.00 | 120.00 |
| Nuvacron* | 2.5 liters | 50.25/ liter | 125.63 | 502.52 |
| Nogos* | 1.34 liters | 42.64/ liter | 57.14 | 228.56 |
| Sprayer* | 1 | | 50.00# | 200.00 |
| maliya (land revenue) and abiana (water rate) | | approx. 48/acre | 12.00 | 48.00 |
| | Total not including labor | | 365.77 | 1463.08 |
| | labor | | 460.50 | 1842.00 |
| | Total Cost | | 826.27 | 3305.08 |

*Supplied to Sardar at no cost.
#Sprayer bought for about Rs. 600; estimated life is six years, and assuming use on two quarter acre crops per year, the prorated cost is Rs. 50.

Table 3 shows the total income from the cotton experiment. To the cotton market value of Rs. 510, Rs. 100 was added as the estimated firewood value of the stalks, giving a total income of Rs. 610, or Rs. 2440 on a per acre basis.

Table 3. Income from Cotton Experiment

| Item | Quantity | Rate Rupees | Value Rupees | Sub-Total |
|---|---|---|---|---|
| cotton sold | 2 maund | 150/maund | 300.00 | |
| | 1 maund | 180/maund | 180.00 | |
| cotton not sold yet | 8 seers | 150/maund | 30.00 | 510.00 |
| estimated value of stalks for firewood | 4 maund | 4/maund | | 100.00 |
| | | Total | | 610.00 |
| | | (Rs. 2440 on a per acre basis) | | |

Table 4 shows if labor costs are excluded from the analysis, the cotton experiment shows a profit of around Rs. 244 (Rs. 976 per acre) which is respectable but not spectacular.[6] This is certainly higher than the usual profit from cotton in Khizar. However, if labor costs are included, the experiment shows a net loss of about Rs. 216. Farmers in Khizar do not normally calculate the cost of their own labor systematically and explicitly, Mr. Sardar feels that if labor costs are calculated no crop shows a profit; nevertheless, in this case Mr. Sardar is inclined to include the labor cost because of the abnormally high labor input. The return seemed too low for Mr. Sardar for the effort invested.

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6/It was not possible to plant a rabi crop for 1978-79, so this return on a quarter acre of land is a yearly return. From this point of view it is probably lower than other crops might have been.

Table 4. Profit and Loss from Cotton Experiment

| | Cost | | Income | | Difference | |
|---|---|---|---|---|---|---|
| | Experiment | Per Acre | Experiment | Per Acre | Experiment | Per Acre |
| Not including labor | 365.77 | 1463.08 | - | - | 244.23 | 976.92 |
| labor | 460.50 | 1842.00 | - | - | - | - |
| Total | 826.27 | 3305.08 | 610.00 | 2440.00 | (-216.27) | (-865.08) |

Conclusions

Mr. Sardar Mohammad suggests there were three major problems with the method used:

1. The plant spacing of 3-4 inches was too close. Since the plants tend to grow very large, especially on the rich soil of his land, he suggests the optimum spacing is about two feet. The bed width should be increased from forty to fifty inches.

2. Delta Pine is not the appropriate variety of cotton for this area; B-557 would be more appropriate.

3. The major problem, which was in part at least a result of the above two, was that insect infestation was very heavy and reduced production. In August to early September there were literally thousands of bolls (no count was made, unfortunately), most of which dropped off because of insects. Mr. Sardar believes the insecticide used was too weak to control the pests, and feels Malathion or Endrine would be better if it is available unadulterated. The lack of adequate insect control was undoubtedly also due to poor coverage with the spray because of the heavy vegetation growth.7/

Mr. Sardar Mohammad is impressed with the usefulness of beds and furrows especially since his soil tends to crust after irrigation. He also recognizes the advantages of beds and furrows in reducing damage to young plants when there is too much rain and in saving irrigation water. He plans to plant his next sugar cane crop on beds. Further, though he had abandoned growing cotton some years ago, he plans to plant cotton next year using beds and furrows and modifying the cultivation practices as discussed above. The input of insecticides and perhaps fertilizer will probably have to be decreased for economic reasons.

7/Mr. Sardar Mohammad did not remove and destroy the cotton stubble as quickly as he should have; in fact he did not at the time understand the reason for its prompt removal. He does the farming along, thus his time is at a premium and removal of stubble did not have high priority. He eventually plowed it under in late January, 1979.

Other farmers in Khizar were impressed by his crop but were intimidated by all the spraying and labor required. Furthermore, they would be unlikely to invest very much money in insecticides and the like--especially considering the high risks involved and the fact that the returns from spraying are not clear. If a bed shaper were available to them at a minimum cost, however, some farmers would probably adopt a simplified version of the above method of cultivating cotton.

Acknowledgments

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## Appendix I

Table A. Post-sowing Irrigation and Rainfall

| Month | Number of Irrigations | Rainfall | |
|---|---|---|---|
| | | No. Days | Amount |
| May | 3 | 0 | 0 |
| June | 2 | 2 | 23 mm |
| July | 0 | 13 | 267 mm |
| August | 0 | 5 | 133 |
| September | 1 | 2 | 10 mm |
| October | 1 | 0 | 0 |
| November | 0 | 0 | 0 |
| December | 1 | 0 | 0 |
| Total | 8 | 22 | 433 mm |

Table B. Consumption of Insecticide (ounces)

| Month | Nuvacron | Nogos | Malathion |
|---|---|---|---|
| May | 0 | 0 | 16 |
| June | 14 | 4 | 0 |
| July | 12 | 7 | 0 |
| August | 22 | 11 | 0 |
| September | 12 | 8 | 16 |
| October | 16 | 8 | 16 |
| November | 12 | 8 | 0 |
| December | 0 | 0 | 0 |
| Total | 88 | 47 | 48 |
| | (22 lbs. per acre) | (11.75/acre) | (12 lbs/acre) |

Table C. Consumption of Fertilizer

| Month | D.A.P. | | Urea | |
|---|---|---|---|---|
| | Amount | Per Acre | Amount | Per Acre |
| May | 27 | 108 | 6 | 24 |
| June | - | - | 26 | 104 |
| August | - | - | 23 | 92 |
| Total | 27 | 108 | 55 | 220 |

Table D. Picking Dates of Cotton

| Number | Dates | Quantity (Seers) |
|---|---|---|
| 1 | September 23-24 | 16 |
| 2 | October 9 | 32 |
| 3 | October 28 | 40 |
| 4 | November 10 | 20 |
| 5 | December 10 | 10 |
| 6 | December 28 | 10 |

128 seers =
262.4 lbs.
3 maunds, 8 seers
(1049.6 lbs. on a
per acre basis)

## Appendix II

Tentative Field Schedule for Growing Delta Pine 25

| Days prior to or after sowing | Tentative Date | Actual Date | Field Activity |
|---|---|---|---|
| 10-14 | 4/10 | 5/5 | Apply roni irrigation 4 to 5 inches in order to wet soil profile 4-5 ft. deep. |
| 3 | 4/18 | 5/8 | Cultivate and plank field. Make sure field has been cultivated well enough so that it will make a good seedbed. |
| 0 | 4/20 | 5/8 | Broadcast 3 bags Single Super Phosphate and 10 seer Urea/ acre |
| | | 5/9-10 | Bed-shaping and sowing may be done in one operation if the WAPDA bedshaper-planter is used. The furrow opener should be set on 80 in. centers for making broadbeds and the seed furrow |

| Days prior to or after sowing | Tentative Date | Actual Date | Field Activity |
|---|---|---|---|
| | | 5/11 | opener on 40-inch centers. Sow acid delinted Delta Pine 25 seed at the rate of 12-14 seers per acre. The seed should be sown at a depth of 1 inch. |
| | | 5/12 | Beds should be irrigated as soon after sowing as possible. Never wait more than one or two days to apply this irrigation as the seedbed is much drier in this method of field preparation than it would be in traditional basin sowing of cotton. It is important that the irrigation water be applied carefully. Do not allow the water to overtop the beds as this may cause severe crusting problems. Once the furrows are 3/4 full of water, reduce the amount of water coming into the field until the water neither rises or lowers in the furrow. Soak the beds for 30 to 45 minutes or until observations of the beds indicate the soil has become wet 6 to 8 inches from the edge. |
| 17-19 | 5/5 | 5/29-31 | Thin the cotton stand down to 1 plant every 3 to 4 inches. Weed the field at the same time to reduce labor. A population of 35,000 plants per acre is the most ideal plant population of Delta Pine 25 for consistent high yields. |
| | | 6/1 | Spray #1: Apply 1 lb. of Nuvacron 40 per acre. |
| 21 | 5/12 | 6/2 | Apply irrigation making sure beds soak 30 to 45 minutes after furrows are full |
| 28-21 | 5/19 | 6/4-6 | Clean field of all weeds. |
| 28 | 5/19 | 6/9 | Spray #2: Apply 2 lbs. of Nuvacron 40 per acre. |
| 42 | 6/2 | 6/22 | Spray #3: Apply 2 lbs. of Nuvacron 40 per acre. |

| Days prior to or after sowing | Tentative Date | Actual Date | Field Activity |
|---|---|---|---|
| | | 6/26 | Broadcast 55 seers Urea/acre in the furrows. Apply irrigation making sure beds soak for 30 to 45 minutes. |
| 56 | 6/16 | 7/11 | Spray #4: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/acre. |
| 60 | 6/20 | | First bloom flush may begin during this week. |
| 63 | 6/23 | 7/28 | Spray #5: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/acre. Apply irrigation making sure beds soak for 30 to 45 minutes. |
| 70 | 6/30 | 8/1 | Spray #6: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/acre. |
| 75-125 | 7/5-9/25 | | Drain fields after heavy rain. |
| 77 | 7/7 | 8/12 | Spray #7: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/acre. |
| 77-87 | 7/7 | 8/19 | Broadcast 45 seer Urea/acre in the furrows prior to or immediately following a rain. If no rain apply a light irrigation, just allowing furrows to fill, before turning water off. This will dissolve the Urea and carry it into the root zone. Otherwise Nitrogen will be lost. |
| 84 | 7/14 | 8/21 | Spray #8: Apply 1½ lbs. of Nuvacron 40 and 1 lb. of Nogos/acre. |
| 91 | 7/21 | 8/26 | Spray #9: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/acre. |

| Days prior to or after sowing | Tentative Date | Actual Date | Field Activity |
|---|---|---|---|
| 98 | 7/28 | 9/7 | Spray #10: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 105 | 8/4 | 9/17 | Spray #11: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 112 | 8/11 | 9/27 | Spray #12: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 119 | 8/18 | 10/12 | Spray #13: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 115-120 | 8/20 | 9/23-24 | First Picking |
| 126 | 8/25 | 10/29 | Spray #14: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 133 | 9/1 | 11/6 | Spray #15: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 140 | 9/8 | 11/15 | Spray #16: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 147 | 9/15 | | Spray #17: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 148 | 9/16 | | Apply irrigation (2 in.) |
| 154 | 9/22 | | Spray #18: Apply 1½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 161 | 9/29 | | Spray #19: Apply 1 ½ lbs. of Nuvacron 40 and 1 lb. Nogos/ acre. |
| 162 | 9/30 | 9/18 | Apply irrigation (2 in.) |
| 183 | 10/21 | 10/16 | Apply irrigation (2 in.) |

| Days prior to or after sowing | Tentative Date | Actual Date | Field Activity |
|---|---|---|---|
| 220-240 | 12/17 | 12/28 | Last Picking. |
| 241 | 12/18 | | Remove and destroy all cotton stubble as soon after the last picking as possible to remove source of insect infestation of next year's cotton crop. |

# APPENDIX 2

## RICE PRODUCTION GUIDELINES[1]

D. G. Westfall, Muhammad Hanif, Fateh Muhammad[2]

### INTRODUCTION

The primary purpose of this production guideline is to provide the Agriculture Officer with the basic knowledge required to advise farmers in the latest rice production practices. It is meant to be brief, factual and easy to read and use. For this reason referencing to scientific publications has not been done although the majority of the material presented here was obtained from such publications.

Rice is grown on about 4 million acres in Pakistan. About 50% of this area is in the Punjab with a production of 1.31 million tons. Punjab production figures for the last several years are given in Table 1. Some high yielding varieties have been imported from the International Rice Research Institute (IRRI) in the Philippines and production technology is being improved in Pakistan. Pakistan has not only become self-sufficient in rice but also exports large quantitites of high quality rice. This export results in a good source of foreign exchange. So far export has been to the Middle East, Far East and some African countries. However, there is a big market over the entire globe for the world famous high quality Basmati varieties and the demand continues to exceed the supply available for export.

The production of a good rice crop that will give top yields involves the integration of the latest production practices. The practices that will result in maximum yields are given in the publication.

### NURSERY ESTABLISHMENT

Establishing a good nursery is the first important step in the production of a good crop of rice. Essentially all

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1/Prepared by Colorado State University Water Management Research Project for use in the Agricultural Officer Training Course for the Pakistan On-Farm Water Management Research Development Program. The training program is conducted at the University of Agriculture at Faisalabad under the Direction of the Irrigation & Drainage Department.

2/Associate Professor, Department of Agronomy, Colorado State University; Agronomist, Punjab Water Management Project and Associate Professor, Agronomy, University of Agriculture, Faisalabad, respectively.

Table 1. Acreage and production (in thousands) of rice in Punjab.[1]

| Variety | 1972-73 Acreage | 1972-73 Production (tons) | 1972-73 Yield (mds/A) | 1973-74 Acreage | 1973-74 Production (tons) | 1973-74 Yield (mds/A) | 1974-75 Acreage | 1974-75 Production (tons) | 1974-75 Yield (mds/A) |
|---|---|---|---|---|---|---|---|---|---|
| Basmati | 1205 | 585 | 12.62 | 1305 | 622 | 12.39 | 1292 | 639 | 12.86 |
| IRRI | 274 | 211 | 20.03 | 287 | 218 | 19.75 | 329 | 255 | 20.16 |
| Local | 550 | 338 | 15.98 | 576 | 348 | 15.70 | 652 | 417 | 16.63 |
| Total | 2029 | 1134 | 14.41 | 2168 | 1178 | 14.13 | 2273 | 1311 | 15.00 |

1/1976-77 Annual Report, Rice Research Institute, Kala Shah Kaku.

rice is produced from transplanted seedlings. There are many considerations to be kept in mind when establishing a nursery to insure the production of an adequate supply of healthy seedlings for transplanting.

1. The rice nursery should be sown at a place which has easy access to water, preferably near a tubewell. If a tubewell is not available it should be located near the main water channel where water is available frequently.

2. Only good quality seed of high viability (germination) should be used. Pest infested, injured or dead seeds should not be used. The germination of the seed should be tested. This can be done by placing sand in a pot and planting the seed on the surface of the sand. The seeds should be kept constantly moistened and some paper or a fine layer of sand placed on the seeds to guard against high evaporation. The percent germination should be calculated as follows:

$$\text{Percent Germination} = \frac{\text{No. of seeds germinated}}{\text{Total No. of seeds sown}} \times 100$$

Seeds with a germination of 95% or more should be used. If this quality of seed is not available the seeding rate should be increased to compensate for the seeds that will not germinate. This method of checking seed germination is usually time consuming and farmers are usually not willing to follow this recommendation. Another way of evaluating seed viability is to put the seed in water. Those seeds which remain floating on the water surface should be discarded and the seeds that sink should be used for sowing a nursery. This method is not as reliable as a germination test, but is easier for the farmers to follow.

3. The entire nursery should not be sown at one time. At least two sowing dates should be used with an interval of 25 days. If the rice nursery is sown at the same time it will have to be transplanted at one time. Since labor during transplanting season is not always available it may be impossible to transplant all the fields at the same time. Secondly, limitations of irrigation water could also be a problem and prevent the transplanting of all the rice fields at the same time.

4. Harmful insects and diseases must be controlled by spraying or dusting. All farmers should plan to do this operation. The recommendations for this are

covered under the Pest Control section. It should be remembered that a pest infested or disease borne nursery will result in a crop heavily attacked by the pest or disease. The crop yield can be reduced drastically.

Time of sowing: The time of nursery sowing differs slightly with variety. The recommended sowing times are generally as follows:

a. Coarse Varieties: May 20 to June 8
b. Fine Varieties: June 1 to June 30

Seed Germination: Dry and selected seed should be soaked in water, piled on the floor and covered with a jute bag. No more than 15 seer of seed should be placed in one pile. The seed should be occasionally stirred and remoistened. Germination will start in 2-3 days and they should be sown in the nursery immediately.

Seeding Rate: The nursery should be sown at a rate of ½ seer of seed per marla (272.25 $ft^2$). Two lbs of ammonium sulfate or one lb of urea/marla should be applied at sowing. It has been observed that farmers generally sow more than two seers of seed per marla but this is not necessary. This is probably a result of using poor quality of seed over the years. Sowing too many seeds results in the reduction of seedling vigor and the plants become weak and pale because of excessive crowding. Root injury to a weakened plant at transplanting reduces the vigor of these plants. Unhealthy plants also become more susceptible to pests and diseases.

Sowing Method: Rice nurseries are sown in a number of ways:

1. Sowing in puddled nursery: The nursery should be grown on small plots of 10 marlas or less. Precision land leveling is convenient on small plots and should be done before sowing. Puddled soil should be prepared so that a soil-water suspension is formed. The germinating seed should be broadcast in this soil-water suspension and the water from the nursery drained and replaced by fresh water. This will ensure a free supply of oxygen to the establishing seedlings. The nursery should not be allowed to dry out otherwise weeds will start to grow. Usually weeding is not required. About 6 marlas of nursery are sufficient for planting one acre of rice. The nursery should be transplanted in 25-35 days. The effect of seedling age at transplanting on yield is shown in Table 2. When the seedlings are over 35 days the yields start to decrease.

2. Sowing in dry nursery: The land is thoroughly plowed and planked while in vattar to give a pulverized condition. The nursery should be irrigated 15 days before sowing and the germinating weeds plowed under. Plots of ½ marla each should be prepared, precisely leveled, seed broadcast and covered with a layer of well rotted farm yard manure. Irrigation water should be applied slowly so that the seed and the farm yard manure are not washed away to collect at one place. Excessive irrigation should be avoided. This type of nursery generally has good germination capability but weeds can become a problem. About 3-4 marlas are sufficient to plant one acre. The nursery is ready to transplant in 30-40 days. This is slightly longer than the previous method because pregerminated seed is not used.

3. Sowing by "lobbing": This method is followed in the area of D. G. Khan. The nursery is thoroughly plowed in vattar to a pulverized fine condition. A layer of well rotted farm yard manure and rice husk or gram bhosa 2-3" thick is spread on the soil surface and burned. The ashes are buried in the soil with a spade and the soil is given a light irrigation. Rice seed is sown at a rate of 2½ seer/marla. Water is applied daily till the seeds start germinating. Three days after germination 3 inches of water is applied. About 1 seer ammonium sulfate or ½ seer urea should be applied twice at weekly intervals. These seedlings are ready to transplant within 30-40 days.

SEEDBED PREPARATION OF FIELDS

Heavier soils, such as clay or clay loam, that have a good moisture retention capacity are best suited for rice production. There are two basic methods of seedbed preparation for rice production, puddling and dry preparation. In the puddling method all plowing and planking is done in standing water while in the dry method the plowing and planking is done when the soil is in vattar. Each method is accomplished as follows:

1. Puddling method: Irrigation water (4") should be applied 15-20 days before the scheduled date of transplanting. When the field has 2-3" water it should be plowed 4-6 times and planked 2-3 times. Care should be taken so the water depth is not excessive because high and low spots will not be visible and removed during planking. There are several advantages of using the puddling method for seedbed preparation. They are:

a. Weeds are removed and regrowth is reduced compared to dry seedbed preparation.
b. Percolation of water into the deeper soil profile is reduced.
c. Transplanting is easier to accomplish and seedlings are easily established and do not fall over.

2. Dry preparation: Seedbed preparation of dry, unflooded fields is relatively easier than is puddling. Four to six plowings followed by 2-3 plankings should be done. Similar yields have been obtained from fields that were transplanted in puddled and dry prepared fields. Where weeds are a problem or not controlled chemically, dry seedbed preparation should not be used because weeds will be a problem and reduce yields substantially. There are several advantages of dry seedbed preparation. They are:

   a. Less time is required.
   b. Seedlings adjust very quickly to seedbeds prepared by this method.
   c. It is much easier to plow a dry prepared field as compared to a puddled field after harvest.

RICE SOWING OR TRANSPLANTING

Two methods of establishing a rice stand in the field are possible: (1) direct sowing of seed into a soil at field capacity or in standing water; (2) transplanting of seedlings that have been growing in the nursery. The main difference that results from the two methods is weed infestations. Transplanted fields always have a lighter weed infestation than do fields where sowing seed into soil at field capacity or in standing water is used.

Direct Sowing: When this method is used the field is plowed and planked as stated above and then precisely leveled. Planting by this method should be done about 20 days before the recommended dates for transplanting. Direct sowing can be done in a number of ways:

1. Sowing at field capacity: The fields are thoroughly prepared and flooded 2-3 days before sowing. Seed is sown when the fields are at field capacity. Sowing by this method may be done by broadcast or sowings in line using the kera method. It has been observed that the germination of seed in the submerged condition can be reduced due to poor oxygen supply. Sowing in lines and broadcast does not make much difference although broadcasting may be the preferred method because it is the easiest.

2. Sowing in standing water: The seed is broadcast in 1-2" standing water and then drained after 36 hours. The field should not be allowed to dry up. Frequent irrigations every 4-5 days will be required to keep the field in the proper moisture condition. The disadvantage in this method is that some seeds may remain floating on the water surface which reduces germination. Soaking of the seed for 24 hours before sowing will eliminate this problem.

Advantages of direct sowing:

1. Transplanting of rice is highly labor consuming. At peak transplanting season shortages of labor are very common. Direct sowing has the advantage that it does not involve much labor.

2. The farmer does not have to plant a nursery.

3. Puddling is not required.

Disadvantages of direct sowing:

1. The germinating seeds are susceptible to attack and consumption by insects, birds and rodents.

2. If irrigation water is not maintained at the proper level weed infestation problems arise which reduces the yield of the crop.

Transplanting Seedlings: In Pakistan, sowing of rice is usually done by transplanting seedlings. Nurseries are grown and the seedlings are transplanted to the field. Transplanting is done in two ways:

1. Sowing in irregular fashion: Sowing in this method is done irregularly. There is no measurement of plant to plant distance. The farmers merely transplant the seedlings using their judgment as to how dense the stand should be. Poor stands usually result from this method.

2. Sowing in lines: Sowing in this method is done in lines. The main advantage of this method is that definite spacings can be set and better populations usually occur.

Time of Transplanting: The seedlings should be transplanted when they are 25-35 days old (Table 2). The nursery should be seeded so transplanting can occur during the following periods:

a. Coarse varieties: late June
b. Fine varieties: July

Table 2. Effect of age of seedlings at transplanting time on the yield of rice.[1]

| Age of seedling at transplanting | Yield[2] (mds/acre) |
|---|---|
| 15 | 52.3 |
| 25 | 56.6 |
| 35 | 55.4 |
| 45 | 51.3 |
| 55 | 47.7 |
| 65 | 44.8 |

1/Asmat Ali Shah, Saeed Ahmad, M. Afzal
Rice Research Institute, Kala Shah Kaku, 1974.
2/Average yield of a number of varieties.

Table 3. Effect of spacing on the yield of rice.[1]

| Spacing (inches) | Plant population level | Yield[2] (mds/acre) |
|---|---|---|
| 6 x 6 | 174240 | 34.1 |
| 4.5 x 9 | 154880 | 35.7 |
| 9 x 9 | 77440 | 41.3 |
| 12 x 12 | 43560 | 38.7 |
| 18 x 18 | 19360 | 35.7 |

1/Majid, Rice Research Institute, Kala Shah Kaku.
2/Average of a number of varieties.

Table 4. Effect of number of plants per hill on the yield of rice.[1]

| No. of plants per hill | Yield (mds/acre) | |
|---|---|---|
| | Basmati 370 | IR-4 |
| one | 16.2 | 65.1 |
| two | 14.1 | 66.9 |

1/A. Majid, Rice Research Institute, Kala Shah Kaku.

PLANT POPULATION: An optimum plant population level is necessary to ensure maximum yields. There are many reports in the literature that show optimum population levels are from 80,000 to 100,000 plants per acre. Recent results from the Rice Research Institute at Kala Shah Kaku (Table 3) show that a 9" x 9" spacing results in good yields. This spacing is recommended for all varieties. If this level of plant population is obtained on broadcast or line transplanted fields the differences in yields are nominal. There are various opinions regarding the number of plants required per hill. Research at Kala Shah Kaku has indicated that one plant per hill will yield as well as two plants per hill (Table 4). However, based on other data the Rice Recommendation Committee of the Seminar on Rice Production held at Sambara Inn, Larkana (1976) has recommended 2-3 seedlings per hill for some varieties. This number is usually not followed by farmers.

VARIETY: There are two main categories of rice varieties, coarse and fine.

1. Coarse varieties: These varieties are high yielders. The cooking quality of these varieties is not as good as the fine varieties and they are not preferred in local or international markets over the fine varieties. These varieties get lower prices in the market. Some of the coarse varieties are:
   a. Jhona 349
   b. IR-8
   c. IR-6

2. Fine varieties: These varieties are not as high yielding as the coarse varieties. However, they have excellent cooking quality and have a good market over the entire globe. The international fame of these varieties results in a big source of foreign exchange earning to Pakistan. Some of the fine rice varieties are:
   a. Basmati 370
   b. Basmati 6129
   c. Basmati 198

The general characteristics of the coarse and fine varieties are shown in Table 5. The chalkiness and poor cooking quality of the available coarse varieties has resulted in their limited acceptance although they are high yields. New high yielding varieties under testing do not have these adverse characteristics and hold good promise for the future.

FERTILIZATION: Much research work has been done on fertilizer requirements of rice. The fertilizer requirements are determined by soil type, initial soil nutrient status, variety, and available irrigation water resources.

Table 5. Characteristics of rice varieties.

| Sr No. | Characteristics | Varieties Jhona 349 | IR-8 | IR-6 | Basmati 370 | Basmati 6129 | Basmati 198 |
|---|---|---|---|---|---|---|---|
| 1 | Plant height (cm) | 167.5 | 95.0 | 95.0 | 170.0 | 170.0 | 137.5 |
| 2 | Leaf color | Green | Dark green | Dark green | Green | Green | Dark green |
| 3 | Leaf habit | Droopy | Erect | Erect | Droopy | Droopy | Semi erect |
| 4 | Stem stiffness | Weak | Very stiff | Stiff | Weak | Weak | Stiff |
| 5 | Growth period (days transplanting to maturity) | 95 | 110 | 110 | 120 | 120 | 130 |
| 6 | Yield (md/A) | 25-30 | 55-60 | 45-50 | 20-25 | 20-25 | 30-35 |
| 7 | Grain character | | | | | | |
| | a) kernal length (mm) | 6.36 | 6.14 | 6.60 | 7.00 | 7.70 | 6.90 |
| | b) kernal width (mm) | 2.00 | 2.43 | 2.00 | 1.83 | 1.80 | 1.90 |
| | c) kernal thickness (mm) | 1.94 | 1.94 | 1.70 | 1.60 | 1.66 | 1.69 |
| 8 | Aroma | No | No | No | Yes | Yes | Yes |
| 9 | Chalkiness | No | Very chalky | Slightly chalky | No | No | No |
| 10 | Cooking quality | Not good | Not good | Good | Better | Best | Good |

Pakistani soils are generally low in organic matter, deficient in available nitrogen, phosphorus and sometimes potash. The deficiency of available zinc has also been observed as a limiting factor in rice production at some locations.

## Nutrient Deficiency Symptoms

The deficiency symptoms of the nutrients that have been found to be deficient are given below. Since many soils are high in salinity the symptoms for high salt injury are also given. If any of these symptoms are observed immediate steps should be taken to correct the situation. Delay will result in a reduction of yields.

Nitrogen: Plants are stunted with a limited number of tillers. Leaves are narrow and short, erect and yellowish-green, except young leaves which are greener. Old leaves die when light straw colored.

Phosphorus: Plants are stunted with a limited number of tillers. Leaves are narrow and short, erect and dirty dark green. Young leaves are healthier than the others and old leaves die when brown colored. Reddish or purplish color may develop on leaves if the variety has a tendency to produce anthocyanin pigment.

Potassium: Plants are stunted, but tillering is only slightly reduced. Leaves are short, droopy and dark green. On lower leaves, yellowing takes place at the interveins, starting from the tip, and eventually these dry to a light-brown color. Sometimes brown spots may develop on dark-green leaves.

Zinc: The mid-ribs of the younger leaves, especially the base, become chlorotic. The more general symptoms are the appearance of brown blotches and streaks in lower leaves, followed by stunted growth. Tillering may continue. The size of the leaf blade is reduced, but that of the leaf sheath is little affected. In the field, uneven growth and delayed maturing are characteristics of zinc deficiency.

High salt injury: Stunted growth and reduced tillering. The tips of leaves become whitish and, frequently, some parts of the leaves become chlorotic.

Fertilizer Recommendations: The following fertilization practices may be followed. The choice of a particular recommendation is dependent upon a farmer's situation but commercial fertilizers will give good results consistently and is usually preferred.

1. Application of farm yard manure: If it is used a well rooted farm yard manure should be applied at a rate of 6-10 tons per acre one month before transplanting and thoroughly mixed with the soil.

2. Green manuring: Various research investigations conducted on green manuring for rice have indicated Dhaincha (Sesbania sesban) is a green manure crop for rice as compared to Guaro (Cyamopsis Tsoralioides). If it is used it has the following advantages:
   a. It is a quick growing plant and grows 4-5' high in 10-12 weeks.
   b. It can grow very well in standing water, can tolerate salinity, and decomposition in the soil is rapid as compared to other green manure crops.

   Dhaincha should be grown early in April and plowed down after 10-12 weeks.

3. Fertilizers: Application of heavy rates of nitrogen can result in lodging of the tall growing varieties. The short strawed varieties, particularly IR varieties, are more resistant to lodging and respond well to higher nitrogen fertilizer rates. Fertilizer recommendations for the most commonly grown varieties for rich, medium and low nature fertility status soils are given in Table 6. The proper timing of fertilizer application is also important if maximum returns are to be obtained.

Application of Zinc: Zinc deficiencies often occur in calcareous soils. These symptoms usually occur 15-20 DAT. The general recommendation is that 10 lbs zinc sulfate ($ZnSO_4$) be broadcast in the field after transplanting. This recommendation is correct for most soils. However, some may need more zinc while others do not need this amount. The application of 10 lbs zinc sulfate will not harm the plants if the soil is not deficient in zinc. The roots of the nursery plants may also be dipped in a solution of zinc oxide prepared by dissolving 2 lbs of zinc oxide in 10 gallons of water before transplanting.

IRRIGATION: The two systems of irrigation of rice that are commonly used are continuous flood and alternate wetting and drying.

Continuous Flooding: In this system rice fields are continuously flooded and water is applied frequently. Continuous flooding has a number of effects on rice plants and production, some beneficial and some detrimental. The detrimental effect results from too deep of flood.

1. Continuous flooding results in elongating the plants and the risk of loding of the crop increases if the water is too deep.

Table 6. Fertilizer recommendations for rice in the Punjab.[1]

| Variety | Soil fertility status | Quantity of fertilizers/A | Method and time of application |
|---|---|---|---|
| IR-6 and Bas-198 | Rich | 1 bag DAP plus ½ bag Urea (45 lb N+50 lb $P_2O_5$) | At transplanting before last plowing |
| | | ½ bag Urea (25 lb N) | 22-25 DAT[2] |
| | | ½ bag Urea | 45-50 DAT |
| IR-6 and Bas-198 | Medium | 1 bag DAP plus 1 bag Urea 70 lb N+50 lb $P_2O_5$) | At transplanting before last plowing |
| | | ½ bag Urea | 25 DAT |
| | | ½ bag Urea | 40-45 DAT |
| IR-6 and Bas-198 | Poor | 1 bag DAP plus 1 bag Urea | At transplanting before last plowing |
| | | 1 bag Urea (50 lb N) | 20-25 DAT |
| | | ½ bag Urea | 40-45 DAT |
| Basmati 370 and Pak-Basmati | Rich and medium | ½ bag DAP (10 lb N+25 lb $P_2O_5$) | At transplanting before last plowing |
| | | ½ bag Urea | 20-25 DAT |
| | | ½ bag Urea | 40-45 DAT depending on condition of crop |
| Basmati 370 and Pak-Basmati | Poor | ½ bag DAP plus ½ bag Urea (35 lb N+25 lb $P_2O_5$) | At transplanting before last plowing |
| | | ½ bag Urea | 20-25 DAT |
| | | ½ bag Urea | 40-45 DAT depending on condition of crop |

1/Recommendations of Rice Production Seminar (1976) arranged by ESSO Chemicals (ENGRO) at Sambar Inn on May 31 - June 1, 1976.

2/DAT = Days after transplanting.

2. Tillering capacity is decreased and ultimately yield will be decreased if the water is too deep.

3. Continuous flooding controls weeds very effectively. If water is maintained 2" deep grasses are controlled and at 3" depth broad leaf weeds are controlled.

4. Continuous flooding increases solubility and availability of iron, manganese and phosphorus to the plant.

Alternate Wetting and Drying: Alternate wetting and drying affects plant growth in a number of ways:

1. Alternate wetting and drying encourages more tillering and decreases plant height and the risk of loding.

2. Weeds can become a big problem in this system and result in decreased yields.

3. Nitrogen fertilizer use is less efficient.

Various irrigation intervals have been tried. Research studies conducted at Kala Shah Kaku indicate that rice should be irrigated on a 5 day interval. Irrigation intervals of more than 5 days will reduce the weight per panicle, number of panicles per hill and yield per acre. At a 5 day interval the field does not get dry and remains in the form of soil-water suspension. If weed infestations are a potential problem this method should not be used. Continuous flooding would be preferred.

Critical Periods of Irrigation: There are three critical stages of the growth of the rice plant where water stress will reduce yields. These are at tillering, earing and maturing stage. A water deficit at any of these stages will reduce crop yields. Basmati varieties should not be allowed to go without water for over 15 days under any circumstances. However, there are some stages when irrigation water can be saved. In research experiments conducted at Kala Shah Kaku rice fields have been successfully drained at 40 DAT for 4-14 days without affecting crop yield. Weed infestation problems need to be considered. The depth of irrigation water should not exceed 3". At early stages of growth the water depth should be less but adequate enough to control weeds.

Consumptive Use of Water: The consumptive use of water is the amount of water that is required to grow the crops. This includes both irrigation and rain water. The consumptive use of rice is approximately 44 to 47 inches of water depending on the planting date and maturity (growth duration) of the variety. The earlier the planting date the higher the consumptive use because of the high evapotranspiration ($ET_p$) rates that occur during the hot dry season. During late May and early June the $ET_p$ will be around 0.35 in/day while during the last of July and first of August this value will be about 0.25 in/day.

To determine the consumptive use for a crop one must consider crop water use characteristics, climatic conditions and soil factors. It has been found that consumptive use calculations using equations developed by Jensen and Haise in the United States and local climatic data closely estimate the water required to grow crops in Pakistan. Consumptive use calculations based on this technique, and substantiated experimentally, are shown in Table 7 for rice grown at three different planting dates. Weekly consumptive use values range from 1.57 inches to 3.20 inches of water. As stated above, this water requirement can be met either by irrigation water or rainfall. Since the peak water consumption period falls during the monsoon season a substantial amount is satisfied by rainfall. Because of this the number of irrigations is highly variable and will often vary from 6 to 15 depending on the season.

A graph showing the accumulative consumptive use over the season is shown in Figure 1. This example is of a 120 day maturing variety (Basmati). The shape of the curve for shorter maturing varieties or different planting dates is very similar.

SURFACE DRAINAGE: Proper surface drainage is also important in rice production. Even though rice can tolerate water much better than any other crop, water standing too deep on the rice field can reduce yields. Wherever possible the depth of water should not exceed 3 inches. During the Monsoon season this is sometimes impossible but adequate drainage should be provided for so the excess water can be drained off when the flood water level recedes.

CROP PROTECTION[3]: Crop protection includes insects, animals, diseases as well as weed control. The methods of control include cultural, mechanical and/or chemical.

Insect Control: The common insects that attack rice are as follows:

1. Yellow Stem Borer: Active period is April to October.

3/From "Recommendations of Rice Production Seminar," held at Larkana on May 31-June 1, 1976; organized by Exxon Chemicals Pakistan Limited.

Table 7. Consumptive use of water for rice at three planting dates. Early planting date assumes a 110 day variety (IR) and later planting dates 120 day varieties (Basmati).

| Time after transplanting | Planting date | May 25 | June 15 | July 1 |
|---|---|---|---|---|
| | Harvest date | Sept. 13 | Oct. 13 | Oct. 27 |
| (weeks) | | Consumptive use (in/week) | | |
| 1 | | 2.15 | 1.97 | 1.57 |
| 2 | | 2.42 | 2.13 | 1.76 |
| 3 | | 2.70 | 2.30 | 1.96 |
| 4 | | 2.90 | 2.44 | 2.19 |
| 5 | | 3.02 | 2.55 | 2.39 |
| 6 | | 3.10 | 2.72 | 2.60 |
| 7 | | 3.14 | 2.89 | 2.80 |
| 8 | | 3.17 | 3.00 | 2.99 |
| 9 | | 3.19 | 3.17 | 3.05 |
| 10 | | 3.20 | 3.19 | 3.14 |
| 11 | | 3.20 | 3.20 | 3.20 |
| 12 | | 3.15 | 3.15 | 3.15 |
| 13 | | 3.07 | 3.06 | 3.03 |
| 14 | | 2.97 | 2.97 | 2.94 |
| 15 | | 2.80 | 2.85 | 2.72 |
| 16 | | 2.60 | 2.74 | 2.45 |
| 17 | | - | 2.61 | 2.02 |
| | Total | 46.78 | 46.94 | 43.96 |

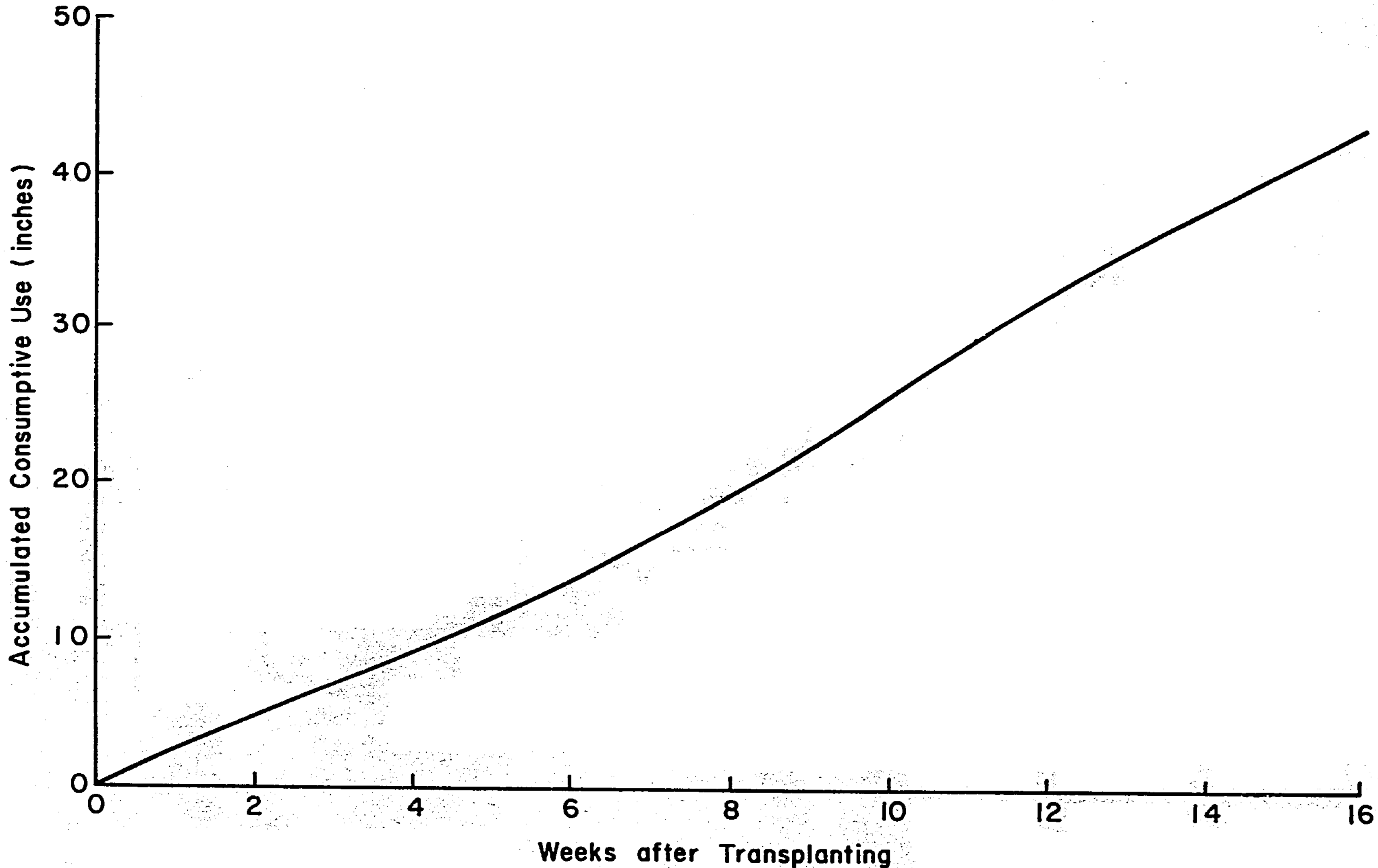



Figure 1. The accumulative consumptive use of water by rice.

2. White Stem Borer: If plant is attacked before panicle formation, then the central shoot is cut down at the base and white heads appear which have no grains.

3. Pink Stem Borer: Dead hearts and white heads occur as in the case of the white stem borer.

4. Lead Hopper: Sucks plant juices.

5. Weevil: Attacks plant roots.

The control of the major insect pests like stem borers can be undertaken by cultural, mechanical or chemical methods. The first two are generally only partially effective under a heavy infestation history and generally the chemical method is the only effective method. If the insecticide is applied properly according to the manufacturer's specifications effective control will be achieved. Many cases of insecticide failure that have been reported are caused by improper application rates, timings and/or methods.

Chemical Control Methods

1. Nurseries: The nursery should be treated as shown in Table 8 with one of the chemicals. An application should be made 8-10 days after planting or 15-20 days after planting depending on the insecticide used. Since stem borer infestation is readily carried to the field in the seedlings at transplanting treatment of the nursery is very important.

2. Transplanted Crop: The pest infestation should be checked at least once a week. If the infestation level is above 1% the first granular application should be made 25 DAT and the second application 50 DAT. The chemicals shown in Table 8 are recommended at the dose rates given. It is recommended that for granular application 3" deep water should be maintained on the crop continuously for 3 days after application to produce the best results.

Cultural Control Methods

1. Plowing the rice fields with a furrow turning plow by the end of February to bury the stubbles where the larvae hibernates is necessary to control stem borer. This conforms to regulations by the West Pakistan Agricultural Pest Ordinance, 1959.

2. The harvested paddy should be removed from the field immediately after harvest to minimize the migration of larvae from the harvested crop to the stubble.

Table 8. Recommended insecticides of control of rice borer.

| Insecticide | Nursery: 1st treatment (8-10 days old) | Nursery: 2nd treatment (15 days old) | Transplanted crop: 1st application (25 DAT) | Transplanted crop: 2nd application (50 DAT) |
|---|---|---|---|---|
| Basudin 10% gr. | | | | |
| i) Coarse | 20 | - | 15 | 15 |
| ii) Basmati | 20 | - | 15 | 20 |
| Gamma BHC 10% Dust & DDT 10% Dust | 2.5+7.5 | - | - | - |
| Sevidol 8/8 gr. (Sevin 8%+BHC 8%) | - | 20 | 20 | 20 |
| Ekalux 5% gr. | - | 15 | 20 | 30 |
| Furadan 3% gr. | - | 15 | 15 | 20 |
| Padan 10% gr. | - | 15 | 15 | 20 |
| Lebaycid 50% | 1 | - | - | - |

Mechanical Control Methods

1. Use of a light at night for collection and destruction of moths is recommended. If aerial spraying is being carried out it is further recommended that it should synchronize with the peak emerging period of the moths or rice stem borers.

2. Collection and destruction of egg masses of the moths and the "dead hearts" of rice plants should be done repeatedly.

Harmful Animals: Rats and mice can cause considerable damage to rice as well as to watercourses that supply water to the crop. Protective measures should be taken against these pests. Birds are a big problem particularly during harvest. Protection measures are as follows:

1. Treat the holes with phostoxin/Detia tablets with ½ to 1 tablet per hole.

2. Baiting throughout the field near the holes with anti-coagulants like Rocumin mixed with broken rice at 1:40 ratio should be done.

3. Shooting and baiting of birds will be helpful in reducing their population.

Diseases: The main disease that attacks rice is rice blast although others can occur. The protective measures are as follows:

1. Sow only disease resistant varieties.

2. Sow only disease free seed.

3. Plants showing blight or blast symptoms (pockmarks on the leaves) should be uprooted and destroyed.

4. Spray rice crop once about 10 days before earing and then 10 days after completion of earing with Dithane M-45 or Antracol at the rate of 2 lbs dissolved in 100 gallons of water/A. The effectiveness of these chemicals is questionable.

Smut and Rizoctonia are controlled by treating rice seed with 2 oz. of Vitavax per 22 seer seed. All nursery seed should be treated with Vitavax.

Weed Control: Weed infestations in rice are a major problem and cause large reduction in yields if not controlled. Weeds should not be allowed to grow and removed later for animal fodder. When weeds compete with rice for nutrient, space and light for this long they cause yields to be reduced substantially. Weeds should be controlled when they are small and not allowed to compete with rice. The major weeds that infest rice fields are:

Deela (Cyperus Sotandus), Dhidan (Echinochloa Crusgalli), Sawank (Enchinochloa Calonum), Mirch Booti (Sphenoclea Zeylanica) Naru (Paspalum Distichum), Ghooin (Cyperus Difformis), Bhoin (Cyperus Iria), Chati Bhoin (Fimbristylis Littoralis), Kuta Kami (Nymphaea Steelata) are the weeds that infest rice fields and must be controlled. Deela, Dhidan, Sawank, Mirch Booti and Naru are the worst, most common weeds. Several methods are useful in controlling weeds. Proper water depth is one of the most important factors. If a water depth of 2-3 inches is maintained weed infestation levels will be kept to a minimum. Under heavy weed pressures additional methods of control will be necessary. Cultural control, to include transplanting of weed free seedlings, is always an important factor in controlling weeds. Much research is being done on chemical control of weeds. Some chemicals are available or will be in the near future that have excellent weed control characteristics. As is with all pesticides their success is highly dependent on the use of proper application rates, timings and methods as specified by the manufacturer.

The achievement of proper weed control involves an integrated approach including cultural as well as chemical control. The following procedures are recommended:

<u>Cultural Control</u>

1. <u>Seedbed preparation</u>

   a. Puddling of fields helps to control weed population by destroying growing weeds and by producing soil conditions which reduce the growth of weeds. This method is the best cultural method to follow.
   b. Plowing and planking the fields in vattar and then allowing the weeds to grow and plow again after about 15 days interval also helps control weeds.

2. <u>Sowing weed free nursery</u>: Care should be taken that the nursery should be weed free. This includes sowing of weed free seed. If weeds are transferred along with the nursery plants during transplanting they grow faster than the rice seedlings and cannot be controlled without hand weeding.

3. <u>Method of sowing</u>: Sowing by transplanting helps minimize weeds as compared with the broadcast (direct) sowing.

4. Sowing in lines: This method allows easier eradication of weeds by hand or mechanical methods as compared to irregular sowing.

5. Irrigation: If 2-3" water depth is maintained in the field for one month the rice plants will be properly established. The interception of solar radiation due to shading or rice plants will not allow weeds to grow. If the field dries up, a heavy weed infestation will occur.

Chemical Control: Although this method is not widely used by farmers it is the best method available for control of weeds and is gaining wider acceptance every year. Typical yield responses to the use of herbicides are shown in Figure 2. Yields were increased by 27.4 mds/A. This type of response is not unusual and farmers with weed infestation problems can expect similar results if proper rate, timing and application methods are followed.

The herbicides that are in various stages of standardization and registration are given in Table 9. By the 1980 crop it is anticipated that all these herbicides will be standardized and registered for use by the farmers. Presently only Stam F-34 is generally available. It has not been widely accepted because the field must be drained for spraying. Proper flooding after spraying is required to get weed control. This is not always possible. All the other herbicides in Table 9 are applied in 2-3" of flood water as granuals, or liquid in the case of Treflon-R. This method is much easier for the farmer and proper weed control will be achieved. A great potential exists for the use of herbicides in the increased production of rice and all farmers should be encouraged to adopt this practice.

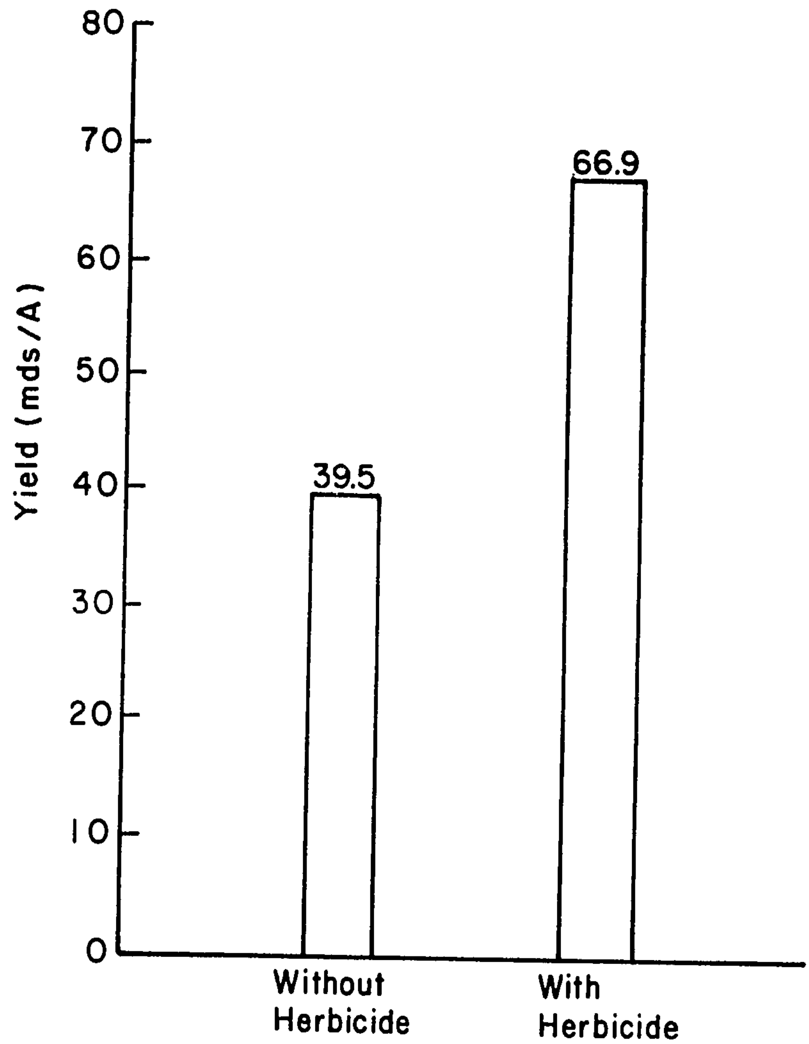
HARVESTING

The last important step in the production of a good rice crop is proper harvesting. The following recommendations should be followed.

1. Time: Rice should be harvested when the upper grains in the ear dry up and the lower grains are somewhat green. This usually occurs about one month after 50% ear formation in the field.

2. Method: The fields should be dried before harvesting. Irrigation should be stopped 15 days before harvest and the standing water drained. Harvesting is usually done with the sickle. Combine harvesters are not very common; however, they are used in some areas.

3. Threshing: A soil platform or bund of 2' x 2' should be erected, pasted with soil, dried and the rice ears




*From A. Majid, Saeed Ahmad and Manzoor Ahmad, Rice Research Institute at Kala Shah Kaku.

Figure 2. Yield of rice with and without herbicide weed control.*

Table 9. Herbicide recommendations for control of weeds in rice.

| Name | Rate of application of material (lb/A) | Time of application |
|---|---|---|
| Stam F-34 (36% E.C.) | 4.5 l/A | 15-20 DAT on dry field |
| TOK 7% granual | 29 | 5-6 DAT on flood water |
| Satum 10% granual | 25 | 20-30 DAT in flood water |
| Machete 5% granual | 33 | 20-30 DAT in flood water |
| Treflan-R (E.C.) | 2.4 l/A | 5-6 DAT dribbled in flood water |

struck against this platform by hand. Stationary motor driven harvesters are becoming very common and should be used when available. They are much faster and do a better job with less labor than hand threshing. Rental rates are very reasonable.

GRAIN STORAGE

After the rice has been threshed it should be stored in a place where it can be kept dry and free of rats, mice, birds and stored grain insects. If this is not accomplished large losses of grain can occur. This is an important step in the rice production sequence and should not be overlooked.

# Appendix I

The recommendations for planting date, varieties and fertilizer rates for the Sind, NWFP and Baluchistan are slightly different than those given in the main text. Specific recommendations are given below if they differ from those in the main text.

## TIME OF SOWING NURSERY

| Sind | Zones | Time of sowing |
|---|---|---|
| | Southern region (Kotri Barrage Area) | April 25 to June 10 |
| | Central region (Sukkur Barrage Area) | May 10 to June 15 |
| | Northern region (Guddu Barrage Area) | May 20 to June 30 |
| NWFP | | |
| | For plains | 1st week of June |
| | Submountainous regions | 3rd week of June |
| Baluchistan | | May 20 |

## SEEDBED PREPARATION

In the Sind and Baluchistan seeding should be done on sterilized seedbeds.

## RECOMMENDED VARIETIES

**Sind**

Southern Zone IR-6(Mehran 69), IR-8(IRRI-Pak) and Kharai Gunja
Central Zone IR-6, IR-8 and Kangni X Torh
Northern Zone IR-6, IR-8 and IR-841 (Abbasi-72)

**NWFP** IR-8, IR-9 and Bas-370 in plains. YRL-I, JP.5 and Bas C.622 in submountainous area.

**Baluchistan** IR-6 and IR-8 for plains.

## FERTILIZER RECOMMENDATIONS

**Sind**

| Variety | Quantity of fertilizer/A | Method and time of application |
|---|---|---|
| Local tall | 1/2 to 3/4 bag Urea (25-37 lb N) | 14 DAT* |
| IR-6 and IR-8 | 1 bag DAP + 1 bag Urea ($70$ lb N + $50$ lb $P_2O_5$) | One day before transplanting |
| | 1 bag Urea (50 lb N) | 45-55 DAT* (At panicle initiation) |
| IR-841 | 1 bag DAP + 3/4 bag Urea | 35-40 DAT* (At panicle initiation) |

Fertilizer applications recommended before transplanting can be made 10-15 DAT without loss of yield.

*DAT = Days After Transplanting.

# APPENDIX 3

## THE RESPONSE OF SUGARCANE TO WATER STRESS AND NITROGEN FERTILIZER

Bashir Sabir, John Reuss and A. C. Early[1]

### INTRODUCTION

The relationship between fertilizer response and water supply is an important one in Pakistan where water supplies are limited and many crops encounter water stress at one or more times during the growing season. Many agriculturists are imbued with a "limiting factors" concept of response to crop inputs. According to this concept if one factor or input is in sufficiently short supply to limit crop yields, increased amounts of other inputs will not increase production.

When applied to water and fertilizer this philosophy leads to the conclusion that if water stress is likely to be significant fertilizer application should be drastically reduced or dispensed with entirely. This concept is widespread among farmers and professional agriculturists alike and is particularly prevalent in Pakistan. Whether or not the concept is valid is of vital importance to both the farmer planning his cropping and fertilizer program and to the long range planner responsible for decisions on invesments in fertilizer capacity and water supply schemes.

This report gives the results of three years research on the relationship between the response to water and nitrogen in sugarcane, conducted at the Mona Reclamation Experimental Project. A detailed economic analysis is included using production surfaces determined by regression techniques.

### METHODOLOGY

The experiments were conducted at the Phularwan Research Farm of the Mona Reclamation Experimental Project, Bhalwal, during the years 1975-76 and 77. The soil at this location may be characterized as a nonsaline, nonsodic medium loam

Five levels of water application and five levels of irrigation were used as follows:

1/SRO Agronomy, MREP; Chief of Party, CSU WMRP in Pakistan; and former Agricultural Engineer, CSU WMRP, now at International Rice Research Institute, Manila.

| | Nitrogen levels lb/A | | Irrigation coefficient |
|---|---|---|---|
| $N_1$ | 0 | $I_1$ | 0.4 |
| $N_2$ | 100 | $I_2$ | 0.6 |
| $N_3$ | 150 | $I_3$ | 0.8 |
| $N_4$ | 200 | $I_4$ | 1.0 |
| $N_5$ | 250 | $I_5$ | 1.2 |

The "irrigation coefficient" as used here is defined as the ratio of irrigation applied to the pan evaporation minus rainfall. Stated another way, an irrigation coefficient of 0.6 means that 60% of pan evaporation minus rainfall is replaced by irrigation. The depth of water to be applied at each irrigation was calculated as follows:

1. Take the difference between the total pan evaporation and the total rainfall for the period in question.
2. Divide by the assumed irrigation efficiency (0.9) to determine the total depth of application for a coefficient of 1.0.
3. Multiply by the appropriate coefficient for the treatment in question.

Two irrigations of 4 inches each during stand establishment were common to all treatments. The irrigation frequencies were as follows:

Irrigation at 2 week interval until "closing in."
Irrigation at 3 week interval until post monsoon period.
Irrigation at 4 week interval after monsoon.

Heavy irrigations were avoided and when irrigation in amounts of less than 1.2 inches were indicated the irrigation was not applied but the amount called for was included in the calculation for the next period. Application amounts were controlled through the use of calibrated siphon tubes and a fixed head.

An incomplete factorial design comprised of the following treatment combinations was used:

| Irrigation coefficients | N rates (lb/A) | | | | |
|---|---|---|---|---|---|
| | 50 | 100 | 150 | 200 | 250 |
| 0.4 | X | | X | | X |
| 0.6 | | X | | X | |
| 0.8 | X | | X | | X |
| 1.0 | | X | | X | |
| 1.2 | X | | X | | X |

These 13 treatment combinations were set out in a randomized block design using two repeats.

One half the total nitrogen was applied at seeding and one-half at closing in. After land preparation the nitrogen was applied with a kharif drill in lines below the rows where the cuttings were to be placed. After the cuttings were placed above these lines a ridger shovel was run between the rows to create a furrow between the rows and to cover the cuttings with soil. The ridge was offset from the center of the rows to avoid emergence from the top of the ridge. The fertilizer scheduled for closing in was applied next to the stools by the dibble method.

The sugarcane was sown following winter fodder in order to assure a low residual nitrogen fertility level. A basal dose of 140 kg $K_2O$/ha in the form of potassium sulphate and 100 kg $P_2O_5$/ha in the form of single superphosphate was broadcast over the entire area prior to planting.

## RESULTS AND DISCUSSION

The mean yields by treatments and years are shown in Tables 1, 2 and 3. Yields were poor in 1975, good in 1976 and fair in 1977. In all three years there were obvious effects of both nitrogen and irrigation treatments. With the incomplete factorial design used here we can best evaluate these effects using a regression analysis. Three regression models were tested as follows:

Model I

$$Y = b_o + b_1 N + b_{11} N^2 + b_2 W + b_{22} W^2 + b_{1.2} NW \quad (1)$$

Model II

$$Y = b_o + b_1 N^{.75} + b_{11} N^{1.5} + b_2 W^{.75} + b_{22} W^{1.5} + b_{1.2} N^{.75} W^{.75} \quad (2)$$

Model III

$$Y = b_o + b_1 N + b_{11} N^2 + b_2 W + b_{22} W^2 + b_{1.1} NW + b_{11.2} N^2 W + b_{1.22} NW^2 \quad (3)$$

Where: Y - yield in mds/acre
N - nitrogen applied, lb/acre
W - irrigation water applied, acre in./acre

The b values are the regression coefficients as determined by a least squares fit. The relationship between the irrigation coefficients and the inches of water actually applied (irrigation delta) are shown in Table 4.

The standard errors of estimates and $R^2$ values showed no advantage to using Model II over Model I. Model I is much

Table 1. Mean yields of sugar cane (mds/acre) as affected by irrigation coefficient and nitrogen . (1975)

| Irrigation Coefficient* % | Nitrogen/Acre 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|
| 120 | 438 | | 620 | | 628 |
| 100 | | 486 | | 607 | |
| 80 | 400 | | 572 | | 623 |
| 60 | | 436 | | 509 | |
| 40 | 340 | | 475 | | 517 |

*Percent of pan evaporation minus rainfall.

Table 2. Mean yields of sugar cane (mds/acre) as affected by irrigation coefficient and nitrogen. (1976)

| Irrigation Coefficient* % | Nitrogen/Acre 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|
| 120 | 550 | | 787 | | 1053 |
| 100 | | 612 | | 1001 | |
| 80 | 511 | | 741 | | 935 |
| 60 | | 564 | | 913 | |
| 40 | 425 | | 652 | | 839 |

*Percent of pan evaporation minus rainfall.

Table 3. Mean yields of sugar cane (mds/acre) as affected by irrigation coefficient and nitrogen. (1977)

| Irrigation Coefficient* % | Nitrogen/Acre 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|
| 120 | 529 | | 756 | | 908 |
| 100 | | 566 | | 848 | |
| 80 | 477 | | 653 | | 769 |
| 60 | | 518 | | 746 | |
| 40 | 398 | | 596 | | 707 |

*Percent of pan evaporation minus rainfall.

Table 4. Relationship between irrigation coefficient and irrigation water applied

| Coefficient | 1975 | 1976 | 1977 |
|---|---|---|---|
| | | YEAR | |
| | | Acre/in. | |
| .4 | 22.27 | 24.72 | 26.8 |
| .6 | 31.90 | 33.08 | 36.2 |
| .8 | 41.54 | 41.44 | 45.6 |
| 1.0 | 51.33 | 49.81 | 55.0 |
| 1.2 | 60.81 | 58.16 | 64.4 |

Table 5. Regression coefficients for yield of sugar cane (mds/acre) as a function of nitrogen (lbs/acre) and irrigation delta (inches) for a polynomial of the form:

$$Y = b_o + b_1 N + b_{11} N^2 + b_2 W + b_{22} W^2 + b_{1.2} N_W$$

| | 1975 | 1976 | 1977 |
|---|---|---|---|
| $b_o$ | 118.52 | 65.85 | 168.1 |
| $b_1$ | 2.3013 | 2.6036 | 2.713 |
| $b_{11}$ | - 0.00482 | -0.00246 | -.00422 |
| $b_2$ | 5.4722 | 10.8710 | 2.822 |
| $b_{22}$ | - 0.03326 | -0.10052 | .00448 |
| $b_{1.2}$ | 0.00306 | 0.01397 | .00808 |
| $R^2$ | 0.952 | .954 | .973 |
| SEE* | 26.88 | 56.93 | 33.86 |

*Standard Error of Estimate

easier to use for economic analyses than Model II so Model II was discarded. Model III gave slightly better fit parameters for the 1975 data than did Model I indicating the quadratic interaction terms did contribute to fit. However, Model I was more efficient for both the 1976 and 1977 data than was Model III. Therefore for consistency and ease of calculation Model I was selected for all three years. The regression effects were highly significant in all cases. Coefficients and fit parameters are shown in Table 5.

First a simple examination of Tables 1, 2 and 3 shows that substantial increases in yield were obtained from nitrogen fertilizer and that the water stress treatments yielded less than those treatments with more nearly adequate water. It is also quite plain that nitrogen responses were obtained not only from full irrigation treatments but that those treatments under stress also responded to nitrogen application.

One method of utilizing these models is by means of the isoquant diagrams shown in Figures 1, 2 and 3. These are actually contour maps of the yield as a function of water and nitrogen, and can be used to determine the water and nitrogen levels required to produce any yield under the conditions of the experiment. These diagrams are constructed by rearranging Model I in terms of either N or W. For instance, Model I can be rearranged to this form:

$$O = b_{11}N^2 + (b_1 + b_{1.2}W)N + (b_o + b_2W + B_{22}W^2 - Y) \qquad (4)$$

This is quadratic equation of the form,

$$ax^2 + bx + c = 0 \qquad (5)$$

so for any preselected value of Y and W, we can solve for the corresponding N level by means of the standard quadratic formula:

$$X = \frac{b \pm \sqrt{b^2 - 4ac}}{2a} \qquad (6)$$

Where: $a = b_{11}$

$b = b_1 + b_{1.2}W$

$c = b_o + b_2W + b_{22}W^2 - Y$

Note that at many of the yield levels a particular yield can be obtained with a good many combinations of levels of N and water. The most economical water and N combination for any yield depends on the relative costs of water and nitrogen fertilizer.

In general these diagrams show that even at the highest levels of N and water utilized, yields were still increasing

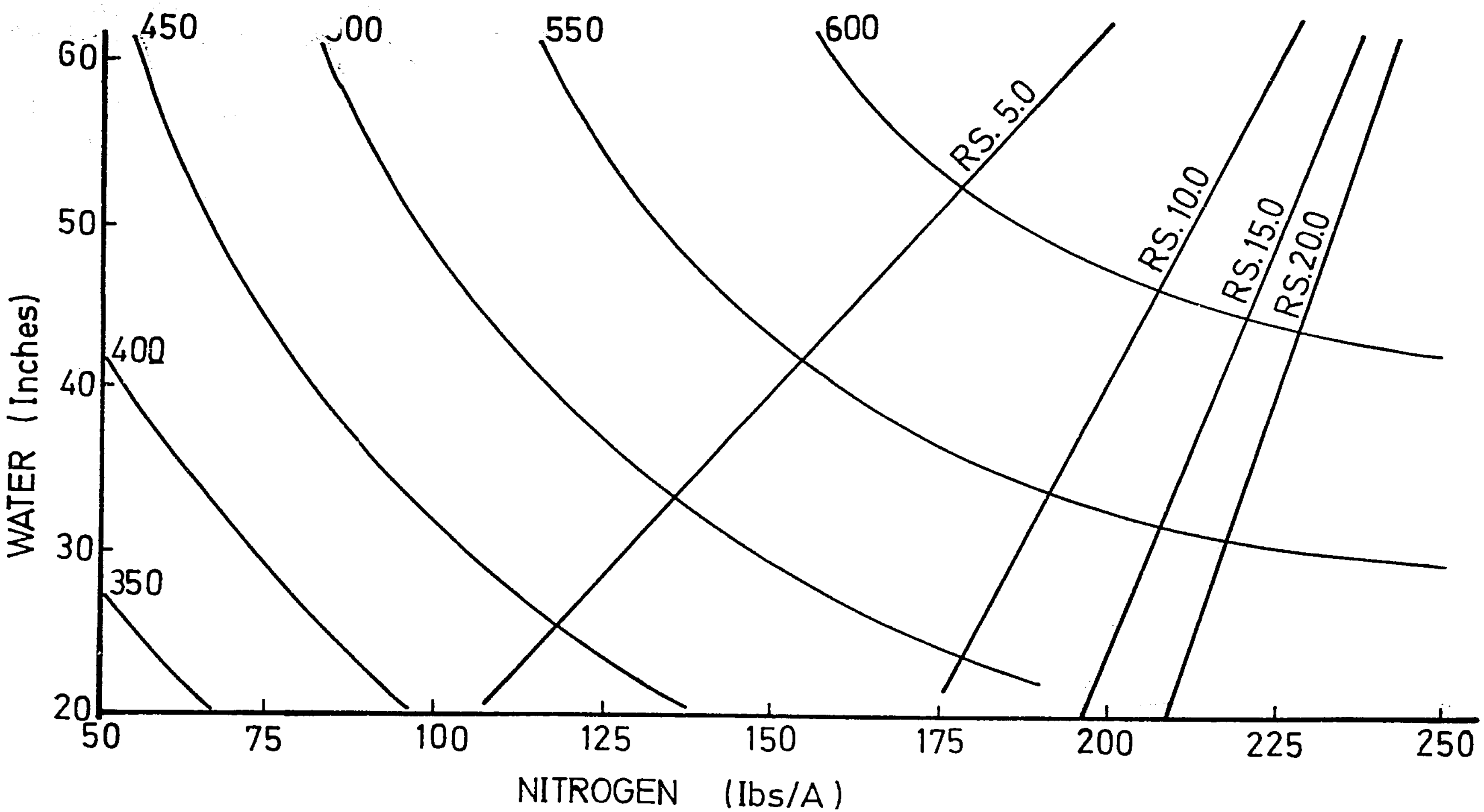



Figure 1. Yield isoquants (maunds/acre) for sugarcane as a function of water and nitrogen in 1975. Diagonal lines represent optimum ratio for producing the indicated yield at various costs of water.

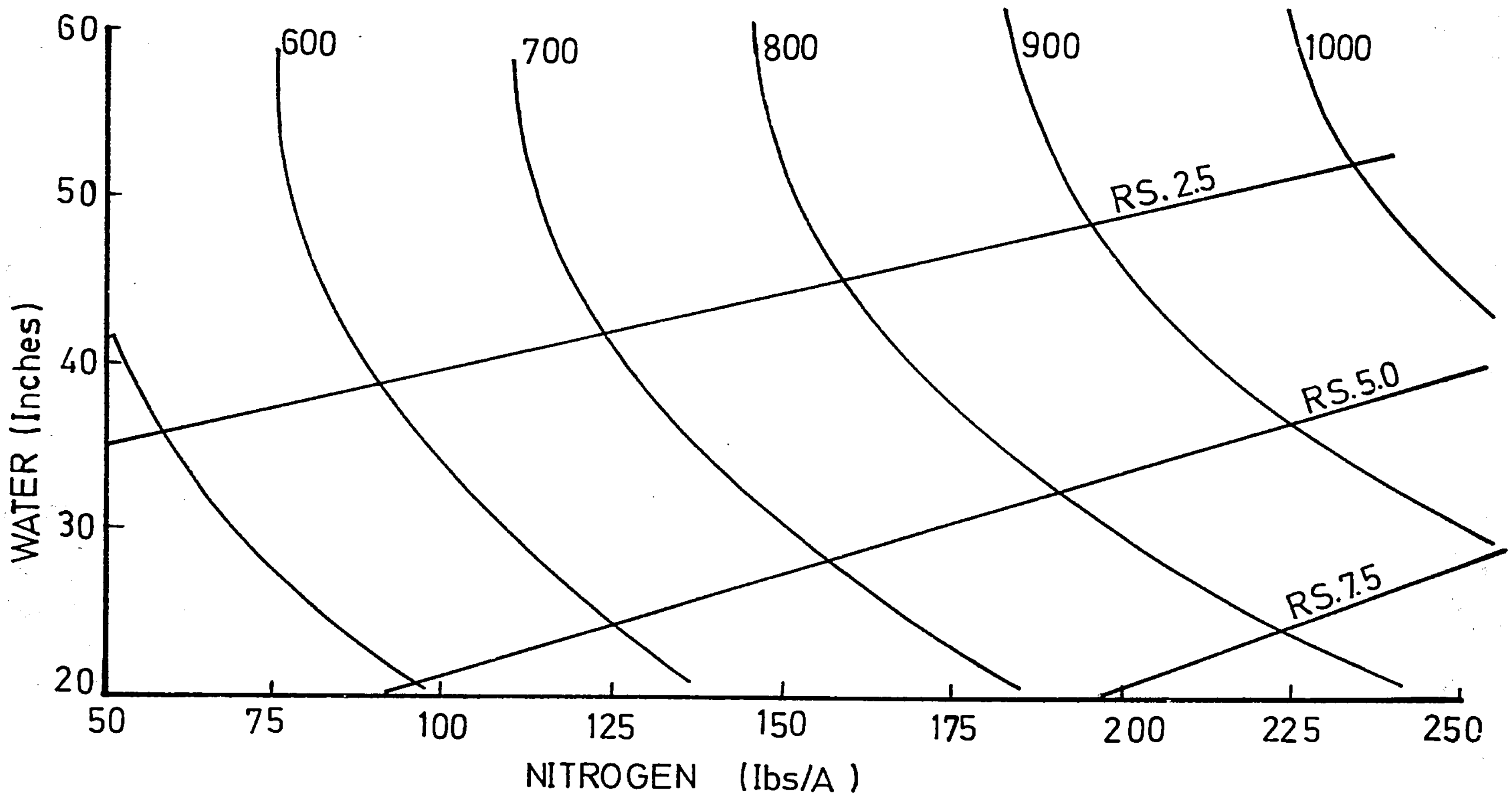



Figure 2. Yield isoquants (maunds/acre) for sugarcane as a function of water and nitrogen in 1976. Diagonal lines represent optimum ratio for producing the indicated yield at various costs of water.

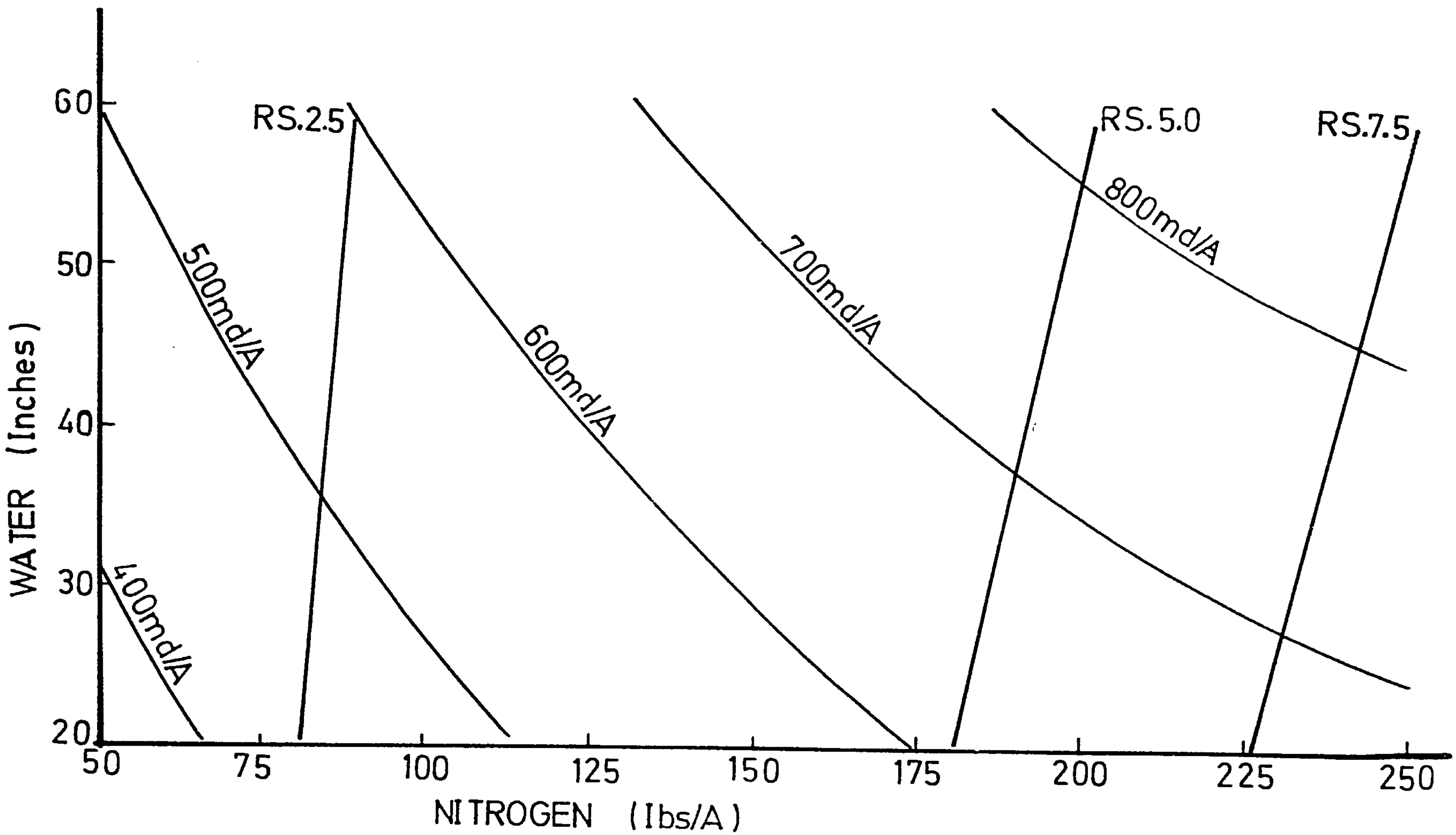



**Figure 3.** Yield isoquants (maunds/acre) for sugarcane as a function of water and nitrogen in 1977. Diagonal lines represent optimum ratio for producing the indicated yield at various costs of water.

as increments of water and N were added. Exceptions to this were that at low N in 1976 the lines are almost vertical at high water levels. This means that increasing water would not further increase yields. In 1975 at high N levels the lines are nearly horizontal so in this case further additions of N would not have increased yields.

Another useful property of these surfaces is that at any point on the surface the marginal product produced by an increment of one of the inputs is given by the partial differential of yield with respect to that input. Therefore the marginal products of nitrogen and water are given by:

$$\frac{\partial Y}{\partial N} = b_1 + 2b_{11} N + b_{1.2} W \tag{7}$$

$$\frac{\partial Y}{\partial N} = b_2 + b_{22} W + b_{1.2} N \tag{8}$$

Where: $\frac{\partial Y}{\partial N}$ is the increase in yield per lb of N at any level of N and W and $\frac{\partial Y}{\partial N}$ is the increase in yield per inch of water, i.e. the marginal products of N and W.

The marginal value product is obtained by multiplying the marginal product by the price received for the cane. In this case we have used Rs.4.6/md as the price of cane in the yield. Tables 6 and 7 show the marginal value product of nitrogen and water at various levels of application of these two inputs. As expected the marginal value product of N decreases as the rate of application increases, but only in 1975 did the marginal value product of the 200-250 lb/acre increment decrease to below the cost level (about Rs.1.5/lb).

The marginal value product of water declined as the rate of water application increased in two of the three years but in 1977 the marginal value product increased slightly as the amount of irrigation increased.

The interaction between water and nitrogen was small but the trend of the three years was consistent. The marginal value product of water tended to increase slightly as the nitrogen rate increased and the marginal value product of nitrogen increased slightly as water application increased. This type of interaction would be expected, but the surprising result is that the interaction was very small. Nitrogen applied under conditions of water stress consistently gave almost as much return as that applied with more water. For instance at 150 lbs N per acre an additional pound of N costing Rs.1.5 would have returned Rs.4.29, 10.19, and 7.59 in 1975, 1976 and 1977 respectively if only 25 inches of water were used. If 60 inches of water had been applied the able 6. Marginal value products of nitrogen (Rs/pound) for sugar cane at various nitrogen & irrigation levels

| Irrigation Delta | Nitrogen, (lbs/acre) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | | | 100 | | | 150 | | | 200 | | | 250 | | |
| Inches | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 |
| 25 | 8.72 | 12.45 | 11.47 | 6.50 | 11.32 | 9.53 | 4.29 | 10.10 | 7.59 | 2.07 | 9.06 | 5.64 | -.15 | 7.93 | 3.74 |
| 30 | 8.79 | 12.77 | 11.65 | 6.57 | 11.64 | 9.71 | 4.36 | 10.51 | 7.77 | 2.14 | 9.38 | 5.83 | -.09 | 8.25 | 3.89 |
| 35 | 8.86 | 13.09 | 11.84 | 6.64 | 11.96 | 9.90 | 4.43 | 10.83 | 7.96 | 2.21 | 9.70 | 6.02 | -.01 | 8.57 | 4.07 |
| 40 | 8.93 | 12.42 | 12.03 | 6.71 | 12.28 | 10.08 | 4.50 | 11.15 | 8.14 | 2.28 | 10.02 | 6.20 | .06 | 8.89 | 4.26 |
| 45 | 9.00 | 13.74 | 12.21 | 6.79 | 12.61 | 10.27 | 4.57 | 11.47 | 8.33 | 2.35 | 10.34 | 6.39 | .13 | 9.21 | 4.45 |
| 50 | 9.07 | 14.06 | 12.40 | 6.86 | 12.93 | 10.46 | 4.64 | 11.79 | 8.51 | 2.42 | 10.66 | 6.57 | .20 | 9.53 | 4.63 |
| 55 | 9.14 | 14.38 | 12.58 | 6.93 | 13.25 | 10.64 | 4.71 | 12.12 | 8.70 | 2.49 | 10.98 | 6.76 | .27 | 9.85 | 4.82 |
| 60 | 9.21 | 14.70 | 12.77 | 7.00 | 13.54 | 10.83 | 4.78 | 12.44 | 8.89 | 2.56 | 11.31 | 6.95 | .34 | 10.17 | 5.00 |

Table 7. Marginal value products of water (Rs/acre foot) for sugar cane at various nitrogen and irrigation levels

| Irrigation Delta | Nitrogen, (lbs/acre) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | | | 100 | | | 150 | | | 200 | | | 250 | | |
| Inches | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 | 1975 | 1976 | 1977 |
| 25 | 222 | 360 | 194 | 227 | 399 | 213 | 222 | 438 | 235 | 244 | 477 | 258 | 255 | 515 | 283 |
| 30 | 199 | 305 | 196 | 211 | 343 | 216 | 205 | 382 | 238 | 227 | 421 | 260 | 233 | 460 | 285 |
| 35 | 183 | 249 | 198 | 188 | 288 | 218 | 188 | 327 | 241 | 211 | 366 | 262 | 216 | 404 | 287 |
| 40 | 166 | 194 | 199 | 172 | 233 | 221 | 172 | 271 | 244 | 188 | 310 | 365 | 199 | 349 | 288 |
| 45 | 144 | 139 | 202 | 155 | 177 | 223 | 150 | 216 | 247 | 172 | 255 | 268 | 177 | 294 | 290 |
| 50 | 127 | 83 | 205 | 139 | 122 | 226 | 133 | 161 | 249 | 155 | 260 | 270 | 161 | 238 | 292 |
| 55 | 111 | 28 | 208 | 116 | 66 | 228 | 111 | 105 | 252 | 133 | 144 | 273 | 144 | 183 | 294 |
| 60 | 89 | -28 | 210 | 100 | 11 | 231 | 94 | 50 | 255 | 116 | 89 | 275 | 122 | 127 | 296 |

returns would be Rs.4.78, 12.44 and 8.89. These small differences would not seem to justify reducing nitrogen rates if water stress was likely. Also they do not support the hypothesis that lack of adoption of the nitrogen fertilizer practice in Pakistan is due to the fact that water supplies are commonly less than optimum. In these trials nitrogen use was very nearly as profitable where 25 inches of water were applied as where 50 inches were applied.

Standard micro-economic theory tells us that for any output level the optimum level of inputs is defined by the point on a graph such as Figures 1, 2, and 3 where the iso-cost lines defined by the ratio of cost of the inputs $\frac{C_W}{C_N}$ is tangent to the yield isoquants. Mathematically, for any Y this can be expressed as:

$$\frac{\partial Y}{\partial N} = \frac{C_N}{C_W} \tag{9}$$

or taking $\partial Y/\partial N$ and $\partial Y/\partial W$ from (7) and (8) we have:

$$\frac{b_1 + 2b_{11} N + b_{1.2} W}{b_2 + 2b_{22} W + b_{1.2} N} = \frac{C_N}{C_W} \tag{10}$$

The algebra is rather complicated but for any given Y the original model (Eq. 1), and (Eq. 10) gives us two equations in two unknowns to find the optimum combination of N and for any Y and ratio of cost of N to cost of water $\frac{C_N}{C_W}$.

This solution again reduces to a quadratic of the form of Eq. 5 with coefficients a, b, and c as follows:

$$c = b_o k_2 - b_1 k_o + \frac{b_{11} k_o^2}{k_2} - k_2 Y$$

$$b = b_1 k_1 + \frac{2b_{11} k_o k_1}{k_2} + k_2 b_2 + b_{1.2} k_o$$

$$a = \frac{b_{11} k_1^2}{k_2} + b_{22} k_2 = b_{1.2} k_1$$

Where $k_o$, $k_1$, and $k_2$ are defined as:

$$k_o = \frac{b_2 C_N}{C_W} - b_1$$

$$k_1 = \frac{2b_{22} C_N}{C_W} - b_{1.2}$$

$$k_2 = 2b_{11} - \frac{b_{1.2} C_N}{C_W}$$

The optimum levels of N and W for producing specified yields at various assumed costs for water are given in Table 8 and are plotted on Figures 1, 2, and 3. These turn out to be less useful than hoped for, due to the rather wide difference between years. In 1975 and 1977 the only lines within the range of data are those for less than Rs.7.5 per acre-inch. In 1975 several optimum combinations appear within the range of the data.

Considered as a whole it appears that unless water is very cheap, i.e. less than Rs.5 per acre-inch, moderate yields would be produced more economically by using less than optimum water but applying nitrogen at rates well in excess of 100 lb/acre.

The optimum point of production for these surfaces is usually defined as that point at which the marginal value of the input is equal to the cost of the input. For the two inputs N and P this can be written as:

$$(b_1 + 2b_{11} N + b_{1.2} W) P = C_N \tag{11}$$

$$(b_2 + 2b_{22} W + b_{1.2} N) P = C_W \tag{12}$$

Again we have two equations in two unknowns which can be solved to (13) and (14).

$$W = \frac{\frac{C_W}{P} - b_2 - \frac{b_{1.2}}{2b_{11}} \left(\frac{C_N}{P}\right) + \frac{b_{1.2} b_1}{2b_{11}}}{2b_{22} - \frac{b_{1.2}^2}{2b_{11}}} \tag{13}$$

$$N = \frac{\frac{C_N}{P} - b_1 - b_{1.2} W}{2b_{11}} \tag{14}$$

While these points are often very useful they do not generally prove useful for these data, as in 1976 and 1977 the optimum points for realistic values of water do not fall within the range of the data and extrapolation beyond the range of the data does not give reliable results. The optimum production values for 1975 are given in Table 9. The optimum levels of water were quite sensitive to the cost of water but the optimum nitrogen level proved quite insensitive to the cost of water and its associated optimum water application. This insensitivity of the optimum nitrogen rate to cost of water is a result of the coefficient of the interaction term between nitrogen and water being very small. This small interaction term is characteristic of all three years' data.

Table 8. Optimum water and nitrogen rates for producing specified yield levels at different water costs.

| Water Cost Rs/Acre in. | | 400 | | 500 | | 600 | | 700 | | 800 | | 900 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | I | N | I | N | I | N | I | N | I | N | I | N | I |
| 1975 | | | | | | | | | | | | | | | |
| 2.5 | .60 | 57 | 38 | 97 | 49 | 152 | 64 | | | | | | | | |
| 5.0 | .30 | - | - | 135 | 33 | 178 | 53 | | | | | | | | |
| 10.0 | .15 | - | - | 178 | 24 | 207 | 46 | | | | | | | | |
| 15.0 | .10 | - | - | 197 | 22 | 220 | 45 | | | | | | | | |
| 20 | .075 | - | - | 208 | 20 | 228 | 44 | | | | | | | | |
| 30 | .050 | - | - | - | - | 236 | 44 | | | | | | | | |
| 1976 | | | | | | | | | | | | | | | |
| 2.5 | .60 | - | - | 60 | 35 | 91 | 38 | 124 | 41 | 158 | 45 | 194 | 48 | 232 | 52 |
| 5.0 | .30 | - | - | 95 | 21 | 125 | 24 | 156 | 38 | 189 | 32 | 324 | 36 | - | - |
| 7.5 | .20 | - | - | - | - | - | - | - | - | 223 | 24 | - | - | - | - |
| 1977 | | | | | | | | | | | | | | | |
| 2.5 | .60 | - | - | 84 | 36 | 89 | 59 | - | - | - | - | - | - | - | - |
| 5.0 | .30 | - | - | - | - | - | - | 190 | 37 | 199 | 55 | - | - | - | - |
| 7.5 | .20 | - | - | - | - | - | - | 231 | 27 | 242 | 45 | - | - | - | - |

Table 9. Optimum levels of nitrogen and irrigation for various water costs (1975)

| Water lost Rs/Acre in. | Water inches | Nitrogen lbs/acre |
|---|---|---|
| 2.5 | >60 | 231 |
| 5. | >60 | 229 |
| 10 | 60 | 224 |
| 15 | 43 | 219 |
| 20 | 27 | 214 |

The optimum points for 1975 can also be located from Table 10 which shows the income less cost of water and nitrogen for 1975. At all water application levels and water costs the net income increases with nitrogen up to 200 lbs/acre but drops off slightly at 250 lbs/acre. For water costs up to Rs.10/acre-inch the net income increases with each increment of water added even at the highest water level. However, when water costs Rs. 15/acre-inch the maximum income falls between 40 and 50 inches and when water costs Rs.20 per acre-inch it peaks at about 30 inches. These peaks, of course, are given as 43 and 20 inches in Table 9.

In 1976 and 1977 the rates of neither nitrogen or water were extended high enough to accurately locate the points of maximum net income. In 1976 and 1977 at all water levels and water costs the 250 lbs N/acre rate gave a higher net than the 200 lb/acre. In 1976, 50 and 60 inch applications were about equally profitable at a water cost of Rs.2.5/inch but at a water cost of Rs.5 the most profitable rate was 50 inches, falling to 40 inches or less at the higher water costs. In 1977 both nitrogen and water were most profitable at the highest rates used.

In summary, a couple of points should be emphasized. Nitrogen responses were only slightly decreased by water stress and substantial rates of nitrogen were profitable even on stressed treatments in all years. The optimum water application is, of course, dependent on the cost of water, whether it is the actual cost to him or the opportunity cost of using it for another crop or increasing his cropping intensity. The optimum levels of water application varied among the three years, but in two of the three years applications of less than 50 inches were more profitable than 60 inch applications when water costs exceed Rs.10 per acre-inch.

Finally it should be recognized that these results consider only bulk cane yields and not sucrose content. While farmers in Pakistan are presently paid on the basis of bulk yield, it is well known that high rates of nitrogen often depress sucrose levels. Therefore in order to assess the true value of the output it will be necessary to include sucrose measurements in work of this type.

Table 10. Income less cost of water and nitrogen in 1975 for various assumed water costs. Nitrogen is assumed to cost Rs.1.5/lb and the net value of cane is Rs.4.6/md.

| Water inches | Nitrogen lbs/acre | Cost of Water, Rs/Acre in. 2.5 | 5.0 | 10. | 15 | 20 |
|---|---|---|---|---|---|---|
| 20 | 50 | 1350 | 1300 | 1200 | 1100 | 1000 |
| | 100 | 1652 | 1602 | 1502 | 1402 | 1302 |
| | 150 | 1844 | 1794 | 1694 | 1594 | 1494 |
| | 200 | 1924 | 1874 | 1774 | 1674 | 1574 |
| | 250 | 1894 | 1844 | 1744 | 1644 | 1544 |
| 30 | 50 | 1508 | 1433 | 1283 | 1133 | 983 |
| | 100 | 1817 | 1742 | 1592 | 1442 | 1292 |
| | 150 | 2015 | 1940 | 1790 | 1640 | 1490 |
| | 200 | 2102 | 2027 | 1877 | 1727 | 1577 |
| | 250 | 2079 | 2004 | 1854 | 1704 | 1554 |
| 40 | 50 | 1634 | 1534 | 1334 | 1434 | 934 |
| | 100 | 1950 | 1850 | 1650 | 1450 | 1250 |
| | 150 | 2156 | 2056 | 1856 | 1656 | 1456 |
| | 200 | 2250 | 2150 | 1950 | 1750 | 1550 |
| | 250 | 2234 | 2134 | 1934 | 1734 | 1534 |
| 50 | 50 | 1736 | 1605 | 1355 | 1105 | 855 |
| | 100 | 2054 | 1929 | 1679 | 1429 | 1179 |
| | 150 | 2266 | 2141 | 1891 | 1641 | 1391 |
| | 200 | 2367 | 2242 | 1992 | 1742 | 1492 |
| | 250 | 2358 | 2233 | 1983 | 1733 | 1483 |
| 60 | 50 | 1795 | 1645 | 1346 | 1046 | 746 |
| | 100 | 2126 | 1976 | 1676 | 1376 | 1076 |
| | 150 | 2345 | 2195 | 1895 | 1595 | 1295 |
| | 200 | 2453 | 2304 | 2004 | 1704 | 1404 |
| | 250 | 2452 | 2302 | 2002 | 1702 | 1402 |

Table 11. Income less cost of water and nitrogen in 1976 for various assumed water costs. Nitrogen is assumed to cost Rs.1.5/lb and the net value of cane is Rs.4.6/md.

| Water | Nitrogen | Cost of Water, Rs./Acre in. | | | | |
|---|---|---|---|---|---|---|
| inches | lbs/acre | 2.5 | 5.0 | 10. | 15 | 20 |
| 20 | 50 | 1628 | 1578 | 1477 | 1378 | 1278 |
| | 100 | 2131 | 2081 | 1981 | 1881 | 1281 |
| | 150 | 2578 | 2528 | 2428 | 2328 | 2228 |
| | 200 | 2968 | 2918 | 2818 | 2718 | 2618 |
| | 250 | 3301 | 3251 | 3151 | 3051 | 2951 |
| 30 | 50 | 1904 | 1829 | 1679 | 1529 | 1379 |
| | 100 | 2439 | 2364 | 2214 | 2064 | 1914 |
| | 150 | 2918 | 2843 | 2693 | 2543 | 2393 |
| | 200 | 3340 | 3265 | 3115 | 2965 | 2815 |
| | 250 | 3706 | 3630 | 3481 | 3330 | 3181 |
| 40 | 50 | 2087 | 1988 | 1787 | 1587 | 1387 |
| | 100 | 2655 | 2555 | 2355 | 2155 | 1955 |
| | 150 | 3166 | 3066 | 2866 | 2666 | 2466 |
| | 200 | 3620 | 3520 | 3320 | 3120 | 2920 |
| | 250 | 4018 | 3918 | 3718 | 3518 | 3318 |
| 50 | 50 | 2178 | 2053 | 1803 | 1553 | 1303 |
| | 100 | 2778 | 2653 | 2403 | 2153 | 1903 |
| | 150 | 3321 | 3196 | 2946 | 3696 | 2446 |
| | 200 | 3808 | 3683 | 3433 | 3183 | 2933 |
| | 250 | 4237 | 4112 | 3862 | 3612 | 3362 |
| 60 | 50 | 2177 | 2027 | 1727 | 1427 | 1127 |
| | 100 | 2809 | 3659 | 2359 | 2059 | 1758 |
| | 150 | 3384 | 3234 | 2934 | 2634 | 2334 |
| | 200 | 3903 | 3753 | 3452 | 3153 | 2852 |
| | 250 | 4365 | 4215 | 3914 | 3615 | 3314 |

Table 12. Income less cost of water and nitrogen in 1977 for various assumed water costs. Nitrogen is assumed to cost Rs.1.5/lb and the net value of cane is Rs.4.6/md.

| Water inches | Nitrogen lbs/acre | Cost of Water, Rs./Acre in. 2.5 | 5.0 | 10. | 15 | 20 |
|---|---|---|---|---|---|---|
| 20 | 50 | 1529 | 1479 | 1379 | 1279 | 1179 |
| | 100 | 1969 | 1919 | 1819 | 1719 | 1619 |
| | 150 | 2313 | 2263 | 2163 | 1062 | 1963 |
| | 200 | 2559 | 2509 | 2409 | 2309 | 2209 |
| | 250 | 2709 | 2659 | 2559 | 2459 | 2359 |
| 30 | 50 | 1663 | 1588 | 1438 | 1288 | 1138 |
| | 100 | 2122 | 2047 | 1897 | 1747 | 1597 |
| | 150 | 2484 | 2409 | 2259 | 2109 | 1959 |
| | 200 | 2749 | 2674 | 2524 | 2372 | 2224 |
| | 250 | 2917 | 2842 | 2692 | 2542 | 2392 |
| 40 | 50 | 1800 | 1700 | 1500 | 1300 | 1100 |
| | 100 | 2278 | 2178 | 1978 | 1778 | 1578 |
| | 150 | 2659 | 2559 | 2359 | 2159 | 1959 |
| | 200 | 2942 | 2842 | 2642 | 2442 | 2242 |
| | 250 | 3129 | 3029 | 2829 | 2629 | 2429 |
| 50 | 50 | 1942 | 1817 | 1567 | 1317 | 1067 |
| | 100 | 2439 | 2314 | 2064 | 1814 | 1564 |
| | 150 | 2838 | 2713 | 2463 | 2213 | 1963 |
| | 200 | 3140 | 3015 | 2765 | 2515 | 2265 |
| | 250 | 3345 | 3220 | 2970 | 2720 | 2470 |
| 60 | 50 | 2088 | 1938 | 1638 | 1338 | 1038 |
| | 100 | 2603 | 2453 | 2153 | 1853 | 1553 |
| | 150 | 3021 | 2871 | 2571 | 2271 | 1971 |
| | 200 | 3342 | 3192 | 2892 | 2592 | 2292 |
| | 250 | 3566 | 3416 | 3116 | 2816 | 2516 |

APPENDIX 4

# AN AGRONOMIC AND ECONOMIC EVALUATION OF THE EFFECT OF IRRIGATION AND NITROGEN ON COTTON YIELDS IN MULTAN DISTRICT1/

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## INTRODUCTION

Cotton is one of the most important agricultural crops in Pakistan. Acreage varies from 4.5 to 5.0 million acres each year. It supports the local textile industry which is of major economic importance to the country and except in years of low production exports are a significant source of foreign exchange. The average cotton yield presently is about 1200 kg/ha. Yields in Pakistan are only 50% of Egypt's despite the fact that both countries grow cotton under irrigated conditions. In Arizona, where climatic conditions are similar to Pakistan's, a high state of irrigation technology, balanced fertility program and a scientific pest control program have brought average yields to more than 3 times those of Pakistan. Cotton yields of 2500 kg/ha can be achieved in Pakistan under proper irrigation, fertilizer and pest control management.

Efficient use of irrigation water is a major problem in Pakistan. Only 50% of the total supply of water is estimated to be effectively available for crop use. Efficient management of the available water could improve crop yields and reduce water-logging and salinity substantially. Many surveys, field observations and experiments have revealed that farmers over irrigate. They apply heavy irrigation to the crop whenever the water is available without seriously considering its effects on yields or crop needs.

These heavy irrigations not only increase the waterlogging problem by adding water to the aquifer but in the case of cotton accelerate excessive vegetative growth and decrease yield. A balance between leaching requirement and optimum

1/Research conceived and conducted by Agronomists of Exxon Chemical Pakistan Ltd. Statistical analysis and final report completed with the assistance of Colorado State University Water Management Research Project in Pakistan.

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crop requirement must be reached. Another major problem that results from excessive irrigation that it results in leaching of nutrients, particularly nitrogen, out of the root zone. The desired balance between irrigation and nitrogen requirement of cotton has not been determined. These studies were conducted to determine this balance. The purposes of these studies were: (1) to develop a response relationship between irrigation intensity and nitrogen fertility rate, (2) to determine the number of irrigations that are required to grow a cotton crop, and (3) determine the optimum input of water and nitrogen to achieve maximum economic yields at various costs of water and cotton prices.

## MATERIAL AND METHODS

The effect of number of irrigations (I) and nitrogen (N) fertility rate on cotton yield was investigated at four locations (Table 1) in 1977. Planting dates and the physical and chemical analysis of the soils are given in Table 1.

Table 1. Location, Planting Date, Chemical and Physical Characteristics of Cotton Irrigation by Nitrogen Experiments Sites in 1977.

| Experiment No. | Village | Farmer | Planting Date | pH | E.C. (mmhos/cm) | P ... | K ppm | Na ... | Texture |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Qadirpur | Saleem | June 15 | 8.5 | 1.25 | 9.5 | 320 | 260 | SiCL |
| 2 | Mozah Sniganpur | Yousaf | June 19 | 8.6 | 1.25 | 4.5 | 200 | 200 | CL |
| 3 | Mozah Sniganpur | Yousaf | June 19 | 7.9 | 8.0 | 8.5 | 250 | 1082 | SiCL |
| 4 | Cotton Research Station | - | June 18 | | | | | | |

The sodium (Na) contents and electrical conductivity (E.C.) of the soil at location 3 was rather high but good yields were obtained. Experiment 1, 2 and 3 were conducted in farmers' fields under local growing and cultural conditions while experiment 4 was conducted on the Cotton Research Station at Multan. A randomized complete block experimental design was used with 5 irrigation treatments, 4 nitrogen fertility treatments and 4 replications. The irrigation treatment and their dates are shown in Table 2. The N rates used were 50, 75, 100 and 125 lbs N/A or 56, 84, 112 and 140 kg N/ha respectively. The variety B-557 was planted at a seeding rate of 33 kg/ha using a drill at 20 cm spacing. All experiments were located in the Multan area and growing season precipitation data from the Cotton Research Center are shown on Table 3.

Table 2. Date of Irrigations for Cotton Experiments, 1977.

| Experiment No. | No. of Irrigations | Date of Irrigation |
|---|---|---|
| 1 | 3 | Aug. 14, Sept. 5, Sept. 25 |
| | 4 | July 23, Aug. 16, Sept. 5, Oct. 1 |
| | 5 | July 23, Aug. 14, Sept. 5, Sept. 25, Oct. 10 |
| | 6 | July 23, Aug. 11, Aug. 28, Sept. 13, Sept. 25, Oct. 10 |
| | 7 | July 23, Aug. 11, Aug. 24, Sept. 5, Sept. 18 Oct. 1, Oct. 12 |
| 2 & 3 | 3 | Aug. 18, Aug.24, Sept. 24 |
| | 4 | July 21, Aug. 18, Aug. 24, Sept. 25 |
| | 5 | July 21, Aug. 18, Sept. 25, Oct. 6 |
| | 6 | July 21, Aug. 16, Aug. 25, Sept. 13, Sept. 25, Oct. 6 |
| | 7 | July 21, Aug. 16, Aug. 24, Sept. 4, Sept. 20, Oct. 1, Oct. 12 |
| 4 | 3 | Aug. 16, Sept. 13, Oct. 10 |
| | 4 | July 21,* Aug. 21, Sept. 13, Oct. 8 |
| | 5 | July 21,* Aug. 19, Sept. 13, Oct. 3, Oct. 18 |
| | 6 | July 21,* Aug. 16, Sept. 3, Sept. 18, Oct. 3 Oct. 18 |
| | 7 | July 21,* Aug. 16, Aug. 28, Sept. 13, Sept. 28 Oct. 13, Oct. 25 |

*This irrigation withheld due to 1.9" rain received on July 18.

Table 3. Precipitation During Cotton Season at Multan in 1977

| Precipitation | Date | |
|---|---|---|
| 0.25 | June 14) | Planting Season |
| 0.14 | June 15) | |
| 0.22 | July 9 ) | |
| 1.90 | July 18) | |
| 0.22 | Sept. 4) | Growing Season |
| 0.26 | Sept. 5) | |

Table 4. The Effect of Number of Irrigations and Nitrogen Fertility Rate on Cotton Yields

Experiment No. 1 (Farmer - Saleem)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha 56 | 84 | 112 | 140 | Average |
|---|---|---|---|---|---|
| 3 | 818 | 1045 | 823 | 1072 | 940 |
| 4 | 1268 | 1418 | 1651 | 2135 | 1618 |
| 5 | 1240 | 1315 | 1782 | 2219 | 1639 |
| 6 | 1035 | 1255 | 939 | 1418 | 1162 |
| 7 | 783 | 885 | 971 | 1196 | 959 |
| Average | 1029 | 1184 | 1233 | 1608 | |

Statistically Significant effects:

N**

I**

N X I**

S.E.$\bar{y}$ = 137.0

L.S.D.(0.05) = 388 kg/ha

A $7.43m^2$ plot was harvested for yield. This involved several pickings by hand. Plant population counts were also taken in this area at harvest. An initial statistical analysis of the yield and plant population data was made using an Analysis of Variance with the following degrees of freedom (df).

| Source | d.f. |
|---|---|
| Total | 79 |
| Rep (r) | 3 |
| Nitrogen (N) | 3 |
| Irrigation (I) | 4 |
| NxI | 12 |
| Error | |
| RxI | 12) |
| RxN | 9) |
| RxNxI | 36) |
| | 57 |

Regression modeling techniques were used to further evaluate the data as explained in the Results and Discussion.

## RESULTS AND DISCUSSION

The yields of the four cotton experiments conducted are shown in Tables 4, 5, 6 and 7. The effect of N fertility rate and number of irrigations had a statistically significant effect on cotton yield in experiments 1, 2 and 3 (Tables 4, 5 and 6 respectively) but not in experiment 4 (Table 7). The interaction of N by I was statistically significant in experiment 1 only.

The plant populations at harvest are shown in Tables 8, 9, 10 and 11. There was no significant effect of N or irrigations on plant populations in any of the experiments. Generally, plant populations were between 40,000 to 50,000 plants/ha which is considered an acceptable range to achieve good yields.

A more detailed and meaningful evaluation of the effect of number of irrigations and N fertility rate on cotton yields can be accomplished by regression analysis. The four yield regression models that were evaluated are:

Model 1 $$Y = bo + b_1N + b_2N^2 + b_3I + b_4I^2 + b_5NI \quad (1)$$

Model 2 $$Y = bo + b_1N^{3/4} + b_2N^{1\frac{1}{2}} + b_3I^{3/4} + b_4I^{1\frac{1}{2}} + b_5N^{3/4}I^{3/4} \quad (2)$$

Model 3 $$Y = bo + b_1N + b_2N^2 + b_3I + b_4I^2 + b_5NI + b_6NI^2 \quad (3)$$

Table 5 The Effect of Number of Irrigations and Nitrogen Fertility Rate on Cotton Yields

Experiment No. 2 (Farmer - Yousaf)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha | | | | Average |
|---|---|---|---|---|---|
| | 56 | 84 | 112 | 140 | |
| 3 | 857 | 1287 | 1129 | 1117 | 1098 |
| 4 | 1433 | 1777 | 1873 | 2333 | 1854 |
| 5 | 1502 | 1866 | 2216 | 2533 | 2029 |
| 6 | 1055 | 1408 | 1223 | 1512 | 1300 |
| 7 | 885 | 1043 | 1389 | 1342 | 1165 |
| Average | 1147 | 1476 | 1566 | 1767 | |

Statistically Significant Effects:

N**

I**

N X I = N.S.

S.E.$\bar{y}$ = 137.3

L.S.D. (0.05) = 388 kg/ha

Table 6 The Effect of Number of Irrigations and Nitrogen Fertility Rate on Cotton Yields

Experiment No. 3 (Farmer - Yousaf)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha | | | | Average |
|---|---|---|---|---|---|
| | 56 | 84 | 112 | 140 | |
| 3 | 860 | 1322 | 1159 | 1384 | 1181 |
| 4 | 1465 | 1591 | 1725 | 2160 | 1735 |
| 5 | 1453 | 1950 | 2333 | 2315 | 2013 |
| 6 | 1132 | 1349 | 1268 | 1542 | 1323 |
| 7 | 865 | 1063 | 1206 | 1379 | 1128 |
| Average | 1155 | 1455 | 1538 | 1756 | |

Statistically Significant Effects:

N**

I**

N X I = N.S.

S.E.$\bar{y}$ = 178.6

L.S.D. (0.05) = 504 kg/ha

Table 7 The Effect of Number of Irrigations and Nitrogen Fertility Rate on Cotton Yields

Experiment No. 4 (Cotton Research Station)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha 56 | 84 | 112 | 140 | Average |
|---|---|---|---|---|---|
| 3 | 1221 | 1063 | 1260 | 1201 | 1186 |
| 4 | 1122 | 1201 | 1102 | 1184 | 1152 |
| 5 | 1260 | 1082 | 1636 | 808 | 1197 |
| 6 | 1339 | 1379 | 1572 | 1357 | 1412 |
| 7 | 1161 | 1142 | 1201 | 1379 | 1221 |
| Average | 1221 | 1173 | 1354 | 1186 | |

Statistically Significant Effects:

N = N.S.

I = N.S.

N X I = N.S.

S.E.$\bar{y}$ = 258.3

Table 8 Plant Population of Cotton Experiment at Harvest as Influenced by Number of Irrigations and Nitrogen Fertility Rate

Experiment No. 1 (Farmer - Saleem)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha 56 | 84 | 112 | 140 | Average |
|---|---|---|---|---|---|
| 3 | 39684 | 44404 | 38671 | 45738 | 42126 |
| 4 | 39684 | 36991 | 43737 | 46751 | 41790 |
| 5 | 48110 | 48432 | 48432 | 48110 | 48271 |
| 6 | 47764 | 42724 | 40697 | 39363 | 42637 |
| 7 | 47418 | 39684 | 48432 | 42724 | 44564 |
| Average | 44532 | 42447 | 43994 | 44537 | |

Statistically Significant Effects:

N = N.S.

I = N.S.

N X 1 = N.S.

Table 9 Plant Population of Cotton Experiments at Harvest as Influenced by Number of Irrigations and Nitrogen Fertility Rate

Experiment No. 2 (Farmer - Yousaf)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha 56 | 84 | 112 | 140 | Average |
|---|---|---|---|---|---|
| 3 | 44404 | 45738 | 48110 | 41710 | 44992 |
| 4 | 44725 | 47097 | 44725 | 42056 | 44651 |
| 5 | 45071 | 49445 | 45738 | 47764 | 47003 |
| 6 | 43737 | 45738 | 47418 | 42378 | 44819 |
| 7 | 47097 | 45071 | 45738 | 48778 | 46672 |
| Average | 45007 | 46618 | 46346 | 44537 | |

Statistically Significant Effects:

N = N.S.

I = N.S.

N X I = N.S.

Table 10 Plant Population of Cotton Experiments at Harvest as Influenced by Number of Irrigations and Nitrogen Fertility Rate

Experiment No. 3 (Farmer - Yousaf)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha 56 | 84 | 112 | 140 | Average |
|---|---|---|---|---|---|
| 3 | 41043 | 37930 | 44404 | 38350 | 40431 |
| 4 | 45071 | 44404 | 40364 | 37337 | 41787 |
| 5 | 41710 | 47418 | 47418 | 40351 | 44226 |
| 6 | 44725 | 40376 | 45071 | 41365 | 42884 |
| 7 | 42378 | 46430 | 39017 | 45738 | 43391 |
| Average | 42986 | 43312 | 43255 | 40628 | |

Statistically Significant Effects:

N = N.S.

I = N.S.

N X I = N.S.

Table 11 Plant Population of Cotton Experiments at Harvest as Influenced by Number of Irrigations and Nitrogen Fertility Rate

Experiment No. 4 (Cotton Research Station)

| Number of Irrigations | Nitrogen Fertility Rate kg/ha 56 | 84 | 112 | 140 | Average |
|---|---|---|---|---|---|
| 3 | 42716 | 48110 | 52805 | 52484 | 49030 |
| 4 | 45071 | 45071 | 44725 | 46405 | 45318 |
| 5 | 52138 | 42378 | 47418 | 52484 | 48605 |
| 6 | 43391 | 47764 | 48778 | 50779 | 47678 |
| 7 | 50112 | 47418 | 49791 | 45746 | 48266 |
| Average | 46686 | 46148 | 48703 | 49580 | |

Statistically Significant Effects:

N = N.S.

I = N.S.

N X I = N.S.

Table 12 Coefficients of Determinations ($R^2$) and Standard Error of Estimates (SEE) of Regression Models 1, 2, 3 and 4 for Experiments 1, 2 and 3.

| | Experiment 1 | Experiment 2 | Experiment 3 | Experiment Mean |
|---|---|---|---|---|
| Model 1 | | | | |
| $R^2$ | 0.827 | 0.885 | 0.859 | 0.873 |
| SEE | 215.5 | 205.5 | 203.2 | 193.8 |
| Model 2 | | | | |
| $R^2$ | 0.827 | 0.881 | 0.850 | 0.869 |
| SEE | 215.2 | 205.9 | 209.6 | 196.9 |
| Model 3 | | | | |
| $R^2$ | 0.937 | 0.951 | 0.907 | 0.948 |
| SEE | 137.2 | 134.9 | 173.5 | 130.3 |
| Model 4 | | | | |
| $R^2$ | 0.905 | 0.951 | 0.899 | 0.947 |
| SEE | 152.4 | 126.6 | 164.3 | 118.8 |

Model 4 $Y = bo + b_1N + b_2I^2 + b_3NI + b_4NI^2$ (4)

where:

$Y$ = yield in kg/ha
$N$ = kg N/ha
$I$ = number of irrigations
$b$ = Coefficients as determined by least square

The correlation coefficients ($R^2$) and standard error estimates (SEE) evaluating the models fit to the experimental results for experiments 1, 2 and 3 are shown in Table 12. Since the effects of irrigations and N were not statistically significant in experiment Number 4 no further analysis of the data was justified. The $R^2$ values and standard error of estimate of models 3 and 4 were obviously better for all three experiments than were models 1 and 2. Consequently, models 1 and 2 could be eliminated. The $R^2$ values for model 3 were equal to or slightly higher than model 4 but the standard error of estimates were substantially higher in experiments 2 and 3 as well as with the experiment means. Examination of the yield results showed that the nitrogen response was linear which indicates a $N^2$ term would not be justified. Based on these observations it was determined that model 4 represented the best fit. Model 4 is simply model 3 with the $N^2$ and one I term dropped. This also made the calculations less complicated. The b values used in model 4 are as follows:

$bo$ = 795.58
$b_1$ = -60.950
$b_2$ = 1.351
$b_3$ = 31.292
$b_4$ = -3.401

The response surface showing the yield as a function of N fertilizer rate and number of irrigations using model 4 is shown in Figure 1. The individual solutions of regression model 4 are given in Table 13. Figure 1 is a graphic representation of these solutions over all the irrigations and N rates.

These results show that maximum yields were obtained between 4 and 5 irrigations. As can be seen in Figure 1 the N response surface is linear over the entire N fertilizer range of 55 to 140 kg N/ha. In the future higher rates of N should be used in order to establish the point of diminishing return in relation to N. The point of diminishing return was obtained with the number of irrigations.

These models are very useful in that various pieces of important economic information can be derived from them. First the marginal product of nitrogen at any level of N and I can be calculated by taking the partial derivative with respect to N.

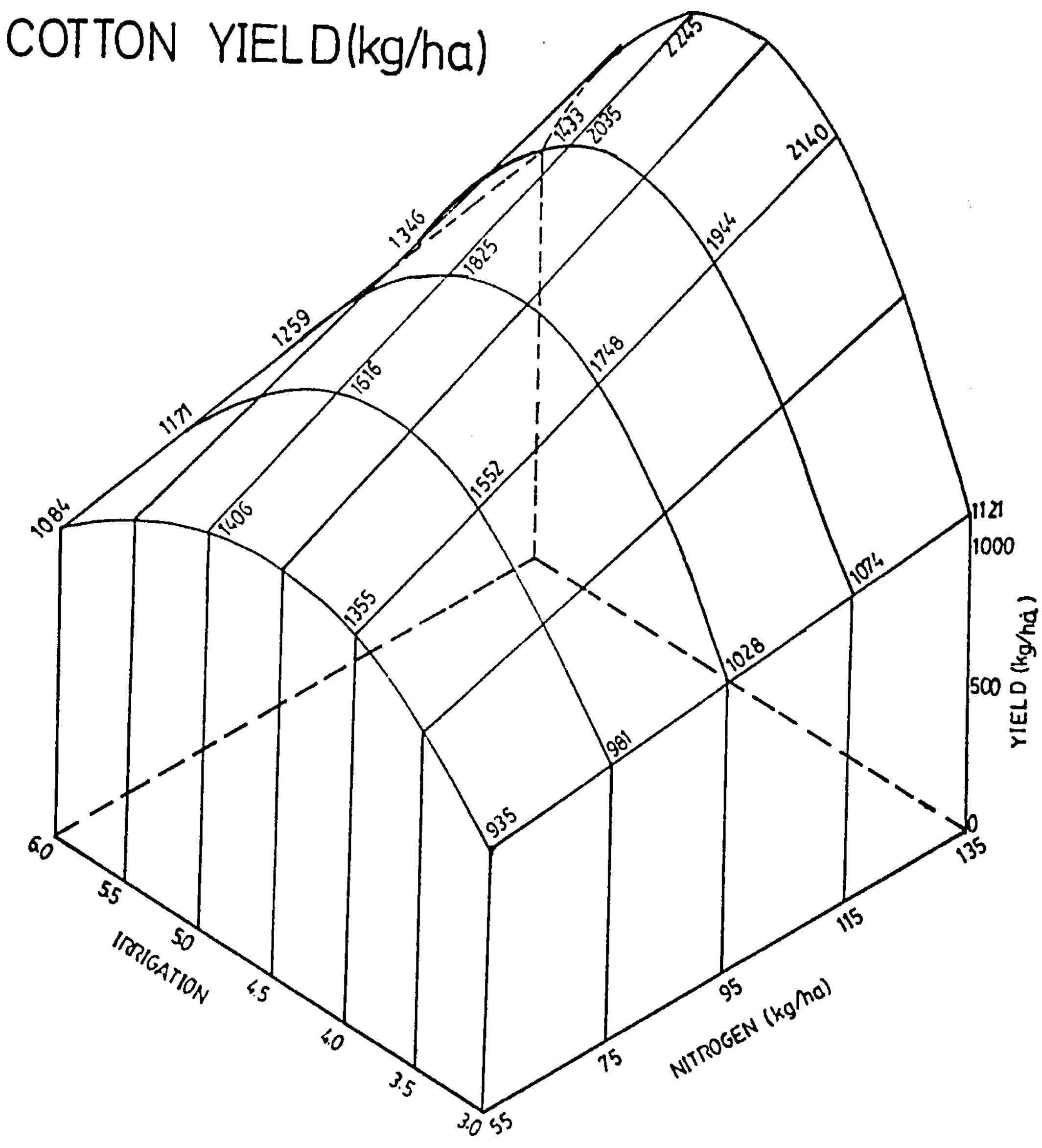


Figure 1. Response surface of yield as a function of nitrogen fertilizer rate and number of irrigations.

Table 13 The Response Surface of the Effect of Number of Irrigations and Nitrogen Rate on Cotton Yields as Predicted by the Regression Model

| N (kg/ha) | IRRIGATIONS 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6 |
|---|---|---|---|---|---|---|---|
| 55 | 935 | 1192 | 1356 | 1428 | 1406 | 1291 | 1084 |
| 75 | 981 | 1330 | 1552 | 1647 | 1616 | 1457 | 1171 |
| 95 | 1028 | 1469 | 1748 | 1867 | 1825 | 1622 | 1259 |
| 115 | 1074 | 1607 | 1944 | 2087 | 2035 | 1788 | 1346 |
| 135 | 1121 | 1745 | 2140 | 2307 | 2245 | 1953 | 1433 |

Table 14. Marginal Product of Nitrogen (kg Cotton/kg N) at Each of Four Irrigation Levels

| Number of Irrigation | Marginal Product (kg Cotton/kg N) |
|---|---|
| 3 | 2.32 |
| 4 | 9.80 |
| 4.6* | 11.03 |
| 5 | 10.48 |
| 6 | 4.36 |

*Theoretical maximum

Table 15. Return on Investment in Nitrogen at Various Irrigation Levels Based on Different Values of Cotton

| Price of Cotton | | Number of Irrigations | | | | |
|---|---|---|---|---|---|---|
| Rs/md | Rs/kg | 3.0 | 4.0 | 4.60* | 5.0 | 6.0 |
| 115 | 3.08 | 2.15 | 9.07 | 10.22 | 9.72 | 4.04 |
| 125 | 3.34 | 2.34 | 9.87 | 11.12 | 10.58 | 4.40 |
| 135 | 3.61 | 2.53 | 10.68 | 12.01 | 11.43 | 4.76 |
| 145 | 3.88 | 2.72 | 11.47 | 12.92 | 12.29 | 5.11 |
| 155 | 4.14 | 2.90 | 12.23 | 13.78 | 13.11 | 5.45 |

* Theoretical Maximum yield

The marginal product of N is the amount of cotton (kg/ha) that will be produced by an additional unit (kg/ha) of nitrogen and has the units of kg Cotton/kg N. For model 4 the marginal product is given by:

$$\frac{\partial Y}{\partial N} = b_1 + b_3 I + b_4 I^2 \tag{5}$$

Model 4 is linear with respect to N as only first order terms in N are present. Therefore, eq. (5) has only terms in I telling us that the marginal product of N is dependent only on the number of irrigations and is independent of N rate. The level of irrigation at which the maximum N response will be obtained, i.e. the marginal product of nitrogen is a maximum and can be found by taking the derivative of eq. (5) with respect to I and setting it equal to zero. The derivative of (5) with respect to I is:

$$\frac{d\{\frac{\partial Y}{\partial N}\}}{dI} = b_3 + 2b_4 I \tag{6}$$

This tells us that the change in the marginal product of N is a linear function of the number of irrigations and the irrigation level at which the maximum yield increase per kg of N is found where:

$$b_3 + 2b_4 I = 0 \tag{7}$$

and

$$I = \frac{-b_3}{2b_4} \tag{8}$$

Substituting the coefficient from model 4 into eq. (8) we find that the maximum response to N will be obtained where I = 4.6 or the maximum yield was obtained at a theoretical 4.6 irrigations at all N rates.

We can determine the marginal product of N at 4.6 irrigations by substituting 4.6 for I in eq. (5). By doing this we find that at 4.6 irrigations we can increase yield of cotton by 11.03 kg/ha for every kg of N applied, i.e., the marginal product is 11.03 kg cotton/kg N. Because incremental response to N is the same at all N levels the return on investment is given by the marginal product times the price received for the cotton divided by the cost of N:

$$R = \frac{MP_c}{C_N} \tag{9}$$

where:

R = the return on investment
M = marginal product (kg cotton/kg N)
$P_C$ = price of cotton
$C_N$ = cost of N

Where M is 11.03 kg cotton/kg N the return on investment is 11.21 for each rupee invested if cotton sells for Rs. 3.4/kg (Rs. 125/md) and N costs Rs. 3.31/kg.

The above is somewhat theoretical as it is difficult to apply 4.6 irrigations. However, by substituting into eq. (5) we can calculate the marginal product of N at each irrigation level (Table 14). From the marginal products given in Table 14 we can now calculate the return on money invested in nitrogen at any number of irrigations and prices of cotton (Table 15).

Nitrogen fertilizer was a good investment at all irrigation levels but the return was much better at 4 or 5 irrigations than at 3 or 6 irrigations. The current cotton price to farmers is approximately Rs. 3.61/kg (Rs. 135/md). If we estimate harvesting and transportation costs to be Rs. 0.27/kg (Rs. 10/md) the farmer's return approximately is Rs. 3.34/kg (Rs. 125/md). Using this figure (Rs. 3.34/kg) in Table 15 it can be seen that the farmers return on N investment ranges from 2.34 to as high as Rs. 10.58 at 5 irrigations (not considering the theoretical optimum of 4.6 irrigations). The return on N increases by over 7 between 3 and 4 irrigations and decreases by over 6 between 5 and 6 irrigations. This relationship shows the critical need for proper irrigation to obtain maximum return from fertilizer N investment.

Another useful way of using these surfaces is to plot the yield isoquants as a function of the inputs as shown in Figure 2. The heavy curved lines are the yield isoquants. They can be thought of as "contour lines" of equal yield on Figure 1. From these diagrams we can quickly determine the approximate yield that can be expected from any level of N and number of irrigations.

The yield isoquants may be determined by first rearranging the equation of model 4 to the form:

$$N = \frac{Y - b_o - b_2 I^2}{b_1 + b_3 I + b_4 I^2} \tag{10}$$

For each yield isoquant N levels are calculated for a series of irrigation levels between I = 3 and I = 6. The resulting points are plotted giving the isoquants as shown.

Note that in the area where I is less than 4.60 increasing either N or I will increase yields. For example, the combination 121 kg N/ha and 4.0 irrigations resulted in a cotton yield

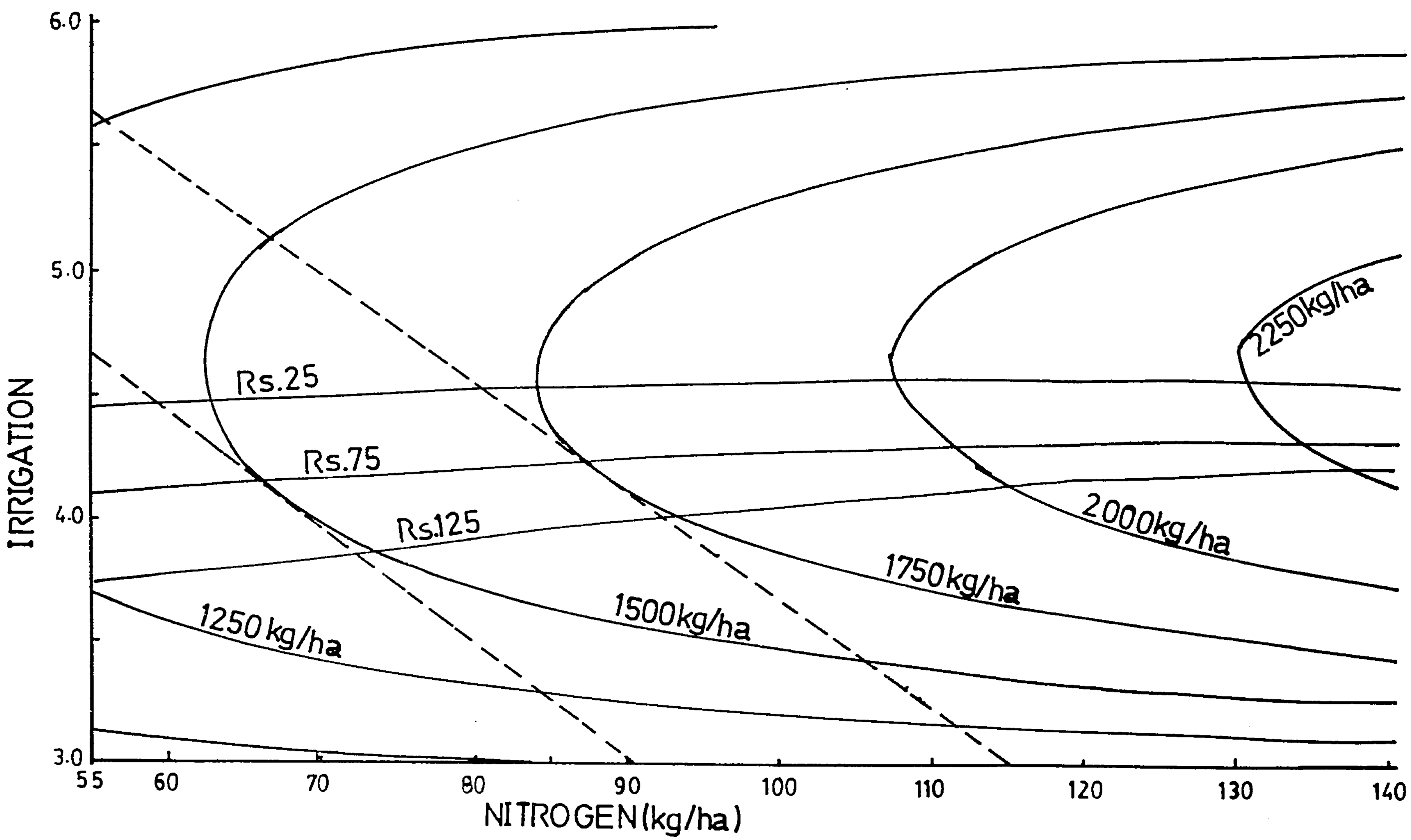


Figure 2. Cotton yields isoquants as a function of nitrogen and irrigations. Dashed diagonal lines are isocost lines for Rs. 3.31/kg N and Rs. 30 irrigation. Horizontal lines show optimum combination for producing specified yields.

of 2000 kg/ha. If the number of irrigations could be increased to 4.6, the theoretical optimum, only 107 kg N/ha would be required to produce a yield of 2000 kg/ha. One can see that the requirement for more N input increases very rapidly on either side of the theoretical optimum number of irrigations of 4.6. This points out the very sensitive relationship that exists between N and irrigation. Over or under irrigation increases the N input requirement substantially to achieve the same yield and when the irrigations vary far from the theoretical optimum no amount of nitrogen input will keep yields high.

If one input is scarce or costly it may be possible to compensate by increasing the other input to some extent as explained above. The optimum levels of N and I will depend on the cost of N and irrigation. Costs of N are fairly well known but irrigation costs vary depending on the source of water as well as the opportunity costs of using the water to produce other crops. This is particularly important where land lies fallow due to lack of water. The most profitable combination of N and I to produce any specified yield level depends on the relative price of N and I, i.e. $C_N/C_I$. Consider any point N, I on Figure 2. The total cost (T) of N and irrigation at that point is given by:

$$C_N(N) + C_I(I) = T \tag{11}$$

In our example we have plotted I on the vertical axis so we will solve eq. (11) for I.

$$I = \frac{T}{C_I} - \frac{(C_N)(N)}{C_I} \tag{12}$$

Equation (11) describes a straight line with slope $C_N C_I$. All points on any straight line with slope $C_N/C_I$ will have the same total cost T. Such lines are termed isocost lines. The two dashed diagonal lines on Figure 2 are isocost lines for Rs. 75/irrigation and Rs. 3.31/kg N or for any other combination of water and nitrogen costs such that $C_N/C_I$ equals 0.0441. The line that is tangent to the 1500 kg/ha yield isoquant has a total cost of N and irrigation of Rs. 528 and the total cost on the line tangent to the 1750 kg/ha isoquant is Rs. 607.

Standard micro-economic theory tells us that the optimum combination of these two inputs to produce any specified yield level is the point at which the isocost line with slope $C_N/C_I$ is tangent to the yield isoquant. Thus as Rs. 75 per irrigation and Rs. 3.31/kg N the point of tangency is to the 1500 kg/ha yield isoquant at 66.6 kg N/ha and 4.1 irrigation. At 1750 kg/ha yield the optimum combination is 1750 kg/ha yield the optimum combination is 88.1 kg N/ha and 4.2 irrigations. Mathematically, this point of tangency can be expressed by:

$$\frac{\partial I}{\partial N} = - \frac{C_N}{C_I} \tag{13}$$

An analytical determination of these points of tangency is complicated so we have used an iterative method that is relatively easy with a small desk top computer or even a programmable calculator. Going back to eq. 10 for each yield isoquant we calculate the N values for the complete range of irrigations 3 to 6 in small increments. The $\frac{\Delta I}{\Delta N}$ values are thus calculated for the increments and the points selected where:

$$- \frac{\Delta I}{\Delta N} \approx \frac{C_N}{C_I} \tag{14}$$

Table 16 was constructed in this manner using costs of irrigation varying from Rs. 25 to Rs. 125. These values are plotted as the horizontal lines in Figure 2 for irrigation costs of Rs. 25, 75 and 125 only. As the cost of irrigation increases the optimum N levels to produce a given yield increase and the optimum irrigation levels decrease. For example, if the cost of irrigation is Rs. 25 from Figure 2 (or Table 16) we see that the optimum economic combination of irrigations and nitrogen to achieve a 1750 kg/ha yield is 4.5 irrigations and 84.4 kg/ha. If the cost of irrigations increases to Rs. 125 and optimum economic combination changes to 4.0 irrigations and 93.6 kg N/ha to achieve the same yield of 1750 kg/ha.

However, the optimum levels of irrigations and N are actually rather insensitive to changes in irrigation cost in this range. This is because the marginal product due to N (kg cotton/kg N) is very sensitive to the number of irrigation as shown in Table 14.

The above is somewhat of an academic exercise as it assumes a continuous rather than a discrete irrigation variable. Probably a more useful procedure is to examine the profitability of 4 or 5 irrigation at various costs of irrigation. These costs are calculated using eq. (11) and are shown in Table 17. Four irrigations generally produce the specified yields cheaper than five irrigations, particularly where irrigation costs are high. At high yields and low water costs the production cost for 4 irrigations are very similar to those for 5 irrigations. For example, if the cost of irrigation is Rs. 125/irrigation the cost of N plus irrigation to achieve a 1000 kg/ha yield is Rs. 562 and 679 at 4 and 5 irrigations respectively. However, at the 1750 kg/ha yield and irrigation costs of Rs. 25 the cost of N and irrigation is about Rs. 415 for both 4 and 5 irrigations.

The figures in Table 17 are the variable costs of N and I only for the various yields. These do not tell the whole story since the fixed costs of production are much higher than are the variable costs from N and I. If we assume a fixed

Table 16 The Optimum Nitrogen Fertility Rate (N) and Number of Irrigations (I) Combinations that will Produce a Specific Yield at Various Cost per Irrigation. Nitrogen is assumed to cost Rs. 3.31/kg.

| Irrigation Costs Rs/Irrigation | $C_N/C_I$ | Cotton Yield (kg/ha) 1000 | | 1250 | | 1500 | | 1750 | | 2000 | | 2250 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N 1/ | I 2/ | N | I | N | I | N | I | N | I | N | I |
| 25 | .1324 | 18.0 | 4.1 | 39.7 | 4.4 | 62.0 | 4.4 | 84.4 | 4.5 | 107.0 | 4.5 | 129.6 | 4.5 |
| 50 | .0662 | 21.2 | 3.8 | 42.3 | 4.1 | 63.8 | 4.3 | 85.9 | 4.4 | 108.2 | 4.4 | 130.5 | 4.4 |
| 75 | .0441 | 24.1 | 3.6 | 45.2 | 4.0 | 66.6 | 4.1 | 88.1 | 4.2 | 110.0 | 4.3 | 132.2 | 4.4 |
| 100 | .0331 | 26.6 | 3.5 | 48.3 | 3.8 | 69.4 | 4.0 | 90.7 | 4.1 | 112.4 | 4.2 | 134.2 | 4.3 |
| 125 | .0265 | 28.9 | 3.5 | 51.2 | 3.7 | 72.3 | 3.9 | 93.6 | 4.0 | 115.0 | 4.1 | 136.5 | 4.2 |

1/ Optimum N level (kg/ha)

2/ Optimum number of irrigations

Table 17 Cost of Nitrogen Fertilizer (N) and Irrigation (I) at 4 or 5 Irrigations as Affected by Cotton Yields and Irrigation Costs. Nitrogen is assumed to cost Rs. 3.31/kg.

| Irrigation Costs | 1000 | | 1250 | | 1500 | | 1750 | | 2000 | | 2250 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rs/Irrigation | 4I 1/ | 5I | 4I | 5I | 4I | 5I | 4I | 5I | 4I | 5I | 4I | 5I |
| | Rs. (Cost of N plus I) | | | | | | | | | | | |
| 25 | 162 | 179 | 246 | 258 | 331 | 337 | 415 | 416 | 500 | 495 | 584 | 574 |
| 50 | 262 | 304 | 346 | 383 | 431 | 462 | 515 | 541 | 600 | 620 | 684 | 699 |
| 75 | 362 | 429 | 446 | 508 | 531 | 587 | 615 | 666 | 700 | 745 | 784 | 824 |
| 100 | 462 | 554 | 546 | 633 | 631 | 712 | 715 | 791 | 800 | 870 | 884 | 949 |
| 125 | 562 | 679 | 646 | 758 | 731 | 837 | 815 | 916 | 900 | 995 | 984 | 1074 |

1/ 4I - 4 Irrigations

cost of production of Rs. 1500/ha we can modify eq. (11) by adding this to the variable costs and dividing by the yield to calculate a unit production cost (UPC) with the units of Rs/kg cotton produced, eq. (11) then becomes:

$$\frac{C_N(N) + C_I(I) + \text{Fixed Costs}}{Y} = UPC \qquad (13)$$

Using eq. (13) we can then construct Table 18 for the various costs of irrigations and yields. The difference in unit production costs of 4 or 5 irrigations is very small at low irrigation costs and increases slightly as the cost of water increases. At higher production levels this spread in cost is decreased. The efficiency of production increases substantially as yields increase. If each irrigation costs Rs. 50 the unit production cost decreases from Rs. 1.76/kg cotton at a 1000 kg/ha yield with 4 irrigation to as low as Rs. 0.97/kg cotton at 2250 kg/ha. A decrease in unit production cost of Rs. 0.79/kg cotton represents a 45% decrease in production costs as a result of higher yields. The data in Table 18 clearly demonstrates the more efficient production that is obtained when yields are maximized. Any appropriate fixed cost could be used in eq. (13) to calculate unit production costs.

Table 18 Unit Production Costs ( Rs/kg Cotton) Assuming a Rs. 600/ha Fixed Cost and Variable Costs of N and I at Various Cotton Yield

| Irrigation Cost | Cotton Yield kg/ha 1000 | | 1250 | | 1500 | | 1750 | | 2000 | | 2250 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rs/Irrigation | 4I | 5I | 4I | 5I | 4I | 5I | 4I | 5I | 4I | 5I | 4I | 5I |
| 25 | 1.66 | 1.68 | 1.40 | 1.41 | 1.22 | 1.22 | 1.09 | 1.09 | 1.00 | 1.00 | 0.93 | 0.92 |
| 50 | 1.76 | 1.80 | 1.48 | 1.51 | 1.29 | 1.31 | 1.15 | 1.17 | 1.05 | 1.06 | 0.97 | 0.98 |
| 75 | 1.86 | 1.93 | 1.56 | 1.61 | 1.35 | 1.39 | 1.21 | 1.24 | 1.10 | 1.12 | 1.02 | 1.03 |
| 100 | 1.96 | 2.05 | 1.64 | 1.71 | 1.42 | 1.47 | 1.27 | 1.31 | 1.15 | 1.18 | 1.06 | 1.09 |
| 125 | 2.06 | 2.18 | 1.72 | 1.81 | 1.49 | 1.56 | 1.32 | 1.38 | 1.20 | 1.25 | 1.10 | 1.14 |

## SUMMARY

The results of three irrigations by N experiments on cotton indicate that proper irrigation of cotton is a very critical variable input to cotton production. The theoretical optimum number of irrigations was 4.6 while over and under irrigation decreased yields substantially. The response to N was linear over the entire fertility rate range of 55 to 140 kg/ha.

Regression analysis using a yield model allowed us to perform an economic evaluation of production as influenced by prices of N, irrigations and cotton. The marginal product of N (kg cotton/kg N) was 11.03 at the theoretical optimum number of irrigations. This decreased to 2.32 and 4.36 at 3 and 6 irrigations, respectively. The return on investment in nitrogen when the cotton price was Rs. 3.34/kg (Rs. 125/md) was a maximum of 11.12 at the theoretical optimum number of irrigations and decreased to 2.34 when under irrigation occurred (6 irrigations). Fluctuations in the price of cotton over the range of Rs. 3.09 to 4.14/kg did not change the return on investment in N as much as did over or under irrigation by one irrigation. This shows the return on N investment is more heavily influenced by proper irrigation than by the price of cotton.

The unit production cost was influenced more by yield than by the difference in cost of 4 or 5 irrigations. If a fixed cost of production was assumed to be Rs. 1500/ha the production costs/kg cotton varied markedly. If each irrigation cost Rs. 50 the unit production cost decreased from Rs. 1.76/kg cotton at a 1000 kg/ha yield to Rs. 0.97 at 2250 kg/ha with 4 irrigations. The difference in unit production costs of 4 vs 5 irrigation was only Rs. 0.04/kg if water cost Rs. 50 and never over Rs. 0.12 when water costs Rs. 125/irrigation. This spread in cost decreased as yield increased.

Based on the yield results and economic analysis of these experiments it is evident that proper irrigation is of critical importance to production of cotton. Farmers often apply more than 5 irrigations but these results indicate that over irrigation decreases yields significantly. The adverse effect of over irrigation cannot be overcome by increasing the N input. Therefore, farmers need to be cautioned that over irrigation will decrease yields and decrease their net income to a point where return on fixed and variable costs make cotton production uneconomical.

# APPENDIX 5

## THE EFFECT OF HERBICIDES AND MECHANICAL WEED CONTROL ON MAIZE YIELDS

B. A. Sabir, M. M. Iqbal, D. G. Westfall and A. Ghaffar[1]

### INTRODUCTION

The practice of using herbicides to control weeds in crops is in its infancy in Pakistan. The Government has approved only a few herbicides for use by the farmers and very few farmers have accepted this new technology as part of their production program. A considerable amount of education must be done in order to inform the farmers of the benefits herbicides have on crop yields. Also, additional field performance data are needed on herbicide efficacy and selectivity.

The field demonstration reported here was undertaken to accomplish three objectives: (1) to demonstrate to farmers the potential beneficial effects of herbicides in controlling weeds in maize as compared to conventional methods, (2) to determine the efficacy and selectivity of serveral herbicides and (3) to determine the potential economics of herbicide use.

### MATERIALS AND METHODS

A field demonstration on weed control in maize was conducted on Tubewell 56 in the Mona Reclamation Experimental Project area. The demonstration consisted of six treatments as follows:

| Treatment No. | Treatment Name | Application Rate (kg material/ha) |
|---|---|---|
| 1 | Gramoxone | 1.5kg pre & 1.5kg post-emergence |
| 2 | Afalon | 1.5kg pre-emergence |
| 3 | Primextra | 5kg pre-emergence |
| 4 | Best hand weed control | Three hoeings |
| 5 | Normal weed control | Two hoeings |
| 6 | Check | No weed control |

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At the present time none of these herbicides are standardized for use on maize. Gramoxone is a fast acting contact herbicide, therefore, contact to any beneficial plants should not occur. It is approved for use on sugarcane but the distributor suggested that it be tried as a pre-emergence herbicide on maize. Afalon has a broad range of recommended crop uses in various countries, among them maize. It is absorbed through the roots and leaves of weeds and has a persistence of several weeks. It is recommended as a pre-emergence spray at 1.5-2.0kg/ha for maize. Primextra is recommended for use on maize in many countries. It is absorbed by roots and leaves of weeds and controls a wide range of broadleaf weeds and grasses. Its recommended rate of application is 4-6 kg/ha, depend on soil type.

Plot size was 8.4 x 61m with two replications. A seeding rate of 4.9 kg/ha of the maize variety Akbar was planted in 75 cm spaced rows on July 13. The uniform preplant fertilizer application rate of 93-56-30 kg/ha ($N-P_2O_5$ - $K_2O$) was applied on July 12 and 19 kg N/ha was applied on August 16, before irrigation. All plots received three irrigations during the growing season, i.e., on August 16, September 14 and 28. About 3 inches of water was applied at each irrigation. With the exception of the weed control treatments all cultural practices were the same on all plots throughout the growing season. The hoeings with the Khurpa were accomplished during August and the herbicides were applied on the flat three days after planting. The post-emergence application of Gramoxone was made on August 13 as a directed spray so leaf contact on the maize plants did not occur. Weed counts were made before this second application.

The entire plot was harvested for cob yield on October 8. The weight of the cob (cob + grain) was determined on the field moist basis. The grain yield was estimated by multiplying the cob weight by 2/3. Statistical analysis using an analysis of variance and LSD test was used to determine the statistically significance of the various treatments on yields.

## RESULTS AND DISCUSSION

Field observations after the application of the herbicides showed that only Primextra controlled weeds adequately when applied pre-emergence under the conditions of this demonstration. The weed counts of the various treatments are shown in Table 1. There were 158 and 148 weeds/$m^2$ in the Gramoxone and Afalon treatments, respectively, while weeds control was 100% with Primextra. Evidently some efficacy occurred with Gramoxone and Afalon because the weed counts in those plots were lower than the weedy check. The performance of these herbicides, as judged by weed counts, would not be acceptable while Primextra performed very well. Since Gramoxone did not exhibit weed control pre-emergence, a second application was made on August 13. Complete weed control occurred at this time but some damage to the maize was observed.

Table 1. Weed counts in various treatments on August 12 and weight of weeds removed from the hand weeded treatments.

| Treatment | Weeds Number/$m^2$ | (kg/ha) |
|---|---|---|
| Gramoxone | 158 | |
| Afalon | 148 | |
| Primextra | 0 | |
| Best hand weed control | 0 | 4120 |
| Normal hand weed control | 0 | 4480 |
| Check (No weed control) | 200 | |

Table 2. The effect of herbicides and mechanical weed control on the yield of maize.

| Treatment | Dose (kg/ha) | Time of Application | Yield (kg/ha) Cob | Grain* |
|---|---|---|---|---|
| Gramoxone | 1.5 + 1.5 | Pre-plus post | 1983 | 1322 |
| Afalon | 1.5 | Pre-emergence | 1771 | 1181 |
| Primextra | 5.0 | Pre-emergence | 2358 | 1572 |
| Best hand weed control | | Three hoeings | 2067 | 1378 |
| Normal weed control | | Two hoeings | 1847 | 1231 |
| Check | | No weed control | 1349 | 899 |
| | | Mean | 1896 | 1264 |

| | Cob | Grain | |
|---|---|---|---|
| LSD (.05) | 205.4 | 136.9 | C.V. = 10.26% |
| LSD (.01) | 322.0 | 214.7 | |

*Cob yield X 2/3 = grain yield.

The total amount of weeds (weight basis) removed from the two hand weeded treatments was very large (Table 1). These figures show the large weed infestation levels that exist in farmers fields.

The yield results from each treatment are shown in Table 2. The highest yield was obtained with Primextra which resulted in a yield of 2358 kg cob and 1572 kg/ha grain. This is significantly higher (.05 level) than the best hand weed control method of three hoeings. The yield of the Primextra treatment was highly significantly greater than the other two herbicides. There were no significant differences in the yields of the Gramoxone, best hand control and normal weed control. The Afalon treatment resulted in the lowest yield of all the herbicides but still highly statistically significantly greater than the weedy check. There was over a 1000 kg/ha difference in the cob yield between the weedy check and Primextra and 673 kg/ha difference in grain yields.

The cost of each treatment varies with each chemical and manual weed control method (Table 3). The maximum cost was incurred with best hand weed control method (Rs. 444.78). The cost of herbicides ranged from Rs. 151.27 and Rs. 294.57/ha which was less than the cost of normal weed control (Rs. 296.52). While comparing return on chemical with normal weed control, the return of Rs. 299.95, Rs. 581.65, Rs. 43.39 and Rs. 101.64 was obtained for Gramoxone, Primextra, Afalon and best hand weed control, respectively (Table 4). A loss of Rs. 267.88 was obtained when no weed control was compared with normal weed control. Similarly, when the various weed control methods were compared with no weed control, a return of Rs. 567.83, Rs. 849.53, Rs. 315.27, Rs. 369.52 and Rs. 267.88 was recorded for Gramoxone, Primextra, Afalon, best hand weed control and normal hand weed control, respectively. The weed control effect with Gramoxone occurred from the post-emergence application. Gramoxone is a contact killing herbicide and should not be used as a post-emergence spray of corn. Contact on the corn leaves will kill or severely damage the plants. The use of a directed spray, as was used in the study, could not be guaranteed under farmer conditions. Therefore, its post-emergence use is not suggested for further testing.

Based on these results Primextra appears to be the most economical and best method of weed control in maize. It has a broad range of efficacy, is selective with no maize damage occurring. The manufacturer of this chemical indicated it will be standardized and regularized for use in the near future.

It is not known exactly what percent of the farmers do not use any weed control measures in maize but it is thought to be a large percentage. Some method of weed control is required if good yields are to be obtained. Primextra appears to be the best alternative that is potentially available.

Table 4. The comparison of costs and returns as affected by chemical and conventional method of weed control in maize. The production costs of weed control methods only are considered.

| Treatment | Cost | Gross Return | Net Return | Return compared to normal weed control | Return compared to no weed control |
|---|---|---|---|---|---|
| | Rs/ha | | | | |
| Gramoxone | 151.27 | 2247.40 | 2096.13 | 299.95 | 567.83 |
| Primextra | 294.57 | 2672.40 | 2377.83 | 581.65 | 849.53 |
| Afalon | 164.13 | 2007.70 | 1843.57 | 43.39 | 315.27 |
| Best hand weed control | 444.78 | 2342.60 | 1897.82 | 101.64 | 369.52 |
| Normal hand weed control | 296.52 | 2092.70 | 1796.18 | | 267.88 |
| Check (No weed control) | | 1528.30 | 1528.30 | (267.88) | |

Table 3. Cost incurred by different chemicals and manual weed control methods in maize.

| Treatment | Cost of Material | Labor Cost | Sprayer cost (hired) | Total |
|---|---|---|---|---|
| | Rs/ha | | | |
| Gramoxone | 77.14 | 49.42 | 24.71 | 151.27 |
| Primextra | 220.44 | 49.42 | 24.71 | 294.57 |
| Afalon | 90.00 | 49.42 | 24.71 | 164.13 |
| Best hand weed control | | 444.78 | | 444.78 |
| Normal hand weed control | | 296.52 | | 296.52 |
| Check (No weed control) | | | | |

SUMMARY

The effect of three herbicides, two hand weeding treatments and no weed control on the yield of maize was investigated in field demonstration plots. The use of Primextra herbicide to control weeds resulted in cob and grain yields of approximately 100% greater than the weedy check. Yields obtained from Gramoxone and Afalon were highly statistically significantly lower than those obtained with Primextra. The Primextra treatment also out yielded the hand weeded treatments but Gramoxone and Afalon did not. The lack of greater yields from these two herbicides was due to damage to the maize with Gramoxone and lack of weed control with Afalon when applied under the conditions of this demonstration.

The total cost incurred by different herbicides was much less than the cost of best weed hand control method. The return, compared with no weed control, was very good particularly with Primextra.

Additional work needs to be undertaken to educate the farmers as to the potential benefit to them that herbicides can be on crop yields. Also much more research must be undertaken to determine herbicide efficacy and selective in order to get governmental approval for herbicide use by farmers.

# APPENDIX 6

# YIELD TRENDS AND ADOPTION OF IMPROVED AGRICULTURAL PRACTICES IN MONA PROJECT AREA 1964-65 to 1973-74

M. M. Wahla, J. O. Reuss and Bashir Ahmed[a]

## INTRODUCTION

During the period 1965-74 the Extension Agronomy Section of the Mona Reclamation Experimental Project conducted crop cutting surveys on wheat, cotton, rice and sugarcane. This paper summarizes part of the data collected in these surveys along with an evaluation of changes in crop production that have occurred during the period. It is a period of special significance due to the introduction of improved practices, including chemical nitrogen fertilizer as well as high yielding varieties of some crops, particularly wheat. The wheat data through 1971 have been previously reported[1] but the inclusion of later years in this paper along with some additional statistical analysis allow us to present a more complete picture.

## MATERIAL AND METHODS

The crop cutting surveys reported here were conducted by the Extension Agronomy Section of the Mona Reclamation Experimental Project. Data was collected from perennial and nonperennial canal command areas and from uncommanded (tubewell only areas). The data from these three types or command areas are reported separately. The sample numbers from the perennial, nonperennial and uncommanded areas are generally in the ratio of 2:1:1. Within this ratio a stratified sampling procedure was used to weight the selection of command areas according to the density of that crop within the command area. Within these strata canal outlets, fields and the location of the sample harvested area within the field were selected at random according to a set procedure. The procedure for wheat has been previously described.[1] In all cases harvested areas were 16½ feet by 33 feet. Ancillary information such as number of irrigations, number of plowings, fertilizer applied, etc., were collected by interview of the farm operators.

Various methods of statistical analysis were employed. Confidence intervals were calculated by standard methods assuming the "Normal" or "Gaussian" distribution (2, Chapter 2). Fertilizer effects were generally evaluated by separating fields to which chemical nitrogen fertilizer was applied from those that did not receive such fertilizer. The mean yield difference between these two groups was then

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tested by means of the "t" tests for groups of unequal size (2, Chapter 4). This procedure was selected rather than regression analysis because in most cases the high percentage of fields that were not fertilized resulted in a highly unequal distribution of points with respect to the independent variable which is undesirable in regression analysis. Regression analyses were used in some cases to try and relate such parameters as number of irrigations or number of plowings to yield.

## RESULTS AND DISCUSSION

### A. Wheat

The mean wheat yields with confidence intervals, percentage of high yielding varieties and mean number of irrigations are shown in Tables 1 through 3. The perennial cropping area is most important in terms of project production. The project mean cropped acreage during the period 1965-66 to 1970-71 was 123,410 acres with a range of from 111,597 to 131,984. Out of this the mean perennial command area cropped acres ranged from 84,506 to 93,434 with a mean of 90,020 acres. Thus 73% of the mean cropped acreage was in the perennial canal command area. During this time the mean yield on the perennial canal command area increased from just under 20 mds/acre to about 30 mds/acre. Most of this increase occurred during the period starting with the 1968-69 season and ending with the 1971-72 season. During this period the percentage of high yielding varieties i.e. Mexi-pak or other semidwarfs increased from 3% to about 93%. The percentage of fields to which commercial nitrogen fertilizer was added increased from about 13% to 55%, and the average nitrogen use over all perennial command acres increased from 1.5 to 21.0 lbs N/acre during the same period (Table 4).

The mean yields with confidence intervals for the perennial area are plotted in Figure 1. We have established a base line of 19.8 md/acre on Figure 1 using the mean yields prior to the 1967-68 season and the unfertilized yield for the 1967-68 season. This provides a 4 year base largely unaffected by the adoption of fertilizer and high yielding varieties. We also find that from the 1972 season onwards the fertilizer use was relatively constant, both in terms of the percentage of fields to which nitrogen fertilizer was added and the rate per acre (Table 4). The average yield for these last three years is 30.1 md/acre. Thus during the period of rapid adoption the yields increased by 10.3 md/acre or 52% of the baseline period. These yield increases apparently are largely due to improved varieties and fertilizer although other improved practices could play a role. The fertilized fields during the last three years received an average of 39.7 lbs N/acre which works out to an average of 22.5 lbs N/acre over all fields including those not fertilized.

Table 1. Summary of wheat yields, use of high yielding varieties and number of irrigations for the perennial canal command area.

| Year | Number of fields | Mean yield | Standard deviation | Confidence interval (.95) | High yielding varieties Number | High yielding varieties Percent | Mean No. of Irrigations |
|---|---|---|---|---|---|---|---|
| | | md/A | md/A | ± md/A | | % | |
| 1964-65 | 40 | 19.5 | 9.9 | 3.2 | 0 | 0 | NA |
| 1965-66 | 40 | 18.4 | 8.0 | 2.6 | 0 | 0 | 4.2 |
| 1966-67 | 15 | 22.6 | 8.3 | 4.6 | 0 | 0 | 4.4 |
| 1967-68 | 40 | 20.9 | 11.9 | 3.8 | 3 | 7.5 | 3.7 |
| 1968-69 | 40 | 23.4 | 9.3 | 3.0 | 27 | 67.5 | 4.5 |
| 1969-70 | 42 | 25.8 | 9.6 | 3.0 | 23 | 54.8 | 4.8 |
| 1970-71 | 41 | 22.6 | 9.0 | 3.0 | 31 | 75.6 | 4.8 |
| 1971-72 | 42 | 30.4 | 11.5 | 2.8 | 39 | 92.9 | 4.4 |
| 1972-73 | 42 | 30.4 | 9.5 | 3.6 | 39 | 92.9 | 4.5 |
| 1973-74 | 42 | 29.6 | 10.9 | 3.4 | 40 | 95.2 | 4.5 |

Table 2. Summary of wheat yields, high yielding varieties and number of irrigations for the non-perennial canal command area.

| Year | Number of fields | Mean yield | Standard deviation | Confidence interval (.95) | High yielding varieties | | Mean No. of Irrigations |
|---|---|---|---|---|---|---|---|
| | | | | | Number | Percent | |
| | | md/A | md/A | ± md/A | | % | |
| 1964-65 | 20 | 20.6 | 7.2 | 3.4 | 0 | 0 | NA |
| 1965-66 | 20 | 15.6 | 6.4 | 3.0 | 0 | 0 | 2.9 |
| 1966-67 | 10 | 27.4 | 8.3 | 6.0 | 0 | 0 | 3.1 |
| 1967-68 | 20 | 18.9 | 11.4 | 5.3 | 2 | 10.0 | 2.9 |
| 1968-69 | 20 | 21.2 | 11.2 | 5.3 | 16 | 80.0 | 4.0 |
| 1969-70 | 21 | 20.2 | 5.8 | 2.7 | 15 | 75.0 | 3.4 |
| 1970-71 | 21 | 18.1 | 11.0 | 5.0 | 13 | 61.9 | 3.8 |
| 1971-72 | 21 | 23.2 | 8.4 | 3.8 | 19 | 90.5 | 2.5 |
| 1972-73 | 21 | 25.2 | 8.1 | 3.7 | 15 | 71.4 | 4.1 |
| 1973-74 | 21 | 23.8 | 9.2 | 4.2 | 17 | 81.0 | 4.4 |

Table 3. Summary of wheat yields, high yielding varieties, and number of irrigation for the uncommanded area.

| Year | Number of fields | Mean yield | Standard deviation | Confidence interval (.95) | High yielding varieties Number | Percent | Mean No. of Irrigations |
|---|---|---|---|---|---|---|---|
| | | md/A | md/A | ± md/A | | % | |
| 1964-65 | 20 | 21.7 | 9.5 | 4.4 | 0 | 0 | NA |
| 1965-66 | 40 | 12.7 | 7.7 | 2.5 | 0 | 0 | 3.1 |
| 1966-67 | 5 | 26.6 | 7.6 | 9.4 | 0 | 0 | 2.2 |
| 1967-68 | 20 | 19.3 | 11.0 | 5.1 | 3 | 15.0 | 3.7 |
| 1968-69 | 20 | 17.6 | 10.4 | 4.9 | 13 | 65.0 | 4.4 |
| 1969-70 | 19 | 20.4 | 7.2 | 3.5 | 7 | 36.8 | 4.3 |
| 1970-71 | 21 | 19.6 | 9.4 | 4.3 | 16 | 76.2 | 4.8 |
| 1971-72 | 21 | 28.1 | 8.9 | 4.1 | 17 | 81.0 | 4.0 |
| 1972-73 | 21 | 27.0 | 7.6 | 3.5 | 21 | 100.0 | 4.7 |
| 1973-74 | 21 | 29.2 | 5.9 | 2.7 | 20 | 95.2 | 5.2 |

Table 4. Nitrogen fertilizer use and wheat yields on fertilized and unfertilized fields in the perennial command area.

| Year | Percent ferti-lized | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Ferti-lized fields | All fields | Not ferti-lized | Ferti-lized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1964-65 | 2.5 | 0.3 | 11.0 | 19.5 | ** | -- | -- | -- |
| 1965-66 | 2.5 | 0.3 | 11.0 | 18.4 | -- | -- | -- | -- |
| 1966-67 | 13.3 | 1.5 | 25.9 | 22.6 | -- | -- | -- | -- |
| 1967-68 | 25.0 | 6.5 | 22.6 | 20.7 | 18.6 | 25.9 | 7.3 | 1.72(.90) |
| 1968-69 | 37.5 | 8.5 | 20.6 | 23.4 | 21.3 | 27.0 | 5.7 | 1.94(.90) |
| 1969-70 | 28.6 | 11.6 | 50.8 | 25.8 | 24.1 | 30.1 | 6.0 | 1.91(.90) |
| 1970-71 | 36.6 | 18.1 | 43.4 | 22.6 | 21.8 | 24.2 | 2.4 | 0.77 |
| 1971-72 | 54.8 | 23.7 | 40.0 | 30.4 | 26.6 | 33.5 | 6.9 | 2.64(.975) |
| 1972-73 | 57.1 | 22.9 | 40.6 | 30.4 | 26.4 | 33.3 | 6.9 | 2.63(.975) |
| 1973-74 | 54.8 | 21.0 | 38.4 | 29.6 | 25.1 | 33.1 | 8.3 | 2.64(.975) |

* Number in parentheses is the probability of a real effect.

** Fertilizer response not calculated for years in which less than 20% of the fields were fertilized.

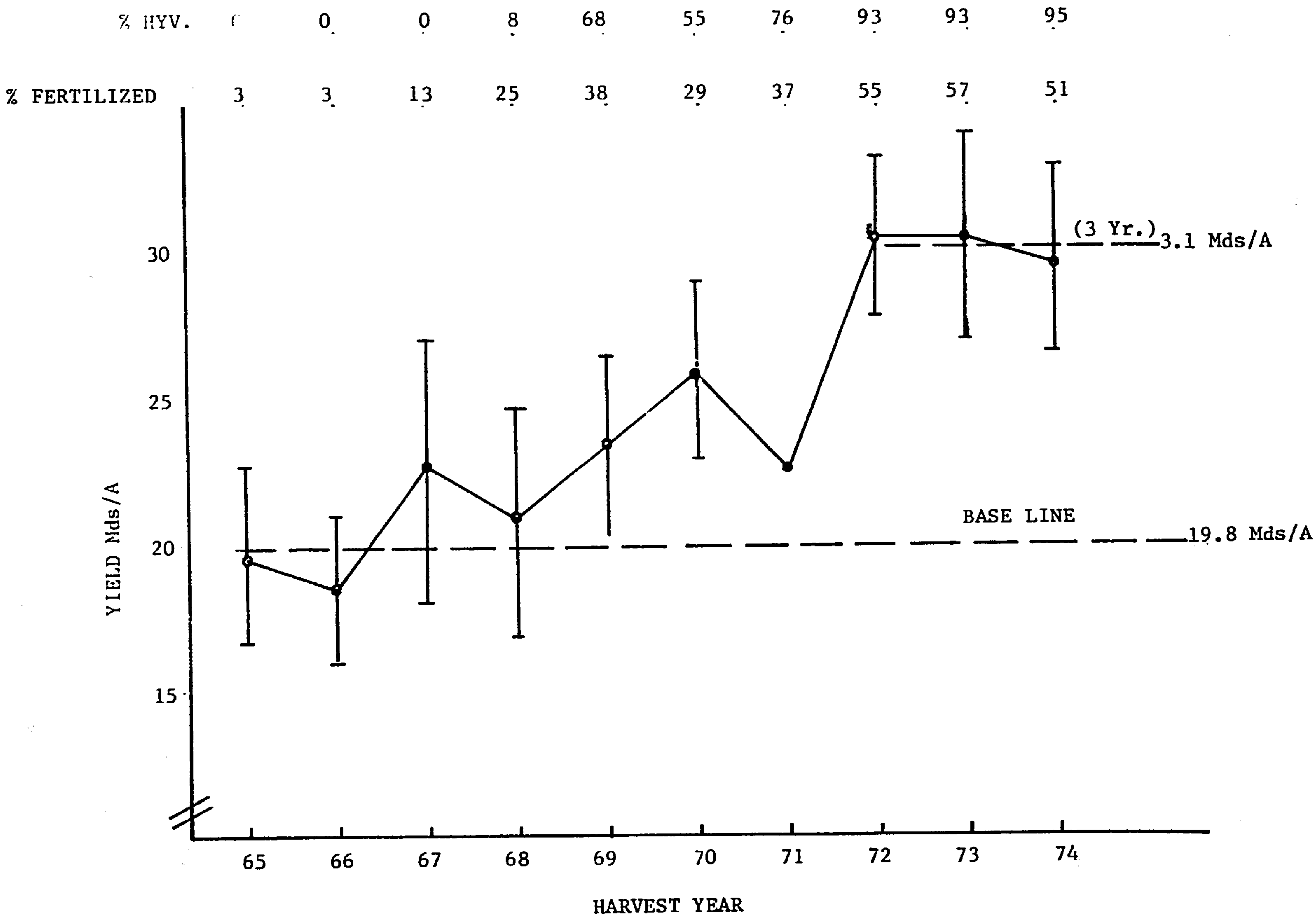


Figure 1. Mean wheat yields with confidence intervals from the Mona crop cutting survey. (Perennial Area)

Using the data shown in Tables 1 and 4 we have attempted to separate the effect of fertilizer and high yielding varieties on the yield increase experienced over this period (Figure 2). During the rapid adoption period yields of the unfertilized fields increased from 19.8 to 26.0 md/acre. As adoption of HYV's was well over 90% by this time, this increase of 6.2 md/acre can be considered largely due to improved varieties. The difference between the final three years average of 30.1 md/acre and the unfertilized average for the same period is 30.1 minus 26.0 or 4.1 md/acre. This 4.1 value provides an estimate of the effect of fertilizer in improving the overall yield. This 4.1 md/acre increase was achieved by an average of 22.5 lbs N/acre or 5.5 lb N/md. We have calculated the benefit-cost ratio assuming urea at Rs. 75 per bag plus 10% interest and application charges or Rs. 1.65 per lb of N. Wheat is assumed to have a value of Rs. 37.50/md less 10% harvesting cost or Rs. 33.75/md. The cost of the increased yield due to fertilizer is Rs. 9.08/md and the benefit-cost ratio is 3.72 which represents a return on invested capital of 272%. During the final three years the fertilized fields averaged 33.3 md/acre as compared to the project average of 30.1 md/acre. The difference of 3.2 md/acre is an estimate of the increased average yield that might be expected if all fields were fertilized at an average rate of about 30 lbs N/acre instead of only 55% of the fields. We also note that the increased yield of the fertilized fields was significant at the 0.975 probability or 97.5% level during the final three years.

Responses on the nonperennial and uncommanded areas (Tables 5 and 6) were much less consistent, although this undoubtedly is partly caused by the lower number of samples taken each year.

The average yields for the final three years were 30.1, 24.1, and 28.7 md/acre for the perennial, nonperennial and uncommanded areas respectively and reflect a general tendency for yields to be highest in the perennial area, lowest on the nonperennial with the uncommanded area lying between.

The percentage of fields fertilized was lower in the nonperennial area than in the perennial and uncommanded areas. The average number of irrigations also tends to be lower on the nonperennial area than the other two command types but this difference is less in the last few years. The percentage of coarse textured soils (sandy and sandy loam) is much higher on the uncommanded area than in the nonperennial or perennial areas (Table 7). This difference undoubtedly explains the higher irrigation levels and nitrogen application in the uncommanded area than in the nonperennial area.

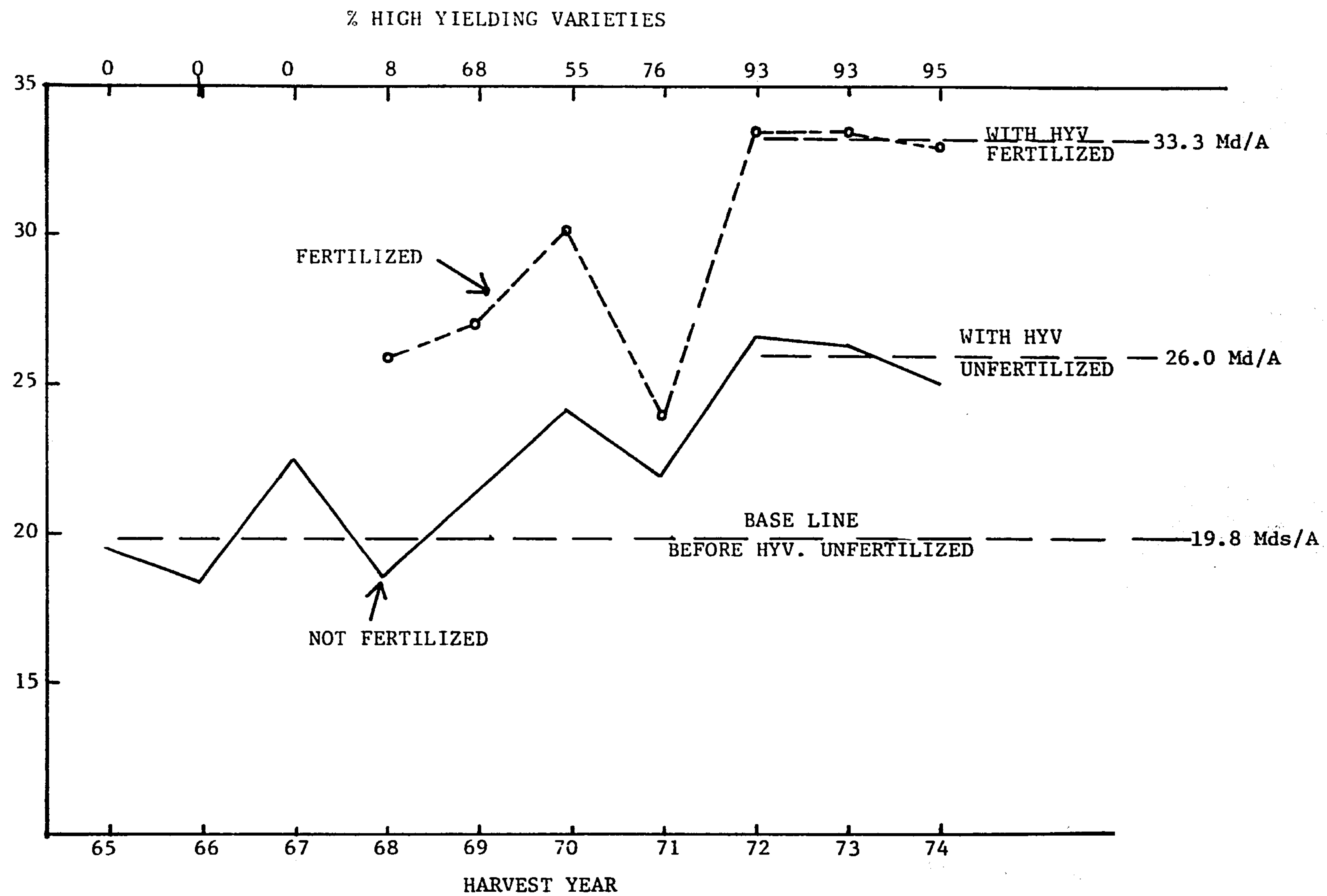


Figure 2. Mean yields of fertilized and unfertilized wheat fields. (Perennial Area)

Table 5. Nitrogen fertilizer use and wheat yields on fertilized field in the non-perennial canal command area.

| Year | Percent fertilized | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Fertilized fields | All fields | Not fertilized | Fertilized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1964-65 | 0 | 0 | 0 | 20.6 | ** | -- | -- | -- |
| 1965-66 | 0 | 0 | 0 | 15.6 | -- | -- | -- | -- |
| 1966-67 | 10 | .3 | 2.7 | 27.4 | -- | -- | -- | -- |
| 1967-68 | 15.0 | 2.9 | 19.3 | 18.9 | -- | -- | -- | -- |
| 1968-69 | 45.0 | 9.3 | 20.7 | 21.2 | 21.2 | 21.2 | 0 | NA |
| 1969-70 | 23.8 | 5.7 | 24.0 | 20.2 | 20.3 | 20.0 | -.3 | .12 |
| 1970-71 | 38.1 | 9.5 | 24.9 | 18.1 | 15.2 | 24.9 | 9.7 | 1.90(.90) |
| 1971-72 | 4.8 | 2.4 | 50.0 | 23.2 | -- | -- | -- | -- |
| 1972-73 | 23.8 | 10.7 | 45.0 | 25.2 | 23.7 | 29.8 | 6.1 | 1.51(.80) |
| 1973-74 | 47.6 | 23.8 | 49.9 | 23.8 | 21.7 | 39.3 | 7.6 | 2.39(.95) |

* Number in parentheses is the probability of a real effect.

** Fertilizer responses not calculated for years in which less than 20% of the sampled fields were fertilized.

Table 6. Nitrogen fertilizer use and wheat yields on fertilized and unfertilized fields in the uncommanded area.

| Year | Percent ferti-lized | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Ferti-lized fields | All fields | Not ferti-lized | Ferti-lized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1964-65 | 0 | 0 | 0 | 21.7 | ** | -- | -- | -- |
| 1965-66 | 0 | 0 | 0 | 12.7 | -- | -- | -- | -- |
| 1966-67 | 0 | 0 | 0 | 26.6 | -- | -- | -- | -- |
| 1967-68 | 25.0 | 3.2 | 12.8 | 19.3 | 18.2 | 22.6 | 4.38 | .93 |
| 1968-69 | 30.0 | 4.7 | 15.5 | 17.6 | 16.5 | 23.8 | 7.3 | 1.67 |
| 1969-70 | 28.6 | 11.9 | 39.5 | 20.4 | 18.8 | 23.9 | 5.1 | 1.50 |
| 1970-71 | 42.9 | 21.9 | 51.0 | 19.6 | 17.9 | 21.8 | 3.9 | .90 |
| 1971-72 | 38.1 | 21.4 | 56.1 | 28.1 | 29.3 | 26.2 | -3.1 | -.77 |
| 1972-73 | 57.1 | 27.0 | 47.2 | 28.7 | 24.3 | 31.9 | 7.6 | 2.57(.975) |
| 1973-74 | 57.1 | 24.4 | 42.7 | 29.2 | 29.14 | 29.17 | .30 | .01 |

* Number in parentheses is the probability of a real effect.

** Fertilizer responses not calculated for years in which less than 20% of the sampled fields were fertilized.

Table 7. Soil texture and salinity as reported in the Mona crop cutting survey during the 1964-74 period.

| | Clay | Loam | Sandy loam | Sandy | Saline |
|---|---|---|---|---|---|
| | % of samples reported | | | | |
| Perennial | 30 | 30 | 31 | 9 | 5 |
| Nonperennial | 18 | 39 | 39 | 4 | 4 |
| Uncommanded | 8 | 8 | 68 | 16 | 4 |
| Hazardous | | | | | |

The linear regression of yield on the number of irrigations for the three different types of canal command areas are shown in Table 8. While there is good reason to believe that these relationships would not in fact be linear, the generally low correlations along with observation of scatter diagrams indicate that more complex regression models would probably not result in improved relationships. On the perennial command area there was no discernible relationship between yield and number of irrigations until the last three years when significant correlations were noted. These significant correlations suggest that increased irrigation would benefit at least some fields.

This interpretation is probably correct but some care must be taken as there is a tendency for number of irrigations to be related to fertilizer applied. Thus in 1972-73 the fertilized fields averaged 4.8 irrigations while those not fertilized averaged only 4.1 irrigations. Similarly in 1973-74 the fertilized and unfertilized fields received an average of 5.2 and 3.7 irrigations respectively. A high level of management is reflected in more than one practice as one might expect, so that in order to achieve the higher yields from fertilizer some fields might require one or two additional irrigations. On the other hand a good deal of research at Mona and elsewhere in the Punjab has shown that very good yields can be obtained with 3 or 4 irrigations and certainly not more than 5 should be required. These data show that in the perennial command area the wheat fields receiving 6 or more irrigations were 26% and 29% of the total in 1972-73 and 1973-74 respectively. Assuming 3 acre-inches per irrigation this overirrigation represents an average of 1 acre-inch per acre of wheat planted, or if properly used enough water to increase wheat acreage by about 7%. Alternately the amount of water applied in excess of 5 irrigations would be almost exactly the amount required to supply those fields receiving 3 or less irrigations with 4 irrigations.

The relationship between yields and number of irrigations is more erratic on the uncommanded land with quite a close relationship occurring in 1970-71 but not in the other

Table 8. Regression coefficients and coefficients of determination ($r^2$) for the regression of yield of wheat on number of irrigations in the perennial canal command area, non-perennial canal command area, and the uncommanded area.

| Year | n | Intercept | Slope | $r^{2*}$ |
|---|---|---|---|---|
| Perennial canal command area | | | | |
| 1964-65 | 20 | 25.5 | -2.0 | 0.07 |
| 1965-66 | 40 | 19.8 | -0.4 | 0.01 |
| 1966-67 | 15 | 22.45 | 0.0 | 0.00 |
| 1967-68 | 40 | 18.6 | 0.6 | 0.01 |
| 1968-69 | 40 | 18.1 | 1.2 | 0.03 |
| 1969-70 | 42 | 19.4 | 1.3 | 0.04 |
| 1970-71 | 41 | 19.5 | 0.9 | 0.03 |
| 1971-72 | 42 | 20.4 | 2.3 | 0.09(.95) |
| 1972-73 | 42 | 13.0 | 3.9 | 0.22(.99) |
| 1973-74 | 42 | 12.5 | 3.8 | 0.24(.99) |
| Non-perennial canal command area | | | | |
| 1964-65 | 9 | 30.1 | -2.0 | 0.05 |
| 1965-66 | 20 | 20.0 | -1.5 | 0.12 |
| 1966-67 | -- | -- | -- | -- |
| 1967-68 | 20 | 6.0 | 1.9 | 0.33(.99) |
| 1968-69 | 20 | 31.7 | -2.6 | 0.05 |
| 1969-70 | 21 | 18.5 | 0.5 | 0.01 |
| 1970-71 | 19 | 19.6 | 0.1 | 0.00 |
| 1971-72 | 21 | 12.7 | 4.2 | 0.36(.99) |
| 1972-73 | 21 | 13.3 | 2.7 | 0.30(.99) |
| 1973-74 | 21 | 8.9 | 4.0 | 0.40(.99) |
| Uncommanded area | | | | |
| 1964-65 | 14 | -- | -- | -- |
| 1965-66 | 14 | 18.6 | 3.3 | 0.18 |
| 1966-67 | -- | -- | -- | -- |
| 1967-68 | 20 | 18.3 | 0.3 | 0.00 |
| 1968-69 | 19 | 10.2 | 2.1 | 0.07 |
| 1969-70 | 21 | 16.6 | 0.9 | 0.03 |
| 1970-71 | 21 | -6.6 | 5.5 | 0.56 |
| 1971-72 | 21 | 25.2 | 0.7 | 0.01 |
| 1972-73 | 21 | 21.6 | 1.5 | 0.11 |
| 1973-74 | 21 | 21.9 | 1.4 | 0.06 |

*Number in paretheses is the probability of a real effect.

years. On the nonperennial canal command area the correlation with irrigations was particularly marked in the last three years, even though the average number of irrigations applied was almost as great as that round in the perennial area.

The regressions of yield on number of plowings were calculated for the wheat data and are shown in Table 9. In a majority of the cases no relationship could be detected but several significant correlations were obtained. These significant results are in excess of the number that would be expected by chance and all of the significant correlations are the result of a positive relationship between yield and number of plowings. This erratic pattern is difficult to interpret and is again complicated by the tendency for the farmers' practices to be interrelated. There is a definite tendency for fertilizer application to be related to number of plowings, at least in the later years when the fertilizer practice was most common. For the four years starting with the 1970-71 season the mean number of plowings on fields that were not fertilized were in chronological order 3.8, 4.0, 3.7, and 4.5, while for the fertilized fields the means for the same years were 4.9, 4.6, 4.8, and 5.00. In this situation it is very difficult to determine whether or not the number of plowings has an effect independent of fertilizer application. It does show clearly that the farmer who is diligent in his field operations is also the one most likely to adopt the fertilizer practice.

B. Rice

The mean rice yields with confidence intervals for the perennial, nonperennial and uncommanded areas are shown in Table 10. Yields in 1973 were the highest of those surveyed during the 1966-73 period with the exception of the uncommanded area where the 1972 yields were slightly higher. Yields on the perennial command area ranged from 18.9 md/A in 1966 to 27.6 md/A in 1973. Unfortunately the yield trends are much less consistent than those for wheat. The 1972 average yield on the perennial area is less than the 1968 yield and only exceeds that of 1966 by 3.1 mds/acre. While there is probably a real gain in productivity we cannot be confident that a significant gain has been made. Again the yields on the nonperennial areas are much more variable between years than those on either the perennial or uncommanded area. The reasons for the higher variability on the nonperennial area are not readily apparent. Perhaps it is related to the fact that in all years except 1972 the percentage of fields that were fertilized was lower on the nonperennial area than on the other two areas (Tables 11 and 12).

Nitrogen use consistently increased up to 1970 or 1971, but since then has been inconsistent. In 1973 only 31.0% of the perennial command fields were fertilized and the average

Table 9. Regression coefficients and coefficients of determination ($r^2$) for the regression of yield of wheat on number of ploughing in the perennial canal commanded area, non-perennial canal commanded area and the uncommanded area.

| Year | n | Intercept | Slope | $r^{2*}$ |
|---|---|---|---|---|
| Perennial canal commanded area | | | | |
| 1964-65 | -- | -- | -- | -- |
| 1965-66 | -- | -- | -- | -- |
| 1966-67 | 15 | 23.72 | -0.12 | 0.00 |
| 1967-68 | 40 | 16.90 | 0.86 | 0.05 |
| 1968-69 | 40 | 27.34 | -1.03 | 0.02 |
| 1969-70 | 42 | 14.24 | 3.07 | 0.15 |
| 1970-71 | 40 | 13.36 | 2.52 | 0.31(.999) |
| 1971-72 | 42 | 28.21 | 0.50 | 0.01 |
| 1972-73 | 42 | 22.62 | 1.78 | 0.08(.90) |
| 1973-74 | 42 | 17.34 | 2.55 | 0.27(.999) |
| Non-perennial canal commanded area | | | | |
| 1964-65 | -- | -- | -- | -- |
| 1965-66 | -- | -- | -- | -- |
| 1966-67 | 10 | 21.99 | 0.55 | 0.06 |
| 1967-68 | 20 | 8.11 | 2.46 | 0.25(.95) |
| 1968-69 | 20 | 31.38 | -3.23 | 0.09 |
| 1969-70 | 21 | 22.77 | -0.80 | 0.06 |
| 1970-71 | 19 | 18.76 | 0.29 | 0.01 |
| 1971-72 | 21 | 20.21 | 0.57 | 0.02 |
| 1972-73 | 21 | 27.05 | -0.37 | 0.02 |
| 1973-74 | 21 | 22.10 | 0.55 | 0.05 |
| Uncommanded area | | | | |
| 1964-65 | -- | -- | -- | -- |
| 1965-66 | -- | -- | -- | -- |
| 1966-67 | -- | -- | -- | -- |
| 1967-68 | 20 | 14.09 | 1.15 | 0.07 |
| 1968-69 | 20 | 11.14 | 2.25 | 0.15(.90) |
| 1969-70 | 20 | 19.27 | 0.32 | 0.01 |
| 1970-71 | 21 | 16.87 | 0.66 | 0.02 |
| 1971-72 | 21 | 10.34 | 3.94 | 0.40(.99) |
| 1972-73 | 21 | 18.36 | 2.31 | 0.25(.95) |
| 1973-74 | 21 | 30.59 | -0.29 | 0.01 |

* Number in parentheses is the probability of a real effect.

Table 10. Mean yields and numbers of irrigation on rice.

| Year | Number of fields | Mean yield | Standard deviation | Confidence interval (.95) | Mean number of irrigations |
|---|---|---|---|---|---|
| | | md/A | md/A | ±md/A | |
| Perennial area | | | | | |
| 1966 | 54 | 18.9 | 7.14 | 2.0 | 8.5 |
| 1968 | 40 | 21.7 | 9.59 | 3.1 | 10.5 |
| 1969 | 40 | 22.1 | 8.14 | 2.6 | 10.8 |
| 1970 | 40 | 19.2 | 8.40 | 2.7 | 12.7 |
| 1971 | 52 | 22.5 | 8.45 | 3.6 | 12.3 |
| 1972 | 39 | 22.0 | 9.36 | 3.0 | 12.2 |
| 1973 | 42 | 27.6 | 8.59 | 2.7 | 11.5 |
| Non-perennial area | | | | | |
| 1966 | 37 | 12.2 | 5.84 | 1.9 | 9.8 |
| 1968 | 20 | 22.2 | 4.05 | 1.9 | 12.3 |
| 1969 | 20 | 26.7 | 7.34 | 3.4 | 12.2 |
| 1970 | 21 | 14.6 | 6.49 | 3.0 | 12.8 |
| 1971 | 21 | 17.0 | 6.45 | 3.0 | 13.0 |
| 1972 | 20 | 21.0 | 8.88 | 4.2 | 12.6 |
| 1973 | 21 | 26.3 | 6.34 | 2.9 | 9.7 |
| Uncommanded area | | | | | |
| 1966 | -- | -- | -- | -- | -- |
| 1968 | 20 | 16.0 | 7.39 | 3.5 | 12.4 |
| 1969 | 10 | 19.5 | 7.80 | 5.7 | 12.9 |
| 1970 | 20 | 19.5 | 7.90 | 3.7 | 13.6 |
| 1971 | 21 | 19.3 | 7.74 | 3.5 | 11.9 |
| 1972 | 19 | 22.8 | 5.42 | 2.6 | 8.4 |
| 1973 | 19 | 21.7 | 4.40 | 2.1 | 11.7 |

Table 11. Nitrogen fertilizer use and rice yields on fertilized and unfertilized fields in the perennial canal command area.

| Year | Percent ferti- lized | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Ferti- lized fields | All fields | Not ferti- lized | Ferti- lized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1966 | 18.5 | 2.3 | 12.6 | 18.9 | -- | -- | -- | -- |
| 1968 | 25.0 | 2.8 | 11.4 | 21.7 | 20.6 | 25.1 | 3.4 | 0.95 |
| 1969 | 45.0 | 10.8 | 24.1 | 22.1 | 19.4 | 24.7 | 5.2 | 2.02(.95) |
| 1970 | 37.5 | 11.3 | 30.2 | 19.2 | 16.7 | 23.3 | 6.6 | 2.51(.95) |
| 1971 | 52.4 | 19.7 | 37.6 | 22.5 | 21.1 | 23.8 | 2.7 | 1.00 |
| 1972 | 43.6 | 15.7 | 35.9 | 22.6 | 15.4 | 30.5 | 15.2 | 8.34(.999) |
| 1973 | 31.0 | 10.6 | 34.4 | 27.6 | 26.9 | 29.0 | 2.2 | .71 |

* Number in parentheses is the probability of a real effect.

Table 12. Nitrogen fertilizer use and rice yields on fertilized and unfertilized fields in the nonperennial and uncommanded areas.

| Year | Percent fertilized | Mean N Applied: All fields | Mean N Applied: Fertilized fields | Mean Yields: All fields | Mean Yields: Not fertilized | Mean Yields: Fertilized | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| Nonperennial Area | | | | | | | | |
| 1966 | 14 | 1.8 | 13.5 | 12.2 | -- | -- | -- | -- |
| 1968 | 10 | 3.8 | 37.8 | 22.2 | -- | -- | -- | -- |
| 1969 | 20 | 4.6 | 23.1 | 26.7 | 26.1 | 29.6 | 3.6 | .83 |
| 1970 | 19 | 8.8 | 46.3 | 14.6 | 13.9 | 17.3 | 3.4 | 0.65 |
| 1971 | 38.1 | 10.3 | 27.0 | 17.0 | 14.8 | 18.3 | 3.5 | 1.15 |
| 1972 | 50.0 | 21.6 | 43.2 | 21.0 | 19.6 | 22.5 | 3.0 | 0.71 |
| 1973 | 23.9 | 10.8 | 45.2 | 26.3 | 25.3 | 29.6 | 4.3 | 1.19 |
| Uncommanded Area | | | | | | | | |
| 1966 | | | | | | | | |
| 1968 | 25 | 5.7 | 22.7 | 16.0 | 4.4 | 20.8 | 6.4 | 1.59 |
| 1969 | 50 | 13.5 | 27.0 | 19.5 | 19.1 | 19.8 | 0.7 | .14 |
| 1970 | 45.0 | 17.6 | 39.1 | 19.5 | 18.5 | 20.8 | 2.3 | .61 |
| 1971 | 51.9 | 16.8 | 27.1 | 19.3 | 16.6 | 20.9 | 4.2 | 1.32 |
| 1972 | 52.6 | 15.9 | 30.2 | 22.8 | 24.3 | 21.5 | -2.8 | -1.07 |
| 1973 | 52.6 | 21.9 | 41.6 | 21.7 | 19.1 | 24.1 | 5.0 | 2.81(.975) |

* Number in parenthesis is the probability of a real effect.

nitrogen application on these fertilized fields was only 34.4 lbs N/acre. The average over all fields was only 10.6 lbs N/acre. These low fertilizer applications cannot produce consistently high yielding rice. Perhaps we should be less concerned about the exact optimum dose and concentrate on the more widespread adoption of a reasonable minimum. The comparison of yield of fertilized fields and non-fertilized fields is not particularly sensitive, which is not surprising due to the low average doseage. Even so in three of the six years tested in the perennial command area the differences were significant at the 0.95 probability level. The relatively large and consistent response on the perennial area in 1972 was surprising but a recheck of the data has confirmed its accuracy. The responses to fertilizer was generally positive on the nonperennial and uncommanded areas but in only one case could a significant difference be detected in an individual year. However, the mean response tested over years and over the two command areas proved to be significant at the .99 probability level.

The weighted mean fertilizer response was 7.74 lbs N per maund increase on the perennial area and 9.34 lbs/md for the combined nonperennial and uncommanded areas. Assuming an N cost of Rs. 1.65/lb, the nitrogen costs per md of increase were Rs. 12.77 and Rs. 15.41 respectively. The benefit-cost ratio is of course dependent on price which in turn depends on the type of rice grown. However, at an average price of Rs. 100/md the benefit-cost ratio would be 6.7 and 7.8. These benefit-cost ratios appear to be much better than those found for applying nitrogen fertilizer to wheat.

While the nitrogen does seem to have had an effect as mentioned above the overall gain in yields over the period of the survey is much less certain than that for wheat. In contrast to the wheat situation where high yielding varieties have been heavily adopted the change in rice varieties has been much less dramatic (Table 13). The Basmati types have become even more popular in recent years than previously, as the market preference for these varieties has made them more desirable than the higher yielding coarse types. The Karnal variety, which is coarser than some of the other Basmati types, has gained popularity while the coarse Jhona variety appears to have been largely displaced.

While rice crops require a large number of irrigations, surprisingly it was not possible to demonstrate any relationship between yields and number of irrigations. The regression of yield on number of irrigations are shown in Table 14. Only one was significant at the 95% level and 4 at the 90% level, little more than would be expected by chance for this number of regressions. Yield is determined by many factors, but if water limitations were seriously reducing yields we would expect a closer relationship. There

Table 13. Rice varieties reported in the Mona Crop cutting survey during the period 1966-1973.

| Varieties | 1966 | | | 1968 | | | 1969 | | | 1970 | | | 1971 | | | 1972 | | | 1973 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P** | N** | U** | P | N | U | P | N | U | P | N | U | P | N | U | P | N | U | P | N | U |
| **Fine Types** | | | | | | | | | | | | | | | | | | | | | |
| Basmati* | 24 | 4 | | 26 | 12 | 13 | 17 | 10 | 3 | 24 | 10 | 12 | 13 | 12 | 10 | 13 | 3 | 9 | 18 | 8 | 14 |
| B-197, 622 or 198 | | | | 1 | 2 | 2 | | | | | | | 1 | | | 3 | | | 1 | 7 | |
| Bhegmi | | 17 | | 1 | | | | | | 1 | | | | | | | | | | | |
| Mushkan | 4 | 3 | | 1 | | | 3 | 1 | 3 | 2 | 1 | 3 | | | 2 | | | 2 | 1 | | 1 |
| Karnal | | | | 5 | | | 16 | 3 | 4 | 13 | 8 | 5 | 19 | 7 | 5 | 23 | 13 | 4 | 22 | 6 | 4 |
| Others | 4 | 1 | | | 2 | | 1 | | | | | | 1 | | | | | 1 | | | |
| **Coarse Types** | | | | | | | | | | | | | | | | | | | | | |
| Jhona | 21 | 11 | | 4 | 2 | 4 | 2 | 6 | | | 2 | | 2 | 2 | 3 | | 2 | 3 | | | |
| Irri | | | | 2 | 1 | 1 | | | | | | | | | | | | | | | |
| Others | | 1 | | | 1 | | 1 | | | | | | | | | | | | | | |
| Total Reported | 53 | 37 | | 40 | 20 | 20 | 40 | 20 | 10 | 40 | 21 | 20 | 36 | 21 | 18 | 39 | 20 | 19 | 42 | 21 | 19 |

* Includes B-370 and those simply listed as "Basmati".

** P = Perennial, N = Non-perennial, U - Uncommanded.

Table 14. Regression coefficients and coefficients of determination for the regression of yield of rice on number of irrigations.

| Year | n | Intercept | Slope | $r^{2*}$ |
|---|---|---|---|---|
| Perennial area | | | | |
| 1966 | 48 | 13.6 | .02 | .070(.90) |
| 1968 | 40 | 18.6 | .30 | .004 |
| 1969 | 40 | 24.4 | - .22 | .007 |
| 1970 | 40 | 34.1 | -1.19 | .102 |
| 1971 | 42 | 17.8 | .40 | .027 |
| 1972 | 39 | 13.4 | .694 | .070(.90) |
| 1973 | 42 | 27.7 | .01 | .000 |
| Non-perennial area | | | | |
| 1966 | 37 | 10.6 | .16 | .011 |
| 1968 | 19 | 21.7 | .07 | .001 |
| 1969 | 20 | 31.5 | - .39 | .021 |
| 1970 | 21 | 17.1 | - .20 | .006 |
| 1971 | 21 | 17.3 | - .03 | .000 |
| 1972 | 20 | 9.7 | .98 | .190(.90) |
| 1973 | 21 | 20.1 | .64 | .400(.95) |
| Uncommanded area | | | | |
| 1966 | -- | -- | -- | -- |
| 1968 | 20 | 22.7 | - .54 | .044 |
| 1969 | 10 | 15.5 | .31 | .015 |
| 1970 | 21 | 22.1 | - .19 | .004 |
| 1971 | 21 | 15.0 | .36 | .010 |
| 1972 | 19 | 22.8 | .01 | .000 |
| 1973 | 19 | 16.0 | .49 | .081(.90) |

* Number in parenthesis is the probability of a real effect.

is no support here for the view that increased water supplies would markedly increase rice yields.

C. Sugarcane

The yields of sugarcane in the three types of command areas are shown in Table 15. There appears to be a slight decline in yields over the years on the perennial canal command area. Linear regression analysis for the perennial area results in the equation:

$$\text{Yield} = 524 - 13.68 \text{ (years)}$$

where time is expressed in years, starting with zero. The coefficient of determination ($r^2$) is 0.55 which is significant at the 95% level. This indicates the decline is probably real. The nonperennial command area appears quite different. The yields were lower at the start of the period but by the end of the period were as high or higher than those in the perennial command area. The regression equation was

$$y = 319 + 17.5 \text{ (years)}$$

with an $r^2$ value of 0.75 which is significant at the 99% level. The yield trend on the uncommanded area was slightly positive over time but the regression was not significant.

Nitrogen fertilizer use in the perennial area increased from an average over all fields of 0.56 lbs. N/acre to 38.9 lbs. N/acre over the period (Table 16). Only in 1971-72 and possibly in 1970-71 does it appear that yields or fertilized fields were demonstrably higher than those on unfertilized fields. If a weighted mean response is calculated we find a value of 0.76 maunds of sugarcane per pound of N applied. Assuming a cost of Rs. 4.5/maund after harvesting costs have been deducted the benefit-cost ratio is only 2.07. Due to the lack of any consistent nitrogen response (Tables 17 and 18) we have not made this calculation for the other two command areas.

In no case could we show a significant correlation between yields and number of irrigations on the perennial area (Table 19), although there were a few apparently real effects in the other two areas.

The varieties grown have shown a shift from Co.312 and L.44 towards L.54 in the later years (Table 20). Unfortunately, this shift in varieties has not been accompanied by increased production.

The decline in production per acre in the perennial area, which as noted above comprises over 70% of the project area, is very disturbing. Even the increased use of fertiilizer has not had sufficient effect to balance whatever

Table 15. Mean sugar cane yields and number of irrigations for the Mona crop cutting survey.

| Year | Number of fields | Mean yield md/A | Standard deviation md/A | Confidence interval (.95) ±md/A | Mean number of irrigations |
|---|---|---|---|---|---|
| Perennial area | | | | | |
| 1965-66 | 40 | 478 | 192 | 61 | 7.0 |
| 1966-67 | 15 | 570 | 201 | 111 | 7.1 |
| 1967-68 | 39 | 517 | 174 | 56 | 9.5 |
| 1968-69 | 40 | 498 | 162 | 51 | 8.6 |
| 1969-70 | 42 | 424 | 157 | 49 | 11.2 |
| 1970-71 | 41 | 433 | 120 | 38 | 10.5 |
| 1971-72 | 42 | 438 | 124 | 39 | 11.3 |
| 1972-73 | 41 | 445 | 97 | 31 | 11.2 |
| 1973-74 | 42 | 423 | 137 | 43 | 11.9 |
| Non-perennial area | | | | | |
| 1965-66 | 20 | 319 | 158 | 74 | 5.60 |
| 1966-67 | 10 | 305 | 126 | 90 | 7.90 |
| 1967-68 | 20 | 351 | 127 | 60 | 10.9 |
| 1968-69 | 20 | 434 | 126 | 59 | 10.4 |
| 1969-70 | 19 | 370 | 116 | 56 | 11.7 |
| 1970-71 | 21 | 413 | 126 | 56 | 11.8 |
| 1971-72 | 21 | 429 | 60 | 28 | 10.3 |
| 1972-73 A* | 21 | 418 | 70 | 32 | 11.0 |
| B | 20 | 208 | 63 | 30 | 10.2 |
| 1973-74 | 21 | 466 | 160 | 73 | 10.5 |
| Uncommanded | | | | | |
| 1965-66 | 20 | 365 | 165 | 75 | 9.5 |
| 1966-67 | 5 | 366 | 126 | 158 | 8.0 |
| 1967-68 | 20 | 399 | 89 | 42 | 11.4 |
| 1968-69 | 20 | 410 | 146 | 69 | 11.2 |
| 1969-70 | 20 | 414 | 179 | 84 | 13.5 |
| 1970-71 | 21 | 361 | 95 | 45 | 8.9 |
| 1971-72 | 21 | 409 | 68 | 31 | 11.0 |
| 1972-73 | 15 | 424 | 193 | 111 | 10.5 |
| 1973-74 | 15 | 406 | 46 | 26 | 11.1 |

* In 1973 two independent sets of samples were taken from the non-perennial command area.

Table 16. Nitrogen fertilizer use and yields of sugar cane on fertilized and unfertilized fields in the perennial canal command area.

| Year | Percent ferti-lizer | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Ferti-lized fields | All fields | Not ferti-lized | Ferti-lized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1965-66 | 5.0 | 0.56 | 11.22 | 478.3 | -- | -- | -- | -- |
| 1966-67 | 73.3 | 11.7 | 15.9 | 571.2 | 479.0 | 604.7 | 125.7 | 0.95 |
| 1967-68 | 38.5 | 6.4 | 16.6 | 517.1 | 517.4 | 518.9 | 1.51 | 0.03 |
| 1968-69 | 72.5 | 11.3 | 15.6 | 497.6 | 508.3 | 393.6 | -14.7 | -0.25 |
| 1969-70 | 61.9 | 19.8 | 32.0 | 423.8 | 401.4 | 437.7 | 36.3 | 0.71 |
| 1970-71 | 43.9 | 21.9 | 49.8 | 433.2 | 404.0 | 470.6 | 66.6 | 1.77(.90) |
| 1971-72 | 57.1 | 31.9 | 55.9 | 438.4 | 389.2 | 475.3 | 86.1 | 2.29(.95) |
| 1972-73 | 63.4 | 25.0 | 39.4 | 445.5 | 445.2 | 445.6 | 0.38 | 0.01 |
| 1973-74 | 83.3 | 38.9 | 46.7 | 422.9 | 464.0 | 414.8 | -49.2 | -0.81 |

* Number in parentheses is the probability of a real effect.

Table 17. Nitrogen fertilizer use and yield of sugar cane on fertilized and unfertilized field in the nonperennial area.

| Year | Percent ferti- lizer | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Ferti- lized fields | All fields | Not ferti- lized | Ferti- lized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1965-66 | 5.0 | 1.1 | 22.5 | 319.0 | -- | -- | -- | -- |
| 1966-67 | 30.0 | 5.6 | 18.6 | 305.6 | 258.5 | 415.7 | 157.2 | 1.80(.90) |
| 1967-68 | 20.0 | 4.5 | 22.5 | 350.8 | 349.2 | 357.5 | 8.31 | 0.10 |
| 1968-69 | 15.0 | 3.9 | 26.3 | 433.8 | 416.8 | 530.0 | 114.0 | 1.24 |
| 1969-70 | 36.8 | 7.7 | 20.8 | 369.5 | 383.5 | 345.6 | -37.9 | -0.64 |
| 1970-71 | 19.1 | 9.4 | 49.5 | 413.2 | 416.4 | 399.5 | -16.9 | -0.21 |
| 1971-72 | 47.6 | 18.9 | 39.6 | 428.5 | 433.9 | 422.5 | -11.4 | -0.41 |
| 1972-73 | 65.9 | 25.0 | 37.9 | 413.4 | 414.5 | 412.8 | - 1.7 | -0.08 |
| 1973-74 | 42.9 | 25.9 | 60.5 | 465.7 | 402.7 | 549.4 | 146.7 | 3.18(.95) |

* Number in parentheses is the probability of a real effect.

Table 18. Nitrogen fertilizer use and yields of sugar cane on the uncommanded area.

| Year | Percent fertilizer | Mean N Applied: All fields | Mean N Applied: Fertilized fields | Mean Yields: All fields | Mean Yields: Not fertilized | Mean Yields: Fertilized | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1965-66 | 35.0 | 4.1 | 11.7 | 365.0 | 389.3 | 319.4 | -69.9 | -0.84 |
| 1966-67 | - | 4.5 | 11.3 | 366.5 | -- | -- | -- | -- |
| 1967-68 | 60.0 | 20.0 | 20.0 | 399.0 | 394.1 | 402.2 | 8.04 | 0.18 |
| 1968-69 | 55.0 | 11.1 | 20.2 | 410.4 | 430.2 | 394.2 | -36.0 | -0.51 |
| 1969-70 | 35.0 | 10.4 | 29.6 | 414.3 | 369.3 | 497.9 | 138.6 | 1.49 |
| 1970-71 | 57.1 | 26.0 | 45.5 | 361.5 | 411.4 | 324.0 | -87.4 | -2.19(.95) |
| 1971-72 | 23.8 | 5.6 | 23.4 | 409.4 | 408.6 | 412.4 | 3.8 | 0.10 |
| 1972-73 | 80.0 | 29.2 | 37.1 | 424.8 | 359.0 | 441.2 | 82.2 | 0.55 |
| 1973-74 | 76.7 | 33.8 | 44.1 | 338.3 | 262.5 | 361.4 | 98.9 | 2.49(.95) |

* Number in parentheses is the probability of a real effect.

Table 19. Regression of yields on number of irrigation for sugar cane.

| Year | n | Intercept | Slope | $r^2$ |
|---|---|---|---|---|
| Perennial area | | | | |
| 1965-66 | 40 | 533 | - 7.7 | .017 |
| 1966-67 | 15 | 509 | 8.7 | .019 |
| 1967-68 | 38 | 382 | 14.3 | .061 |
| 1968-69 | 40 | 604 | -12.3 | .054 |
| 1969-70 | 42 | 297 | 11.5 | .081 |
| 1970-71 | -- | -- | -- | -- |
| 1971-72 | 39 | 362 | 7.6 | .026 |
| 1972-73 | 39 | 429 | 1.3 | .002 |
| 1973-74 A* | 20 | 354 | 6.0 | .024 |
| B | 41 | 431 | - 0.5 | .000 |
| Non-perennial area | | | | |
| 1965-66 | 20 | 90 | 41.0 | .264(.99) |
| 1966-67 | 10 | 325 | - 2.5 | .001 |
| 1967-68 | 20 | 288 | 5.4 | .021 |
| 1968-69 | 20 | 410 | 2.3 | .003 |
| 1969-70 | 19 | 338 | 2.6 | .010 |
| 1970-71 | 21 | 392 | 1.7 | .005 |
| 1971-72 | 21 | 431 | - 0.3 | .000 |
| 1972-73 B** | 21 | 369 | 4.7 | .039 |
| 1973-74 | 21 | -5.1 | 45.9 | .554(.999) |
| Uncommanded area | | | | |
| 1965-66 | 20 | 252 | 12.0 | .104 |
| 1966-67 | 5 | 344 | 2.8 | .003 |
| 1967-68 | 20 | 350 | 4.2 | .022 |
| 1968-69 | 20 | 427 | - 1.4 | .002 |
| 1969-70 | 20 | 291 | 9.4 | .060 |
| 1970-71 | -- | -- | -- | -- |
| 1971-72 | 21 | 480 | - 6.4 | .048 |
| 1972-73 | 15 | 398 | 2.5 | .001 |
| 1973-74 A* | 15 | 298 | 9.7 | .480(.99) |
| B | 10 | 323 | - 2.5 | .013 |

* In 1973-74 two independent sets of samples were taken from the perennial area and uncommanded area.

** Regression only available for B sample in non-perennial area in 1972-73.

Table 20. Use of sugar cane varieties as reported in the Mona crop cutting survey.

| | Varieties | | | | | | |
|---|---|---|---|---|---|---|---|
| | L.54 | L.29 | Co.312 | L.44 | Poni | Other | Total Reported |
| 1965-55 | | | | | | | |
| P* | 9 | 2 | 14 | 14 | | 1 | 40 |
| N* | 2 | 1 | 8 | 6 | | 3 | 20 |
| U* | 10 | | 4 | 6 | | | 20 |
| 1966-67 | | | | | | | |
| P | 6 | 1 | 6 | 2 | | | 15 |
| N | 2 | | 2 | 4 | | 2 | 10 |
| U | | | 2 | 2 | | 1 | 5 |
| 1967-68 | | | | | | | |
| P | 12 | 5 | 15 | 2 | 5 | | 39 |
| N | 5 | | 10 | 5 | | | 20 |
| U | 4 | | 11 | 4 | 1 | | 20 |
| 1968-69 | | | | | | | |
| P | 19 | 1 | 3 | 11 | 6 | | 39 |
| N | 3 | 1 | 11 | 2 | | 3 | 20 |
| U | 4 | 1 | 9 | 6 | | | 20 |
| 1969-70 | | | | | | | |
| P | 28 | 1 | 5 | 3 | 5 | | 42 |
| N | 9 | 3 | 3 | 2 | 2 | | 19 |
| U | 10 | | 8 | 2 | | | 20 |
| 1970-71 | | | | | | | |
| P | 29 | | 6 | 6 | | | 41 |
| N | | | | | | | |
| U | | | | | | | |
| 1971-72 | | | | | | | |
| P | 33 | 3 | 3 | 3 | 3 | | 42 |
| N | 14 | 1 | 5 | 1 | | | 21 |
| U | 17 | 1 | 3 | | | | 21 |
| 1972-73 | | | | | | | |
| P | 32 | 4 | 3 | 2 | | | 41 |
| N | 31 | 5 | 4 | 1 | | | 41 |
| U | 10 | 4 | | 1 | | | 15 |
| 1973-74 | | | | | | | |
| P | 34 | 3 | 2 | 3 | | | 42 |
| N | 20 | | 1 | | | | 21 |
| U | 14 | | 1 | | | | 15 |

* P = Perennial, N = Non-perennial, U = Uncommanded.

other factors are causing this decline. The general lack of any relationship between yield and number of irrigations indicates that lack of irrigation water probably is not a major factor in this decline. Perhaps a serious effort should be made to identify the limiting factors in sugarcane yields if this industry is to remain viable.

D. Cotton

There is little or no evidence for either an increase or decline in cotton yields over the period surveyed (Table 21). Regressions of mean yields on years were not significant for any of the command areas. Yields of cotton are discouragingly low. Only in 1972 was the average of the perennial command area in excess of 10 md/acre.

Yields averaged slightly higher in the perennial command area than in the other two areas. Mean yields for the perennial, nonperennial and uncommanded areas were 8.72, 7.65, and 8.00 mds/acre and the difference between the perennial and nonperennial area is significant at the 95% level.

Nitrogen fertilizer use was quite erratic but generally did increase over the period surveyed (Tables 22-24). On the perennial command area the overall average use of nitrogen was between 13 and 15 lbs N/acre in the final three years of the study and apparently was no longer increasing. Sufficient fields were fertilized on the perennial command area in the final four years of the study to test the difference between fertilized and nonfertilized fields by means of the "t" test. In all four years the response was positive and exceeded the 95% level of significance in two years and the 1% level in 1973. For these four years in the perennial area the overall weighted mean response to nitrogen is 17 lbs N per maund of cotton produced. Again calculating at a cost of Rs. 1.65 per lb N and a price of Rs. 76 per maund of cotton less 10% for harvest and marketing costs we find a benefit-cost ratio for nitrogen fertilizer of 2.44.

The nitrogen fertilizer effect on the nonperennial and uncommanded areas is not plain from these data. In general the number of fertilized fields was too small to perform an effective test and where tests were performed, they were relatively insensitive due to the small numbers.

The regression of yield on number of irrigations is shown in Table 25. On the perennial command area there is plainly a consistent positive relationship between yield and number of irrigations. The regression coefficients averaged 0.88 mds/irrigation and in only two of the eight years did they fail to reach the 5% level of significance. This general significant effect of irrigation for cotton indicates that cotton yields would probably benefit from

Table 21. Mean yields and number of irrigations on cotton.

| Year | Number of fields | Mean yield | Standard deviation | Confidence interval (.95) | Mean number of irrigations |
|---|---|---|---|---|---|
| | | md/A | md/A | ±md/A | |
| Perennial area | | | | | |
| 1966 | 61 | 9.48 | 3.64 | .94 | 4.9 |
| 1967 | 37 | 7.98 | 3.60 | 1.18 | 4.2 |
| 1968 | 41 | 8.15 | 4.22 | 1.32 | 3.3 |
| 1969 | 42 | 6.48 | 4.02 | 1.24 | 3.5 |
| 1970 | 42 | 9.38 | 4.02 | 1.24 | 4.3 |
| 1971 | 42 | 9.62 | 3.98 | 1.22 | 4.1 |
| 1972 | 36 | 10.12 | 2.27 | .76 | 4.1 |
| 1973 | 41 | 8.54 | 4.18 | 1.30 | 3.4 |
| Non-perennial area | | | | | |
| 1966 | 38 | 6.61 | 2.81 | .93 | 4.2 |
| 1967 | 20 | 8.40 | 3.77 | 1.76 | 4.7 |
| 1968 | 20 | 7.71 | 1.86 | .73 | 3.7 |
| 1969 | 21 | 5.90 | 3.61 | 1.94 | 4.3 |
| 1970 | 15 | 6.67 | 3.51 | 1.94 | 4.3 |
| 1971 | 21 | 7.79 | 4.24 | 1.96 | 4.6 |
| 1972 | 20 | 10.03 | 2.21 | 1.03 | 4.0 |
| 1973 | 20 | 8.08 | 3.12 | 1.46 | 3.3 |
| Uncommanded area | | | | | |
| 1966 | 14 | 7.75 | 3.15 | 1.82 | 4.2 |
| 1967 | 19 | 7.65 | 3.18 | 1.53 | 4.5 |
| 1968 | 18 | 8.39 | 3.54 | 1.76 | 3.6 |
| 1969 | 19 | 7.10 | 3.60 | 1.73 | 3.5 |
| 1970 | 23 | 6.96 | 2.59 | 1.12 | 3.9 |
| 1971 | 21 | 6.60 | 2.57 | 1.18 | 4.1 |
| 1972 | 21 | 8.71 | 1.98 | 0.90 | 4.1 |
| 1973 | 21 | 7.82 | 2.11 | 0.92 | 3.1 |

Table 22. Nitrogen fertilizer use and yields of cotton on fertilized and unfertilized fields in the perennial canal command area.

| Year | Percent fertilizer | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Fertilized fields | All fields | Not fertilized | Fertilized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1966 | 1.6 | .4 | 10.1 | 9.48 | -- | -- | -- | -- |
| 1967 | 0 | 0 | -- | 7.98 | -- | -- | -- | -- |
| 1968 | 8.3 | 1.4 | 14.0 | 8.15 | -- | -- | -- | -- |
| 1969 | 7.1 | 2.3 | 31.5 | 6.48 | -- | -- | -- | -- |
| 1970 | 14.3 | 6.0 | 32.0 | 9.38 | 8.82 | 12.80 | 3.98 | 2.18(.95) |
| 1971 | 42.9 | 14.7 | 34.2 | 9.62 | 8.68 | 10.87 | 2.19 | 1.77(.90) |
| 1972 | 27.8 | 13.1 | 47.0 | 10.12 | 9.76 | 11.06 | 1.30 | 1.51 |
| 1973 | 31.7 | 13.3 | 41.9 | 8.55 | 7.39 | 11.05 | 3.66 | 2.73(.99) |

* Number in parentheses is the probability of a real effect.

Table 23. Nitrogen fertilizer use and yields of cotton on fertilized and fields in the nonperennial canal command area.

| Year | Percent ferti- lizer | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Ferti- lized fields | All fields | Not ferti- lized | Ferti- lized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1966 | 2.6 | .7 | 26.2 | 6.61 | -- | -- | -- | -- |
| 1967 | 0 | 0 | -- | 8.40 | -- | -- | -- | -- |
| 1968 | 5.0 | 0.5 | 10.0 | 7.71 | -- | -- | -- | -- |
| 1969 | 14.3 | 3.6 | 25.2 | 5.90 | -- | -- | -- | -- |
| 1970 | 13.3 | 10.1 | 75.6 | 6.67 | -- | -- | -- | -- |
| 1971 | 33.3 | 14.7 | 34.2 | 9.62 | 8.32 | 6.79 | -1.53 | -.69 |
| 1972 | 0 | 0 | -- | 10.03 | -- | -- | -- | -- |
| 1973 | 30.0 | 13.4 | 44.6 | 8.02 | 7.04 | 10.49 | 3.45 | 2.40(.95) |

* Number in parentheses is the probability of a real effect.

Table 24. Nitrogen fertilizer use and yields of cotton fertilized and unfertilized fields. in the uncommanded area.

| Year | Percent ferti- lizer lizer | Mean N Applied | | Mean Yields | | | Response | t value* |
|---|---|---|---|---|---|---|---|---|
| | | All fields | Ferti- lized fields | All fields | Not ferti- lized | Ferti- lized | | |
| | % | lb/A | lb/A | md/A | md/A | md/A | md/A | |
| 1966 | 21.4 | 3.9 | 18.3 | 7.75 | 7.26 | 9.56 | 2.30 | .95 |
| 1967 | 0 | 0 | -- | 7.65 | -- | -- | -- | -- |
| 1968 | 0 | 0 | -- | 8.39 | -- | -- | -- | -- |
| 1969 | 0 | 0 | -- | 7.09 | -- | -- | -- | -- |
| 1970 | 4.3 | 1.0 | 22.5 | 6.96 | -- | -- | -- | -- |
| 1971 | 4.8 | 1.5 | 32.0 | 9.60 | -- | -- | -- | -- |
| 1972 | 19.0 | 6.8 | 35.4 | 8.71 | 8.61 | 9.12 | .51 | .40 |
| 1973 | 19.0 | 7.0 | 36.6 | 7.82 | 7.49 | 9.06 | 1.57 | 1.51 |

* Number in paranthesis is the probability of a real effect.

Table 25. Regression of cotton yields on number of irrigations

| Year | n | Intercept | Slope | $r^{2*}$ |
|---|---|---|---|---|
| Perennial area | | | | |
| 1966 | 61 | 5.79 | .75 | .086(.95) |
| 1967 | 36 | 2.55 | 1.28 | .138(.95) |
| 1968 | 39 | 4.29 | 1.20 | .148(.95) |
| 1969 | 39 | 6.24 | .50 | .000 |
| 1970 | 42 | 4.91 | 1.03 | .150(.95) |
| 1971 | 41 | 5.18 | 1.04 | .113(.95) |
| 1972 | 36 | 10.22 | - .02 | .000 |
| 1973 | 41 | 2.89 | 1.68 | .224(.99) |
| Non-perennial area | | | | |
| 1966 | 38 | 3.98 | .62 | .075 |
| 1967 | 20 | 5.41 | .63 | .021 |
| 1968 | 20 | 8.82 | - .30 | .048 |
| 1969 | 21 | 6.56 | - .15 | .000 |
| 1970 | 15 | 5.37 | .30 | .023 |
| 1971 | 21 | 10.31 | - .55 | .019 |
| 1972 | 18 | 10.64 | - .02 | .005 |
| 1973 | 20 | 5.07 | .91 | .135 |
| Uncommanded area | | | | |
| 1966 | 14 | 2.64 | 1.12 | .163 |
| 1967 | 19 | 6.45 | .27 | .018 |
| 1968 | 18 | 4.51 | 1.09 | .158 |
| 1969 | 19 | 2.48 | 1.31 | .122 |
| 1970 | 23 | 4.17 | .71 | .075 |
| 1971 | 21 | 5.22 | 1.07 | .222(.95) |
| 1972 | 21 | 8.97 | - .07 | .003 |
| 1973 | 21 | 5.32 | .80 | .175(.90) |

* Number in paranthesis is the probability of a real effect.

increased water supplies. It will be noted that no such relationship could be found for rice and sugarcane as discussed above.

Again the effect of irrigation is much less clear on the other two command areas. In the nonperennial area four of the eight coefficients were negative and none were significant at even the 90% probability level. In the uncommanded area seven of the eight slopes were positive and one significant at the 95% and one at the 90% level. There seems to be a pattern of lower and more erratic yields and relationships with other factors on the uncommanded area, even though numbers of irrigations are quite similar. Apparently some other management factors are overshadowing the effect of those we are measuring.

Observations of cotton fields indicate that poor stands are very common in Pakistan. Stand counts were taken at harvest in six of the eight years of the survey. The linear regression of yield on stand in thousands of plants per acre on the perennial area are shown in Table 26.

Five of the six are significant at least at the 95% level and in two cases at the 99% level so there is no doubt that the general relationship is real. Some improvement could probably be attained by fitting a second order polynomial rather than the linear model that has been used. This is evident because all of the intercepts are positive and some are quite large even though we know the yield must be zero at zero population.

The five significant slopes indicate an average yield increase of 0.44 mds/acre per each 1000 additional plants per acre. These relationships plainly show that attention to cultural practices that will result in increased stands offer a major potential for increased yields of cotton.

The varieties reported are shown in Table 27. There appears to have been a shift from the LSS to the AC134 variety over the period, but substantial amounts of the LSS are still grown. This shift has not produced a discernible yield increase and adapted varieties with a high yield potential appear to be badly needed.

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Table 26. Regression of cotton yields in the perennial command area on stand in thousand of plants per acre.

| Year | n | Intercept | Slope | $r^{2*}$ |
|---|---|---|---|---|
| 1966 | (No stand data) | | | |
| 1967 | 37 | 4.74 | .47 | .135(.95) |
| 1968 | 41 | 4.78 | .45 | .141(.95) |
| 1969 | 42 | 1.79 | .50 | .249(.999) |
| 1970 | (No stand data) | | | |
| 1971 | 42 | 4.16 | .577 | .443(.999) |
| 1972 | 36 | 8.38 | .197 | .179(.99) |

* Number in paranthesis is the probability of a real effect.

Table 27. Cotton varieties reported in the Mona crop cutting survey during the period 1966-1973.

| | Varieties | | | |
|---|---|---|---|---|
| | LSS | AC134 | DESI | Total |
| 1966 | | | | |
| P* | 43 | 18 | | 61 |
| N* | 37 | | 1 | 38 |
| U* | 12 | 2 | | 14 |
| 1967 | | | | |
| P | 35 | | 2 | 37 |
| N | 20 | | | 20 |
| U | 19 | | | 19 |
| 1968 | | | | |
| P | 30 | 11 | | 41 |
| N | 20 | | | 18 |
| U | 17 | 1 | | 18 |
| 1969 | | | | |
| P | 37 | 3 | 2 | 42 |
| N | 20 | 1 | | 21 |
| U | 16 | 2 | | 18 |
| 1970 | | | | |
| P | 30 | 9 | 3 | 42 |
| N | 11 | 2 | | 13 |
| U | 15 | 7 | 1 | 23 |
| 1971 | | | | |
| P | 16 | 24 | 2 | 42 |
| N | 16 | 3 | 1 | 20 |
| U | 8 | 12 | 1 | 21 |
| 1972 | | | | |
| P | 11 | 22 | 3 | 36 |
| N | 16 | 4 | | 20 |
| U | 10 | 11 | | 21 |
| 1973 | | | | |
| P | 10 | 29 | 2 | 41 |
| N | 8 | 11 | 1 | 20 |
| U | 7 | 14 | | 21 |

* P = Perennial, N = Non-perennial, U = Uncommanded.

# APPENDIX 7

## A NOTE ON THE FERTILIZER RATIO CONCEPT

John Reuss and Sam Johnson III[1]

The concept of plant nutrient ratios has long been utilized by agronomists and appears to be particularly prevalent in Pakistan. Production experts often express concern that the nutrient ratios utilized by the farmers are not optimum for a particular crop (4). These concerns are reflected in the press and are considered by those charged with planning production and imports. Agronomists interested in plant nutrients may thus find themselves designing experiments to determine the optimum ratios of plant nutrients for different crops grown under different conditions.

For the sake of simplicity we will limit this discussion to two nutrients, nitrogen and phosphorus and the resulting N/P ratios. This is appropriate because these fertilizer elements are the most widely used in Pakistan and crops often respond to their use. However, combinations involving other nutrients or crop inputs are subject to the same principles.

### THE RATIO CONCEPT

First we must recognize that the concept of an optimum ratio does not simply refer to a single rate of N and $P_2O_5$. Suppose we recommend that 90 lb. N and 45 lb. $P_2O_5$ be applied. The N/P ratio of this dose is, of course, 2 : 1. If this ratio only applies to this single rate or dose the concept of ratio would be trivial. In order for N/P ratio to be a meaningful concept it must apply more generally over the range of rates that may be effectively utilized.

Thus there are certain principles inherent in the concept of an optimum ratio for a given crop that are often not understood or at least are not clearly stated. First, an optimum ratio requires that a generalized N-P response surface exists that is reasonably valid for the population of fields with which we are concerned. Secondly, the economic optimum ratio will depend on the relative price of the two inputs. Finally, the concept of an optimum ratio would place severe constraints on the geometry of the response surface. Let us first examine the effect of relative prices.

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## ECONOMIC CONSIDERATIONS

The relationship between optimum ratio and relative price of the nutrients is a key concept. Suppose we have experimentally determined under a given set of conditions the combinations of N and P, applications that will result in a maize yield of 40 mds/acre. Plotted on a graph such as Fig. 1, these combinations constitute a contour line on the response surface, or what is known as an isoquant (2). The two straight lines with negative slopes are isocost lines (2). The broken line has a slope of -2 and all points along that line represent an equal total fertilizer cost if the price of N is twice that $P_2O_5$. The solid isocost line has a slope of -1 and all points on this line represent an equal total fertilizer cost if the price per lb. of N and $P_2O_5$ is the same.

For any N/P cost ratio the least cost combination to produce 40 mds/acre occurs at the point where the slope of the 40 md. isoquant is equal to the N/P cost ratio. In mathematical terms the optimum is described as the point where:

$$\frac{dP}{dN} = \frac{C_n}{C_p} \qquad (1)$$

Where P and N are the ratio of nutrients applied at any constant yield and $C_n$ and $C_p$ are the costs per lb. of the two nutrients. Thus equation (1) states that the first differential of nitrogen applied with respect to phosphorus applied at constant yield is equal to the N/P cost ratio. At this point the optimum ratio of the two inputs is achieved. If these isoquants take the usual shape as shown in Fig. 1, the optimum ratios of N and P are obviously dependent on the relative N and P price. The previously stated principle, that optimum ratios are dependent on the cost price ratios of the inputs, arises from these relationships.

Next we shall examine the constraints these relationships impose on the nature of the N-P response surface if the concept of an optimum N/P ratio is to be valid. If this response surface is represented by yield contours on a graph such as that shown in Fig. 2, any straight line passing through the 0.0 point represents a fixed N/P ratio. For a complete validity of the optimum ratio concept, all isoquants (contours) that any such line might cross, must be crossed at the same slope. If the slope of the contours are not equal along any such line, it means that for the price ratio represented by these slopes the optimum ratio of N and P varies with the nitrogen (or phosphorus) cost, and the concept of an optimum ratio is not valid. These considerations give rise to the principle stated above relative to the very rigid constraints imposed on the geometry of the response surface by this concept. An interesting exercise would be to define these constraints in mathematical

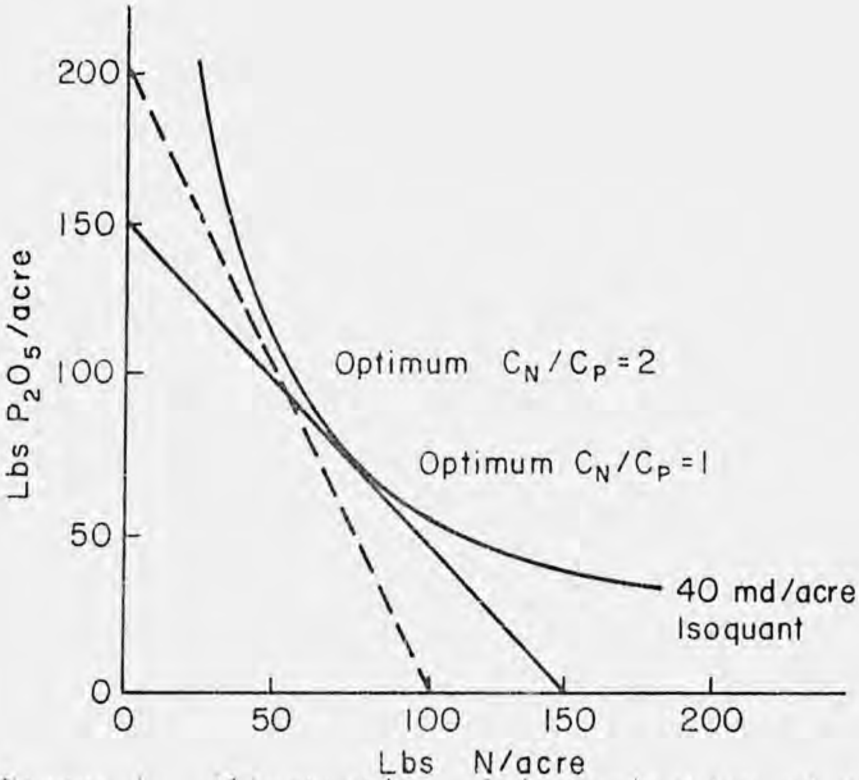


Figure 1. Illustration of determination of optimum combination of N and P for two different N/P price ratios for a sample 40 mds/acre isoquant.

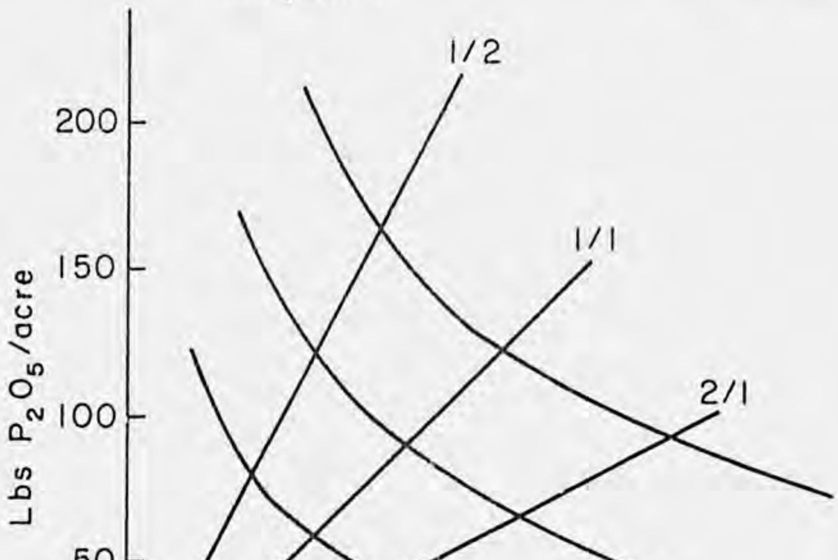


Figure 2. Graphically constructed yield isoquants that appear to satisfy the optimum ratio constraints over the range of N/P ratio from 1/2 to 2/1.

terms so that mathematical response surface models could be similarly constrained and the effect on goodness of fit examined with various data sets. This exercise is unfortunately beyond the scope of the present analysis.

One special case to be considered is the possibility of a response surface of the type shown in Fig. 3 (l). If the response is of this type the two nutrients cannot substitute one for the other. The particular surface shown in Fig. 3 assumes the bends in the yield isoquants occur at a constant N/P ratio represented by the dashed line. Even surfaces that do not allow substitution may not have this property, in which case the optimum ratio would not be independent of fertilizer rate.

Most published two nutrient response surfaces are not in fact of the type shown in Fig. 3, but are rather of the type where substitution dependent on price ratios is allowed. However, we must recognize that most published response surfaces have been determined by a least squares fit of mathematical models that would not allow the non-substitution type of surface. Even if the true surface were of this type a good fit might be obtained from one of the commonly used second order polynomials that would indicate that a moderate amount of substitution was permissible. This possibility should be considered in the interpretation of any data set. The model shown in Fig. 3 will be further discussed below.

It should also be emphasized that in an economic sense whenever the isoquants "bend back upon themselves" or have positively sloped segments they are no longer within the economic range of production (3). The parallel dashed lines in Fig. 4, indicate the points at which the isoquants bend back upon themselves. The lines OC and OL join these points and form the boundaries for the economic region of production. These isoclines (lines, OC and OL) then define the boundaries outside of which our agronomic experiments have no relevancy in terms of economic optimum productions. Such regions are not uncommon in nutrient response surfaces, as when high nitrogen rates results in lodging and loss of yields in small grains.

Fortunately the ratio concept does not necessarily need to be strictly valid for all possible N/P cost ratios to be agronomically useful. The regular contours shown in Fig. 2 would probably meet the criteria sufficiently well to be useful in the range of N/P cost ratios from 1/2 to 2.

## AGRONOMIC CONSIDERATIONS

For the moment let us reconsider the response surface shown in Fig. 3 that does not allow for substitution between the two

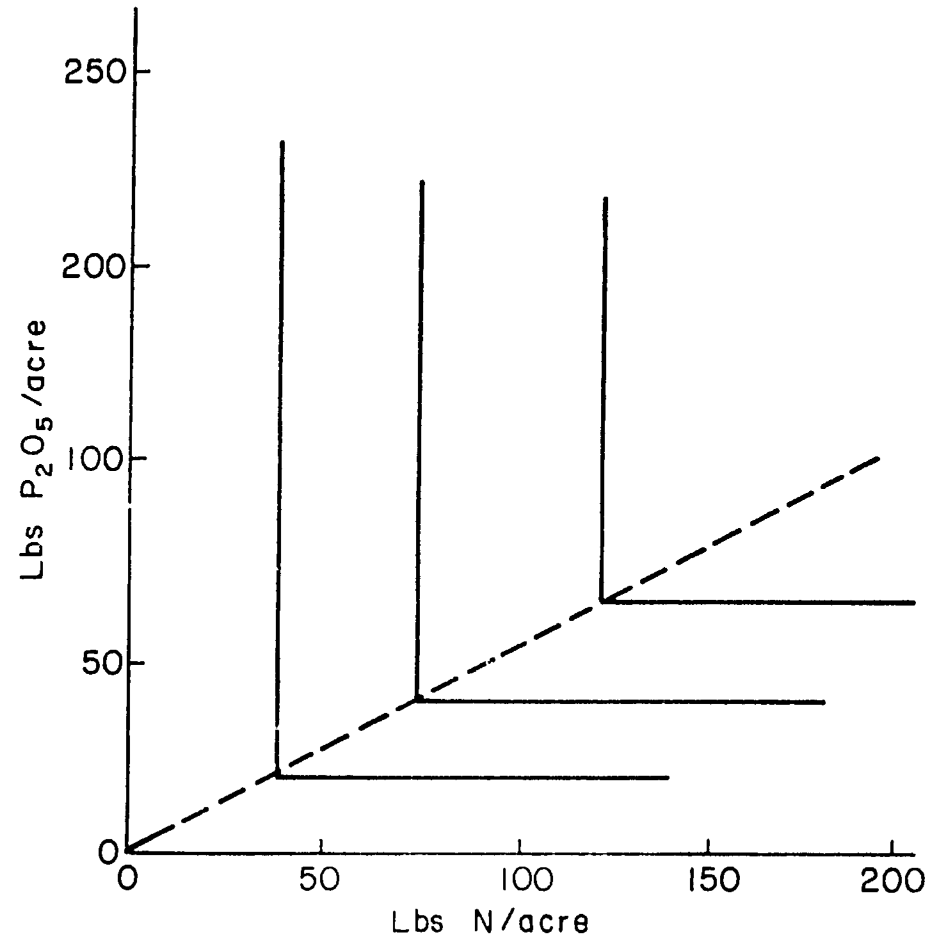


Figure 3. Yield isoquants for an N?P response surface for which no substitutes are allowed and the optimum N/P ratio is independent of rate applied.

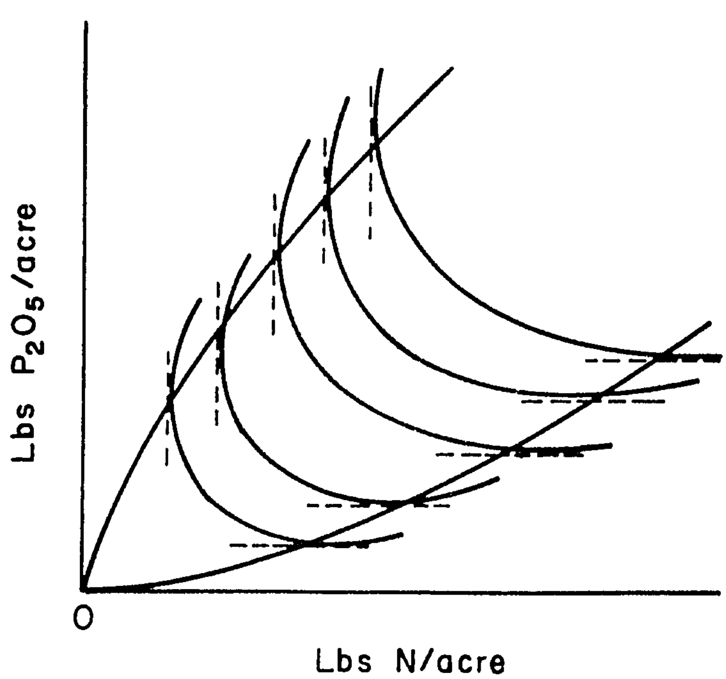


Figure 4. Isoquant map and the relevant range of production.

nutrients. In fact this is the surface that would be generated if the system strictly follows one of the oldest concepts in plant nutrition, that of limiting factors. According to this concept if one factor or nutrient is limiting additional increments of other nutrients will not increase production. Published response surfaces typically have regions where substitution is effective and other regions where it is not. Thus, if one input is in sufficiently short supply it becomes a limiting factor. As mentioned above, it behooves us to be extremely careful in interpreting data from field experiments that we do not in fact create an area in which substitution is allowable by fitting a mathematical model that could not accommodate the surface shown in Fig. 3.

Considering the above discussion it seems anticlimatic to question the agronomic validity of the ratio concept. Many plants use the elements N and P in about a 10/1 ratio, or on the basis of N to $P_2O_5$ would be about 4.4/1. Since the efficiency of uptake is usually less for applied phosphorus than for nitrogen, particularly in the season of application, we often find recommended N/P ratios for non-leguminous crops of about 2/1.

One of the assumptions stated above that must be met for the concept to be valid is that there is a general response surface that will be valid for a particular crop over some geographic area or some particular group of soils. This includes not only the general form of the surface but that the initial levels of N and P, available to the crop without additional fertilizer should be reasonably constant. In practice they are far from constant and the apparent response surfaces obtained from different fields may be drastically different. Thus, the response surface defined from a field experiment will be that starting from some initial N and P values which we will call $N_i$ and $P_i$. The actual surface we plot is in fact that of:

$$\text{Yield} = f\,[(N_i + N_a),\ (P_i + P_a)]$$

Where $N_a$ and $P_a$ are amounts applied. Thus from different fields we are examining different regions of the surface. ; $N_i$ and $P_i$ are usually unknown, conclusions drawn concerning the optimum ratios or the validity of the ratio concept may vary drastically from site to site.

The above assumes that the response surface is the same across sites and only the origin varies. In fact the amount of fertilizer required to produce a given response may vary drastically on different soils. Consider for instance the phosphorus system which can be schematically represented by Fig. 5.

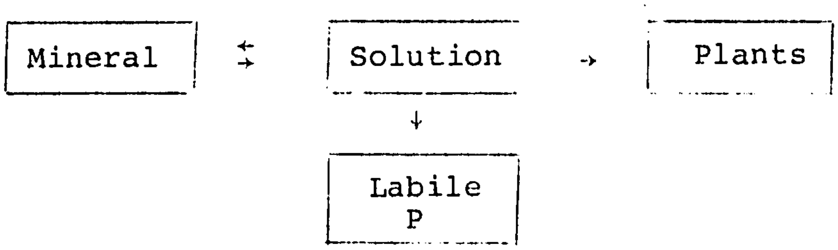


Figure 5. Schematic representation of the soil phosphorus system.

Only a very small fraction of the total P in the soil in solution form at any one time. This is in equilibrium with a somewhat larger pool of so called labile P. This equilibrium is different in different soils. In some soils the labile pool may be relatively small but will maintain a relatively high solution concentration. This is adequate for plant needs until the pool is depleted, but this condition may occur rapidly. Thus, the capacity to supply P may be low, but it can be supplied at a relatively high intensity, i.e., solution concentration. Such soils could be expected to give large response to a minimum application of P but the applied P would be rapidly depleted.

The equilibrium in other soils may be such that the labile pool must be very large before the solution concentration is sufficiently high to maintain maximum plant growth. Thus, these soils have a large capacity to supply P, but at low intensity. In these systems a large application would be required to obtain maximum response per unit of P applied to that crop would be small, and the response surface would appear quite different from that of the soils having a low P capacity associated with a high intensity.

This paper, of course, cannot cover all aspects of the supplying power of the soils for plant nutrients but should be sufficient to illustrate some of the technical and economic limitations of the ratio concept. Raising an alarm over the Pakistan farmers' improper fertilizer ratio not only serves no useful purpose but also illustrates a lack of knowledge of the technical-economic relationships involved. A blanket recommendation for the whole country such as a N/P ratio of 2/1 will not be valid for all areas or farmers.

Farmers in different stages of adoption of improved practices will be applying widely different rates. There is no sound basis for assuming that ratios should be the same for different doses. Actually most fertilizer experiments would have to be drastically redesigned in order to adequately test the ratios concept, even for fixed cost/price relationships.

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# APPENDIX 8

## IMPROVING FIELD CORN STANDS IN CRUSTING SOILS

Larry J. Nelson and C. J. deMooy[1]

### INTRODUCTION

Practical solutions to the problems of stand establishment of field corn in Pakistan were investigated in a field trial conducted at the Colorado State University Agronomy Research Center, Fort Collins, Colorado. Objectives of the study were to determine the effects of: 1) bedding practices; 2) initial seed moisture content at sowing; and 3) soil mulching on stand establishment and yield when soil crusting occurred during the emergence period.

### METHODS AND MATERIALS

The field study was conducted during 1978 on two fields at the Colorado State University Agronomy Research Center, Fort Collins, Colorado. Both of these fields were fallowed during the 1977 season.

The soil on which the study was conducted is a Nunn clay loam, with an organic matter content of 2%, predominantly montmorillonitic clay, and a stable structure. Although this soil is not considered to have serious crusting problems, several Colorado State University agronomists indicated that surface crusts occur which are of sufficient strength to impair emergence of field corn.

A 3 x 3 x 2 x 2 split-split-split plot design, replicated three times, was used for the study. The treatments were:

Main plots: Surface crusting conditions

I. Optimal (noncrusted)
II. Crusted
III. Crust-Thin

Subplots: Bedding practices

A. Broadbed (double row beds)
B. Basins
C. Ridge furrows

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Sub-subplots: Initial seed moisture content at sowing (ISMC).

1. 9% ISMC (air dry)
2, 23.3% ISMC (soaked 4 hours prior to sowing)

Sub-Sub-subplots: Post plant seedbed treatment

i. No mulch
ii. Soil mulch

Ammonium nitrate at 100 kg N per hectare (90 lbs N per acre) was applied with a Gandy fertilizer spreader on a previously plowed and harrowed field on May 25th. The fertilizer was incorporated with a spring-toothed harrow. Rain storms occurring during the last week of May through June 8th delayed further field activity until June 12th, at which time the experimental area was reworked with a spring-toothed harrow and the corn was planted on June 13.

Raised beds (ridge furrows and broadbeds) were constructed with a set of four tractor-mounted listers. A furrow spacing of 76 cm (30 in) and 152 cm (60 in) was used for the ridge furrows and broadbeds, respectively. Furrow depths ranged from 15 to 20 cm (6-8 in) irrespective of bedding type. A tractor-mounted rotary hoe was used to pulverize large clods on the surface of the beds.

A 90-day modified single cross variety of field corn, Pioneer Brand 3975A was chosen for the study. All treatments were sown with a tractor-mounted hand-fed disk seeder, capable of sowing a specific population of 69,190 seeds per hectare (28,000 seeds/acre).

A semi-portable sprinkler irrigation system, powered by a 60 horsepower diesel pump, was used to induce surface crusting on all designated treatments. Laterals (10.2 cm diameters) were set along the east and west edges of the main plots producing an 18 meter spacing between laterals. Rainbird (#35 INT, with .56 cm nozzle openings) part-circle impact sprinkler heads on 60 cm risers spaced at 12 meters were adjusted to spray half-circles into the plots. The sprinkler system was operated at a suboptimal pressure of (50 lbs/in$^2$). The suboptimal operating pressure and large nozzle openings were chosen in order to increase the droplet size and enhance the development of surface crusts. Water application was monitored with a Sparling meter.

All crusted main treatments were sprinkler-irrigated on the morning of June 14th. The following morning all crust-thin main treatments were sprinkler irrigated. The original design was for a 5 cm (2 in) application of water, but early morning winds on both days terminated sprinkler application before the designed depth was reached. Sufficient puddling however, was observed to ensure that soil crusts would develop of sufficient strength to impair emergence. A total of 3.73 cm (1.47 in) and 3.51 cm (1.38 in) of water was applied to crusted and crust-thin main treatments, respectively.

Surface soil temperatures at 1 cm and subsurface soil temperatures at seed-level (7.6 cm) in crusted and noncrusted treatments were monitored with thermocouples during the first ten days of emergence. The Colorado State University agronomy research weather station located approximately 2,000 ft. northwest of the experimental area provided additional information on daily air and soil temperatures along with other climatic data.

Soil crust samples were collected on the 17, 18, 19 and 20th of June for gravimetric soil moisture determination. In addition, soil samples at seed level were collected for gravimetric soil moisture determination.

Stand counts of each sub-sub-subplot were conducted over the period from 4 to 12 days after planting. A final stand count was conducted at harvest (November 25). Stand counts were taken on four rows, 7.6 meters (25 ft) long.

On June 17th a hand-operated sugarbeet soil crust breaker was used to mulch all sub-sub-subplots designated for soil mulching. This instrument was capable of breaking the surface to 1.5 to 4 cm diameter peds within a 6 cm band on either side of the seed row.

On June 22 all no-mulch, crust-thin treatments were thinned to original stand values observed on the 20th of June. Only healthy plants were removed from each row. Plants which had obviously had difficulty in emergence were not removed. This treatment simulated the effects of a more serious crust by reducing the plant population.

Soil moisture was monitored to a depth of 2 meters at 30 cm intervals with a neutron soil moisture probe. Irrigations were scheduled when 50% of the plant available soil moisture had been used. During the growing season the equivalent of 23 cm (9 in) of water was applied to each treatment by surface irrigation with 30 cm diameter gated pipe. All irrigations were monitored with a Sparling meter. Surface irrigations were applied on July 10 (7.6 cm), July 25 (10.2 cm) and August 16 (5.1 cm). Rainfall records indicate a total of 3.3 cm of rain occurred during the growing season.

A heavy frost on September 20th terminated the development of the corn between the dough and the beginning dent stage of development. The plants were permitted to dry in the field until November 25th at which time three rows, 7.6 meters long, were harvested for grain yield. Harvest data included stand counts, numbers of barren stalks and stalks with two ears, moisture content of shelled corn, bushel test weight, and grain yield.

Data were analyzed by a 3 x 3 x 2 x 2 factorial analysis of variance. Significant data were subjected to a LSD mean separation test. All LSD values were calculated at the .05 level.

## RESULTS AND DISCUSSION

### Seedbed Conditions

Temperature records for the 10-day period after sowing are presented in Table 1. Soil temperatures recorded at the Agronomy Research Center were recorded under a grass cover and therefore are somewhat lower than soil temperatures observed at the experimental site. It is also of importance to note that the soil temperatures at the experimental site were recorded between 2:00 and 3:00 p.m., and may not reflect the actual maximum soil temperatures. However, during the first 6 days after sowing, temperatures at seed level in the crust-treatment were 4 to 5°C lower than those observed in the optimal treatment.

Crusted soil samples on the 4th, 5th, 6th, and 7th days after sowing had average gravimetric soil moisture contents of 4.2, 3.3, 2.6 and 2.5% respectively. Visual observations of emergence during this period indicated that the soil crust had developed sufficient strength by the 5th day to inhibit shoot penetration.

### Stand Establishment

Emergence of seedlings was observed in the optimal plots on the 3rd day after sowing. Daily averaged cumulative emergence for all main plot treatments is shown in Figure 1. Substantially lower averaged daily cumulative emergence was observed, during the first 6 days after sowing, in the crust and crust-thin treatments as compared with that of the optimal treatments. Daily averaged cumulative emergence was 58, 45, and 33 percent lower on the 4th, 5th and 6th days after sowing, respectively, than the optimal treatment. Slightly higher emergence rates in the crust-thin treatment resulted from an additional day of favorable seedbed conditions before the sprinkler application was applied.

Figure 2 compares the daily averaged cumulative emergence of optimal versus crusted treatments sown with air-dry seed, mulched and nonmulched. The effects of lower soil temperatures on emergence may be observed by comparing either the mulched or nonmulched optimum treatments with the mulched, crust treatment. Lower soil temperatures on the 4th, 6th,

Table 1. Daily air and soil temperatures recorded at the experimental site and the agronomy research weather station.

| | | June | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| Air temperature $^{o}C$ | max. | 31 | 30 | 31 | 28 | 24 | 27 | 29 | 23 | 28 | 30 |
| | min. | 14 | 13 | 14 | 14 | 16 | 12 | 15 | 13 | 13 | 16 |
| Soil temperature at 1 cm; optimal treatment (2 PM) | | - | - | 43 | 42 | 40 | 41 | 41 | 42 | 43 | 45 |
| Soil temperature at 1 cm; crust treatment (2 PM) | | - | - | - | 31 | 36 | 39 | 42 | 44 | 45 | 47 |
| Soil temperature at 7.6 cm; optimal treatment (2 PM) | | - | - | 30 | 29 | 28 | 29 | 29 | 29 | 28 | 30 |
| Soil temperature at 7.6 cm; crust treatment (2 PM) | | - | - | - | 24 | 24 | 25 | 26 | 28 | 27 | 29 |
| Soil temperature 1½-3 cm; weather station | max. | 33.9 | 34.4 | 35.6 | 36 | 35 | 35.6 | 35 | 35.6 | 35.8 | 38.9 |
| | min. | 14.4 | 15.6 | 15.6 | 16.9 | 14.4 | 16.7 | 17.5 | 15.6 | 16.1 | 19.2 |
| Soil temperature 15 cm; weather station | max. | 26.7 | 26.7 | 28.3 | 28.3 | 28 | 28.8 | 28.1 | 28.1 | 27.5 | 29.7 |
| | min. | 16.7 | 17.8 | 18.1 | 18.9 | 17.5 | 18.9 | 18.5 | 18.8 | 18.6 | 21.1 |

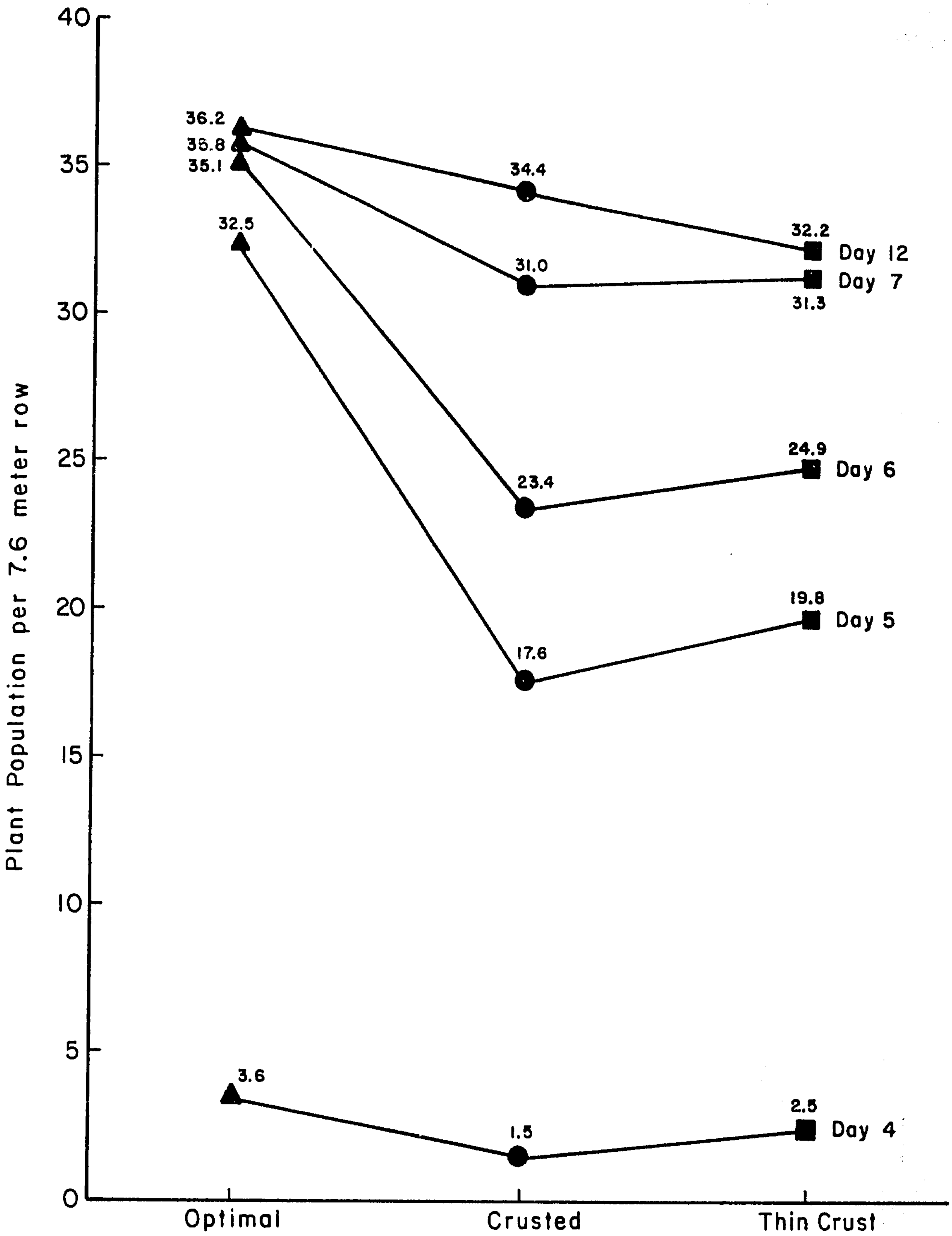


Figure 1. The effect of different crusting treatments on the averaged cumulative emergence of field corn for the 4th, 5th, 6th, 7th and 12th day after sowing.

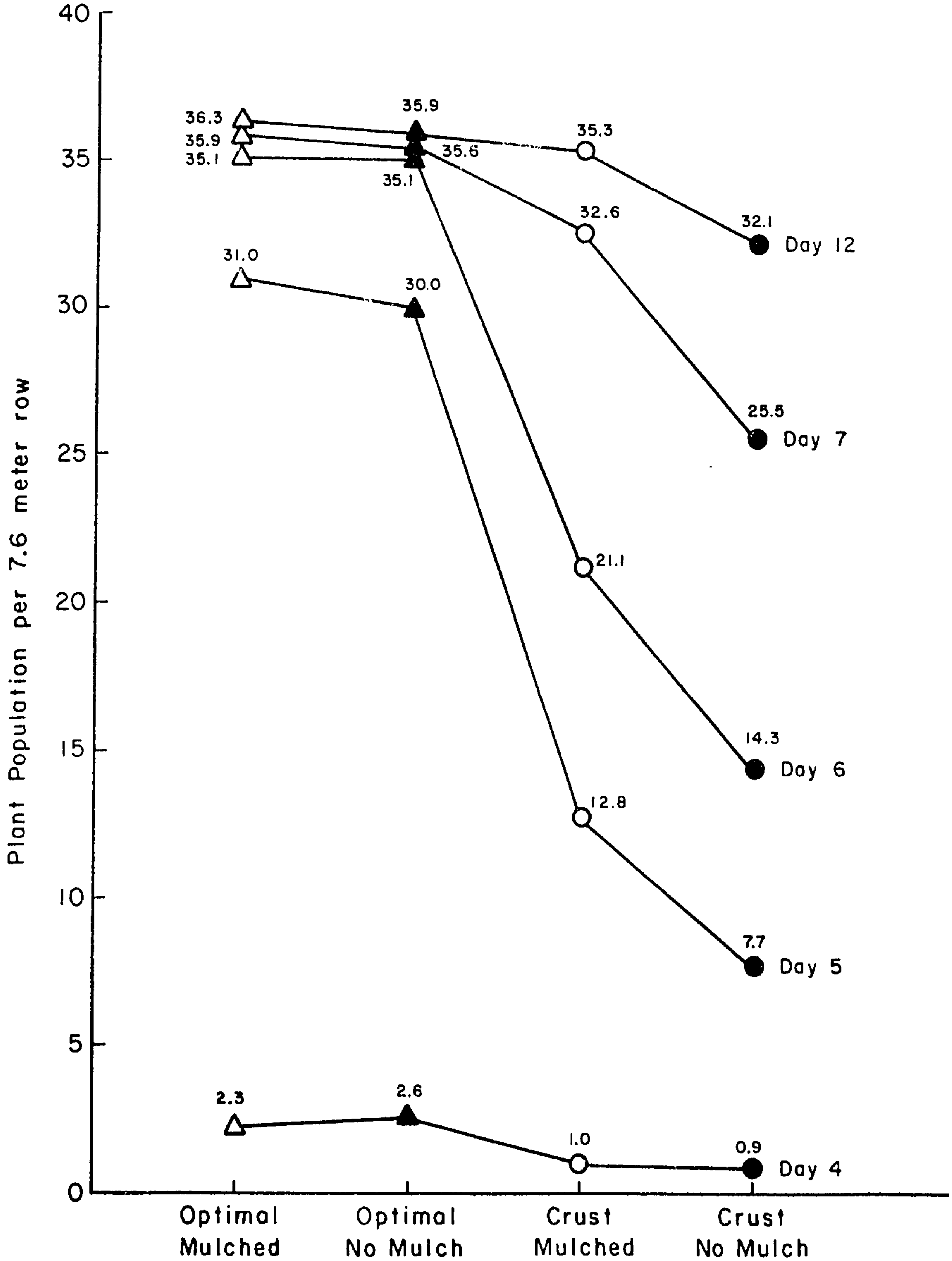


Figure 2. The effect of soil mulching in optimal and crust treatments on averaged cumulative emergence of field corn for the 4th, 5th, 6th, 7th and 12th day after sowing.

and 7th day accounted for a 52, 40 and 8% respective reduction in emergence. Although treatments designated for soil mulching were mulched on the 5th day, soil crusts were of sufficient strength at this time, in addition to low soil temperatures, to effectively reduce daily emergence. Thus, a 57% reduction in emergence between the crust-mulch treatment and the optimum treatments on the 5th day (Figure 2) is the effect of combined soil crusting and lower seedbed temperatures.

The additive effect of lower seedbed temperatures and soil crusting is demonstrated when the crust-no mulch treatment is compared with either of the optimal treatments (Figure 2). Lower seedbed temperatures and soil crusting resulted in a 65, 74, and 28% reduction in emergence on the 4th, 5th, and 6th days after sowing, respectively. By the 8th day seedbed temperatures of the crust treatment approached those of the optimal treatment. Thus, the 11% lower emergence in this treatment on the 12th day is a result of the soil crust. Final stand counts revealed that the emergence in the crust-treatment had not changed significantly.

A consistently higher rate of seedling emergence was observed in basins over that of ridge furrows and broadbeds during the first 7 days after sowing (Figure 3). The higher rates of emergence in basins resulted from problems incurred during sowing. Seedbed preparation in late May was interrupted by 9 days of rainy weather. When field activity was resumed, on June 12th, the field was reworked with a spring-toothed harrow prior to bed formation. Unfortunately, the spring-toothed harrow only reworked the soil to a depth of 5 to 8 cm. As a result, the furrow makers on the disk planter were only capable of sowing the seed at depths of 3.5 to 5 cm in basins, whereas seeding depths in the ridge furrows and broadbeds were 7.5 to 9 cm. The more shallow sowing depths in the basins increased the emergence rate of seedlings by decreasing the distance the shoot had to travel and by exposing the seed to a more favorable heat flux. Sowing seed at more shallow depths may offer a partial solution to improved stand establishment in crusting soils of cooler climates. However under the extreme soil temperature regimes ($40^{o}$-$50^{o}$C), characteristic of the kharif season in Pakistan, this technique would probably result in a high seedling mortality.

Presoaking crop seed prior to sowing is a common practice used by Pakistani farmers to improve emergence in seedbeds characteristically low in available soil moisture content. Previous greenhouse studies (Nelson, 1976) indicated presoaking maize seed for 2-1/4 hours prior to sowing reduced emergence time by as much as 24 hours and significantly improved emergence of seedlings in all but the most seriously crusted soils.

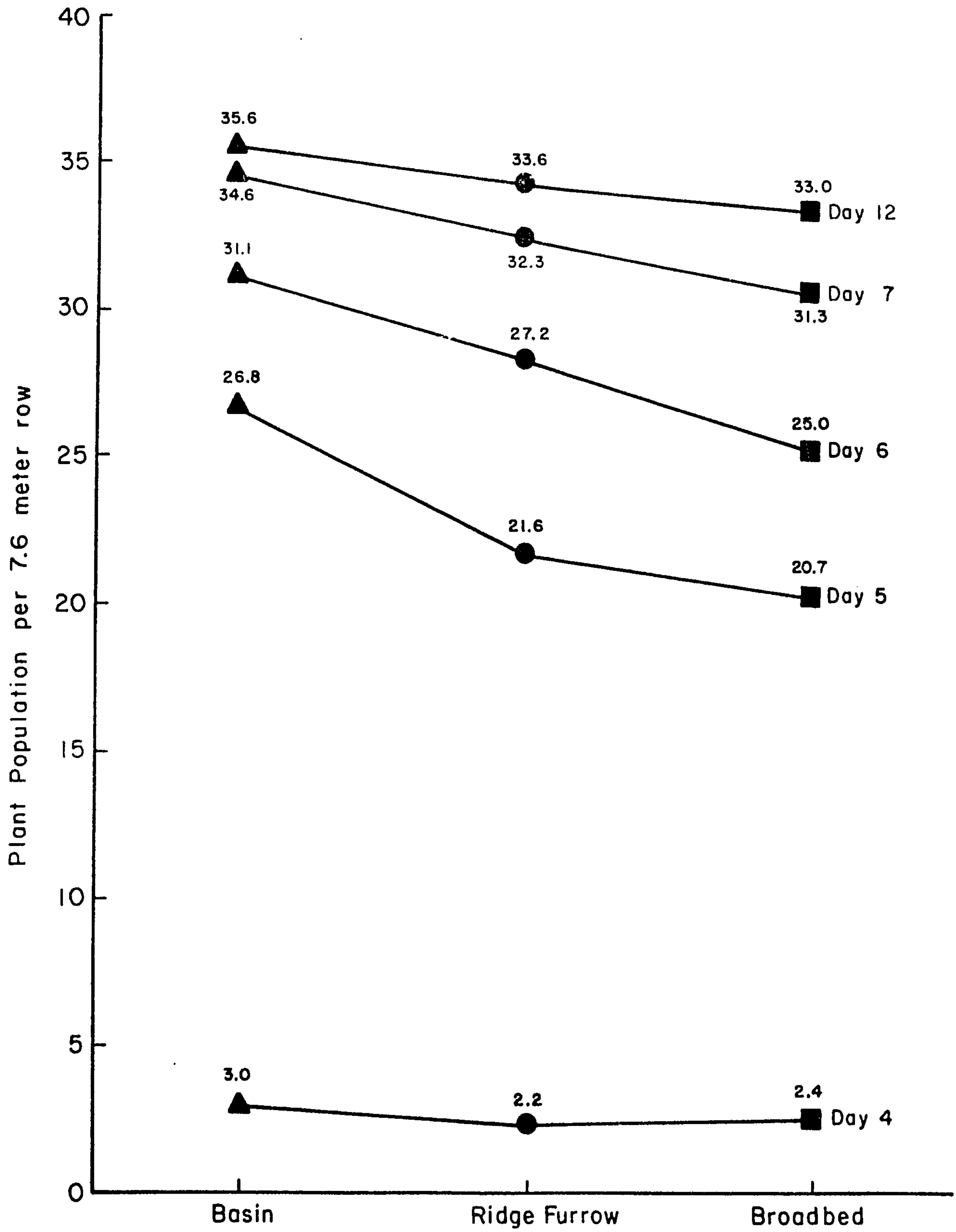


Figure 3. The effect of bedding practices on the averaged accumulated emergence of field corn for the 4th, 5th, 6th, 7th and 12th day after sowing.

The overall effect of higher initial seed moisture content on emergence was found to be highly significant during the first 6 days after sowing. Within nonmulched, crusted treatments significant differences in emergence of presoaked seed (23.3% ISMC) versus air-dry seed (ISMC) occurred throughout the experiment (Figure 4). This difference was most apparent in the nonmulched, crust-thin treatment, where final stands represented those attained on the 8th day after sowing. Final stands of air-dry and presoaked seed in this treatment were 72 and 86%, respectively, of those observed in the optimal treatment.

Soil mulching is a method commonly used in western countries to improve emergence in crusted seedbeds. Surprisingly, few Pakistani farmers realize the positive benefits incurred from mulching a crusted field. However, realization of its importance can lead to some innovative solutions. Mr. Raja Aslam, a farmer at Chak 11, observed WAPDA beldars breaking soil crust with Kurpas (hand hoes) in a CSU-WAPDA trial on his farm. About two weeks later another untimely rain severely crusted 5 acres of cotton he had just sown with a precision planter. As soon as the field had dried sufficiently, Raja Aslam's beldar broke the crust over every seed row in the field. He used a stick, held about the same angle as the shaft of the traditional stick plow, pulled by two leads attached to a pair of bullocks. With this rather crude but effective instrument, Raja Aslam obtained a near normal stand and a respectable yield of 1286 to 1378 kg/ha (14-15 mds/acre) of seed cotton.

Soil mulching on the 5th day after sowing was found to significantly improve emergence in crusted treatments sown with air-dry seed (Figure 2). Crust treatments which were mulched had final stands comparable to those of optimal treatments. Similar treatments which were not mulched were characterized by a much slower rate of emergence and a 10% reduction in the final plant population.

The beneficial effects of soil mulching were more apparent in the crust-thin treatment sown with air-dry seed, where final stands represented those attained on the 8th day after sowing. Soil crusting in this treatment accounted for a 29% reduction in the final plant population, whereas soil mulching resulted in populations nearly equal to those of similar optimal treatments.

## Harvest Results

Frost on September 20 terminated grain development at the start of the beginning dent stage. As a result overall grain yields were low and of poor quality. Average bushel test weight of harvested grain was 15.6% lower than the standard.

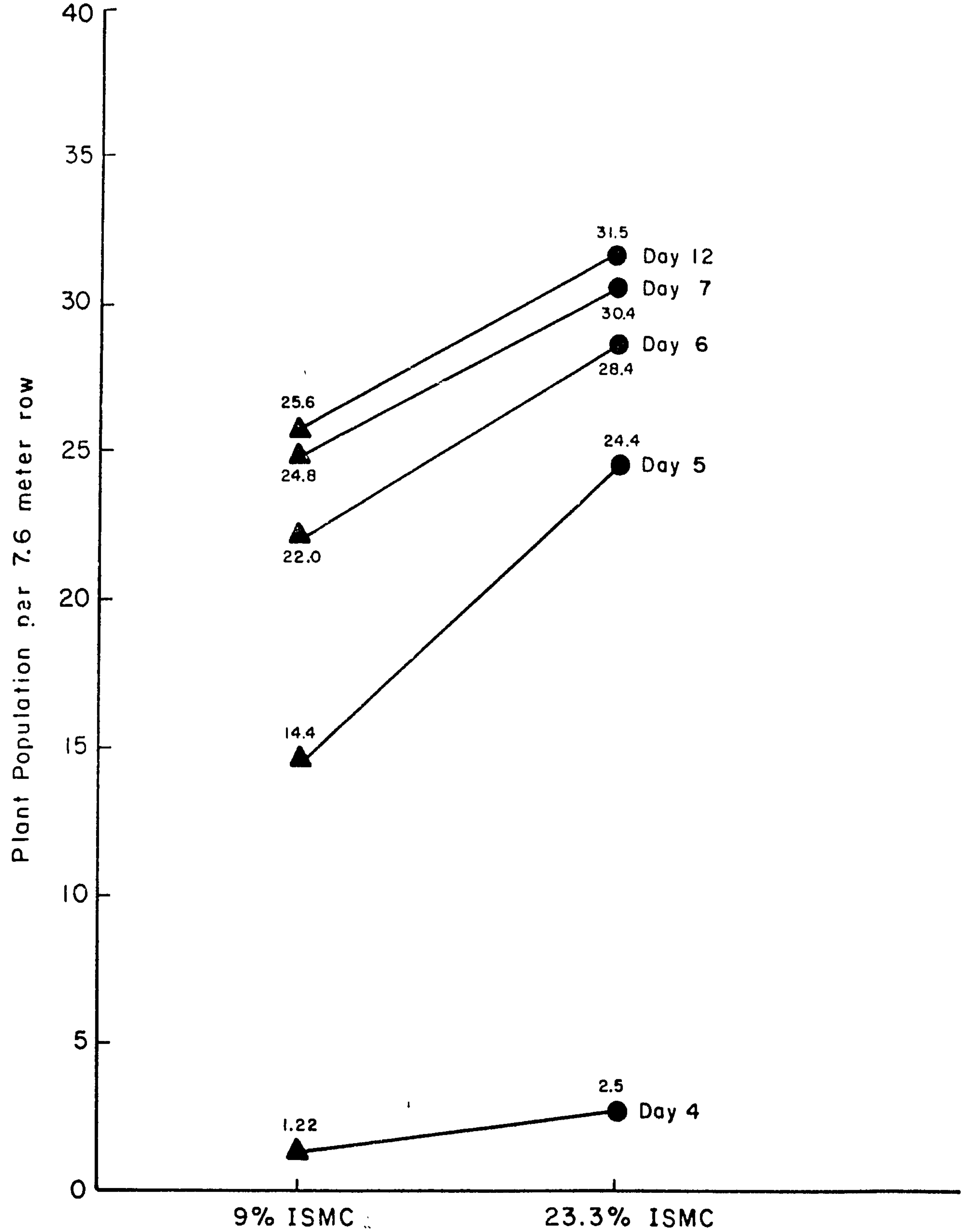


Figure 4. The effect of Initial Seed Moisture Content on averaged cumulative emergence in the crust treatment for the 4th, 5th, 6th, 7th and 12th day after sowing.

The grain yield of optimal, crust and crust-thin treatments were 3,248, 3,177, and 2,966 kg/ha, respectively. Crusting treatments appeared to reduce yields. The differences were not statistically significant.

Substantial variations in grain yield occurred in bedding practice treatments. Average grain yields of basin, ridge furrow and broadbed treatments were 3,345, 3,129, 2,918 kg/ha, respectively. A LSD mean separation test revealed variations in yield were caused by differences between basin and broadbed treatments. Earlier discussions concerning problems with seeding depth in basin plots explained the observed yield differences.

Treatments sown with prehydrated seed had substantially improved grain yields. Crust and crust-thin treatment average grain yield were increased by 334 and 495 kg/ha, respectively, when sown with prehydrated seed (Figure 5). Higher initial seed moisture content also increased average grain yield of more severely crusted broadbed treatments by 490 kg/ha (Figure 6). A slight, but significant, increase in bushel test weight suggests treatments sown with prehydrated seed were slightly more mature when physiological development was halted.

Significant 3-way interactions were observed between crusting, initial seed moisture content and mulching treatments. Mean separation tests revealed crust and crust-thin treatments, sown with air-dry seed, were benefited by soil mulching. Soil mulching of crusts in these treatments increased average yields by 398 and 508 kg/ha, respectively. However, soil mulching of crust treatments, sown with prehydrated seed, resulted in a 297 kg/ha decrease in grain yield. Additional research will be required to explain this phenomenon.

## CONCLUSIONS

Harvest stands of crust and crust-thin treatments were 6 and 11% lower than comparable stands of optimal treatments. Plant populations of these treatments were reduced by the development of a soil crust on the 5th day after sowing. Soil crusting extended the emergence period by an additional 5 to 7 days. The extended period of emergence was caused by low seedbed temperatures and the development of a soil crust.

Final stands of ridge furrow and broadbed treatments were 9 and 12% lower than those observed in basin treatments. The improved stands in basin treatments resulted from a more shallow seeding depth which exposed the seed to a more favorable heat flux and reduced the emergence distance.

Treatments sown with prehydrated seed had significantly higher daily averaged cumulative emergence. By the 5th day

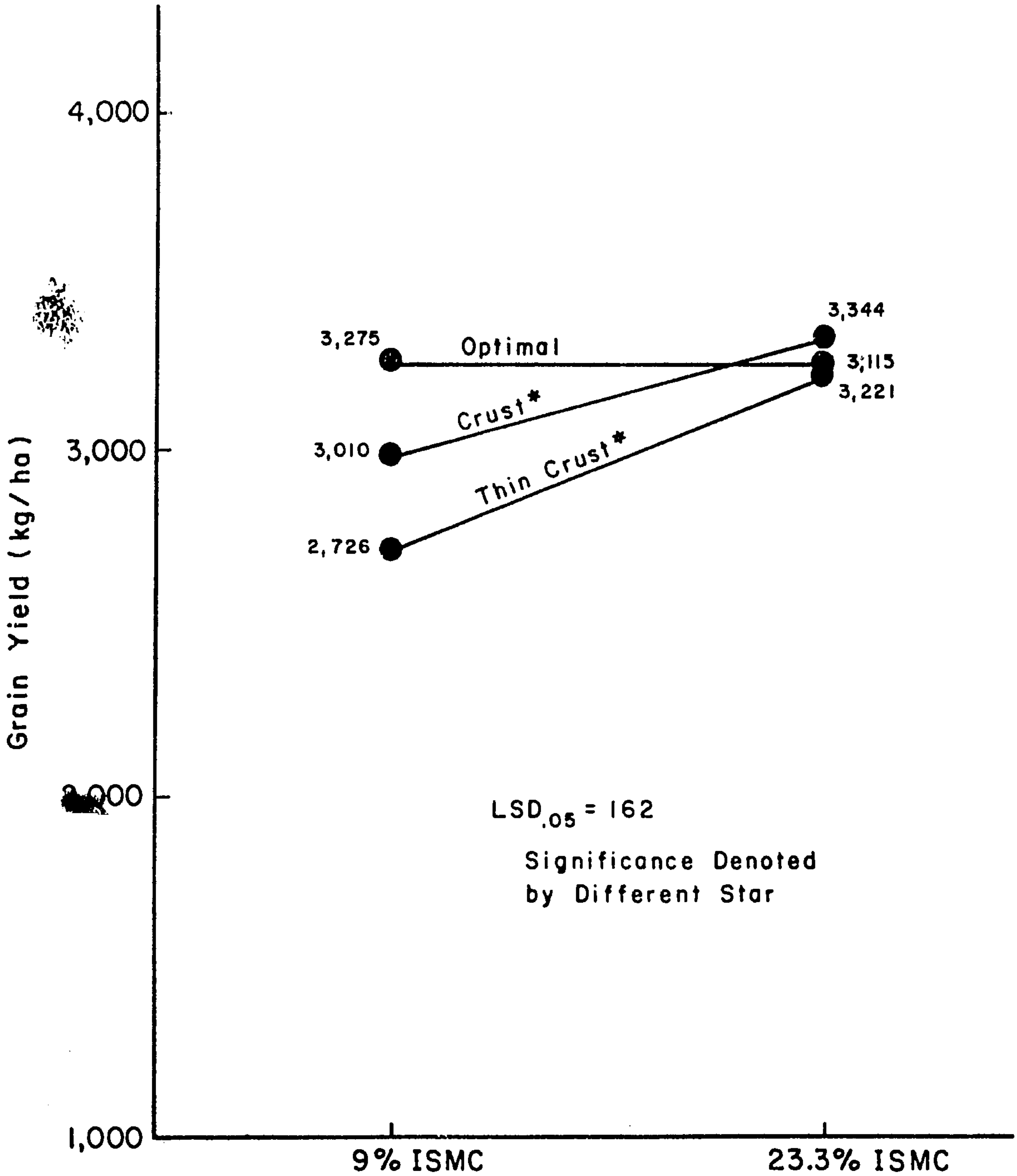


Figure 5. The effect of Initial Seed Moisture Content at sowing on the yield of field corn for optimal, crust and thin-crust treatments.

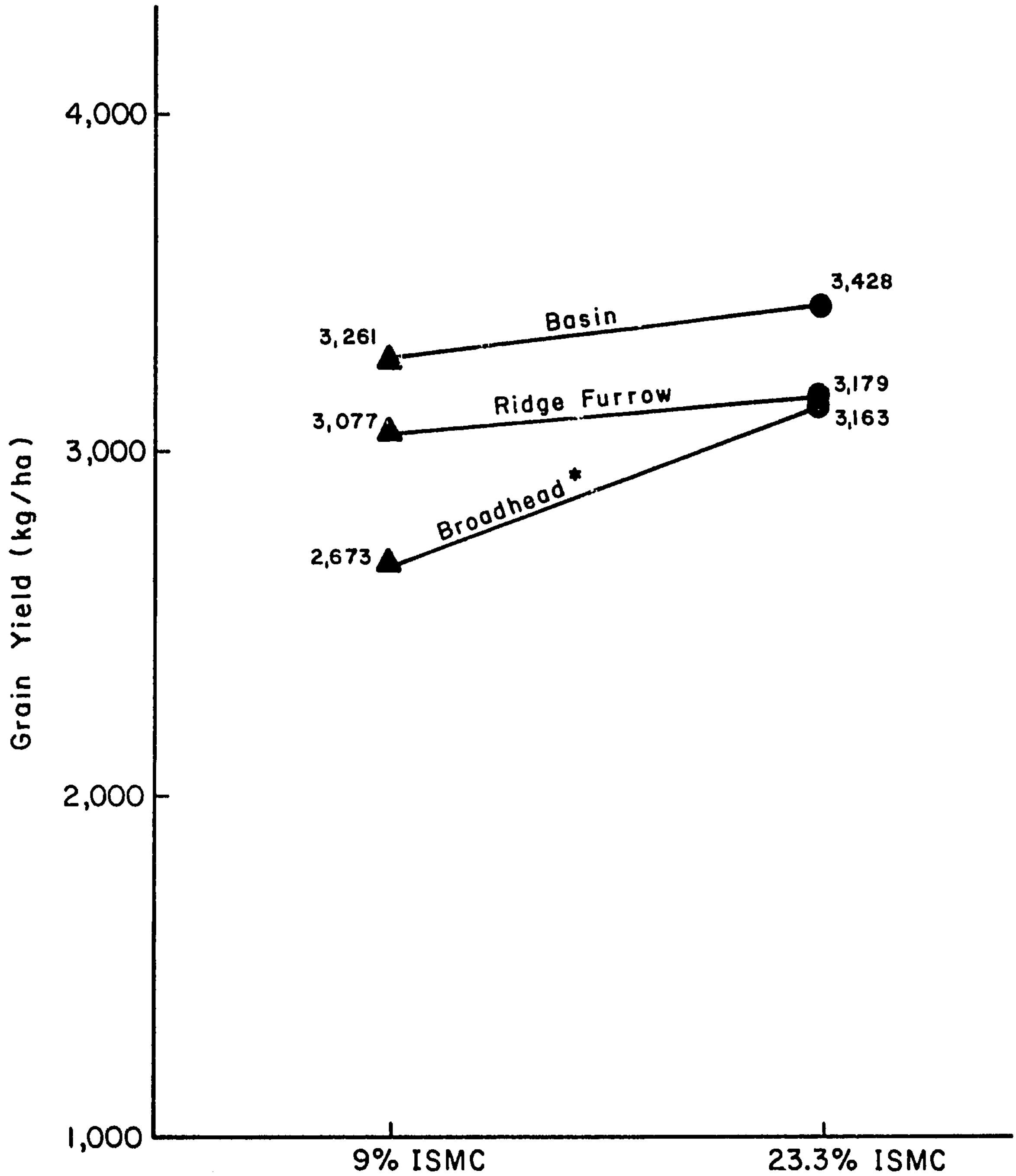


Figure 6. The effect of Initial Seed Moisture Content at sowing on the yield of field corn for basin, ridge furrow and broadbed treatments.

after sowing, crusted treatments sown with prehydrated seed (23.3% moisture content) were near 70% of a full stand, whereas those sown with air-dry seed (9% moisture content) were only 40% of a full stand. The beneficial effects of sowing prehydrated seed were most apparent the nonmulched, crust-thin treatment. Sowing this treatment with air-dry and prehydrated seed resulted in final plant populations which were 72 and 86% of optimal treatments.

Soil mulching on the 5th day after sowing substantially improved emergence in crusted treatments. Crusted treatments which were mulched had final stands comparable with those of optimal treatments. Plant populations were reduced by as much as 10 and 29% in crust and crust-thin treatments which were not mulched.

An abbreviated growing season resulted in lower yields and decreased grain test weights by 15.6%. Although average grain yields of the main treatments were significantly different at only the .44 probability level, observed average yield of optimal, crust and crust-thin treatments were 3,248, 3,177 and 2,966 kg/ha, respectively.

Average grain yield of basin, ridge furrow and broadbed treatments were 3,345, 3,129 and 2,918 kg/ha, respectively. A LSD mean separation test, at the .05 level, revealed yield differences between basin and broadbed treatments to be significant.

Prehydrated seed in crust and crust-thin treatments significantly increased average grain yields by 334 and 495 kg/ha, respectively. Soil mulching increased average grain yields of similar treatments sown with air-dry seed by 398 and 508 kg/ha, respectively. When both prehydrated seed and soil mulching were employed, the yield of crust treatments was not increased, but reduced by 297 kg/ha.

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# APPENDIX 9

## IRRIGATION INFLUENCE ON NITROGEN USE EFFICIENCY AND YIELD OF PADDY RICE

Muhammad Hanif, C. J. deMooy and John Olsen[1]

Most of the C-3 plants, in general, are known for their low water use efficiency (Salisbury and Ross, 1978). Because of certain anatomical and physiological features, the problem is especially accentuated in rice. It is now known that rice yields improve under continuously flooded conditions and are reduced when the fields are allowed to dry well past the field capacity (Grist, 1959). This is especially true at critical growth stages as tillering and blooming. Because of limited irrigation resources, farmers in Pakistan, in general, follow alternate flooding and drying cycles. Canal closures and other causes of periodic drying are common in Pakistan. Because of these fluctuating moisture contents, the oxidation and reduction (redox) status of the soil becomes more conducive to higher nitrogen losses.

It has been hypothesized that most of the nitrogen losses occur in the critical redox range of 12-15 (Lindsay, 1979). Elevated temperatures coupled with frequency and time of exposure of fields to such critical redox levels as imposed by alternate flooding and drying irrigation regimes, generally lead to high nitrogen losses and very low nitrogen use efficiencies in paddy rice. As a result, production usually falls considerably short of the potential production capabilities.

The present investigation was directed to explore the response of paddy rice to various irrigation treatments in terms of nitrogen use efficiency and yield.

### MATERIALS AND METHODS

The study was conducted in the greenhouse using Starbonnet, a day neutral variety of rice.

#### Experiment No. 1

The first crop was sown in January, 1978. The soil for this experiment was taken from the Agronomy Farm, air-dried, and passed through a sieve with openings 5 mm square. The pots were filled with 20 Kg soil on oven-dry basis. A 6 cm thick layer of sand was put at the bottom of each pot

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in order to facilitate siphoning out of leakage from the bottom of the pots. A nalgene pipe of 5 cm diameter and 40 cms length was installed in each pot extending to the sand layer for the purpose of siphoning out water as needed.

Starbonnet rice seed was obtained from the Rice Research Institute, Stutgurt, Arkansas and rice nursery sown on January 1, 1978. The experimental treatments consisted of four irrigation regimes each at three nitrogen levels making a total of 12 treatments, replicated four times in a split-plot design with irrigation in the main plots and nitrogen levels in the sub-plots.

The details of the experimental treatments are given below.

A. IRRIGATIONS (main plots)

1. $I_1$ - Continuous flooding. Flooding is defined as maintaining a water head of about 8 cm on the surface of soil in the pot.

2. $I_2$ - Alternate flooding and drying. The pots were flooded for four days after which the surface water was siphoned off into bottles and the pots dried until tensiometers placed at a depth of 12 cms shows a matric potential ($\Psi m$) of -0.75 bars. Under these laboratory conditions this corresponded amount of drying occurred in about three days or so in mid season crop. After this, the pots were again flooded with water using the previously stored water in bottles and applying additional water as needed.

3. $I_3$ - Same as $I_1$ but 15 days dry spell before blooming. The soil matric potential was allowed to reach about -13 to -14 bars and determined from the desorption curve of the soil and gravimetric soil moisture determination. The soil was then rewet with sufficient water to bring the average water content of the soil to that measured at 2 bars of suction.

4. $I_4$ - Same as $I_1$ but 15 days dry spell after blooming to -13 to -14 bar $\Psi m$. $\Psi m$ was determined in the same way as for $I_3$.

B. NITROGEN TREATMENTS

1. $N_o$ - No nitrogen applied

2. Nb - 50 ppm nitrogen applied through incorporating to a depth of 12 cms

3. Np - 50 ppm nitrogen applied in mudballs placed at a depth of 12 cms.

The nitrogen was applied in the form of urea on January 28, 1978. A basal dose of 50 ppm $P_2O_5$ as concentrated super phosphate was applied to all pots. Soils were flooded with water and puddling of the soil was done by hand. Rice seedlings were transplanted into the flooded pots at the rate of nine plants per pot on the same day. Zinc sulfate was added to all pots in a 1% solution to provide 5 ppm of zinc to the soil on an oven-dry basis. The drying cycles of the various irrigation treatments were imposed as follows:

1. Continuous flooding ($I_1$): no interruption.

2. Alternate flooding and drying ($I_2$): one-week after transplanting.

3. Preflowering dryspell ($I_3$): 12 weeks after transplanting.

4. Post-flowering dryspell ($I_4$): 14 weeks after transplanting.

The day temperature was maintained at 40°C which was lowered to 35°C during the period from flowering to harvest. The night temperature was maintained at 32°C from sowing to flowering and at 26°C from flowering to harvest.

Two liters of leachate were collected from the bottom of each pot at various times during the growth period and the pH and redox potential of soil were measured.

All irrigation treatments were stopped 10 days before harvesting in order to introduce senescence.

The crop was harvested on June 12, 1978, yields recorded and soil samples were collected.

Experiment No. 2

Crop No. 2 was sown in the same way as crop No. 1 except where mentioned. The nursery was sown on June 10, 1978. The pots were filled with 18.6 Kg soil and transplanting was done on July 10, 1978.

$I_1$ and $I_2$ treatments were the same as in crop No. 1. The $I_3$ and $I_4$ treatments involved water stresses at matric suctions of -10 bars and -5 bars, respectively. The three nitrogen treatments were $N_0$ (control), $N_{50}$ (50 ppm nitrogen) and $N_{100}$ (100 ppm nitrogen), applied and incorporated into 12 cm depth. Mudball placement was not studied in this crop. The number of plants per pot was reduced to four. The day and night temperatures were maintained at 35°C and 26°C respectively.

Leachate was collected at the rate of 20 liters per pot by draining the pots from an outlet at the bottom of each pot. The time intervals for imposing the $I_2$, $I_3$, and $I_4$ treatments were almost identical to crop No. 1. Gypsum blocks and gravimetric soil analysis were used to estimate $\Psi m$ for $I_3$ and $I_4$. The crop was harvested at the end of November, 1978.

RESULTS AND DISCUSSION

No statistical analysis of the data have been conducted to date but trends in the data are discussed here.

IRRIGATION TREATMENTS

The continuous flooding treatment is considered as standard (reference) treatment and other results are compared to it. It can be seen from Table 1 that continuous flooding gave the best results at comparable levels of nitrogen for all nitrogen treatments. Continuous flooding, with a dry spell for 15 days at pre- and post- flowering stages (treatments $I_3$ and $I_4$, respectively), resulted in a loss of yield for all nitrogen treatments. The percent yield reductions compared with continuous flooding treatment were 18 for $I_3$ and 15 for $I_4$. A severe dry spell ($\Psi m$ = -13 to -14 bars) for as short a period as 15 days can prove quite damaging. The alternate flooding and drying treatment ($I_2$) showed the lowest yield results at all nitrogen treatments. The mean decrement of yield compared with the continuous flooding treatment was 30 percent.

The data for crop No. 2 are shown in Table 2. A 15-day dry spell at post flowering at -5 bar ($I_4$) level improved the rice yield by 6%. The statistical significance of this effect is uncertain, however. The decrement in yield for 15-days pre-flowering dry spell ($I_3$) at -10 bar matric potential was 11%. The corresponding decrease in yield for alternate flooding and drying was 27% which is comparable to 30% yield loss obtained with crop No. 1.

Chemical analysis of plant, soil and water samples for nitrogen contents is in progress. Nitrogen use efficiency and nitrogen losses associated with the various treatments will be reported at a later date.

Table 1. Effect of irrigation regimes and nitrogen levels on the total dry-matter yield (g/pot) of rice (Crop No. 1), 1978 (means of four replications).

| | $N_O$ | $N_b$ | $N_p$ | Mean | % Change |
|---|---|---|---|---|---|
| $I_1$ | 214 | 248 | 269 | 243 | Reference |
| $I_2$ | 156 | 173 | 174 | 170 | -30 |
| $I_3$ | 179 | 202 | 217 | 199 | -18 |
| $I_4$ | 163 | 226 | 231 | 207 | -14 |
| Means | 178 | 212 | 223 | | |
| % Change | Reference | +19 | +25 | | |

Table 2. Effect of irrigation regimes and nitrogen levels on the total dry matter yield of rice (g/pot), (Crop No. 2), 1978 (means of four replications).

| | $N_O$ | $N_{50}$ | $N_{100}$ | Mean | % Change |
|---|---|---|---|---|---|
| $I_1$ | 125 | 183 | 209 | 172 | Reference |
| $I_2$ | 98 | 141 | 137 | 126 | -27 |
| $I_3$ | 128 | 148 | 182 | 153 | -11 |
| $I_4$ | 143 | 180 | 223 | 182 | +6 |
| Means | 124 | 163 | 188 | | |
| % Change | Reference | +31 | +52 | | |

SUMMARY

Two crops of rice (variety Starbonnet) were sown in January and July, 1978, respectively to find out the irrigation and nitrogen use efficiency of various treatments on the yield of rice. The analytical work on plant and soil samples is in progress in the laboratory. The results show that alternate flooding and drying resulted in considerable loss of yield of (30% and 27% respectively, for Crop No. 1 and No. 2). The decrement in yield for a dry spell of -13 to -14 bar matric potential at pre- and post-flowering stages were almost equal for crop No. 1 indicating the sensitivity of the rice plant to drought stress around bloom. The losses amounted to 18% to 15%, respectively. A pre-flowering dry spell for 15 days at the 10 bars moisture stress level for crop No. 2 showed a yield decrement of 11% whereas a moisture stress of 5 bars at post flowering for 15 days showed a trend to improve the yield by 6%.


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# APPENDIX 10

# EFFECT OF SOIL TEMPERATURE AND MOISTURE ON COTTON GERMINATION UNDER ARID AND SEMI-ARID CONDITIONS

Rafael E. Gonzales, C. J. deMooy and John Olsen[1]

## I. INTRODUCTION

A major problem faced by cotton producers in the arid and semi-arid regions is the establishment of a good stand early in the season which can be insured only by a high and fast rate of germination. Stand uniformity or lack of it greatly affects production and the management of the crop during the crop year. The physical properties of the soil surrounding the seed, primarily high temperature, low moisture content and a physical impedance above the seed, have been recognized as the most common physical factors restricting a successful cottonseed germination and stand in those regions.

The purpose of this study was to analyze the effect of high soil temperatures and different soil moisture content on the rate and percent of emergence of cottonseed at the laboratory and greenhouse. Since soil temperature fluctuates through a daily cycle the experiments were conducted to evaluate the combination of different daily soil temperatures and several moisture regimes representing field conditions and to know if the effect of one is modified by the other and their interaction on cotton seed emergence.

## II. MATERIALS AND METHODS

This research was conducted at Colorado State University in two different studies. The first one was conducted in the laboratory to evaluate the effect of different constant and alternating temperatures on cottonseed germination. The second study was conducted in the greenhouse to evaluate the effect of soil temperature and moisture on the emergence of cottonseed.

### A. STUDY I

Cottonseeds were tested on a two-way thermogradient plate to make a comprehensive comparison of their germination responses to alternating and constant temperature within a range of 14.0 to 46.5C. This device can be used to supply all combinations of alternating and constant temperatures simultaneously within a predetermined range. The temperature

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setting was alternated every 12 hours. Three different varieties of cotton seed were used (i.e. Acala 1517-V (Gossypium hirsutum L.), Acala 1517-70 and Pima s-4 (G. barbadense L.)). The seeds were planted on the entire surface of the plate over a moistened blue-gray blotter paper as substratum, 900 seeds of each variety were planted on each replication 2.5 cm apart. Three replications were made. The study was conducted over an 8-day period with germination count made each 12 hours beginning at 24 hours after planting. A series of computer programs available at Colorado State University Computer Center was used to analyze the results.

B. STUDY II

Daily soil temperature ranges identified as the maximum at which germination occurred in Study I, and several moisture regimes representing field conditions were used to evaluate their effect on cottonseed emergence in the greenhouse. Cotton variety Acala 1517-V with 93% germination was used in the study. The seeds were planted at 2.5 cm depth in a Fort Collins clay loam soil. Plastic pots (40 x 19.5 x 12.5 cm) were used. The pots were watered from the bottom up by capillary action to avoid crust formation on the surface that could cause a decrease in rate of emergence. Experiments were continued for 7 days after planting. Seeds were planted after the desired temperature and moisture treatment were attained. The soil temperature and moisture were checked at seed level three times per day. The rate of emergence was counted twice a day. Two different experiments were conducted in Study II. The experiments were laid out in a split-plot design in time. Analysis of variance and multiple comparison tests were performed.

EXPERIMENT 1

Four different daily soil temperature ranges were used; one at room temperature and three around the maximum temperature for germination found in Study I:

$T_1$26-29C; $T_2$31-36C; $T_3$32-42C; $T_4$32-45C. Three different soil water tensions were used ranging from 1/3 to 3 bars. $M_1$: Field capacity (1/3 bar) for 7 days; $M_2$: 2.0 bars for 7 days; $M_3$: 2.0 bars for 3 days, dry for 2 days but not exceeding 3.0 bars, followed by 2.0 bars for 2 days.

EXPERIMENT 2

Four different daily soil temperature ranges, the same as for Experiment 1, (i.e. 26-29C; 31-36C; 32-42C; 32-45C) and four different water regimes in the soil with higher soil water tension than in Experiment 1 were used.

$M_1$: 2.5 bars for 7 days; $M_2$: 2.5 bars for 3 days, dry for 2 days followed by 2.5 bars for 2 days; $M_3$: 2.5 bars for 2 days, allowed to dry but not exceeding 8 bars for 5 days; $M_4$: 2.5 bars for 1 day, dry for 6 days but not to exceed 8 bars.

Pot Preparation

Plastic containers (40 x 19.5 x 12.5 cm) were used. The pots were watered by capillary action with tygon tubing placed at the bottom of the pots. A vertical tubing attached to two perforated horizontal tubes with a "T" connector was used for this purpose. The horizontal tubing was covered with 1.5 kg of sand on top of which 8.5 kg of a Fort Collins soil was placed. Two gypsum blocks were buried in each pot at seed level to estimate moisture content. The temperature was monitored at seed level with a thermometer.

Temperature and Moisture Control

The daily soil temperature ranges were controlled with special chambers built of wood and plastic with plastiglass cover, each one with a thermostat and electric heater unit attachment. The pots were placed in a sand bed inside the chambers. The sensing area of the thermostat was placed in one of them. Soil temperature was measured at seed level by thermometer, one for each pot. Soil moisture tension was monitored at seed level by the two gypsum blocks in each pot. A moisture retention curve was determined for the soil in the laboratory. Calibration curves were made for each gypsum block.

III. RESULTS AND DISCUSSION

A. LABORATORY GERMINATION STUDY (STUDY I)

The temperature response of cotton seed (Gossypium sp. L.) was tested simultaneously over a 14 to 46.5°C range of alternating and constant temperatures on a thermogradient plate. A series of computer programs was used to analyze the data of three replications. As a final result a plot representing intensity patterns of germination was obtained (Figure 1). The ordinate in Figure 1 represents the temperature gradient imposed during one half of each day. The abscissa represents the temperature gradient maintained during the complementary half. The size of the square represents intensity of germination. A diagonal line from the lower left corner to the upper right corner represents constant temperature, the greater the distance between any point in the figure and the constant temperature line, the more extreme the temperature change when the gradient direction is alternated.

Optimum temperature for germination of cotton occurred between 27.5 to 35°C for constant temperature and 24.25 to

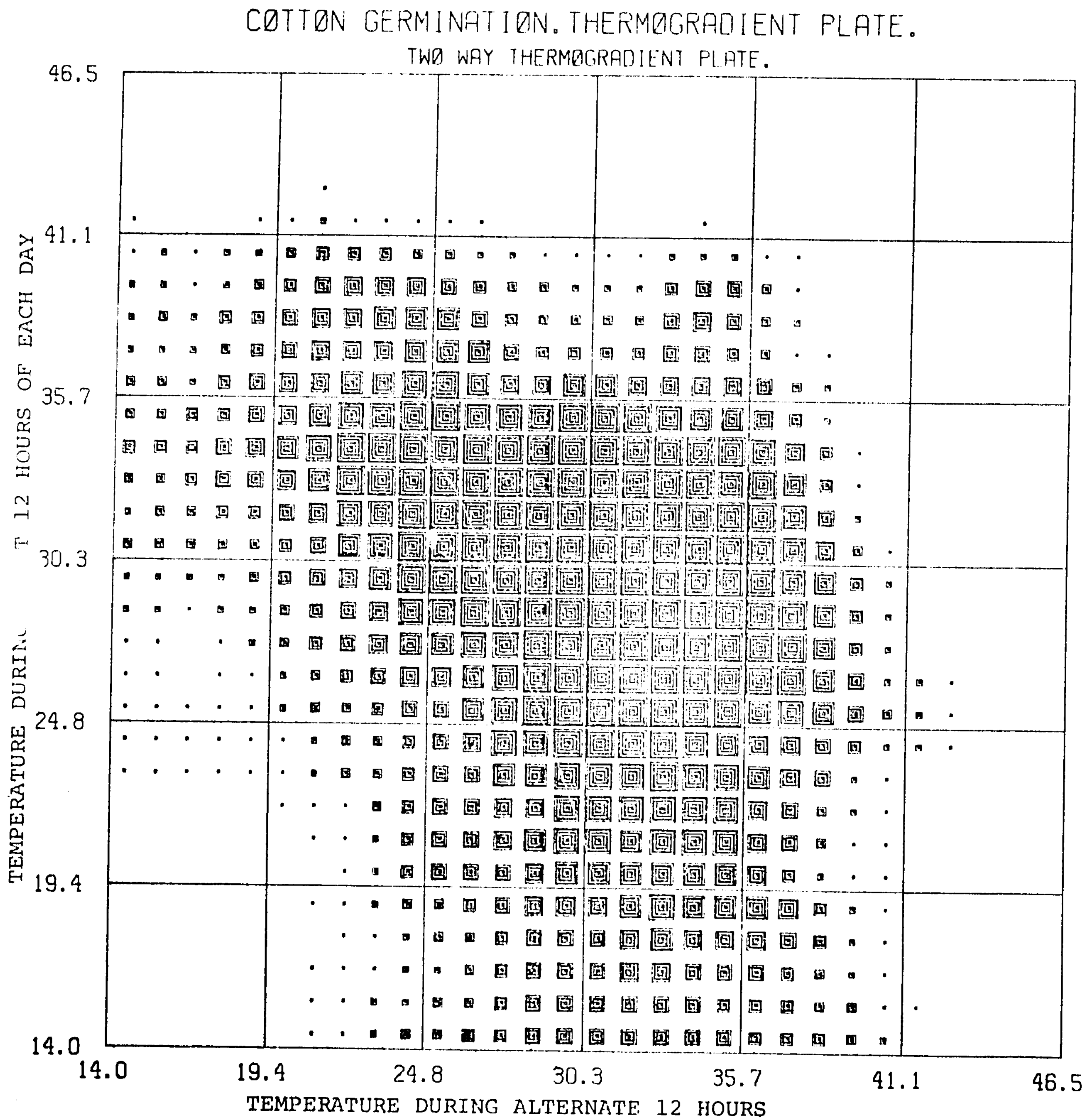

CØTTØN GERMINATIØN. THERMØGRADIENT PLATE.
TWØ WAY THERMØGRADIENT PLATE.
46.5
41.1
35.7
30.3
24.8
19.4
14.0
TEMPERATURE DURING 12 HOURS OF EACH DAY
14.0
19.4
24.8
30.3
35.7
41.1
46.5
TEMPERATURE DURING ALTERNATE 12 HOURS

Figure 1

36.5°C for alternating temperatures. The maximum temperatures at which germination was observed were 38.5 and 42.5°C for constant and alternating temperatures, respectively.

The temperature range of cottonseed germination on a thermogradient plate was wider for alternating than for constant temperatures. A change in temperature within the cordial temperature of cottonseed seem favorable to enhance germination.

B. GREENHOUSE GERMINATION STUDY (STUDY II)

EXPERIMENT 1

The results of Experiment 1 are shown in Figure 2, representing percent emergence as a function of soil moisture and time after planting for each daily soil temperature. Each point represents the average of three replications.

Analysis of variance indicated that significant differences at 99% probability level were found among soil moisture levels for all the temperature treatments on the percent of emergence during the 7-day period. Significant differences at the 95% probability level were found among temperature treatments. When multiple comparison tests were performed it was found that differences in the percent of emergence existed from 60 to 96 hours after planting but not for 144 and 168 hours. As seen from Figure 2 differences in the initial percent of emergence were found at all but 32-42°C for the different moisture treatments, a difference in time of emergence initiation was observed at the lowest and highest daily soil temperature used. At 26-29°C seeds in soil with water tension of 1/3 bar emerged earlier than in the other moisture regimes. In the case of the 31-36°C range ($T_2$) emergence was rapid at all water contents. Emergence was delayed slightly in the 32-42°C temperature range compared to 31-36°C. This delay was more marked in the 32-45°C temperature range within which low water tension resulted in fastest emergence. After approximately 120 hours the percent of emergence among moisture treatments was very similar for all temperatures except 32-45°C. Analysis of variance indicated that significant differences at 1% level were found among the moisture treatments during the 7-day period for temperatures of 32-45°C. Reduced emergence was associated with high moisture tension at the highest temperature, but this relationship was less evident at lower temperatures. At soil temperatures of 32-45°C and moisture tension $M_3$, emergence at 168 hours was 60%. For the same soil moisture $M_3$ and temperature cycles of 26-29°C; 31-36°C and 32-42°C emergence was 90% or higher.

The optimum temperature for cotton emergence was found to be around 36°C. At temperatures up to 42°C the pattern of emergence was found to be very similar for all moisture contents with slower rates of germination at 32-42°C than at

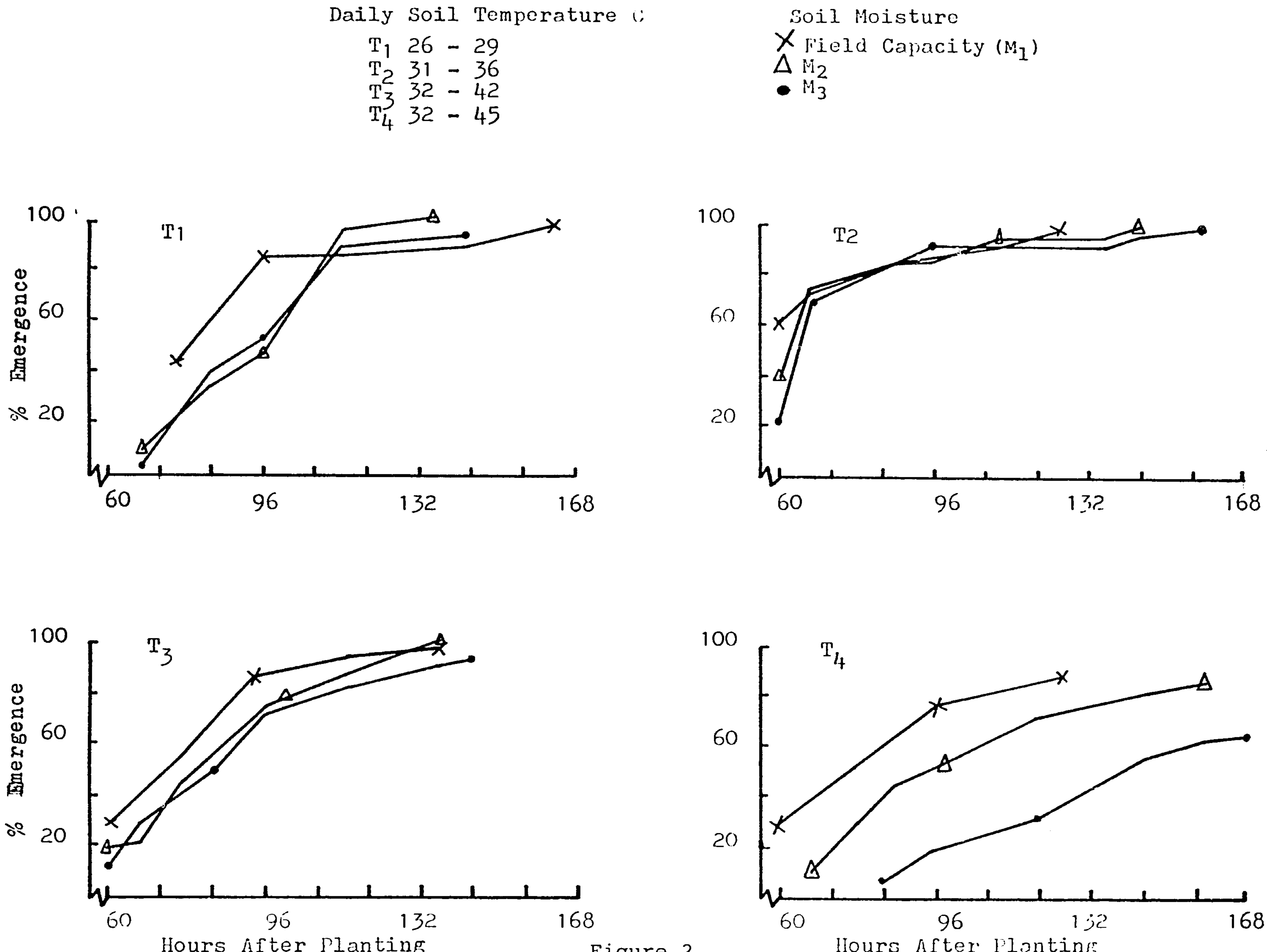

Daily Soil Temperature C
T1 26 - 29
T2 31 - 36
T3 32 - 42
T4 32 - 45
Soil Moisture
Field Capacity (M1)
M2
M3
T1
T2
T3
T4
100
60
20
% Emergence
60
96
132
168
Hours After Planting

Figure 2

temperatures between 31-36$^{o}$C indicating that a slowdown in the rate of emergence can be expected at higher temperatures.

In general, for any given temperature, emergence tended to decrease with increasing soil moisture tension but the differences at the end of the experiment were not statistically significant. The highest temperature caused reductions in germination compared with lower temperature for all three moisture regimes. At the highest temperature the total percent of germination in the field can be expected to vary significantly if differences in soil moisture tension are present. Two to three bars tension will appreciably reduce the rate of germination although the final stand may reach 60%. However, the stands will be further reduced if the moisture tension rises to 3 bars for a few days. Even when water was added after 5 days the rate of germination was not appreciably improved at 32-45$^{o}$C temperatures for $M_3$.

EXPERIMENT 2

It was of interest to know the response of cottonseed emergence for the same daily soil temperature cycle used in Experiment 1 and higher soil water tension values during the 7-day period. The results are given in Figures 3 to 10.

Analysis of variance indicated that the effect of soil temperature, soil water tension and their interactions were highly significant at 1% level for the emergence of cotton at 72, 96, 136 and 168 hours after planting. These analyses and the emergence curves from Figures 3 to 6 suggested that the time for initial germination was longer at the lowest and highest temperature for all moisture treatments. Individual analyses of variance were performed for the four moisture treatments at each temperature. The results indicated that significant differences at 1% level were found among moisture treatments at 32-42$^{o}$C and 32-45$^{o}$C, at 5% level in 26-29$^{o}$C and no differences were found at 31-36$^{o}$C.

Initial germination was faster at 31-36$^{o}$C and 32-42$^{o}$C. In addition, the moisture regime had a larger effect on the initial percentage emergence at 31-36$^{o}$C although final stands were not too different at the temperature ranges of 26-29$^{o}$C and 31-36$^{o}$C.

Moisture conditions had a strong effect on the initial emergence under optimal temperature (31-36$^{o}$C). Good moisture ($M_1$ and $M_2$) resulted in a higher and faster rate of emergence at this temperature than under any other conditions; at this temperature the initial percent of emergence was related to the soil moisture level.

Initial emergence was not greatly effected by temperatures in $T_1$, $T_3$ and $T_4$ treatments, but there was a 12 hour delay in time to first emergence for $M_1$, $M_2$ and $M_3$ at the

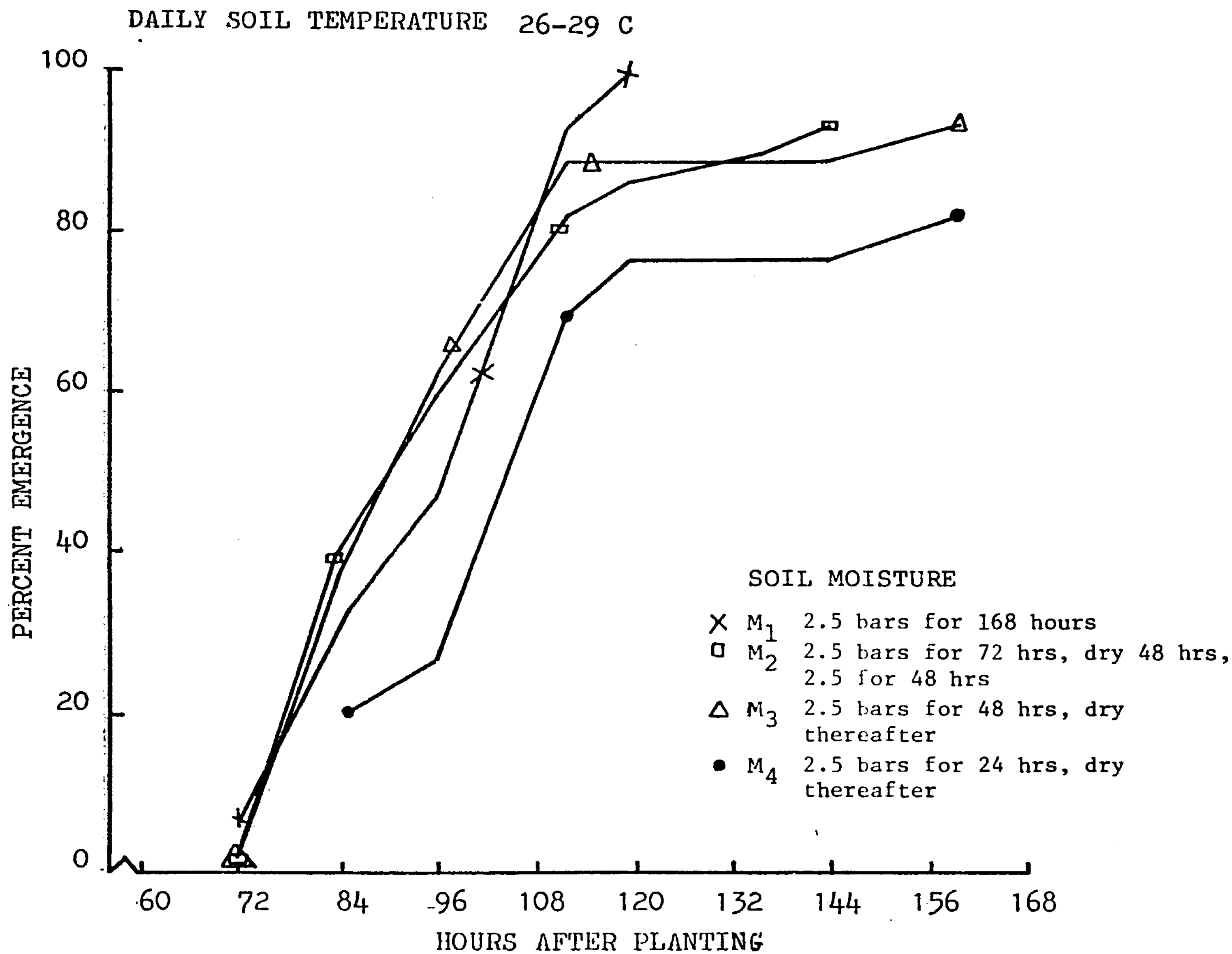

DAILY SOIL TEMPERATURE 26-29 C
PERCENT EMERGENCE
100
80
60
40
20
0
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING
SOIL MOISTURE
M1 2.5 bars for 168 hours
M2 2.5 bars for 72 hrs, dry 48 hrs, 2.5 for 48 hrs
M3 2.5 bars for 48 hrs, dry thereafter
M4 2.5 bars for 24 hrs, dry thereafter

Figure 3

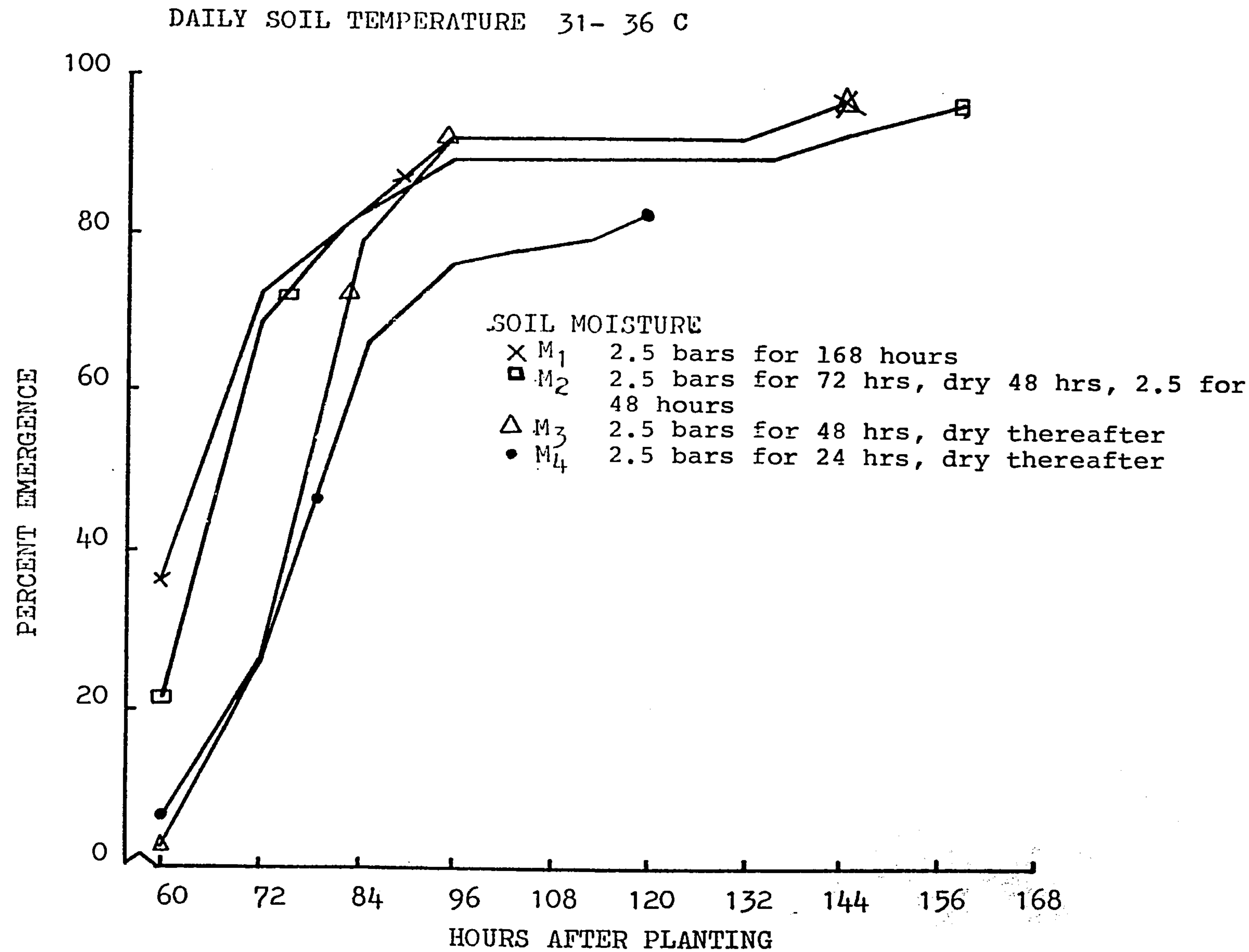
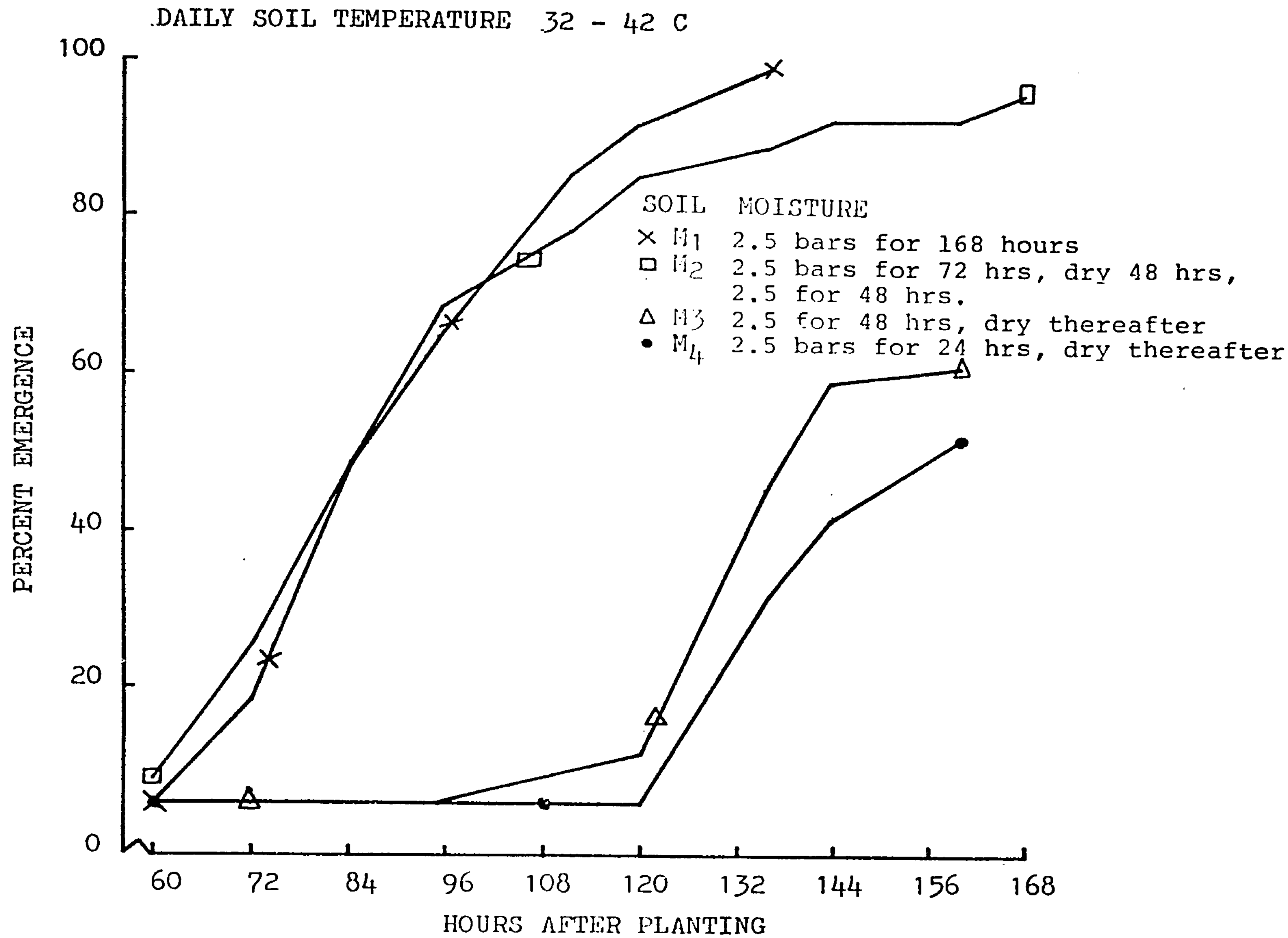
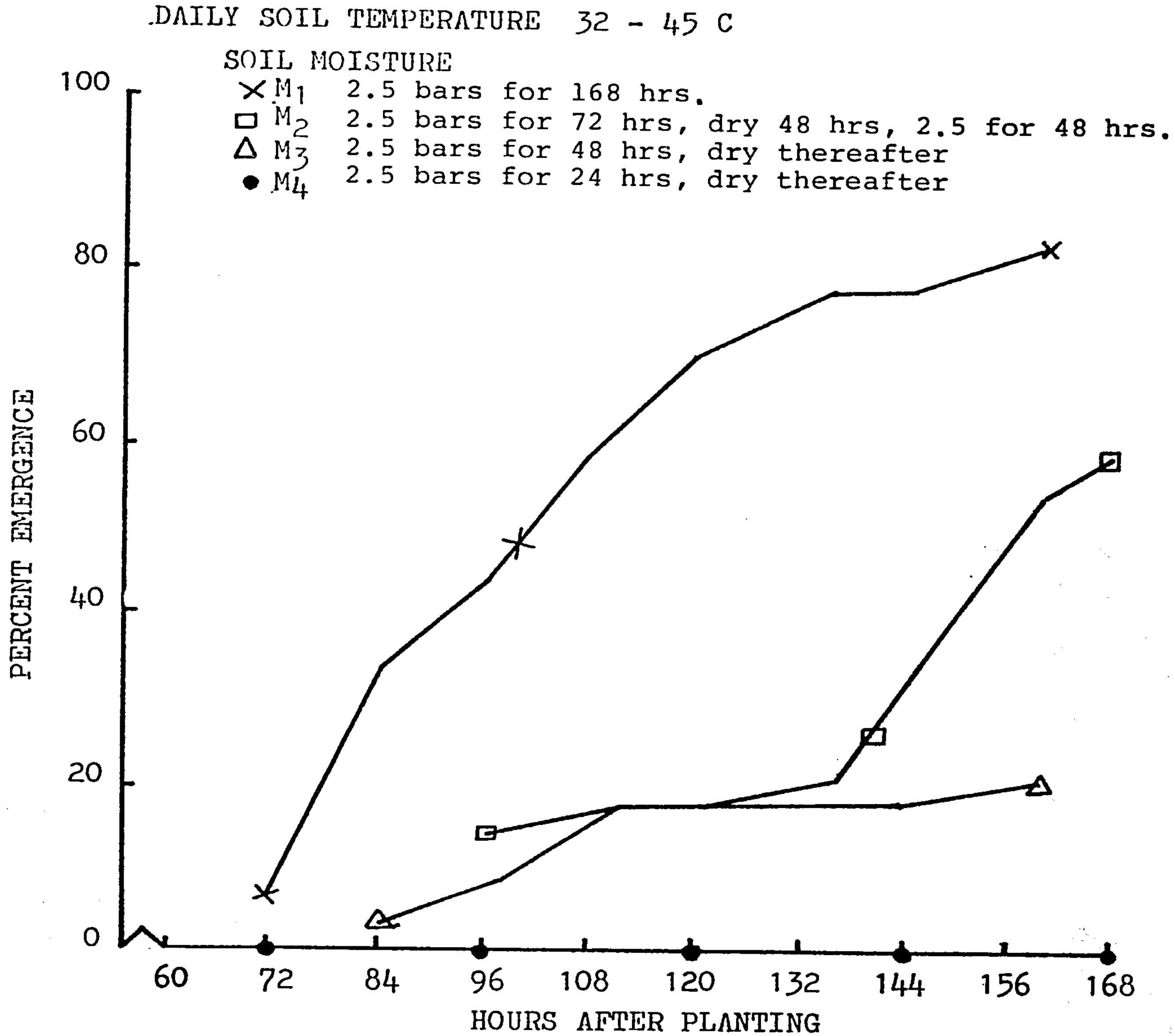

DAILY SOIL TEMPERATURE 31- 36 C
100
80
60
40
20
0
PERCENT EMERGENCE
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING
SOIL MOISTURE
$M_1$ 2.5 bars for 168 hours
$M_2$ 2.5 bars for 72 hrs, dry 48 hrs, 2.5 for 48 hours
$M_3$ 2.5 bars for 48 hrs, dry thereafter
$M_4$ 2.5 bars for 24 hrs, dry thereafter

Figure 4



DAILY SOIL TEMPERATURE 32 - 42 C
PERCENT EMERGENCE
0
20
40
60
80
100
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING
SOIL MOISTURE
M1 2.5 bars for 168 hours
M2 2.5 bars for 72 hrs, dry 48 hrs, 2.5 for 48 hrs.
M3 2.5 for 48 hrs, dry thereafter
M4 2.5 bars for 24 hrs, dry thereafter


Figure 5



DAILY SOIL TEMPERATURE 32 - 45 C
SOIL MOISTURE
M1 2.5 bars for 168 hrs.
M2 2.5 bars for 72 hrs, dry 48 hrs, 2.5 for 48 hrs.
M3 2.5 bars for 48 hrs, dry thereafter
M4 2.5 bars for 24 hrs, dry thereafter
PERCENT EMERGENCE
0
20
40
60
80
100
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING

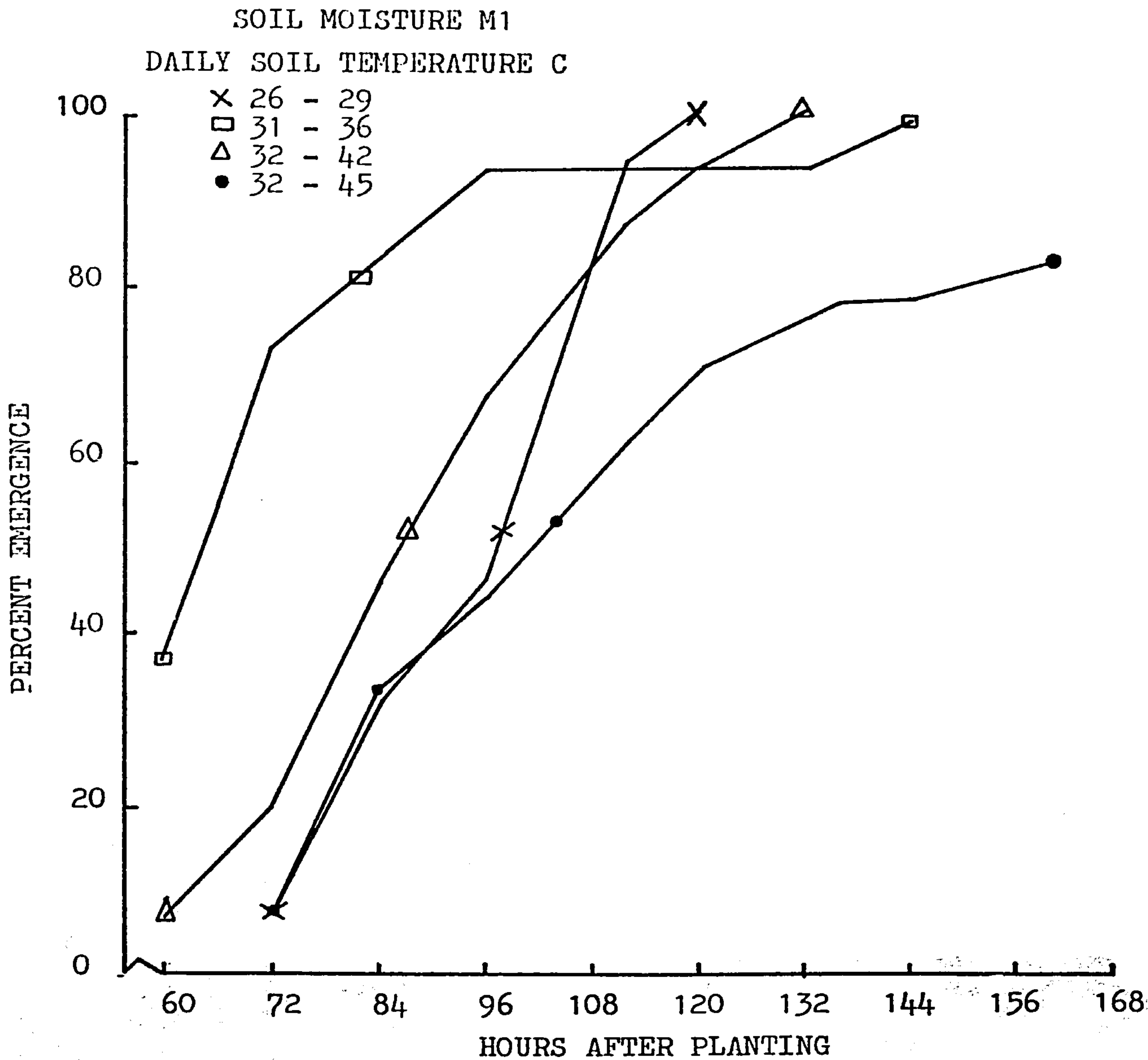

Figure 6

lowest (26-29$^oC$) and $M_1$ at the highest (32-45$^oC$) temperatures, and a 24 or more hour delay for $M_4$ (26-29$^oC$) and $M_3$, $M_2$ (32-45$^oC$).

As temperatures exceeded 40$^oC$ soil moisture tension became a most important factor controlling cottonseed emergence. The greatest moisture stress applied ($M_4$) interfered with the rate of emergence and final stands at all temperatures and the more so at temperatures higher than 40$^oC$. Neither $M_3$ nor $M_4$ permitted more than 20% emergence at temperatures 32-42$^oC$ and 32-45$^oC$, but there was a recovery in germination rate when new moisture was applied after 120 hours in the 32-42$^oC$ temperature range. This moisture was applicated because maximum tension of 8 bars had been reached. The results indicated that 8 bars tension cannot be tolerated during emergence and that timely rain or irrigation within 5 days may still secure a 50% stand of the crop in the 32-42$^oC$ temperature range. At the highest temperature range (32-45$^oC$) the $M_4$ moisture condition failed completely, $M_3$ reached only a final stand of 20%. Even the $M_2$ treatment failed until more water was applied after 5 days. As temperatures rise the moisture condition for emergence becomes more and more critical. This can be seen from Figures 7 to 10, in which the different patterns of germination at each soil moisture tension for the four different soil temperature cycles are shown.

In Figure 7 at the highest moisture content ($M_1$), a difference of about 20% in final germination and more than 48 hours delay in reaching final stand was observed between $T_4$ and the other temperatures, an increase in soil moisture tension to $M_2$ (Figure 8) showed a larger difference in the rate and total emergence between $T_4$ and the other temperatures. As soil moisture tension increased ($M_3$,$M_4$), temperatures higher than 40$^oC$ showed a sharp decrease in rate and percent of germination with a recovery after five days to a value around 55% in the 32-42$^oC$, but recovery did not occur at 32-45$^oC$ as pointed out before.

In general as soil temperature increases above the optimum 31-36$^oC$ range the rate and final emergence of cotton decrease for any moisture treatment, the effects are larger when soil water tensions increase to values of 3 bars or higher. At soil temperature around optimal a good final emergence was achieved, probably because cotton seeds are more tolerant to water stress around optimal soil temperature. Under field conditions any practice that could attenuate the extremely high temperature in soil such as mulching and use of irrigation water and planting deeper can be practiced. Planting during the rainy season and the use of irrigation water at the critical time are recommended. At temperatures around 45$^oC$ a good cotton stand can be obtained only with a good moisture supply to the plants.



SOIL MOISTURE M1
DAILY SOIL TEMPERATURE C
26 - 29
31 - 36
32 - 42
32 - 45
PERCENT EMERGENCE
0
20
40
60
80
100
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING


Figure 7

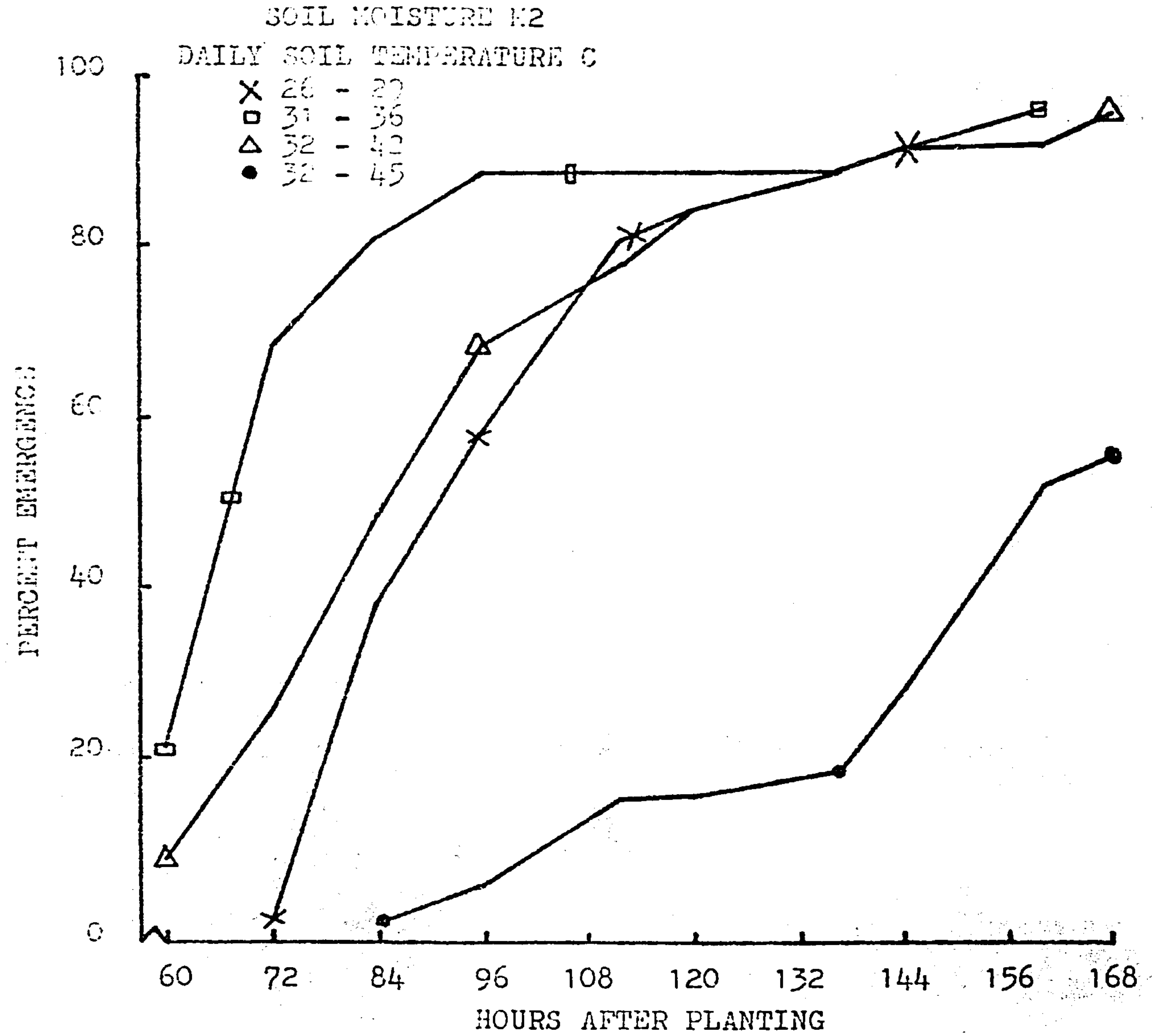
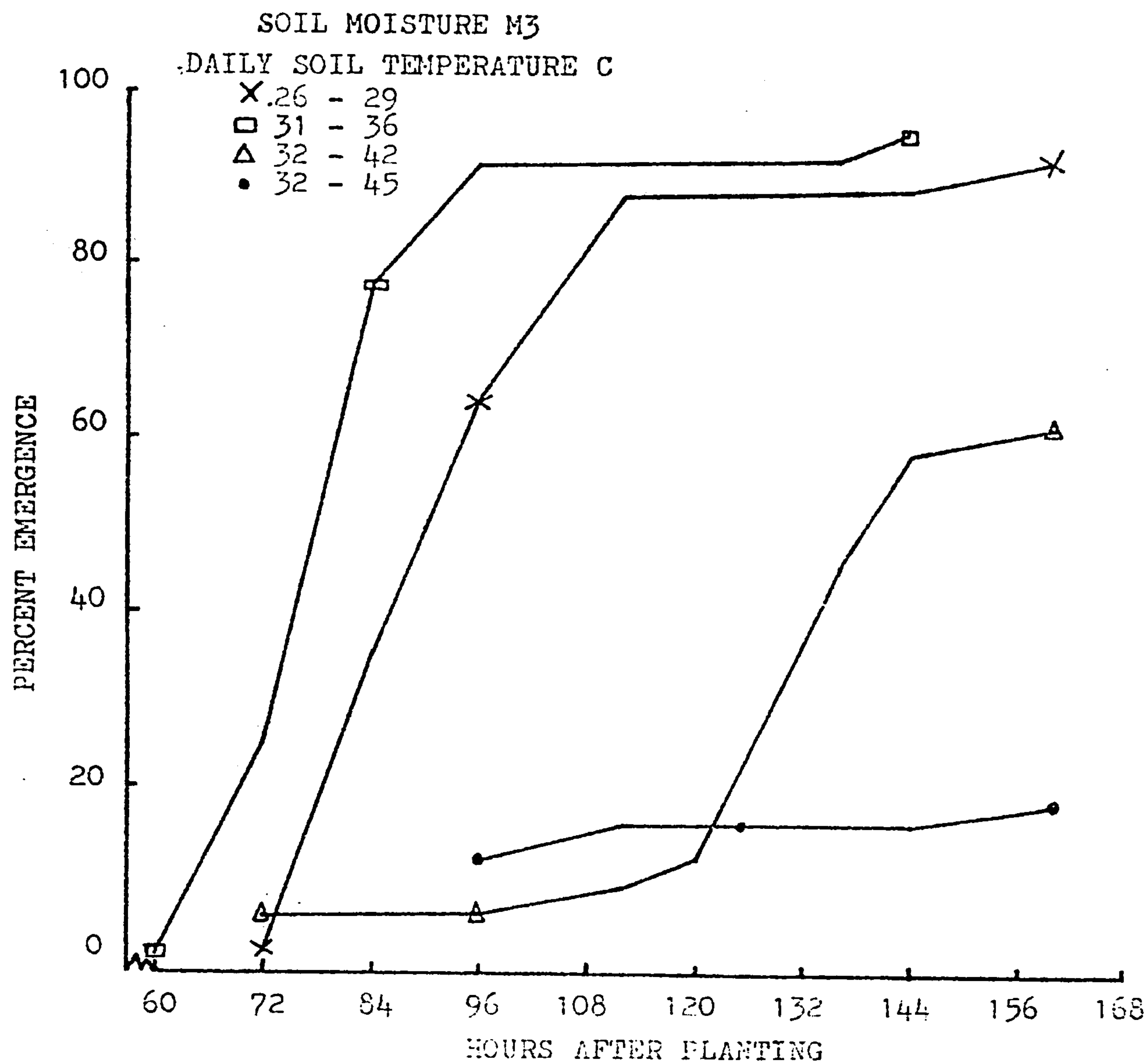
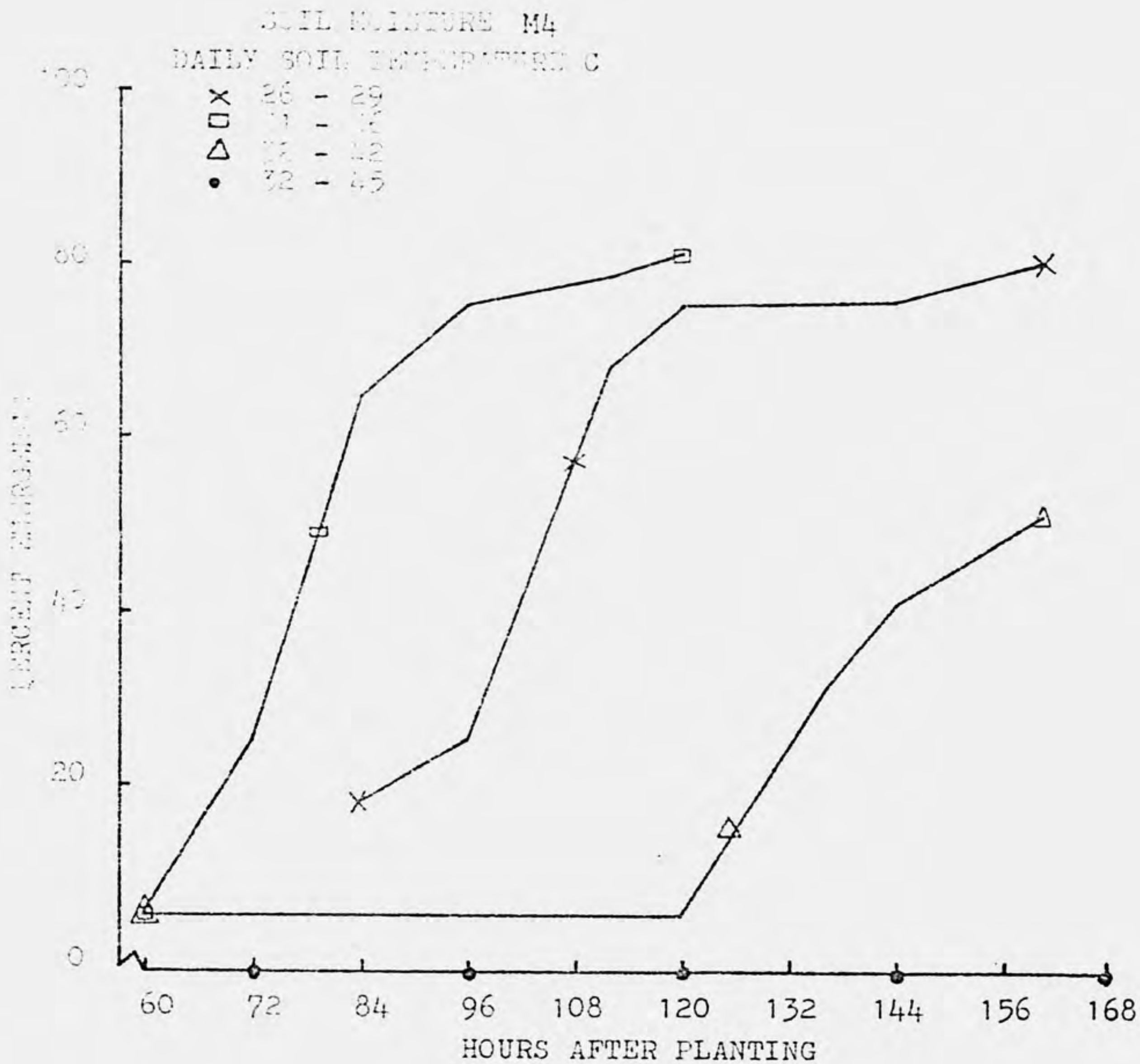

SOIL MOISTURE M2
DAILY SOIL TEMPERATURE C
26 - 29
31 - 36
32 - 42
32 - 45
PERCENT EMERGENCE
100
80
60
40
20
0
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING

Figure 8


SOIL MOISTURE M3
DAILY SOIL TEMPERATURE C
26 - 29
31 - 36
32 - 42
32 - 45
100
80
60
40
20
0
PERCENT EMERGENCE
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING
Figure 9



M4
DAILY
26 - 29
32 - 45
0
20
80
60
72
84
96
108
120
132
144
156
168
HOURS AFTER PLANTING


Figure 10

## IV. SUMMARY

A study was conducted to evaluate the effect of high soil temperatures and high soil moisture tensions on cottonseed (Gossypium sp L.) emergence at the laboratory and greenhouse.

A two-way thermogradient plate was used to evaluate the effect of temperature on germination of cotton. A range of 14 to 46.5°C of constant and alternating temperatures was used. A second study was conducted in the greenhouse to evaluate the effect on emergence of cotton of daily soil temperature cycles which were near the ranges found optimum for emergence in Study I and of soil water tensions ranging from 1/3 up to 8 bars. A Fort Collins clay loam soil was used.

Optimum temperature for germination occurred between 27.5 to 35°C for constant and 24.25 to 36.5°C for alternating temperatures on thermogradient plate. The maximum temperatures at which germination occurred were 38.5 and 42.5°C for constant and alternating temperatures respectively.

Moisture condition had a strong effect on the initial emergence under optimal soil temperature, good moisture resulted in a faster and higher rate of emergence at this temperature (32-36°C) than any other. The time for initial germination was longer at the lowest (26-29°C) and the highest (32-45°C) temperatures for all moisture treatments. At soil water tension between 1/3 and 3 bars and temperature ranges 26-29°C; 32-36°C; and 32-42°C time for initial germination and emergence percent were variable during the first 120 hours among moisture treatments, but no differences were found in the final stand of cotton at the end of the experiments. The effects of high moisture tensions were more evident at the highest temperature cycle (32-45°C) in initial germination rate and final stand on cotton. At soil moisture tension between 2 and 3 bars a total germination of 60% was obtained.

As temperatures exceeded 40°C soil moisture tension became an important factor controlling cotton emergence. The greatest moisture stress applied ($M_4$) reduced the rate of emergence and final stands at all temperatures and more so at temperatures higher than 40°C. At 32-42°C soil temperature, a final stand of 50% was obtained when water was applicated to the soil after 120 hours for the lowest moisture treatments ($M_3$,$M_4$). At 32-45°C a recovery did not occur when water was applicated in the $M_3$ treatment and no germination was obtained at the highest moisture stress ($M_4$). Emergence of cotton is reduced less by soil water stress when temperature is near optimum for emergence.

# APPENDIX 11

## EFFECT OF TILLAGE PRACTICES ON MOISTURE AND NITROGEN STATUS OF SOIL IN DRYLAND WHEAT PRODUCTION

M.A.R. Farooqi, C. J. deMooy, John S. Olsen[1]

### INTRODUCTION

Minimum tillage practices for row crops have gained much ground during recent years because of increasing tillage costs and the need to reduce energy consumption. Nitrogen availability, moisture conservation and management practices are major factors influencing growth and yield of crops.

The dryland agriculture in Pakistan is characterized by cultural practices which lead to excessive loss of moisture and nitrogen in the field, the conservation of which could appreciably increase the yield of wheat per acre.

Relevant work carried out so far includes the study of movement of nitrogen as influenced by varying levels of irrigation (Reddy and Dakshinamurti, 1976; Varga and Sziies, 1977), tillage practices (Meint and Peterson, 1977), attempts toward moisture conservation by means of tillage, and herbicide treatment (Smika and Wicks, 1968), and water conservation with stubble mulch (Greb, et al., 1970).

Studies influencing the moisture and nitrogen status of the soil as a result of various tillage practices in dryland agriculture have received much attention in recent years, and the present research was designed for further study in this area.

### OBJECTIVES

The objectives were as follows:

1. To investigate the possibilities for moisture and nitrogen and energy conservation through minimum tillage practices.

2. To determine the influence of different tillage operations on soil moisture and yield of wheat.

3. To determine the influence of tillage on the movement and vertical distribution of applied N in the soil profile.

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1/Graduate Research Assistant, Professor of Agronomy, Laboratory Assistant, Department of Agronomy, respectively, Colorado State University, Fort Collins, Colorado.

## MATERIALS AND METHODS

One site each under chemical fallow and conventional fallow was selected during the first week of October, 1977, at Otis near Akron in eastern Colorado. Each tillage practice had the following treatments.

1. Chemical fallow
   - A. Stubble left standing
     - (1) Control of weeds by herbicide application.
     - (2) Control of weeds by cultural methods (sweep).
   - B. Stubble layed down
     - (1) Control of weeds by herbicide application.
     - (2) Control of weeds by cultural methods (sweep).

2. Conventional fallow
   - A. Sweep - sweep
   - B. Sweep - disc

The field layout plan with 4 replications is shown in Figures 1 and 2. Moisture and nitrogen samples were taken from 0-5, 5-10, 10-15, 15-20, 20-25, 25-50, 50-75, 75-100, 100-125, 125-150 cm depths. The soil samples were taken before and after snowfall during the 1977-78 season. Also, before sowing of the wheat crop and after the snowmelt in April, 1979 (after emergence of wheat).

The wheat variety Scout was sown in these plots during September 1978. Weed counts were taken at each soil sampling time and observations were recorded on significant growth of weeds, the respective cultural and chemical control measures were taken during June, 1978.

In order to make observations on cropped conditions during 1977-78, another set of fields under both conventional and minimum tillage was selected close to existing conventional and chemical fallow plots. Wheat variety Scout was sown in the fields. The field layout plan with 4 replications is shown in Figures 3 and 4, and data from these plots are given in Table 1 and Figures 5 and 6.

## RESULTS AND DISCUSSION

Moisture and nitrogen analysis of the soil samples taken up to April 1978 have been completed. It is evident from Figures 5 and 6, the percent moisture stored in the soil was higher under minimum tillage conditions and wheat grain yield was 5.1 bu/acre higher (Table 1) than with conventional tillage, due to increased moisture conservation.

Under fallow conditions, it was observed that standing straw treatments in both the chemical and conventional fallow conditions conserved more moisture in the soil compared with straw layed treatments. The same trend continued until the time of sowing of wheat in September, 1978.

Selection of site - Oct. 1977
Sweep treatment - Oct. 1977
Sweep and Disc treatment - June 1978
Sowing of wheat (Stout Var.) - Sept. 1978

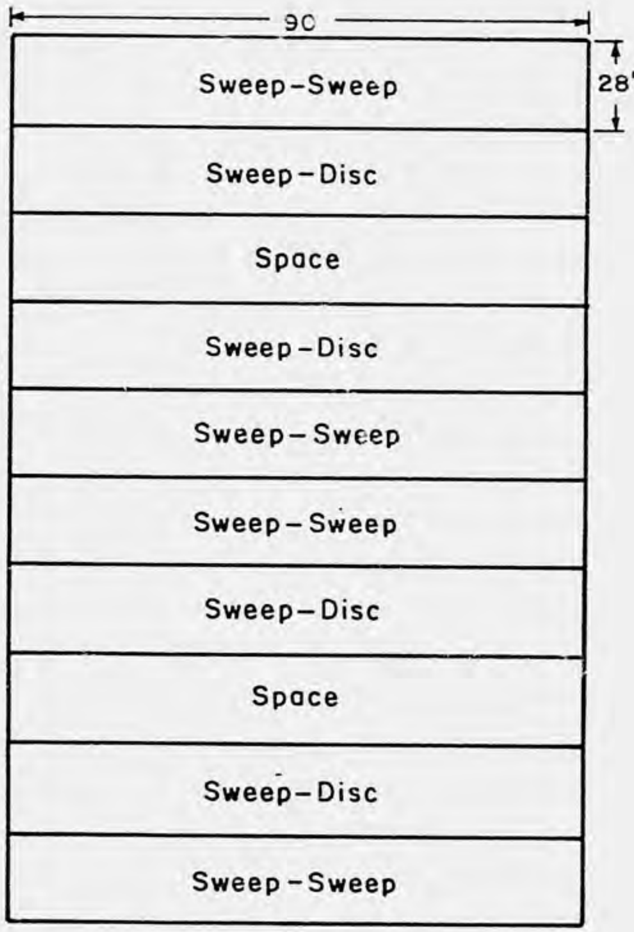


Figure 1. Conventional fallow wheat.


Selection of site - Oct. 1977
Straw layed - April 1978
Emergence of weeds and its control - June 1978
Sowing of wheat (Stout Var.) - Sept. 1978

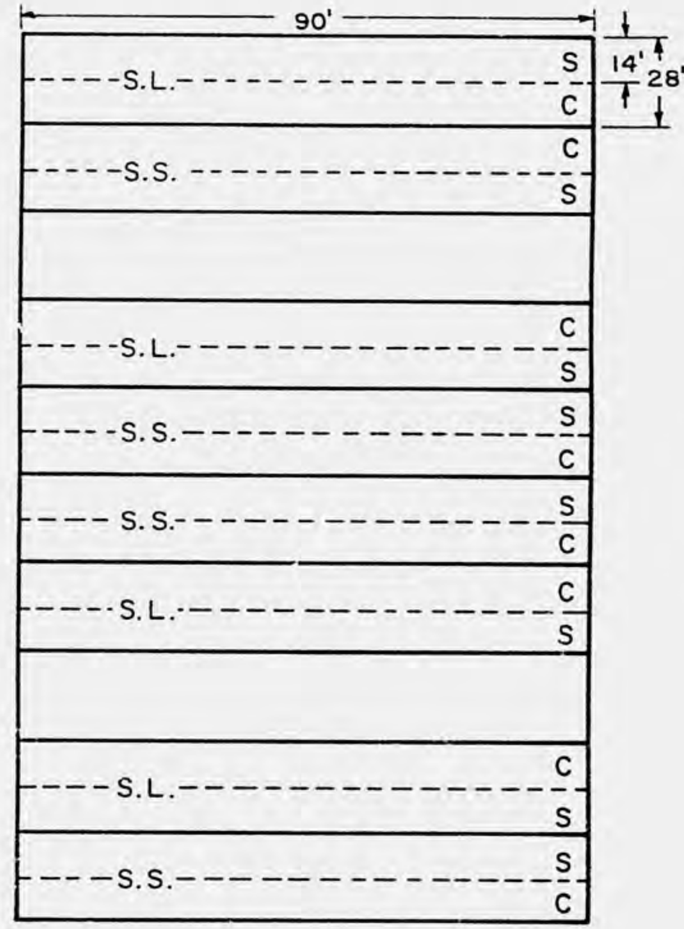


Figure 2. Chemical fallow wheat.

S.L. - Straw Layed
S.S. - Straw Standing
C - Herbicide application on emergence of weeds
S - Sweep on emergence of weed

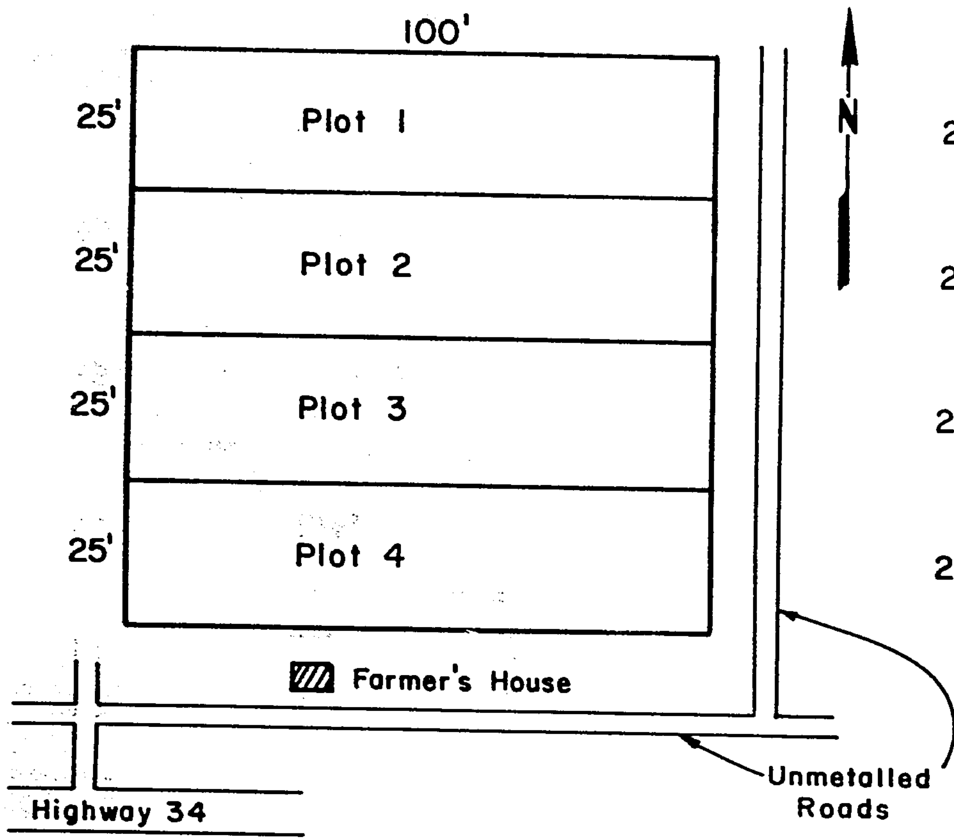


Figure 3. Layout plan. Minimum of tillage wheat experiment. Wheat fall 1977-78

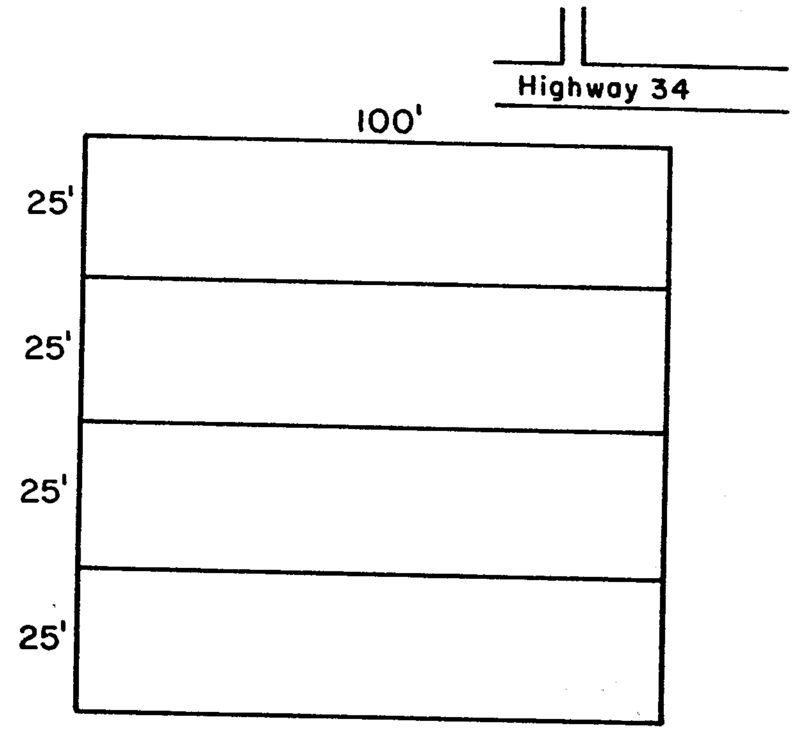


Figure 4. Layout plan of conventional tillage wheat experiment. Wheat fall 1977-78.

Table 1. Wheat (variety Scout) yield as affected by minimum and conventional tillage conditions at Akron.

| Replication No.[1] | Grain yield in bushels/acre[2] | |
|---|---|---|
| | Minimum tillage | Conventional tillage |
| 1 | 28.0 | 20.2 |
| 2 | 24.0 | 18.7 |
| 3 | 22.5 | 18.2 |
| 4 | 24.0 | 19.5 |
| Average | 24.6 | 19.5 |

1/Average of three harvested plots of size 300 sq. ft. each.
2/One bushel weight taken as 55 lbs.

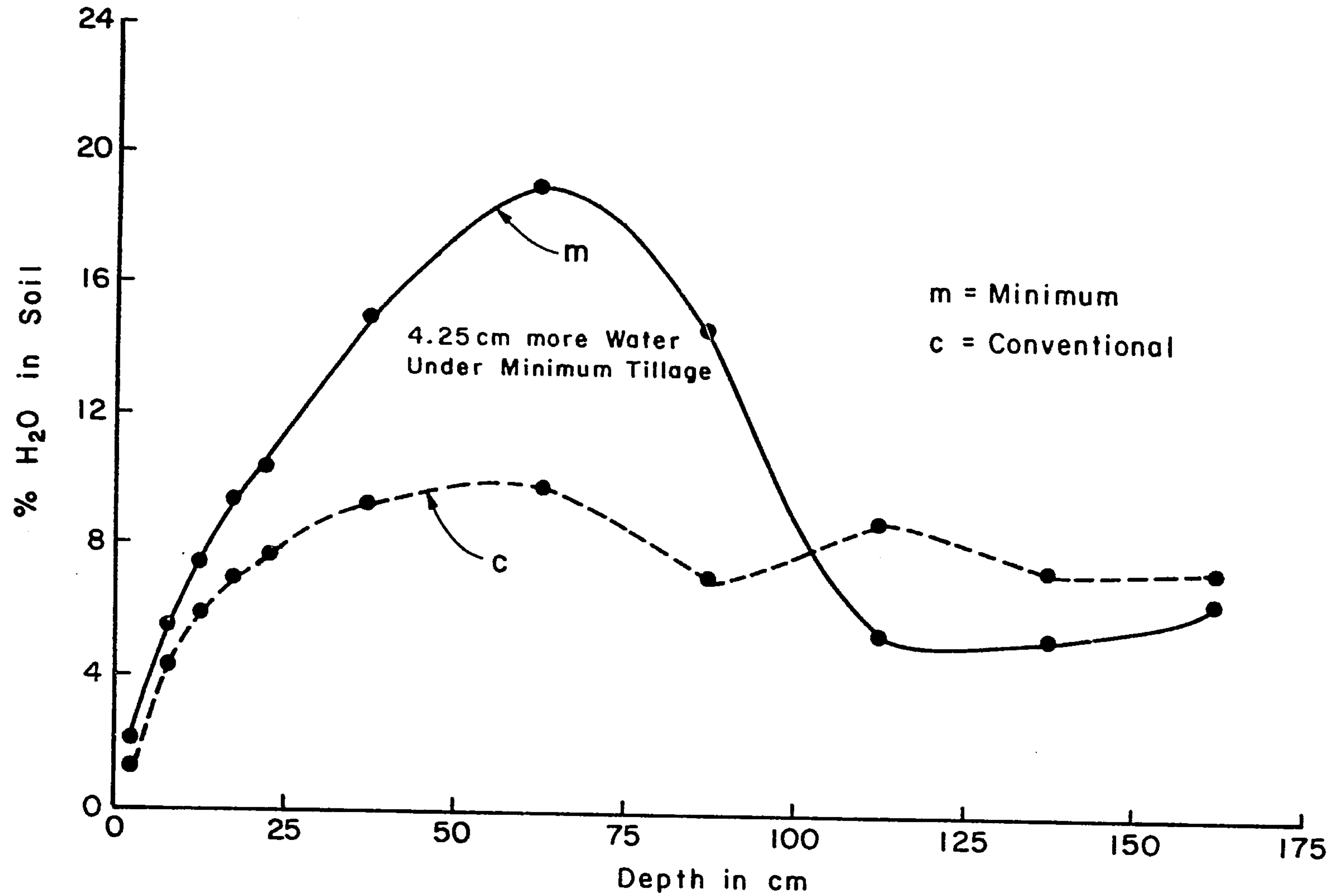


Figure 5. Percent $H_2O$. Minimum vs. conventional tillage after snowmelt. Sampling Date April 29, 1978.

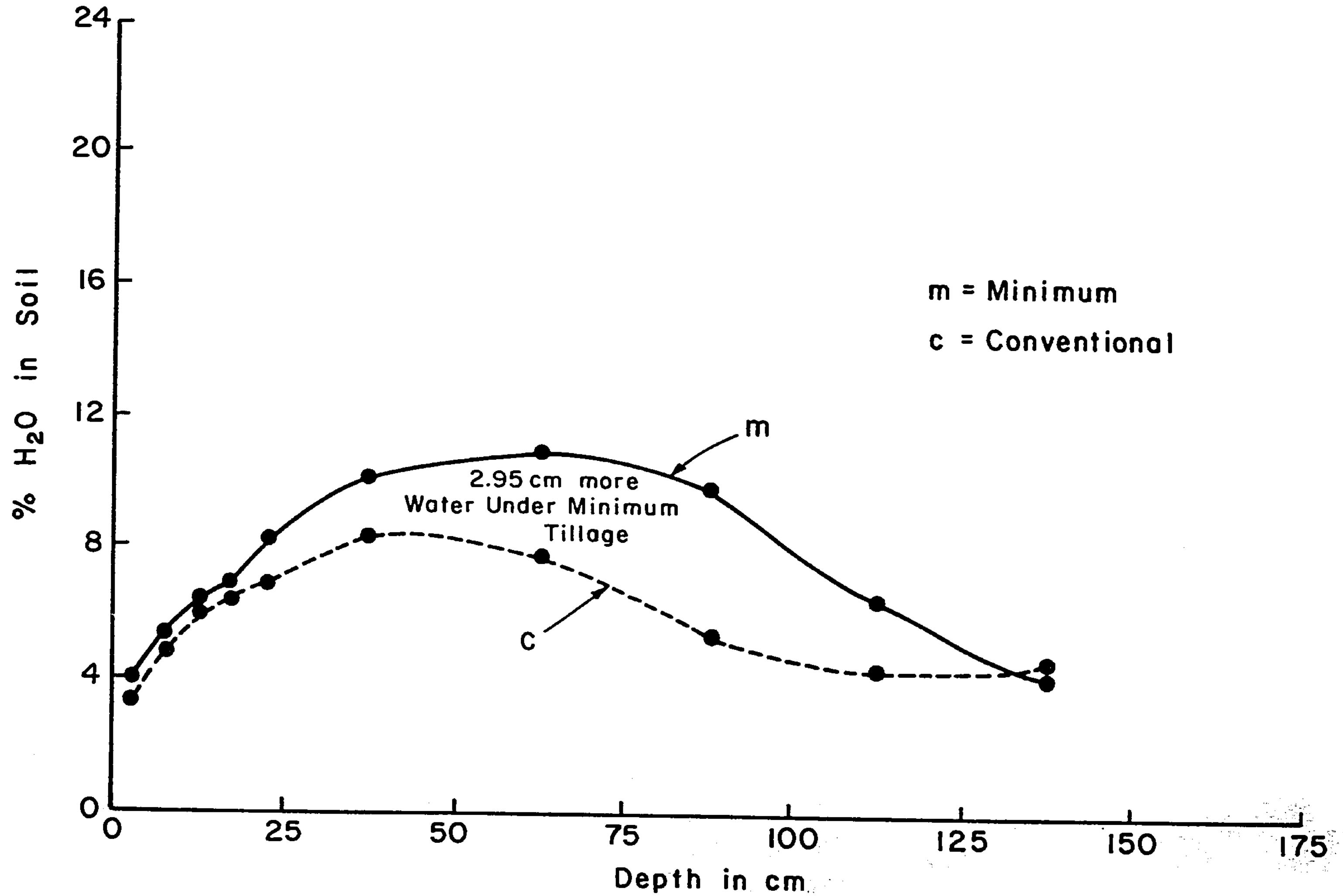


Figure 6. Percent H2O. Minimum vs. conventional tillage at harvesting. Sampleing date July 19, 1978.

## GENERAL CONCLUSIONS

The pivotal problem of dryland agriculture in Pakistan is the conservation of soil moisture which is the single most important factor in increasing the yields from the present very low levels. The present study which is aimed at studying the tillage and moisture conservation practices would help a great deal in solving the problem of dryland agriculture in Pakistan.

Minimum tillage and moisture conservation practices being tested appear to be more effective in conserving moisture in soil than those used by the farmers in the dryland areas of Pakistan. This data may provide evidence to recommend reduction in the amount of plowing currently done during the fallow period, and to adopt other moisture conservation practices such as controlling of weeds and keeping of some straw in the field, etc. The adoption of minimum tillage practices could lead to continuous economization of fossil fuel as there is an increasing trend to tractor cultivation in Pakistan.

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# APPENDIX 12

## BULLOCK-DRAWN GROUNDNUT HARVESTER

N. Illsley, A. Cheema, and L. Ulsaker[1]

Pakistan has approximately 40,000 ha annually planted in groundnuts, producing 56,000 mds of nuts. Virtually all of this crop is harvested by hand. The harvest season extends from mid-November to the end of December. As is typical of many crops in Pakistan, there is a shortage of labor during the harvest season. This labor shortage works a hardship on the farmers in two ways; first, it artifically inflates wages for harvest labor and second it extends the harvest time into the season when the farmers should be preparing the fields for the following crop, thereby jeopardizing the quality of that crop. An improvement in the harvesting methods of nuts would be of real value to the farmers concerned.

The present method of harvesting is to loosen the individual plants with a "kussi" or hoe like tool. In the locality studied it takes three to five strokes around the perimeter of the plant to loosen the soil throughout the plant area. Then the plant is lifted out of the ground by hand and the soil shaken off. The plants are then piled in small stacks to await hand removel of the nuts from the vines. It requires approximately ten seconds of steady working time to loosen a plant in light sandy soil.[2] This does not include rest stops.

If the plants can be loosened from the ground mechanically, thus eliminating the kussi work, and then stored for later removal of the nuts, this will free the land for immediate cultivation and also delay the nut removal operation until a more slack labor season.

Harvesting machines should be developed for both tractor power and for bullock power. Machines do exist in other parts of the world[3] but for various reasons, none of these designs have been successful in Pakistan.

At least three versions of animal drawn groundnut harvesters, based on designs borrowed from other countries, have been tried but not adopted. Their faults include being too heavy, too narrow, too difficult to control, fouling with trash, and requiring too much draft.

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1/Agricultural Engineers, Water Management Research Project, Colorado State University, Agronomist, Experience Inc. Baranni Project.

2/By contrast the harvester lifted one plant per second in a broadcast planted field with a density of between 6 and 10 plants per square meter.

3/Intermediate Technology Development Group, 9 King St. London WC2E 8 HN England.

Aside from avoiding these faults, a successful machine must be able to:

1. hold a cutting depth of 4 to 6 cm, enough to pass under the nuts

2. break up the soil so that the plant may be easily removed

3. cut any deeper roots, such as the tap root, and leave them in the ground

4. to be fabricated in the typical village shops with simple tools and available materials

5. be purchased by the farmer without financial strain

6. be portable enough to be carried to and from fields as easily as a desi plow.

DESIGN

It is not presumed that the design developed in this instance will be the ideal answer for ground nut harvesting elsewhere, just as other designs have not been the answer here. Therefore, to be of greater value to others involved in a similar search, all of the modifications tried will be discussed and their performance commented on.

To minimize draft the blade of the harvester is swept back to a $45^{o}$ angle giving the blade a slicing action in the soil rather than shearing. Therefore, a 55 cm blade is needed to harvest a 40 cm swath which was felt to be a minimum workable width. This was double the width of the harvester that was found to be too narrow.

The swept back angle of the blade causes a side draft which is controlled by using a land side similar to moldboard plows. The land side is 8 cm high by 25 cm long before it tapers down to the point of the blade.

In general appearance the harvester resembles a moldboard plow with the upper portion of the board cut away. The cutting edge of the blade is sharpened from the bottom side so that it enters the soil at an inclined angle of about $5^{o}$. The blade is curved upward to give the soil about 5 cm of lift to fracture the soil and raise the nuts above ground level. The radius of this curviture is about 25 cm. Too short a radius was found to compress the soil too much, which prevented the blade from scouring cleanly. The point of the blade is forged downward to give the implement about 1 cm bottom suck for good penetration. Although the original design was conceived as an attachment to go on existing desi plows, the final models use

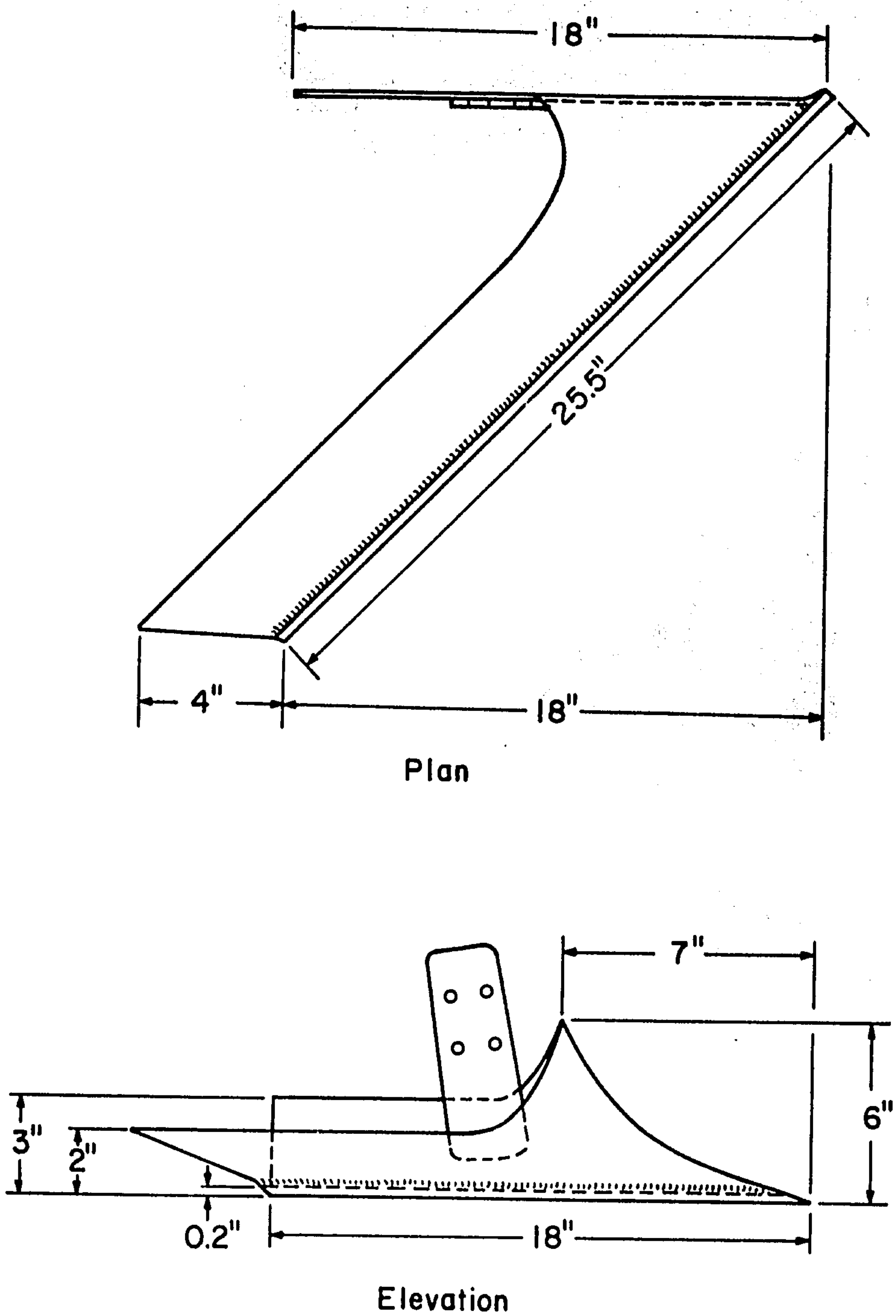


Figure 1. Bullock drawn groundnut harvester.

a shank that bolts directly to a beam. This shank is made of ½" x 4" plate that is sharpened on the leading edge. It is welded to the land side immediately behind the blade and extends up 25 cm. With the beam bolted on the shank there is 15 cm clearance between the beam and blade.

Though it was not felt essential, the final models had a spring steel cutting edge welded onto the blade to give a stronger, longer wearing, sharp cutting edge. A lip is forged on the top side of the blade and the spring steel (used Volkswagen front suspension spring) is welded on using 2.5 cm weldments at 6 cm intervals both top and bottom. There was some concern that the weld joint would cause roughness on the top of the blade on which soil would cling and prevent clean scouring of the blade. By grinding the welds slightly, they were smooth enough that this is not a problem.

All cutting edges are sharpened partly to cut through trash and partly to reduce draft. All sliding surfaces are ground to remove any rough welds, slag from cutting, and black scale or rust, all of which would cause drag and increase draft. The finished harvester ready for bolting onto a beam weighed 7.25 kg.

## FIELD TESTING

The field testing looked at three factors. First, would the harvester lift the groundnut plants and leave them sufficiently loose in the soil that they could be hand lifted as easily as by the traditional kussi method? Second, was the draft requirement low enough that a team of bullocks could pull it for a reasonable length of time without tiring,[4] and thirdly, would the farmers recognize any advantages in using the harvester?

The final version of the harvester, while operating at a depth of 10 cm lifted the soil about 5 cm and simply allowed it to fall off the back of the blade for breakup. In the process the soil was moved forward with the harvester about 15 cm. These figures are visual estimates as there was no available means of making more precise measurements. There was virtually no side movement of the soil as might have been expected from the angle of the blade. The shank left a small furrow comparable to that of a grain drill, and smaller than that left by the desi plow.

Draft tests were made using a small four wheel tractor with three point hitch. A special adapter was fabricated for hitching a bullock implement to the tractor together with a dial spring scale for measuring draft. The draft of a desi plow was used for a bench mark and then the draft of the final model was

4/Bullocks weighing 500-900 kg can deliver 60-80 kg draft according to Hopfem, FAO Ag. Dev. Paper, p. 91, Rome, 1969.

compared with two other versions of groundnut harvesters. The results of these tests are shown in Table 1. There was no recording device on the meter. Instead, the needle was watched for at least two 30 minute trials and the normal maximum and minimum readings were noted. There were definite values that were frequently reached but seldom exceeded. These were the readings used.

With one model in the field, and being used for perhaps half of one season, no conclusive statement can be made about the farmer acceptance of the machine. However, when that model was sought for testing, the farmers who were using it made it very clear that they did not wish to give it up until their harvest was completed. Instead of using this model for the draft tests, an additional model similar to it was made and tested.

It is expected that after these farmers have operated the harvester for this initial season, they will have suggestions that will contribute in making a more refined machine.

DEVELOPMENT

The first version was made as an attachment for desi plows. To fit it on a plow a four-sided cone was made under the mold-board beside the landside. This cone had two ½" set screws, one on top and one opposite the land side, that could be tightened down to clamp the harvester to the wooden hull of the plow. In this way it would fit on different plows provided they were of a similar design. However, it was found that even in one village the variation in plows was so great that there would be at least some plows that would not fit. Further, when making the first field tests, several farmers said that there was no real advantage in making it as an attachment, but rather make a steel shank that could be fitted directly on a beam. They felt the cost of the additional beam would not be too much for the average farmer. The original version also used more of a moldboard to roll the plants and soil to the righthand side of the beam of the plow. In fields that were broadcast rather than planted in rows, occasional plants would balance on the front of the beam due to its width, and not pass to the righthand side. This would quickly gather more plants and clog the harvester so that it had to be cleared by hand. To remedy this, one tine about 45 cm long was welded midway up the shin of the moldboard and curved to the right. This helped but did not eliminate the problem. A piece of angle iron with three tines from 50 cm to 25 cm in length was mounted on the beam well forward to the moldboard again with the tines curved to the right. This still did not solve the problem and threatened to strike the hooves of the bullocks. A coulter, either knife type or rolling disc was considered but not tried, mainly because the next version with the narrow steel shank did not have the clogging problems.

Table 1. Draft for bullock implements

| | Minimum Lbs. | Kg | Maximum Lbs.* | Kg |
|---|---|---|---|---|
| CSU Harvester | 20 | 9 | 35 | 16 |
| Irri Harvester | 30 | 14 | 50 | 23 |
| Barani Harvester | 25 | 11 | 35 | 16 |
| Desi Plow | 20 | 9 | 35 | 16 |

*Draft readings in tilled loam soil at Agricultural Research Farm, Muree Rd., Rawalpindi taken after November plowing, 1978.

The original version also had a moldboard that gave the soil about a 15 cm lift and then used 1 cm diameter steel rods, 15 cm long spaced 6 cm apart to lift the plants further and allow the soil to fall through the spaces. This system moved the average plant foward about one meter and carried a roll of soil about 20 cm high in front of it. This obviously took more energy than was needed for simply lifting the plants. The farmer using the harvester commented that there would be no need for plowing for the following crop after using this for harvesting! To reduce the bulldozing effect, the rods were removed and 10 cm "V" notches were cut in the moldboard in their place. The teeth between the notches were bent down to the horizontal position so that the entire lift was reduced to 8 cm. Even the flat teeth tended to carry too much soil and so were removed leaving only a narrow blade with an 8 cm lift resembling a long conventional plow share with a very short moldboard. This still had a tendency to collect trash on the shin and at the suggestion of one of the farmers most of the moldboard was removed, leaving the share and a portion of a shin. This, together with the shank mount and the spring steel edge on the share was the version left with the farmers for their testing.

# APPENDIX 13

## A REPORT ON THE PRECISION LAND LEVELING AND WATER MANAGEMENT PROJECT IN THE N. W. F. P.

by
W. D. Kemper[1]

### Analysis

The primary objectives of the On-Farm Water Management Program as I perceive these are:

1. To help farmers improve their water management and crop production.

2. To involve them in the improvement process in a manner such that the farmers consider the project to be their own rather than another government give-away program.

3. To help farmers identify and understand their specific problems so that they are self motivated to undertake the work and investment to solve those problems.

4. To use the physical results of the improvement program and the enthusiasm of successful, involved farmers to demonstrate the benefits of the program and motivate other farmers to improve their water management practices.

While some farmers have apparently become sufficiently enthused about land leveling to participate in this program there is little evidence that farmers who have participated in a watercourse improvement program have the enthusiasm to motivate their neighbors to do likewise. The farmer contacted (a tenant) did not seem to feel that the watercourse improvement had made a substantial contribution to solution of their overall problem of short water supply. Apparently their major problems lay in inadequate diversions from the river and over use of water between the diversion and their watercourse by farmers in the upper reaches of this channel. These are long standing basic problems which were not addressed by the improvement program. There is question as to whether they can be solved and the present program may not be sufficiently flexible or adequately developed to address these basic problems.

Several possible solutions come to mind such as:

1. pakka free flow division structures which could be designed to give each group of users its fair share of the water.

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[1]Agricultural Engineer, Colorado State University, Fort Collins, Colorado.

2. a separate deep watercourse traversing the area between the diversion and the improved command area which would make stealing of their water more difficult.

3. assistance to the farmers in the form of guidelines, effective structures, etc., for improving the katcha diversion so there would be adequate water for all concerned.

4. formation of water users association with an executive committee consisting of representatives from each area served which would resolve water allocation problems, with the technical assistance of OFWM personnel and possibly the authorities of tribal councils or civil authorities.

These or other alternatives could probably solve the basic problems for the farmers on this watercourse. However, their implementation would require some inputs which are not currently available or might not be approved as reimbursable under the present program. For instance, neither the OFWMP, SCS or CSU has guidelines or designs for structures to improve the diversion, which have been tested under the conditions involved. It is possible, but not highly probable that the Irrigation Department has been involved in helping some farmers build better semi-katcha diversions. A survey should be conducted to determine how many of these katcha diversions exist, whether their construction and maintenance is a major problem for the farmers and one on which they desire help. If this is a major problem to them, the OFWMP, SCS, CSU, the Irrigation Department and possibly WAPDA should review their experience and available literature to develop some of the most promising approaches such as:

1. low profile gabion dams (which are basically rocks held in place by wire net and are highly labor intensive).

2. low level permanent framework across the channel from which boards, poles or brush could be removed prior to flood periods (or automatically by the floods).

3. well anchored cable(s), across the small river which could be used as support for upright poles providing the framework for the diversion during low flow and which would have release, or break away provision on one side of the rivér when flood pressures rose.

However, since the probability of failure of such semi-katcha structures on a river is high, the initial trials should be clearly labeled as experimental and participating farmers should be carefully informed that there are no guarantees of success.

Moreover careful consideration should be given to their suggestions for improvement of the diversions because they are the most experienced people available regarding the river.

Considerable need was indicated by OFWM staff for extended lining of some watercourses in areas where coarse textures of the soils are allowing large losses of water. In view of the high cost of cement and its vital role in many other development programs of the country, other methods for reducing loss from these watercourses should be evaluated in the field. For instance recent work at the CSU porous media lab. (i.e., see Akram and Kemper, 1978) indicates that infiltration rates of sandy loams and loamy sands can be reduced to surprisingly low levels by compaction when the compaction is carried out at the proper water content. This reduced infiltration rate was persistent if freezing and thawing was not encountered. Possibilities of sealing watercourses in sandy areas with fine sediment, even if such sediment has to be hauled in from adjacent areas and mixed with the irrigation supply, should also be evaluated at the sites where such treatments might be used in cooperation with farmers. The involvement of the farmers in such "research activities" is necessary because they must be convinced that such labor intensive activities are worth the investment. Once they are convinced, they become the best salesmen of such programs to neighboring or visiting farmers.

The research activities which could be considered include determination of the effect of operating level in a watercourse on the rate of loss. Lower average rates of loss in the NWFP and Baluchistan are correlated with operating levels of this apparent relationship, the low operating levels appear to be a result of greater slope, less ponding when water is checked back up to levels needed to feed the field and consequently greater acceptance by the farmer; rather than a conscious design criteria. Several sections of watercourses were observed where the operating level of the water was higher than it needed to be and substantial leakage was observed. Careful elucidation and demonstration of this factor would provide substantial basis for "low level" designs which could save significant amounts of valuable water.

Check structures which can raise the water level up to the required heights from such low level watercourses need to be designed and evaluated for ease of operation and possibly for portability and community use of the closure. If only the main channel is deepened and its slope is appreciable, side branches can be designed so that water will only flow into them when the level in the main branch is checked up. This can eliminate the need for a pakka closure on the outlet from the main channel into the branch. If only one farmer, or a compatible group of farmers, uses the branch, the closure of the check structure can be made portable so the farmer (or farmers) authorized to use that branch and check structure can take it home for safe keeping and to remove the chance of its use by persons who might wish to take water from the watercourse which does not belong to them.

If a highly cooperative group of water users were found, the possibilities of using a single closure on a series of check structures at successive branches could be considered, because normally only one of these checks would be in operation. Such sharing, and consequent reduction in number of closures needed, could allow the fabrication and use of light weight relatively high cost closures (e.g., fiber glass, PVC, etc.) which might avoid some of the persisting chipping of concrete closures which causes increasing leakage with time.

If a competent pakka structure maker is not available in the NWFP a nakka maker who is providing a good product in the Punjab should be convinced to set up a partnership with an NWFP manufacturer because nakka improvement to fill specific needs is accelerated by having an innovative nearby manufacturer who can come to the site, observe the problem and participate with the farmer and the technician in its solution.

Unleveled lands are causing uneven applications of water and in many cases are a major factor in keeping water tables high and dissipating limited water supplies. While some of the owners with extensive holdings are convinced and are participating in the land leveling program more of the farmers with smaller holdings could be encouraged to participate in this program if demonstrations on the fields of their neighbors could be arranged.

Such demonstrations could be arranged on fields which are presently not level, but have relatively uniform grades. The cooperating farmer would be asked to allow monitoring of his normal irrigation practice on such fields for one season; and to harvest his crops by strips which would be defined between elevation contours on his fields, and to allow the research team to help him measure stands and yields in these strips. This would provide functional relationships between amounts of water applied and crop yields and could demonstrate this to the farmer and his neighbors. Subsequent leveling and advice to the farmer on how to apply the amount of water which was found to maximize his yield could demonstrate the benefits of leveling and water control.

In extensive areas, monsoon flooding and lack of surface drainage were given as reasons for the poor maize crops observed. In such areas the benefits of planting on beds or ridges and of draining excess water from maize to drains or rice fields could be demonstrated on the fields described above. The graded furrow trials at Pir Sabak Station should be followed and their feasibility for helping farmers solve some of their problems should be evaluated, by taking some of the farmers to see the graded furrows and discussing their pros, cons and possibilities for their adoption to the farmers needs and resources.

## Recommendations

### For Research

There was not time on this brief tour to develop an information base to make specific recommendations for research activities with certainty that they will provide solutions to the farmer's problems. Consequently the following general approach is recommended which will bring together the personnel and resources to help farmers identify their potentials for improvement and develop programs for attaining those potentials.

1. A research team should be inaugurated immediately to support the On-Farm Water Management Project in the NWFP. This team should be drawn from personnel in the

   a. NWFP, OFWMP office (as assigned by the Director)

   b. National OFWMP office (suggest Mr. Ashraf)

   c. Soil Conservation Service (suggest Whiting, Larson, and Jones as needed)

   d. Colorado State University (suggest Konrad, with Illsley Merrey and others as needed)

   e. Master Planning Unit, Survey and Research Division, WAPDA.

2. Research would include farmer cooperation in the problem identification, planning, execution and evaluation stages.

3. Farmer inputs of labor and capital will be invited for improvements involved in the research. Items authorized for reimbursement by the OFWM project would be paid for from that budget. Minor items would be handled through the CSU operations budget.

4. Rodmen, beldars and other assistance that may be needed would be provided on request by the NWFP, OFWMP.

5 A series of meetings should be held with groups of farmers to determine their water management problems. These meetings should include on-site inspection and discussion of the problems.

6. Where substantial potentials for improvement exist, the farmer(s) will be encouraged to consider one or more approaches which appear to have promise for achieving those potentials. These considerations will include benefit and cost estimates.

7. Based on the economic considerations and the experience and knowledge of the farmer and the technicians, one or more approaches for achieving the potentials for improvement will be implemented and evaluated.

8. If the results are positive and the farmers are pleased and enthused, field days will be arranged to allow them to tell their story.

9. If these same potentials for improvement are widely present in the NWFP and can be addressed within the framework of the current PC-1 of the OFWMP, personnel will be trained in the methods found to be most effective in helping farmers achieve those potentials. If the potential cannot be addressed within the current PC-1, but its achievement would be a good investment for the farmer and the country, a revision of the PC-1 to allow its inclusion would be proposed.

10. Stress should be placed on developing programs which feature the farmer, show him his potentials for improvement, and motivate him to invest his own labor and other resources in the improvement. Insofar as possible he should be given insight, broader options and technical guidance in place of physical materials.

Mr. Ashraf in the National Office should be given primary responsibility for developing the initial stages of this research with Mr. Konrad to work as the primary advisor. Decisions should be made within the first year on whether to: continue the research on this same scale; turn its management over completely to province staff; expand the research to meet the needs under a research agency such as WAPDA, etc.

For the Ongoing Development Program

1. Present teams involving:

   One Water Management Specialist (Team Leader)

   Two Watercourse Engineers

   Five Land Development Officers

   One Agriculture Extension Officer

   should be split to form two teams to accelerate the work. To maintain or increase the work capability of each team they should be augmented with trained sub-engineers and field assistants to provide two teams with compositions as indicated below:

   One Water Management Specialist (Team Leader

   One Watercourse Engineer (with one Field Assistant and one Sub-Engineer)

Two Land Development Officers (each with one F.A. and one Sub-Engineer)

One Extension Officer (with two field assistants)

The Engineers and officers would be expected to continue giving guidance to their FA's and SE's and the field.

2. The Project Director should be given the authority for increasing the proportion of pakka lined watercourses to ten percent of the total if the SCS advisor concurs.

3. Decision on whether or not to proceed with watercourse improvement should be based on benefits and costs estimates with no project to be undertaken unless expected benefits exceed expected costs.

4. Farmers inputs on watercourse improvement project should be at least 20% of the total costs.

5. Watercourses with high loss rates should be selected as the first for improvement because their potential for improvement is greater and opportunities for farmer participation and enthusiasm development are greater. One Engineer with orifice plates or flumes should be able to measure flows and losses on the main channels of at least two watercourses per day, or over 40 per month, which should provide a reasonable spectrum from which to make some of the best choices in a given area. After a few months experience in doing this, the man should be able to screen out the better watercourses and select the poor ones with only a few measurements.

# APPENDIX 14

## WATER DELIVERY EFFICIENCIES ON MN-140: AN UNCOMMANDED WATERCOURSE1/

by

S.A. Bowers, M.S. Shafique, Modh. Yasin, Z.A. Peracha & Bashir Ahmad2/

### INTRODUCTION

Pakistan has one of the world's largest and most sophisticated irrigation systems which supplies approximately 80,000 watercourses. These watercourses are of several types: annual, perennial, tubewell supplemented, and uncommanded. Only the latter's water supply comes entirely from tubewells.

Although earlier studies (2, 5) estimated watercourse conveyance losses at 10-15 percent farmers, particularly at the tail, were still receiving insufficient amounts of water. This contradiction led to further investigation of watercourse conveyance losses. Lowdermilk, et al. (4) in a survey of 40 watercourses found that the average conveyance efficiency for SCARP (tubewell supplemented) watercourses was 47 percent. For non-SCARP watercourses the average delivery efficiency was 54 percent. Lowdermilk, et al. (4) further found that tail farmers received 13-16 percent less water than farmers at the watercourse head.

These earlier studies measured steady-state losses using the inflow-outflow method; Cutthroat flumes (6) were placed at the inlet to the watercourse and at particular locations down channel. The loss was equated to the difference in steady-state discharge between two successive flumes. Kemper, et al. (3) noted that steady state loss measurements did not include operational losses such as wetting of banks, dead storage, etc. From a 15-hour study, where flumes were moved from field to field and measurements made of the total volumes of water delivered, Kemper concluded that "Summation delivery efficiencies of water to fields through watercourses are considerably less than those measured under steady-state conditions." In his short study summation measurements indicated a 59 percent loss while losses calculated from steady-state measurements were 40 percent. Trout, et al. (7) (8) and Bowers and Wahla (1) extended the period of loss measurement to include a complete

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1/Cooperative Study by Mona Reclamation Experimental Project, WAPDA and Colorado State University who works in Pakistan under contract to the United States Agency for International Development Contract No. AID/ta-C-1411.

2/CSU advisor, Senior Hydrologist, MREP, Jr. Agri. Eng. CSU & Jr. Agri. Eng., MREP, respectively.

irrigation turn (warabundi) of 168 hours. In both studies the water was followed from field to field and the volumes of delivered water measured. Trout (7) reported for watercourse MN-81R a means delivery efficiency of 46 percent. After improvement of this watercourse Bowers and Wahla (1) reported a mean delivery efficiency of 56.7 percent.

In the SCARP II area, there are many uncommanded watercourses which are on lands too high to receive canal water and consequently are served only by tubewells. Visually their maintenance and upkeep appears equally as deficient as commanded watercourses. Since these watercourses are served only by tubewells their water lacks the sediments common to canal supplies. This could conceivably influence their seepage rates since sediments tend to seal channels. Thus, in order to evaluate the water conveyance loss under the different conditions found on uncommanded watercourses MN-140 was selected for a full irrigation turn (warabundi) loss study.

## PROCEDURE

A map was made of MN-140 showing each bunded unit, channels, tubewell and other pertinent features (Fig. 1). The watercourse consists of 455 acres and 802 individual bunded fields. The total channel length used in this study, was 36,200 feet. The tubewell discharge was a constant 2.80 cusecs except during the daily rest period from 1700 to 2100. Soil textural analysis was made from the channel banks and beds; textures varied from sands to sandy clay loams (Appendix Table 1). Water samples were taken at the tubewell and various places in the channel and analyzed for quality (Appendix Table 2).

The irrigation turn system (warabundi) for MN-140 is fixed with farmers taking their water in a set order. The turn starts at 0600 on Monday morning and continues in fixed rotation for 168 hours. Despite this fixed order of taking water the farmers do insert some flexibility into the system by utilizing private tubewells, trading water with other farmers on the watercourse and even with adjacent watercourses.

The loss measuring procedure used was the inflow-outflow method where Cutthroat flumes were placed at the watercourse inlet, at the field, and usually at some intermediate point such as the junction between sarkari khal[3] and farmer field channels. In many cases it was impossible to distinguish between the two channel types; consequently, flumes frequently were located only at the tubewell and at the field.

3/Sarkari khal channels are both government authorized and government located watercourse channels.


Figure 1. Base map of watercourse MN-140 showing locations of field flumes.

Field flumes and intermediate flumes moved with the water. Usually several field flumes were set for each intermediate flume. Field flumes were set before the water reached the field and not removed until all channel drainage was complete. This required extra flumes in order that the next field flume be set prior to the arrival of water.

Flume discharges in cusecs were recorded every five minutes throughout the seven day irrigation turn. These discharge values were then plotted against time and the resulting areas under the curve integrated with a planimeter from which total volumes of water were calculated. Figure 2 shows the plot of one day's discharge values. The difference in integrated values between two flumes were equal to the loss. From the sums and differences of all such integrations the mean watercourse conveyance efficiency and loss was calculated.

Frequently, it was impossible to set field flumes exactly at the field irrigated. In such instances the delivery to the field was calculated from a linear extrapolation of the upstream loss. Where more than one field was irrigated from a single field flume the irrigation time weighted average distance from flume to field was calculated and the loss linearly extrapolated to that distance.

The water surface width at full supply level and the corresponding multiple depths across the channel were measured at numerous points in each channel and branch. Using Simpson's rule for integration the cross sectional area at each point was calculated and average channel cross section determined. The product of the average cross sectional area and the distance water flowed gave the channel storage volume for that particular irrigation turn. Where a channel was filled more than once during the turn the total storage volume was increased accordingly. The sum of the drainage, calculated from the plot of field flume discharges, equaled the recovered portion of the channel storage volume.

Operational losses are those which the steady-state loss measurement procedure fails to detect. Trout, et al. (7) defines such operational losses as "water initially infiltrated into dry channel banks, water losses from the watercourses during the movement of water from one field to another, dead storage left in the bottom of channels after their use, and losses resulting from short term breaks or leaks in the watercourses, both intentional and accidental." Operational losses were calculated according to the method proposed by Trout, et al. (7, 8) and earlier alluded to by Kemper (4). The warabundi time allotted for water delivery to a field flume times the maximum steady-state value recorded during the interval minus the total volume discharged through the flume equals the operational loss. In equation form this becomes:

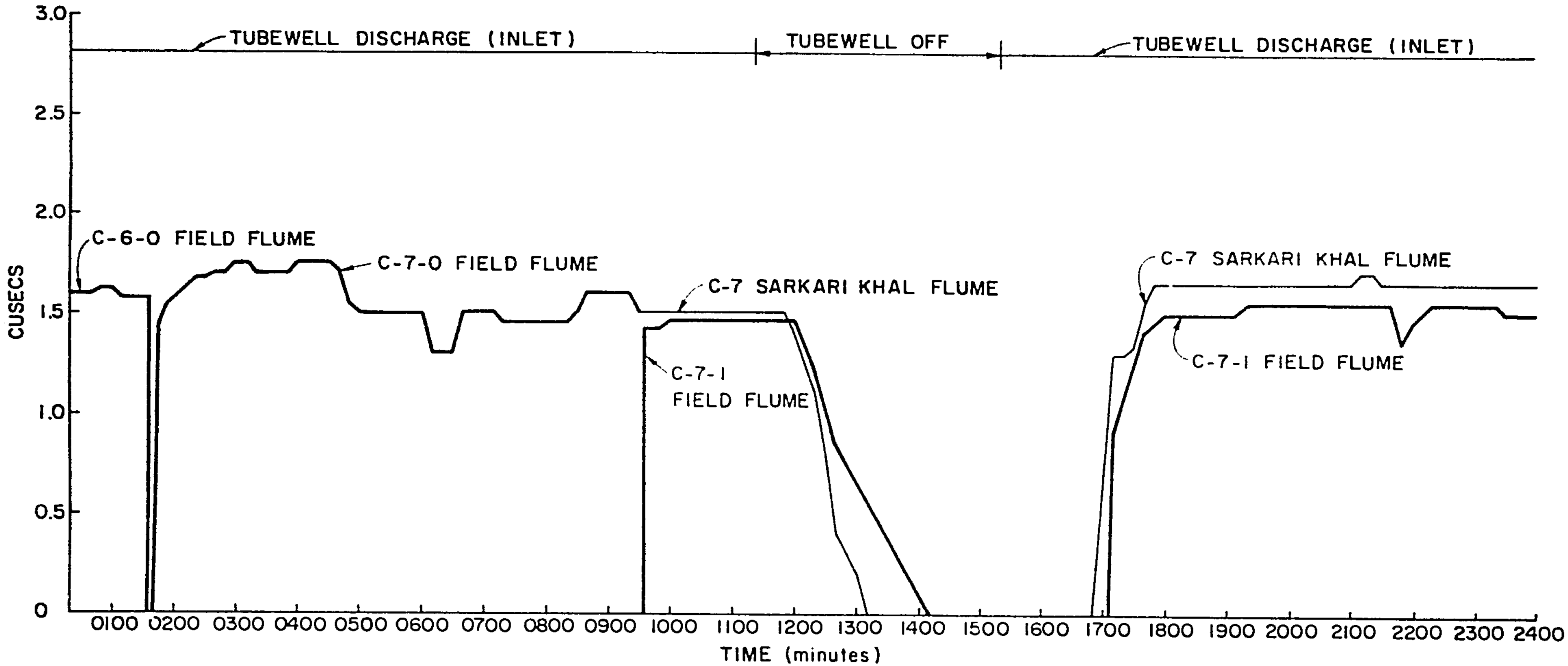


Figure 2. Flume discharges for December 11, 1977.

Operational loss = (Max. field flume steady-state rate x time) - integrated field flume discharge.

The summation of these losses will equal the operational loss during a complete warabundi turn.

In addition to conveyance deliveries and losses, channel seepage was measured by the ponding method in each of the main watercourse branches under three conditions: channel filling, full supply level, and recession. The seepage measurement procedure was to bund a 32.81 ft. (10 M) section and with level, staff gauge, and tape determine the average cross section. Thin rods with needle points were inserted into the channel bottom such that the tips were set at two inch height increments from the mean bottom elevation up to the full supply level. Water was then pumped into the bunded section by means of a constant head and thus constant flow device. The time was recorded as each point was covered and a graph established showing the relation between time and the cumulative filling volume. On the same graph the cumulative input volume of water was plotted as a function of time. The difference between the two curves is the cumulative infiltration (Fig. 3). Cumulative infiltration versus time was then fit with an empirical curve and its first derivative evaluated for the rate of infiltration.

On reaching full supply level the constant flow device was shut off and 10 liters of water were added by bucket each time the full supply indicator point protruded above water. The water surface tension allows that point and the corresponding time to be precisely identified. An empirical curve was established showing cumulative infiltration volume versus time; its first derivative was equated to the rate of infiltration.

During recession no water was added to the bunded section. Time was recorded as each pointer was uncovered. From the established cross section a section length these water level depths were converted to volumes. A curve was established between recession volume and time; the first derivative was equated to rate of infiltration.

## RESULTS AND DISCUSSION

Table 1 shows the summation of tubewell discharges, flume discharges, flume distances, losses, irrigation times, etc., for the entire week of December 6, 1977 to December 13, 1977. (Detailed measurement data are shown in Appendix Table 3.) The total shows that of 32.828 acre ft. discharged from the tubewell 16.936 acre ft. were delivered to the various fields. Thus, the mean delivery efficiency for the watercourse was

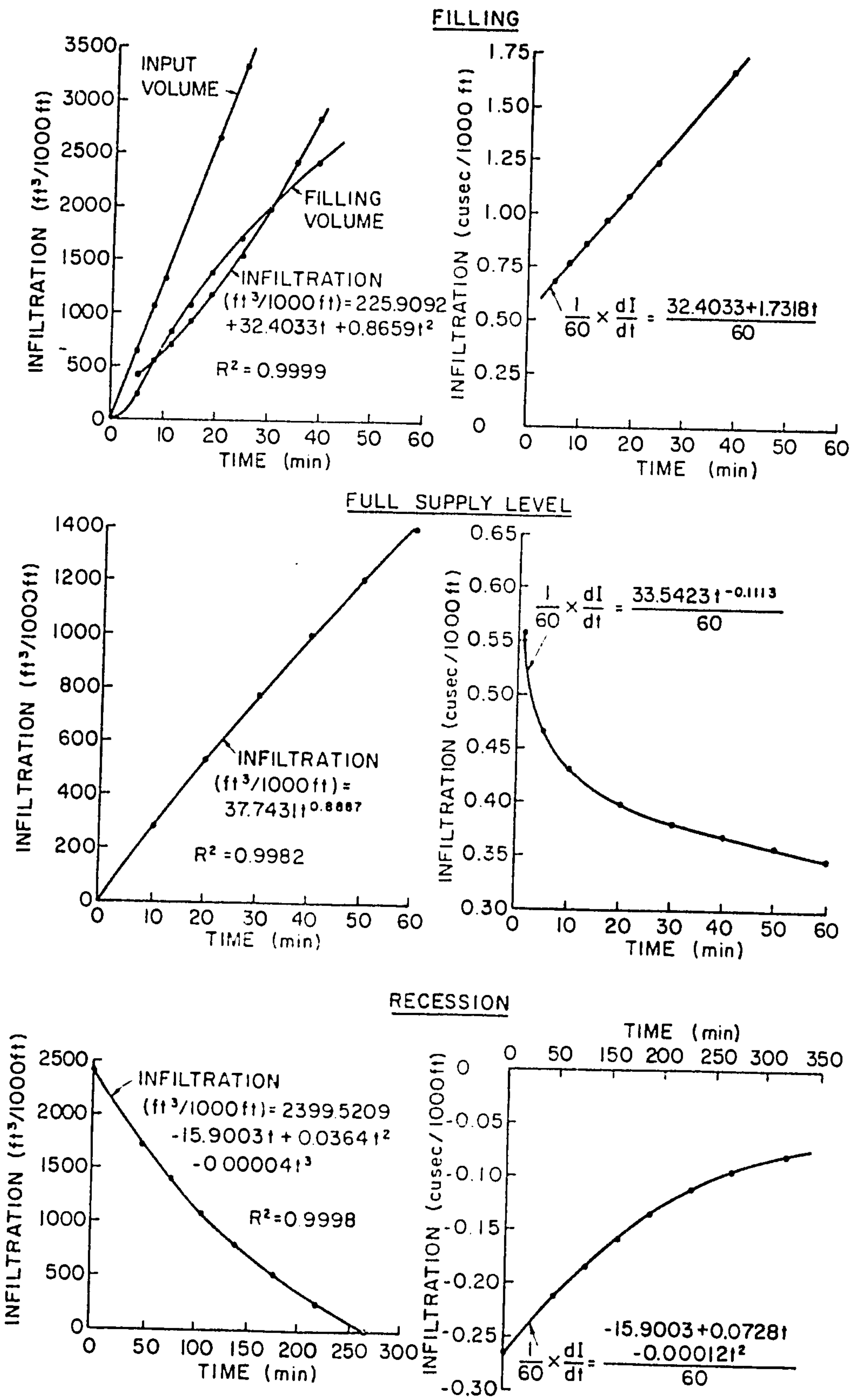


Figure 3. Branch F. Infiltrations measurements during channel filling at full supply level during recession.

Table 1. Seven Day Totals for Discharge, Delivery, etc. on MN-140

| Tubewell Discharge (ac-ft) | Field Flume Discharge (ac-ft) | Projected Delivery to Field (ac-ft) | Total Loss (ac-ft) | Acres Irrigated | Drainage (ac-ft) |
|---|---|---|---|---|---|
| 32.028 | 18.186 | 16.936 | 15.892 | 50.56 | 2.453 |

Table 2. Pond Infiltration Rate During Channel Filling, at Full Supply Level and Recession. Time (Min) and Water Depth is Given with Each Measured Rate. Each Rate is Given in Ft³/Ft²/Day and Cusecs/1000 Ft. of Channel

$\frac{Ft^3/Ft^2/Day}{Cusecs/1,000\ Ft}$ (Min)

Filling

| Br. | 2 in. | 4 in. | 6 in. | 8 in. | 9 in. | 10.25 in | 15 in. |
|---|---|---|---|---|---|---|---|
| A | 9.43/0.44 (2.2) | 11.79/0.55 (5.7) | 13.08/0.61 (9.2) | 13.94/0.65 (13.5) | 14.36/0.67 (16.2) | - | - |
| C. | 6.98/0.52 (5.5) | 8.85/0.66 (13.3) | 11.40/0.85 (24.6) | 13.28/0.99 (32.6) | - | 15.97 (43.9) | - |
| E. | 10.25 (5.2) | 12.66/0.63 (12.5) | 12.46/0.62 (18.3) | 9.85/0.49 (24.8) | - | - | - |
| F. | 13.75/0.77 (8.98) | 17.32/0.97 (15.0) | 22.14/1.24 (24.4) | 29.99/1.68 (39.5) | - | - | - |
| G. | | | | | | | |

Recession

| Br. | 2 in. | 4 in. | 6 in. | 8 in. | 9 in. | 10.25 in | 15 in. |
|---|---|---|---|---|---|---|---|
| A. | - | 2.14/0.10 (126.5) | 3.43/0.16 (67.4) | 5.15/0.24 (19.0) | 6.00/0.28 (0.1) | | |
| C. | 1.74/0.13 (260.0) | 1.74/0.13 (173.9) | 2.15/0.16 (105.7) | 2.68/0.20 (49.7) | - | 3.22/0.24 (0.1) | - |
| E. | 1.41/0.07 (226.58) | 1.61/0.08 (117.6) | 3.62/0.18 (26.0) | - | - | - | - |
| F. | 1.96/0.11 (175.58) | 2.86/0.16 (105.5) | 3.75/0.21 (46.92) | 4.82/0.27 (0.1) | - | - | - |
| G. | | | | | | | |

Full Supply Level

$\frac{Ft^3/Ft^2/Day}{Cusecs/1,000\ Ft}$ (inches) Depth

| Min. / Br. | 5 min. | 10 min. | 20 min. | 30 min. | 40 min. | 50 min. | 60 min. |
|---|---|---|---|---|---|---|---|
| A. | 7.07/0.33 (9) | 6.65/0.31 (9) | 6.43/0.30 (9) | 6.43/0.29 (9) | 6.22/0.28 (9) | 6.00/0.28 (9) | 5.79/0.27 (9) |
| C. | 7.38/0.55 (1025) | 6.71/0.50 (10.25) | 6.04/0.45 (10.25) | 5.77/0.43 (10.25) | 5.50/0.41 (10.25) | 5.37/0.40 (10.25 | 5.23/0.39 (10.25) |
| E. | 9.04/0.45 (8) | 8.64/0.43 (8) | 8.24/0.41 (8) | 8.04/0.40 (8) | 7.84/0.39 (8) | 7.64/0.38 (8) | 7.64/0.38 (8) |
| F. | 8.39/0.47 (8) | 7.68/0.43 (8) | 7.14/0.40 (8) | 6.78/0.38 (8) | 6.60/0.37 (8) | 6.43/0.36 (8) | 6.25/0.35 (8) |
| G. | /0.35 (15) | /0.31 (15) | /0.28 (15) | /0.26 (15) | /0.25 (15) | /0.24 (15) | /0.23 (15) |

51.6 percent. During conveyance from inlet to fields 15.892 acre ft. (48.4 percent) were lost through seepage, operational losses, spillage, leakage, etc. While these figures were based on actual volumetric measurements there are some entries in Appendix 2 that contain partial estimates. In a few instances while measurements through field flumes were in progress a farmer upstream, without notifying the personnel conducting the study, diverted water from the channel. The amount diverted was estimated both visually and by the decrease in discharge through the field flumes. In each case the amount was quite small. Additionally two irrigated fields were too close to the inlet to allow valid loss measurements. During the complete irrigation turn a total of 45.52 killas4/ (50.58 acres) were irrigated; thus, the average depth of irrigation was 4.04 inches. This irrigation depth is much greater than the 3.18 inches on MN-81R as reported by Bowers and Wahla (1); the soils at MN-81R are silt loam. On this watercourse the soils are sandy textured (Appendix Table 1) and due to their higher infiltration rates require more water to cover the field.

Both Trout, et al. (7) and Bowers and Wahla (1) reported water loss rates for each of the two channel types, i.e., the sarkari khal and farmers field channels; in both reports loss rates were greatest in farmer field channels. In this study, even though the two channel types could not always be distinguished from one another, loss rates estimates were based on those instances where separation was possible. The estimated loss rate for the sarkari khal and farmers' field channels were respectively 0.45 and 0.46 cusecs/1000 ft. For the entire watercourse the average loss rate was 0.53 cusecs ft/1000 ft. The time weighted average distance from inlet to field was 3046 ft. The average loss from inlet to field was 0.332 ac. ft. This greater loss rate for the entire watercourse is probably due to the greater number of loss determinations used in its calculation.

Bowers and Wahla (1) developed regression equations relating steady-state losses to initial flow rate, distance from inlet to field, and elevation difference between inlet and field. In this study, the below regression equation relates the average loss rate to the field as a function of distance and distance squared from the inlet, elevation difference and elevation difference squared between inlet and field, and the interaction between distance and elevation difference.

$$\text{Loss (cusecs)} = 0.84061D - 0.13960D^2 - 0.04284E - 0.02203E^2 + 0.07335(DE)$$

$R^2 = 0.433$

STD Error of Estimate = 0.59 cusecs

$F(5,41) = 6.25$5/

Where D = Distance (1000 ft) from the head flume to the field

E = Elevation difference (ft) between the FSL at the branch head and the field

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4/A locally used area unit (220 ft x 220 ft or 1.111 acres).

5/Statistically significant at the 0.01 level.

The $R^2$ value indicates that 43.3 percent of the variability in the loss rates can be attributed to the five above independent variables. In deriving the above equation the curves were forced through the origin.

Table 2 and Figure 3 show the ponding infiltration rates for all three types of infiltration; i.e., during channel filling, full supply level, and at recession. Infiltration rates are given both in terms of cusecs/1000 ft. and $ft^3/ft^2$/day. As expected for sandy soils infiltration rates were high but in every case these rates were highest during channel filling. For example, Table 2 shows that for branch C the maximum infiltration rate during channel filling was 1.19 cusecs/1000 ft (15.97 $ft^3/ft^2$/day); at the full supply level and during recession the maximum rates were 0 55 cusecs/1000 ft (7.38 $ft^3/ft^2$/day) and 0.24 cusecs/1000 ft (3.22 $ft^3/ft^2$/day) respectively. This, of course, was a function of the dry bank and channel conditions. Since only one site was ponded per branch, usually near the head, these figures do not necessarily represent the status of the entire branch. The ponding infiltration rates at full supply level are realistic in comparison with the average channel loss rates calculated from flume discharges. While the full supply infiltration rates from 30-60 minutes (average 0.36 cusecs/1000 ft), which approach steady - state, were somewhat lower than the flume derived loss rates this was expected since ponding measurements were made in selected channel sections where loss was due only to seepage and evaporation.

Table 3 shows the storage volume of the various channels used during this study. Some channels were filled more than once; the total shown reflects the multiple fillings. From the total stored volume of 3.716 acre ft., 2.484 acre ft. (67 percent) were recovered in drainage. Using the time period, the integrated field flume discharge, and the maximum steady-state values at the field flumes it was calculated that 2.417 acre ft. or 15.2 percent of the total loss was due to dead storage and other operational losses. Since the actual dead storage volume was not estimated while in the channel it is impossible to separate it from other operational losses. Of the total volume entering the watercourse 7.36 percent was operational loss.

MN-140 differed from commanded watercourses in the SCARP II in several ways. As mentioned above the water contained no sediments; this certainly contributed to continued high infiltration rates. Another observed difference was the almost complete lack of leakage from and seepage zones parallel to the channel banks except for one short section of branch C which ran at the top of a bank cut. Many of the channels had a steep gradient and high flow velocity which keep the water surface relatively low in relation to the surrounding fields. The low water level in the channels no doubt contributed to decreased leakage. Perhaps also related to this were the

TABLE 3 CHANNEL VOLUMES WITH DATE AND TIMES OF FILLING

| BRANCH | CHANNEL VOLUME AC. FT. | DATE | TIME |
|---|---|---|---|
| F | 0.059 | Dec. 6, 1977 | 0655 to 0910 |
| G | 0.127 | Dec. 6, 1977 | 0910 to 1510 |
| A | 0.008 | Dec. 6, 1977 | 1510 to 1700 |
| E | 0.669 | Dec. 7, 1977 | 2100 to 1700 |
| E | 0.687 | Dec. 8, 1977 | 2100 to 1700 |
| E | 0.607 | Dec. 9, 1977 | 2100 to 0717 |
| C | 0.138 | Dec. 9, 1977 | 0717 to 1700 |
| C | 0.306 | Dec. 10, 1977 | 2100 to 1700 |
| C | 0.220 | Dec. 11, 1977 | 2100 to 1135 |
| C | 0.336 | Dec. 12, 1977 | 1135 to 0600 |
| A | 0.121 | Dec. 12, 1977 | 0600 to 1700 |
| A | 0.053 | Dec. 12. 1977 | 2100 to 2217 |
| E | 0.311 | Dec. 13, 1977 | 2217 to 0300 |
| F | 0.074 | Dec. 13, 1977 | 0300 to 0905 |
| TOTAL | 3.716 | | |

TABLE 4. Rodent Hole Count in Banks of MN-140 and Three Other Watercourses

| BRANCH | | DISTANCE (FT) | RODENT HOLES |
|---|---|---|---|
| | | MN-140 | |
| A | | 6,520 | 34 |
| C | | 25,250 | 158 |
| E | | 36,980 | 73 |
| F | | 5,385 | 13 |
| G | | 4,520 | 22 |
| | TOTAL | 78,655 | 300 |
| | AVERAGE HOLES/1,000 FT | | 3.81 |
| | | MN-79 | |
| MAIN | | 1,000 | 11 |
| | | MN-81 | |
| A | | 1,000 | 28 |
| | | MN-82 | |
| MAIN | | 1,000 | 29 |

very few observed rodent holes in the banks. Table 4 shows a comparison between the density of rodent holes (holes/1000') in the bank of MN-140 with that of three other watercourses. The watercourse average was 3.81 holes/1000'. Thus, MN-140 had, on the average, approximately 1/8 to 1/3 the holes found in the three commanded watercourses. The reason for this difference is not known but one might speculate that sandy soils are unstable for burrowing and tend to collapse.

The loss encountered on MN-140 certainly should justify watercourse improvement. However, the sandy banks and soils found here present a different set of problems than those encountered on previously improved watercourses. Normally grass and weeds are removed from watercourse channels in order to reduce Manning's roughness coefficient and subsequently reduce the high water levels. However, it appears that on this watercourse such grass cover may be essential for bank stability particularly in those sections where steep channel gradients and high flow velocities exist. In addition, the high pond infiltration rates (Table 2) imply that seepage is the major loss component on this watercourse. Since this high seepage rate is probably a function of the soil textures it appears losses could only be partially reduced using the previously developed watercourse earthen improvement techniques. Low cost lining alternative may be required.

## SUMMARY

The average delivery efficiency over a complete irrigation turn (warabundi) for MN-140, an uncommanded watercourse, was 51.6 percent. Of 32.828 ac. ft. discharged into the watercourse 16.936 ac. ft. were delivered to 50.6 acres, the average irrigation depth was 4.04 inches. During conveyance to the fields 48.4 percent of the water was lost. Operational losses accounted for 15.2 percent (2.417 ac. ft.) of the total water lost. Of the 3.71 acre ft. required to fill the channels 67 percent was recovered as channel drainage.

The average infiltration loss rate from inlet to fields was 0.53 cusecs/1000 ft. Ponding infiltration measurement from five selected small channel sections averaged 0.37 cusecs/ 1000 ft over a one hour period with water at full supply level. Water loss from the ponded section was due only to seepage and evaporation. Infiltration rates during channel filling were 1½ - 4 times greater than the full supply infiltration rate. Seepage is a major component of the loss due to the prevailing soil texture. Such high seepage loss probably preclude the earthen watercourse improvement techniques used elsewhere.

Regression equations were developed which related loss rate to distance, distance squared, elevation difference, elevation difference squared, and distance x elevation difference. The $R^2$ value was 43.3 percent; the significance level was 0.01.

Very little leakage or seepage through the channel banks was observed. Rodent holes averaged 3.81 holes/1000 ft. of channel. This was 1/8 to 1/3 the rate of holes found on three other watercourses.

ACKNOWLEDGEMENT

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APPENDIX

TABLE 1 SOIL TEXTURE: LOCATION, DEPTH AND ANALYSIS

| Location | Depth | % Sand | % Silt | % Clay | Texture |
|---|---|---|---|---|---|
| | | 'A' BRANCH | | | |
| Head Right Bank | 0 - 12" | 74.8 | 14.0 | 11.2 | Sandy Loam |
| | 12"- 24" | 76.8 | 12.0 | 11.2 | " |
| | 24"- 36" | 80.8 | 12.0 | 7.2 | Loamy Sand |
| | 36"- 48" | 70.8 | 18.0 | 11.2 | Sandy Loam |
| Head Bed | 0 - 12" | 74.8 | 12.0 | 13.2 | " |
| | 12"- 24" | 84.8 | 3.0 | 7.2 | Loamy Sand |
| | 24"- 36" | 74.8 | 18.0 | 7.2 | Sandy Loam |
| | 36"- 48" | - | - | - | - |
| Head Left Bank | 0 - 12" | 56.8 | 22.0 | 21.2 | Sandy Clay Loam |
| | 12"- 24" | 56.8 | 24.0 | 19.2 | Sandy Loam |
| | 24"- 36" | 66.8 | 18.0 | 15.2 | " |
| | 36"- 48" | 66.8 | 16.0 | 17.2 | " |
| Middle Right Bank | 0 12" | 76.8 | 14.0 | 9.2 | " |
| | 12"- 24" | 74.8 | 14.0 | 11.2 | " |
| | 24"- 36" | 80.8 | 10.0 | 9.2 | " |
| | 36"- 48" | 78.8 | 12.0 | 9.2 | " |
| Middle Bed | 0 - 12" | 80.8 | 12.0 | 7.2 | Loamy Sand |
| | 12"- 24" | 84.8 | 8.0 | 7.2 | " |
| | 24"- 36" | 80.8 | 10.0 | 9.2 | Sandy Loam |
| | 36"- 48' | 78.8 | 12.0 | 9.2 | " |
| Middle Left Bank | 0 - 12" | 76.8 | 12.0 | 11.2 | " |
| | 12"- 24" | 86.8 | 6.0 | 7.2 | Loamy Sand |
| | 24"- 36" | 78.8 | 14.0 | 7.2 | " |
| | 36"- 48" | 74.8 | 14.0 | 11.2 | Sandy Loam |
| Tail Right Bank | 0 - 12' | 70.8 | 18.0 | 11.2 | " |
| | 12"- 24" | 67.6 | 20.0 | 12.4 | " |
| | 24"- 36" | 75.0 | 14.0 | 10.4 | " |
| | 36"- 48" | 71.6 | 16.0 | 12.4 | " |
| Tail Bed | 0 - 12" | 89.6 | 16.0 | 4.4 | Sand |
| | 12"- 24" | 67.6 | 16.0 | 16.4 | Sandy Loam |
| | 24"- 36" | 71.6 | 12.0 | 16.4 | " |
| | 36"- 48" | 71.6 | 12.0 | 16.4 | " |
| Tail Left Bank | 0 - 12" | 83.6 | 8.0 | 8.4 | " |
| | 12"- 24" | 57.6 | 20.0 | 22.4 | " |
| | 24"- 36" | 59.6 | 18.0 | 22.4 | " |
| | 36"- 48" | 57.6 | 20.0 | 22.4 | " |
| | | 'C' BRANCH | | | |
| Head Right Bank | 0 - 12" | 83.2 | 12.0 | 4.8 | Loamy Sand |
| | 12"- 24" | 85.5 | 10.0 | 4.8 | " |
| | 24"- 36" | 83.2 | 10.0 | 6.8 | " |
| | 36"- 48" | 85.2 | 10.0 | 6.8 | " |
| Head Bed | 0 - 12" | 85.2 | 8.0 | 4.8 | " |
| | 12"- 24" | 87.2 | 10.0 | 6.8 | " |
| | 24"- 36" | 71.2 | 6.0 | 12.8 | Sandy Loam |
| | 36"- 48" | 67.2 | 16.0 | 12.8 | " |
| Head Left Bank | 0 - 12" | 87.2 | 8.0 | 4.8 | Loamy Sand |
| | 12"- 24" | 87.2 | 8.0 | 4.8 | " |
| | 24"- 36" | 87.2 | 6.0 | 6.8 | " |
| | 36"- 48" | 85.2 | 8.0 | 6.8 | " |
| Middle Right Bank | 0- 12" | 84.8 | 8.0 | 7.2 | " |
| | 12"- 24" | 90.8 | 6.0 | 3.2 | Sand |
| | 24"- 36" | 92.8 | 4.0 | 3.2 | " |
| | 36"- 48" | 50.8 | 26.0 | 23.2 | Sandy Clay Loam |
| Middle Bed | 0 - 12" | 78.8 | 14.0 | 7.2 | Loamy Sand |
| | 12"- 24" | 60.8 | 22.0 | 17.2 | Sandy Loam |
| | 24"- 36" | 54.8 | 26.0 | 19.2 | " |
| | 36"- 48" | 46.8 | 28.0 | 25.2 | " |

APPENDIX

TABLE 1 (continued)

| Location | Depth | % Sand | % Silt | % Clay | Texture |
|---|---|---|---|---|---|
| Middle Left Bank | 0 - 12" | 86.8 | 8.0 | 5.2 | Loamy Sand |
| | 12"- 24" | 40.8 | 6.0 | 3.2 | Sand |
| | 24"- 36" | 88.8 | 6.0 | 5.2 | " |
| | 36"- 48" | 62.8 | 22.0 | 15.2 | Sandy Loam |
| Tail-Right Bank | 0 - 12" | 88.8 | 4.0 | 7.2 | Sand |
| | 12"- 24" | 84.8 | 6.0 | 9.2 | Loamy Sand |
| | 24"- 36" | 78.8 | 14.0 | 11.2 | Sandy Loam |
| | 36"- 48" | 74.8 | 8.0 | 11.2 | " |
| Tail Bed | 0 - 12" | 84.8 | 12.0 | 7.2 | Loamy Sand |
| | 12"- 24" | 76.8 | 10.0 | 11.2 | Sandy Loam |
| | 24"- 36" | 76.8 | 10.0 | 13.0 | " |
| | 36"- 48" | 76.8 | 4.0 | 13.2 | " |
| Tail-Left Bank | 0 - 12" | 88.8 | 6.0 | 7.2 | Sand |
| | 12"- 24" | 84.8 | 10.0 | 9.2 | Loamy Sand |
| | 24"- 36" | 78.8 | 10.0 | 11.2 | Sandy Loam |
| | 36"- 48" | 76.8 | 12.0 | 11.2 | " |
| | | 'F' BRANCH | | | |
| Head Right Bank | 0 - 12" | 93.2 | 6.8 | 0.0 | Sand |
| | 12"- 24" | 91.2 | 6.8 | 2.0 | " |
| | 24"- 36' | 86.2 | 14.8 | 4.0 | Loamy Sand |
| | 36"- 48" | 67.2 | 20.8 | 12.0 | Sandy Loam |
| Head-Bed | 0 - 12' | 93.2 | 4.8 | 2.0 | Sand |
| | 12"- 24" | - | - | - | - |
| | 24"- 36" | - | - | - | - |
| | 36"- 48" | - | - | - | - |
| Head-Left Bank | 0 - 12' | 87.2 | 10.8 | 2.0 | Sand |
| | 12"- 24" | 87.2 | 8.8 | 4.0 | " |
| | 24"- 36" | - | - | - | - |
| | 36"- 48" | 61.2 | 26.8 | 12.0 | Sandy Loam |
| Middle Right Bank | 0 - 12" | 89.2 | 6.8 | 4.0 | Sand |
| | 12"- 24" | 89.2 | 6.8 | 4.0 | " |
| | 24"- 36" | 91.2 | 4.8 | 4.0 | " |
| | 36"- 48" | 59.2 | 24.8 | 16.0 | Sandy Loam |
| Middle Bed | 0 - 12" | 85.2 | 7.2 | 7.2 | Loamy Sand |
| | 12"- 24" | - | - | - | - |
| | 24"- 36" | 87.6 | 3.2 | 9.2 | Sand |
| | 36"- 48" | 57.6 | 25.2 | 17.2 | Sandy Loam |
| Middle Left Bank | 0 - 12' | - | - | - | - |
| | 12"- 24" | 73.6 | 15.2 | 11.2 | Sandy Loam |
| | 24"- 36" | 69.6 | 11.2 | 19.2 | " |
| | 36"- 48" | 63.6 | 19.2 | 17.2 | " |
| Tail Right Bank | 0 - 12" | 85.6 | 7.2 | 17.2 | " |
| | 12"- 24" | 85.6 | 5.2 | 4.2 | " |
| | 24"- 36" | 79.6 | 9.2 | 11.2 | Loamy Sand |
| | 36"- 48" | 83.6 | 7.2 | 9.2 | " |
| Tail Bed | 0 - 12" | 87.6 | 5.2 | 7.2 | " |
| | 12"- 24" | 81.6 | 9.2 | 9.2 | " |
| | 24"- 36" | 63.6 | 24.0 | 12.4 | Sandy Loam |
| | 36"- 48" | 89.6 | 6.0 | 4.4 | Sand |
| Tail Left Bank | 0 - 12" | 82.6 | 8.6 | 4.4 | " |
| | 12"- 24" | 74.6 | 12.0 | 8.4 | Loamy Sand |
| | 24"- 36" | 79.6 | 10.0 | 10.4 | " |
| | 36"- 48" | 81.6 | 10.0 | 8.4 | " |

APPENDIX

TABLE 1 (continued)

| Location | Depth | % Sand | % Silt | % Clay | Texture |
|---|---|---|---|---|---|
| | | **'E' BRANCH** | | | |
| Head-Right Bank | 0 - 12" | 86.4 | 10.0 | 3.6 | Loamy Sand |
| | 12"- 24" | 90.4 | 8.0 | 1.6 | Sand |
| | 24"- 36" | 81.2 | 14.0 | 4.8 | |
| | 36"- 48" | 71.2 | 20.0 | 8.8 | Loamy 8nd |
| Head Bed | 0 - 12" | 88.4 | 10.0 | 1.6 | Sand |
| | 12"- 24" | 60.4 | 26.0 | 13.6 | Sandy Loam |
| | 24"- 36" | 52.4 | 30.0 | 17.6 | " |
| | 36"- 48" | 49.2 | 32.0 | 18.0 | " |
| Head Left Bank | 0 - 12" | 86.4 | 10.0 | 3.6 | Loamy Sand |
| | 12"- 24" | 77.2 | 16.0 | 6.8 | " |
| | 24"- 36" | 79.2 | 12.0 | 8.8 | " |
| | 36"- 48" | 61.2 | 24.0 | 14.8 | Sandy Loam |
| Middle Right Bank | 0 - 12" | 61.2 | 24.0 | 14.8 | " |
| | 12"- 24" | 70.0 | 18.0 | 12.0 | " |
| | 24"- 36" | 75.2 | 16.0 | 8.8 | " |
| | 36"- 48" | 71.2 | 18.0 | 10.8 | " |
| Middle Bed | 0 - 12" | 81.2 | 10.0 | 0.8 | Loamy Sand |
| | 12"- 24" | 90.0 | 6.0 | 4.0 | - |
| | 24"- 36" | 55.2 | 28.0 | 16.8 | Sandy Loam |
| | 36"- 48" | 57.2 | 28.0 | 14.8 | " |
| Middle Left Bank | 0 - 12" | 85.2 | 10.0 | 4.8 | " |
| | 12"- 24" | 84.0 | 18.0 | 8.0 | Loamy Sand |
| | 24"- 36" | 81.2 | 14.0 | 4.8 | " |
| | 36"- 48" | 71.2 | 18.0 | 10.8 | Sandy Loam |
| Tail Right Bank | 0 - 12" | 60.0 | 22.0 | 18.0 | " |
| | 12"- 24" | [illegible] | 16.0 | 16.0 | " |
| | 24"- 36" | 65.2 | 24.0 | 10.8 | " |
| | 36"- 48" | [illegible] | 24.[illegible] | 18.8 | " |
| Tail Bed | 0 - 12" | 62.0 | 18.0 | 20.0 | " |
| | 12"- 24" | 71.2 | 18.0 | 10.8 | Loamy Sand |
| | 24"- 36" | 63.2 | 20.0 | 16.0 | Sandy Loam |
| | 36"- 48" | 63.2 | 22.0 | 14.8 | " |
| Tail Left Bank | 0 - 12" | 74.0 | 18.0 | 8.0 | " |
| | 12"- 24" | 76.0 | 16.0 | 8.0 | " |
| | 24"- 36" | - | - | - | - |
| | 36"- 48" | 65.2 | 20.0 | 14.8 | Sandy Loam |
| | | **'G' BRANCH** | | | |
| Head Right Bank | 0 - 12" | 81.2 | 13.2 | 5.6 | Loamy Sand |
| | 12"- 24" | 87.2 | 7.2 | 5.6 | " |
| | 24"- 36" | 87.2 | 7.2 | 5.6 | " |
| | 36"- 48" | 87.2 | 7.2 | 5.6 | " |
| Head Bed | 0 - 12" | 81.2 | 13.2 | 5.6 | " |
| | 12"- 24" | 85.2 | 9.2 | 5.6 | " |
| | 24"- 36" | 83.2 | 9.2 | 7.6 | " |
| | 36"- 48" | 69.2 | 17.2 | 13.6 | Sandy Loam |
| Head Left Bank | 0 - 12" | 85.2 | 9.2 | 5.6 | Loamy Sand |
| | 12"- 24' | 87.2 | 7.2 | 5.6 | " |
| | 24"- 36" | 87.2 | 7.2 | 5.6 | " |
| | 36"- 48" | 87.2 | 7.2 | 5.6 | " |
| Middle Right Bank | 0 - 12' | 75.6 | 18.8 | 5.6 | " |
| | 12"- 24' | 73.6 | 16.8 | 9.6 | Sandy Loam |
| | 24"- 36" | 71.6 | 18.8 | 9.6 | " |
| | 36"- 48" | 77.6 | 12.8 | 9.6 | " |

APPENDIX

TABLE 1 (continued)

| Location | Depth | % Sand | % Silt | % Clay | Texture |
|---|---|---|---|---|---|
| Middle Bed | 0 - 12" | 89.6 | 6.8 | 3.6 | Sand |
| | 12"- 24" | 91.6 | 4.8 | 3.6 | Sand |
| | 24"- 36" | 85.6 | 8.8 | 5.6 | Loamy Sand |
| | 36"- 48" | 79.6 | 12.8 | 7.6 | " |
| Middle Left Bank | 0 - 12" | 69.6 | 20.8 | 9.6 | Sandy Loam |
| | 12"- 24" | 75.6 | 14.8 | 9.6 | " |
| | 24"- 36" | 77.6 | 12.8 | 9.6 | " |
| | 36"- 48" | 77.6 | 12.8 | 9.6 | " |
| Tail Right Bank | 0 - 12" | 59.2 | 24.0 | 16.8 | " |
| | 12"- 24" | 58.2 | 24.0 | 16.8 | " |
| | 24"- 36" | - | - | - | - |
| | 36"- 48" | 67.2 | 20.0 | 12.8 | Sandy Loam |
| Tail Bed | 0 - 12" | 65.2 | 20.0 | 14.8 | " |
| | 12"- 24" | 59.2 | 24.0 | 16.8 | " |
| | 24"- 36" | 35.2 | 32.0 | 32.8 | Clay Loam |
| | 36"- 48" | 53.2 | 26.0 | 20.8 | Sandy Loam |
| Tail Left Bank | 0 - 12' | 61.2 | 22.0 | 16.8 | " |
| | 12"- 24" | - | - | - | - |
| | 24"- 36" | 61.2 | 24.0 | 14.8 | Sandy Loam |
| | 36"- 48" | 43.2 | 28.0 | 28.8 | Loam |

APPENDIX

TABLE 2 WATER ANALYSIS: TW MN-140

| LOCATION | Milli Equivalents per litre Ca | Mg | Na | $HCO_3$ | Cl | $SO_4$ | PPM D.S. by (evap.) | EC x $10^6$ at $25^o$ C | $p^H$ | SAR |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | BRANCH G | | | | | |
| Head | 10.0 | 2.0 | 3.8 | 5.0 | 6.0 | 2.5 | 864 | 1350 | 8.1 | 1.68 |
| Middle | 8.0 | 0 | 5.4 | 5.0 | 6.0 | 2.0 | 832 | 1300 | 7.8 | 2.70 |
| Tail | 8.0 | 6.0 | 5.4 | 6.0 | 6.0 | 1.0 | 832 | 1300 | 7.9 | 2.61 |
| | | | | | BRANCH C | | | | | |
| Head | 8.0 | 4.0 | 5.4 | 3.0 | 5.0 | 5.5 | 864 | 1350 | 7.8 | 2.64 |
| Middle | 8.0 | 6.0 | 4.3 | 4.0 | 6.0 | 2.5 | 800 | 1250 | 7.9 | 2.07 |
| Tail | 8.0 | 4.0 | 4.3 | 4.5 | 6.0 | 2.0 | 800 | 1250 | 8.0 | 2.10 |

APPENDIX

TABLE 3 Discharges, losses, distances, drainage, etc. associated with field flume and intermediate flume.

| FIELD FLUME | 1 T.W. Discharge ac-ft | 2 Inter. Flume Discharge ac-ft | 3 Loss to Inter Flume (1-3) ac-ft | 4 Dist. Inlet to Inter Flume 1000ft | 5 Field Flume Discharge ac-ft | 6 Loss Inlet to Field Flume (5-1) ac-ft | 7 Dist. Inlet to Field Flume 1000ft | 8 Loss Inter. to Field Flume ac-ft | 9 Dist. Inter to Field Flume ac-ft | 10 Av. Weighted Dis. Field Flume to Field 1000ft | 11 Projected Del. to Fields ac-ft | 12 Total Loss from Inlet to Field (11-1) ac-ft | 13 Total Distance Field to Inlet 1000ft | 14 Acre Irrigated | 15 Drainage ac-ft | 16 Date Time | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F-1 | 0.521 | 0 | 0 | 0 | 0.34 | 0.181 | 1.20 | 0 | 0 | 0.030 | 0.335 | 0.186 | 1.230 | 0.50 | 0.012 | 6-12-77 0655-1910 | |
| G-1-1 | 1.041 | 1.011 | 0.03 | 1.02 | 0.768 | 0.273 | 1.755 | 0.243 | 0.735 | 0.188 | 0.706 | 0.335 | 1.943 | 2.25 | 0.033 | 6-12-77 0910-1340 | |
| G-1-2 | 0.347 | 0.385 | -0.038 | 1.02 | 0.359 | -0.012 | 1.79 | 0.026 | 0.770 | 0.273 | 0.350 | -0.003 | 2.063 | 0.876 | 0.101 | 6-12-77 1340-1510 | |
| A-5-0 | 0.270 | 0 | 0 | 0 | 0.253 | 0.017 | 0.200 | 0 | 0 | 0.125 | 0.242 | 0.028 | 0.325 | 0.699 | 0.03 | 6-12-77 1510-1620 | |
| A-2-0 | 0.154 | 0 | 0 | 0 | 0.154 | 0 | 0.02 | 0 | 0 | 0.200 | 0.154 | 0 | 0.220 | 0.392 | 0.033 | 6-12-77 1620-1700 | |
| E-1-0 | 0.347 | 0 | 0 | 0 | 0.202 | 0.145 | 0.638 | 0 | 0 | 0.385 | 0.115 | 0.232 | 1.023 | 0.458 | 0 | 6-12-77 2100-2230 | |
| E-2-0 | 0.366 | 0 | 0 | 0 | 0.344 | 0.022 | 0.89 | 0 | 0 | 0.344 | 0.336 | 0.03 | 1.234 | 0.754 | 0 | 6-12-77 2230-0005 | |
| E-3-0 | 0.482 | 0 | 0 | 0 | 0.41 | 0.072 | 1.300 | 0 | 0 | 0.194 | 0.399 | 0.083 | 1.494 | 1.49 | 0 | 7-12-77 0005-0210 | |
| E-3-1 | 0.617 | 0.658 | -0.041 | 1.300 | 0.517 | 0.100 | 1.715 | 0.141 | 0.415 | 0.118 | 0.477 | 0.140 | 1.833 | 1.823 | 0.127 | 7-12-77 0210-0450 | |
| E-4-0 | 0.548 | 0 | 0 | 0 | 0.258 | 0.290 | 1.870 | 0 | 0 | 0.390 | 0.198 | 0.350 | 2.260 | 1.091 | 0 | 7-12-77 0450-0712 | |
| E-4-1 | 0.725 | 0.608 | 0.117 | 1.870 | 0.441 | 0.184 | 2.525 | 0.167 | 0.655 | 0.102 | 0.415 | 0.310 | 2.634 | 1.415 | 0.092 | 7-12-77 0712-1020 | Drainage Estimated |
| E-5-1 | 0.463 | 0.451 | 0.012 | 2.149 | 0.326 | 0.137 | 3.200 | 0.125 | 1.051 | 0.094 | 0.315 | 0.148 | 3.294 | 1.00 | 0.079 | 7-12-77 1020-1220 | |
| E-6-1 | 1.080 | 0.556 | 0.524 | 1.26 | 0.487 | 0.593 | 1.805 | 0.069 | 0.545 | 0.175 | 0.465 | 0.615 | 1.98 | 1.40 | 0.081 | 7-12-77 1220-1700 | |
| E-7-0 | 0.829 | 0 | 0 | 0 | 0.443 | 0.386 | 1.97 | 0 | 0 | 0.173 | 0.409 | 0.42 | 2.143 | 0.750 | 0 | 7-12-77 2100-0035 | |

TABLE 3 (continued) Discharges, losses, distances, drainage, etc. associated with field flume and intermediate flume.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E-7-1 | 1.504 | 1.253 | 0.251 | 1.97 | 0.681 | 0.386 | 3.67 | 0.572 | 1.70 | 0.330 | 0.570 | 0.934 | 4.00 | 1.585 | 0.039 | 8-12-77 0035-0705 | |
| E-7-2 | 0.498 | 0.340 | 0.154 | 1.97 | 0.313 | 0.185 | 3.11 | 0.027 | 1.14 | 0.220 | 0.308 | 0.190 | 3.33 | 0.9 | 0.035 | 8-12-77 0705 0914 | |
| E-7-3 | 1.103 | 0.638 | 0.465 | 1.97 | 0.32 | 0.783 | 2.90 | 0.318 | 0.93 | 0.113 | 0.28 | 0.822 | 3.013 | 0.85 | 0.012 | 8-12-77 0914-1400 | |
| E-8-0 | 0.085 | 0 | 0 | 0 | 0 | 0.085 | 0 | 0 | 0 | 0 | 0 | 0.085 | 0 | 0. | 0.107 | 8-12-77 1400-1422 | |
| E-9-1 | 0.339 | 0.26 | 0.079 | 2.07 | 0.194 | 0.145 | 3.4 | 0.066 | 1.33 | 0.137 | 0.187 | 0.152 | 3.537 | 1.809 | 0.056 | 8-12-77 1422-1550 | |
| E-9-2 | 0.270 | 0.220 | 0.050 | 2.07 | 0.131 | 0.139 | 3.668 | 0.089 | 1.598 | 0.124 | 0.124 | 0.146 | 3.792 | 0.310 | 0.168 | 8-12-77 1550-1700 | Drainage Estimated |
| E-9-3 | 0.324 | 0.050 | 0.274 | 2.07 | 0.052 | 0.272 | 3.62 | - | 1.55 | 0.250 | 0.033 | 0.291 | 3.870 | 0.125 | 0.052 | 8-12-77 2100-2224 | Nopha to field flume for project delivery |
| E-9-4 | 0.27 | 0.205 | 0.065 | 2.07 | 0.152 | 0.118 | 2.4 | 0.053 | 0.33 | 0.184 | 0.122 | 0.148 | 2.584 | 0.437 | 0 | 8-12-77 2224-2334 | |
| E-9-5 | 0.193 | 0.155 | 0.038 | 2.07 | 0.127 | 0.066 | 2.365 | 0.028 | 0.795 | 0.055 | 0.127 | 0.066 | 2.92 | 0.487 | 0.056 | 8-12-77 2334-0024 | |
| E-10-1 | 1.593 | 1.232 | 0.361 | 3.33 | 0.757 | 0.836 | 4.590 | 0.475 | 1.26 | 0.229 | 0.67 | 0.922 | 4.819 | 1.896 | 0.032 | 9-12-77 0024-0717 | |
| E-10-2 | C | 0.134 | -0.134 | 3.33 | 0.116 | -0.116 | 4.220 | 0.018 | 0.89 | 0.05 | 0.115 | -0.115 | 4.27 | 0.388 | 0.115 | 9-12-77 | Drainage water only |
| C-2-0 | 1.466 | 0 | 0 | 0 | 0.647 | 0.819 | 1.307 | 0 | 0 | 0.137 | 0.553 | 0.912 | 1.444 | 1.08 | 0 | 9-12-77 0717-1400 | T.W. remained off for 23 minutes due to C.M.O. during 0937-1002 |
| C-3-1 | 2.025 | 1.016 | 1.009 | 2.100 | 0.907 | 1.118 | 2.338 | 0.109 | 0.238 | 0.250 | 0.792 | 1.232 | 2.588 | 1.759 | 0.117 | 10-12-77 1400-0245 | |
| C-4-0 | 0.945 | 0 | 0 | 0 | 0.257 | 0.688 | 4.72 | 0 | 0 | 0.100 | 0.242 | 0.703 | 4.82 | 0.437 | 0 | 10-12-77 0245-0650 | |
| C-4-1 | 1.543 | 0.686 | 0.854 | 4.72 | 0.387 | 1.156 | 5,528 | 0.299 | 0.808 | 0.197 | 0.314 | 1.229 | 5.725 | 0.899 | 0.034 | 10-12-77 0650-1330 | |
| C-5-0 | 0.490 | 0 | 0 | 0 | 0.282 | 0.209 | 3.60 | 0 | 0 | 0.080 | 0.277 | 0.213 | 3.68 | 0.61 | 0.019 | 10-12-77 1330-1537 | |
| C-6-0 | 1.380 | 0 | 0 | 0 | 0.695 | 0.685 | 3.42 | 0 | 0 | 0.200 | 0.655 | 0.725 | 3.62 | 0.889 | 0.124 | 10-12-77 - 11-12-77 1537-0135 | 1700-2100 T.W. Rest Hours |
| C-7-0 | 1.851 | 0 | 0 | 0 | 1.021 | 0.83 | 3.60 | 0 | 0 | 0.322 | 0.947 | 0.904 | 3.922 | 1.977 | 0 | 0135-0935 | |
| C-7-1 | 2.854 | 1.551 | 1.303 | 3.6 | 1.42 | 1.434 | 4.072 | 0.131 | 0.472 | 0.268 | 1.346 | 1.508 | 4.34 | 2.716 | 0.213 | 0935-0150 | |

APPENDIX

TABLE 3 (continued) Discharges, losses, distances, drainage, etc. associated with field flume and intermediate flume.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C-8-1 | 0.617 | 0.329 | 0.288 | 4.8 | 0.313 | 0.304 | 5.517 | 0.016 | 0.717 | 0.120 | 0.310 | 0.307 | 5.824 | 0.379 | 0.115 | 12-12-77 0150-0430 | |
| C-9-1 | 0.347 | 0.257 | 0.090 | 2.9 | 0.207 | 0.14 | 2.837 | 0.05 | 0.937 | 0.05 | 0.204 | 0.143 | 3.887 | 0.589 | 0.130 | 12-12-77 0430-0600 | Estimated figures No flumes. |
| A-a-0 | 0.135 | 0 | 0 | 0 | 0.135 | 0 | 0 | 0 | 0 | 0 | 0.135 | 0 | 0.200 | 0.31 | 0 | 12-12-77 0600-0635 | Estimated figures No flumes. |
| A-b-0 | 0.167 | 0 | 0 | 0 | 0.159 | 0.008 | 0 | 0 | 0 | 0 | 0.159 | 0.008 | 0.200 | 0.49 | 0 | 12-12-77 0635-0718 | |
| A-1-0 | 0.277 | 0 | 0 | 0 | 0.268 | 0.009 | 0.275 | 0 | 0 | 0.094 | 0.265 | 0.012 | 0.369 | 0.89 | 0.019 | 12-12-77 0718-0830 | |
| A-2-0 | 0.077 | 0 | 0 | 0 | 0.047 | 0.030 | 0.536 | 0 | 0 | 0.200 | 0.0360 | 0.041 | 0.736 | 0.125 | 0 | 12-12-77 0830-0850 | |
| A-C-0 | 0.193 | 0 | 0 | 0 | 0.173 | 0.020 | 0.500 | 0 | 0 | 0.220 | 0.164 | 0.029 | 0.70 | 0.50 | 0 | 12-12-77 0850-0940 | |
| A-3-0 | 0.146 | 0 | 0 | 0 | 0.130 | 0.016 | 1.086 | 0 | 0 | 0.01 | 0.130 | 0.016 | 1.087 | 0.29 | 0.035 | 12-12-77 0940-1018 | |
| A-4-0 | 0.586 | 0 | 0 | 0 | 0.556 | 0.030 | 0.300 | 0 | 0 | 0.173 | 0.539 | 0.473 | 0.473 | 1.568 | 0 | 12-12-77 1018-1250 | |
| A-5-0 | 0.405 | 0 | 0 | 0 | 0.256 | 0.149 | 1.748 | 0 | 0 | 0.142 | 0.244 | 0.161 | 1.89 | 0.630 | 0 | 12-12-77 1250-1435 | |
| A-6-0 | 0.143 | 0 | 0 | 0 | 0.16 | -0.017 | 1.645 | 0 | 0 | 0.063 | 0.160 | -0.017 | 1.805 | 0.413 | 0.04 | 12-12-77 1435-1512 | |
| A-7-0 | 0.417 | 0 | 0 | 0 | 0.402 | 0.015 | 2.354 | 0 | 0 | 0.242 | 0.400 | 0.017 | 2.596 | 1.125 | 0.093 | 1512-1700 | |
| A-8-0 | 0.297 | 0 | 0 | 0 | 0.059 | 0.238 | 1.15 | 0 | 0 | 0.100 | 0.037 | 0.260 | 1.25 | 0.211 | 0 | 2100-2217 | |
| E-11-1 | 1.091 | 0.774 | 0.305 | 2.07 | 0.658 | 0.433 | 3.35 | 0.116 | 1.28 | 0.16 | 0.643 | 0.447 | 3.51 | 1.20 | 0.210 | 2217-0300 | |
| F-2-0 | 1.253 | 0 | 0 | 0 | 0.851 | 0.402 | 1.20 | 0 | 0 | 0.210 | 0.781 | 0.472 | 1.41 | 2.25 | 0.016 | 0300-0825 | |
| F-3-0 | 0.154 | 0 | 0 | 0 | 0.151 | 0.003 | 1.100 | 0 | 0 | 0.102 | 0.151 | 0.003 | 1.202 | 0.5 | 0.028 | 0825-0905 | |
| TOTAL | 32.828 | | | | 18.186 | 14.542 | | | | | 16.936 | 15.892 | | 45.519 | 2.453 | | |

# APPENDIX 15

## DETERMINING MINIMUM COST CROSS SECTIONS FOR LINED CHANNELS[1]

Tom Trout[2]

In lined channels, the material costs are usually a function of the volume of material used. On a per unit length basis, costs will be a function of the cross section area of lining material. The capacity of a given channel also depends upon the cross sectional shape. By utilizing these two relationships, minimum cost cross sections can be determined.

For our purposes, the different lining techniques being tested and installed in Pakistan will be divided into three cases:

1. Partial linings with no bottom;
2. Linings where the same type and thickness of material is used on the bottom and sides; and
3. Linings where the costs of bottom and side materials are different.

In the first case, a minimized cost cannot be derived because there is no cost associated with bottom width. The section should be as wide and shallow as is practical. If the sediment covered channel bottoms have low infiltration rates, as is commonly the case, this case represents a practical, low-cost alternative.

In case two, the cost of material for a given required thickness will be proportional to the length of the wetted perimeter. The objective will be to minimize the wetted perimeter required to achieve the required capacity. A common example of this case is poured concrete trapezoidal channels.

The third case will be the most complex. The costs will vary with different shapes and dimensions; all of which have the same capacity. For example, any number of combinations of bottom widths and depths in a rectangular channel will convey the same amount of water, but only one will minimize the costs.

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1/Presented at the Pakistan Engineering Congress Seminar on Low-Cost Structures, Lahore, Pakistan. April, 1978.

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## BASIC EQUATIONS

The flow capacity of a channel is determined by Manning's Equation:

$$Q = (1/n)\ AR^{2/3}S^{1/2}, \tag{1}$$

Where

$Q$ = flow rate ($m^3$/sec),

$n$ = roughness coefficient (between .015 - .020 for lined channels),

$A$ = cross sectional flow area ($m^2$),

$R$ = hydraulic radius = $A/WP$ (m),

$WP$ = wetted perimeter (m),

$S$ = slope (m/m).

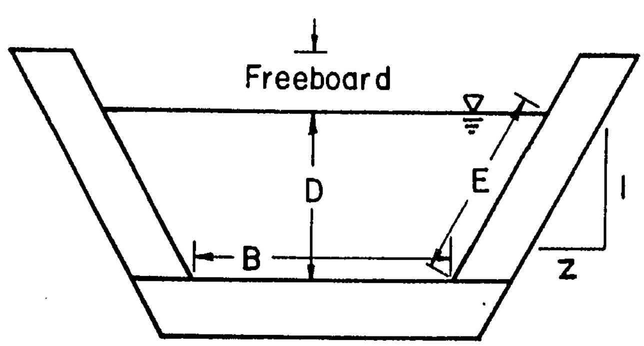
For a given channel, Q, n and S are generally established by the local conditions. The design parameters the engineer must determine are A and R, such that:

$$AR^{2/3} = \frac{Qn}{S^{1/2}} \tag{2}$$

The left side of equation 2 will be termed the hydraulic section, and will be used to indicate the geometrical capacity of the channel. The objective will be to minimize costs for a given required hydraulic section.

Material costs, as stated, are usually a function of the volume of material used. If thickness requirements of the respective materials are specified, then costs on a unit length basis will be a function of length of the wetted perimeter constructed of that material. Figure 1 illustrates the cost calculation for a trapezoidal channel where the base and side material costs are different.

Figure 1. Definition of dimensional terms used in cost calculations for trapezoidal channels.



$$C = bB + 2dE + k \qquad (3)$$

$$C = bB + 2dD\sqrt{z^2 + 1} + k \qquad (4)$$

Where

C = material cost (Rs/m length)

B = bottom width (m)

D = depth (m)

E = length of sides (m)

z = side slope (horizontal to vertical)

b = cost of base material (Rs/$m^2$)

d = cost of side materials (Rs/$m^2$)

k = a constant to take into consideration costs of freeboard materials, corners, etc. (Rs)

## A MINIMUM COST ANALYSIS OF THE SEPARATE CASES

### Case I. Partial Linings with no Bottoms

As stated, since there is no material cost associated with bottom width, this case cannot be optimized to minimize material costs. There are, however, two other types of costs associated with increasing the bottom width. First, there is a cost associated with land taken out of production. Agricultural land in Pakistan normally sells for between Rs 2.5 to Rs 5.0 per square meter (Rs 10,000 to Rs 20,000 per acre).

The second cost is of the lost water which seeps through the unlined bed. Seepage rates through watercourse channel beds are usually less than 1 cm per hour and often below 0.5 cm/hr. At a 0.5 cm/hr seepage rate, a sarkari khal channel which is used on the average of 36% of the time (Trout, 1979), will seep about 15 $m^3/m^2$ of water per year. This water, at Rs 0.1 per $m^3$ (Rs 120/ac-ft), will have an annual value of Rs 1.5; or an initial value, assuming a project life of 20 years and a capital value of 12% per year, of Rs. 11.

With these cost values associated with the bottom width, the partial lining case can be optimized by the same methods as will be presented for Case III.

Since these bottom costs will usually be about half as large as the material costs for the sides, these partially lined sections will still tend to be wide and shallow and practical considerations will often be more limiting than economic considerations.

Cast II: Linings Where the Costs of Base and Side Materials are Equal

For this case, cost is a function of wetted perimeter, and the objective is to minimize the wetted perimeter for a given hydraulic section, or maximize the hydraulic section, $AR^{2/3}$, for a given wetted perimeter.

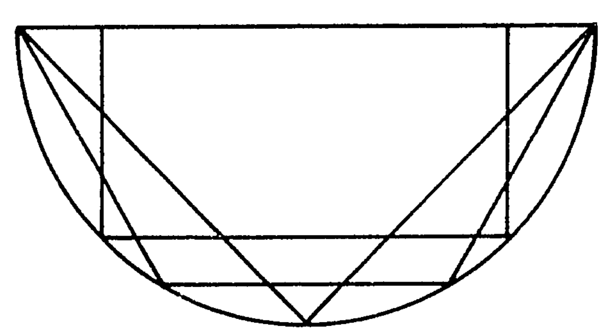
Since:

$$\frac{AR^{2/3}}{WP} = \frac{A \times \frac{A^{2/3}}{WP^{2/3}}}{WP} = \left(\frac{A}{WP}\right)^{5/3} = R^{5/3} \qquad (5)$$

the problem reduces to that of maximizing the hydraulic radius or determining the minimum wetted perimeter that can encompass a given area. The maximum obtainable hydraulic radius for any geometric shape is one-half the depth (D/2)(Albertson, et al., 1960).

A half circle is the most efficient hydraulic section. The minimum wetted perimeter for any other shape will occur when the sides are proportioned such that the shape can be inscribed by a semicircle (Albertson, et al., 1960), as shown in Figure 2.

Figure 2. Hydraulically Optimum Cross Sectional Shapes.



As the number of sides decrease, the length of wetted perimeter required for a given hydraulic section increases. Table 1 gives a comparison of the wetted perimeter lengths required to achieve a hydraulic section of 0.1 for each of the shapes shown in Figure 2.

Table 1. Minimum wetted perimeter required to give a hydraulic section of $AR^{2/3} = 0.1$ for various geometric shapes.

| Geometric shape | Minimum wetted perimeter | % of half circle WP value |
|---|---|---|
| Half circle | 1.33m | 100% |
| Trapezoid | 1.41m | 106% |
| Rectangle | 1.55m | 117% |
| Triangle | 1.55m | 117% |

Table 1 indicates that required wetted perimeters increase 6% from a semicircular to a trapezoidal section and 10% from the optimum trapezoidal to a rectangular section. If material costs vary only with wetted perimeter, they will likewise increase. Of course, differences in labor and installation costs between these sectional shapes could overshadow this difference in material costs.

The trapezoidal shape with the minimum hydraulic radius is a half hexagon where $D = \sqrt{3}/2\ B$ and $z = 1/\sqrt{3}$. If a trapezoidal section with side slopes other than the optimum are desired, the hydraulic radius will be minimized when

$$D = \frac{B}{2(\sqrt{z^2+1} - z)} \quad \text{(Albertson et al., 1960)} \qquad (6)$$

For example, if it is desired to construct a section with a 1:1 side slope ($z = 1$), then $D = 1.21\ B$ will give the least wetted perimeter and the lowest cost. Its wetted perimeter will be about 4% longer than that for the optimum trapezoidal section. Equation 6 can also be used to design trapezoidal sections to reduce losses in earthen watercourses if it is found that losses are strictly a function of wetted perimeter length.

The basic optimum dimensions required for a design of each cross sectional shape can be computed. The formulas for the half circle, rectangle, and trapezoid are given in Table 2. The derivations for these equations are given in Appendix 1.

Table 2. Formulas for designing minimum cost half circle, rectangle, and trapezoidal sections.

| Shape | |
|---|---|
| Half circle | $D = 1.00\left(\frac{Qn}{S^{1/2}}\right)^{3/8}$ |
| Rectangle | $B = 1.83\left(\frac{Qn}{S^{1/2}}\right)^{3/8}$ with $D = B/2$ |
| Trapezoidal | $B = 1.12\left(\frac{Qn}{S^{1/2}}\right)^{3/8}$ with $D = \frac{\sqrt{3}B}{2}$ and $Z = 1/\sqrt{3}$ |

## Case III: Linings Where Costs of Base and Side Materials are Different

In order to determine minimum cost cross sections where different material costs are involved, the equation for the hydraulic section, $AR^{2/3}$, must be solved such that the cost function is minimized. Mathematically this problem is the same as the classical microeconomic problem of minimizing production costs through input (i.e. capital and labor) substitution. Our "production function" is the equation for the hydraulic section. Our inputs are the cross sectional dimensions.

The basic solution technique involves determining the input mixture at which the ratio of the marginal products equals the ratio of the marginal costs.

This mix can be determined for any number of inputs utilizing the Lagrange Multiplier technique, although the mathematics can become very complex. Computer optimization techniques are possible for complex problems.

The only lined channel cross sectional shapes presently being installed or considered utilizing multiple materials in Pakistan are rectangular or trapezoidal. The equation for the hydraulic section of the trapezoidal channel is:

$$AR^{2/3} = \frac{\left[BD + zD^2\right]^{5/3}}{\left[(B + 2D\sqrt{z^2 + 1}\right]^{2/3}}$$

where the parameters are as defined in Figure 1. The cost function is given in equation 4. The rectangular section is the special case where $z = 0$. Although the minimum cost combination can be determined with three input parameters, the algebra involved in the solving of the three simultaneous equations becomes extremely complex.

It was consequently decided to treat the side slope as a constant reducing the problem to one with only two variables. By solving the same problem for a number of side slopes, the optimum side slope and dimensions can be iteratively determined. Under most practical conditions, the choice of side slope is somewhat constrained by the materials and methods employed.

The optimization method involves determining the dimension combination such that the marginal change in hydraulic section is equal to the marginal changes in costs (Eq. 8) and the equation for the hydraulic section (Eq. 2) is satisfied.

$$\frac{\dfrac{\partial(AR^{2/3})}{\partial B}}{\dfrac{\partial(AR^{2/3})}{\partial D}} = \frac{\dfrac{\partial C}{\partial B}}{\dfrac{\partial C}{\partial D}} \tag{8}$$

$$AR^{2/3} = \frac{Qn}{S^{1/2}} \tag{2}$$

Thus we have two simultaneous equations with which to determine the minimum cost combination of B and D.

The algebra involved in solving these equations for trapezoidal channels is given in Appendix 2. The solution is:

$$B = \left[\frac{[1 + 2\sqrt{z^2+1}\ (D/B)]^2}{[(D/B) + z(D/B)^2]^5} \left(\frac{Qn}{S^{1/2}}\right)^3\right]^{1/8} \tag{9}$$

Where:

$$D/B = \frac{e + \sqrt{e^2 + 20(b/d)a}}{2a} \tag{10}$$

and:

$$e = 6\sqrt{z^2+1}\ [(b/d) - 1] + 10z(b/d)$$

$$a = 20(z^2+1) - 4z\sqrt{z^2+1}\ [1 + 4(b/d)]$$

By inserting the desired side slope and side cost to base cost ratio (b/d) into these equations, the minimum cost bottom width and depth can be determined. By solving the equations for several z values, the minimum cost side slope can also be found. Once the desired dimensions are determined the unit material cost of the channel can be calculated with Equation 4.

Most lined channels presently being constructed in Pakistan are rectangular. Under this condition, z = 0, and Equations 9 and 10 reduce to:

$$B = \left[\frac{[1 + 2(D/B)]^2}{(D/B)^5} \left(\frac{Qn}{S^{1/2}}\right)^3\right]^{1/8} \tag{11}$$

Where:

$$D/B = \frac{e_o + \sqrt{e_o^2 + 400(b/d)}}{40} \tag{12}$$

and:

$$e_o = 6[(b/d) - 1]$$

The optimum dimensions can also be determined graphically by plotting equations 7 and 10 for various values of z and choosing the point where the appropriate lines cross. Figures, 3, 4, 5, 6 and 7 are plots of these equations for z = 0, 0.33, 0.5, 0.67, and 1.0 respectively.

To utilize the figures, first choose the figure with the desired z value. Then calculate the hydraulic section (Eq. 2), and follow this $AR^{2/3}$ line until it crosses the line emanating from the origin which represents the desired material cost ratio (b/d).

The point where the two lines cross represent the minimum cost B and D values on the two axes. Total costs can be found by inserting these B and D values into Equation 4.

If this B and D combination is for some reason undesirable, alternative combinations which fulfill the hydraulic requirements can be found by moving along the $AR^{2/3}$ line in either direction. Again, total costs can be calculated by plugging the chosen B and D values into Equation 4.

Additional costs involved in moving away from the optimum dimension combination can also be determined graphically. Draw a line through the optimum point (where the $AR^{2/3}$ and (b/d) lines cross), tangent to the $AR^{2/3}$ curve until it crosses the B axis. Then extend a line from the chosen dimensions, parallel to the first line, until it also crosses the B axis. The difference in the two $B_o$ values on the axis ($\Delta B_o$) times the unit cost of B(6) will give the additional costs ($\Delta C$).

$$\Delta C = b(\Delta B_o) \tag{13}$$

A PRACTICAL EXAMPLE OF LINED CHANNEL DESIGN

It is desired to line a 500 meter section of watercourse channel near a heavily trafficked area to avoid deterioration of the banks and reduce water losses. The design slope of the section is .0004. The design flow is 0.06 $m^3$/sec (about 2 csc). The roughness coefficient, n, will be taken as 0.017 for lined channels. Thus the hydraulic section, $AR^{2/3} = Qn/S^{1/2} = 0.051$.

The material costs at the construction site are:

| | |
|---|---|
| Bricks: | Rs 250 per 1000 |
| Cement: | Rs 30 per bag |
| Sand: | Rs 30 per $m^3$ |
| Aggregate: | Rs 100 per $m^3$ |

At these rates, 1:2:4 concrete will cost about Rs 300/$m^3$ and brick masonry about Rs 225/$m^3$.

Because the construction site involves some fill area and is in coarse textured soils, it was decided that lining the base as well as the sides is desirable.

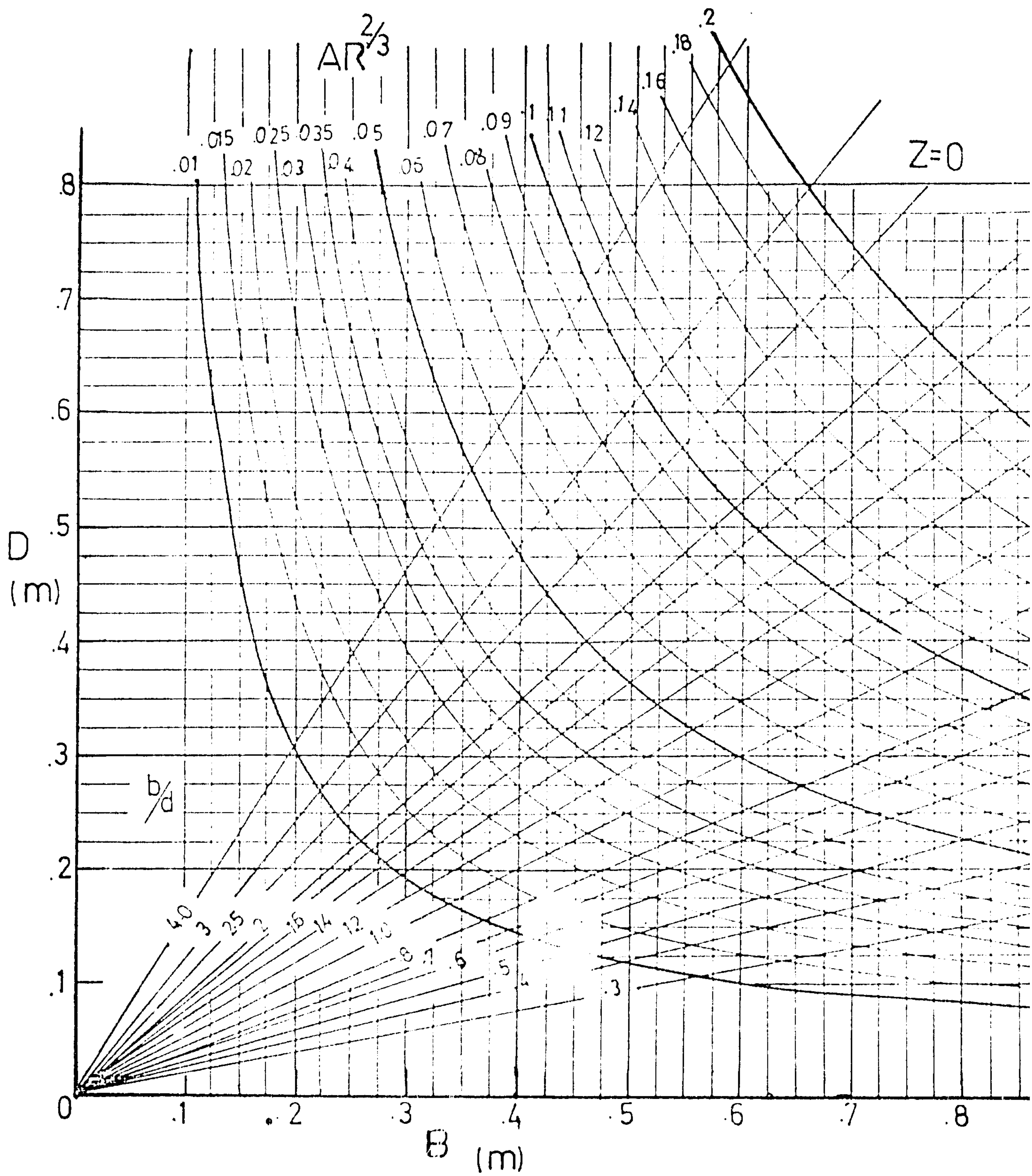



Figure 3. Nomograph for Determining Minimum Cost Dimensions of Small Lined Rectangular Channels (b/d = side wall cost (Rs/m$^2$) ÷ base cost (Rs/m$^2$); and $AR^{2/3} = Qn/S^{1/2}$).

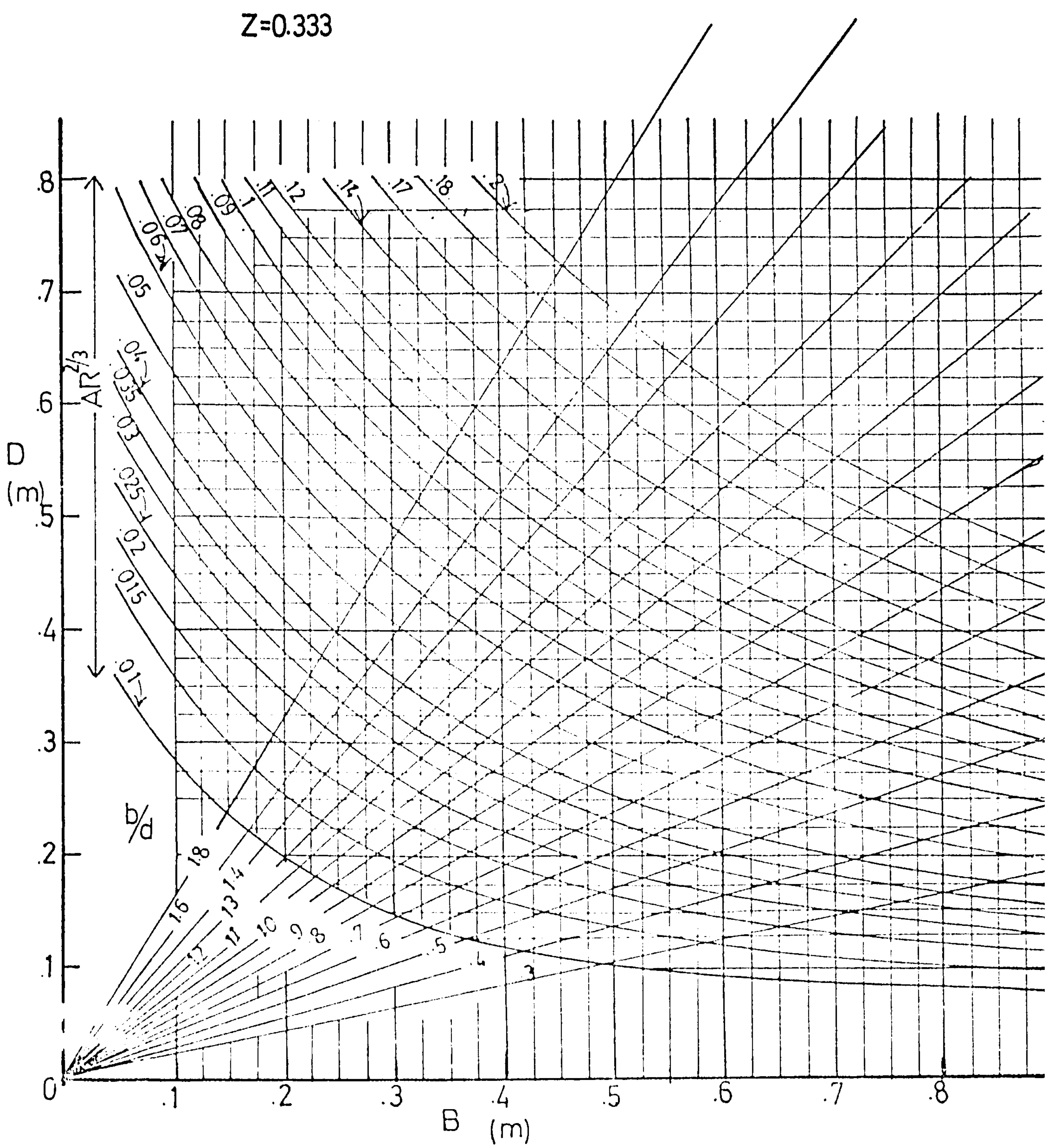



Figure 4. Nomograph for Determining Minimum Cost Dimensions of Small Lined Trapezoidal Channels with Side Slope (z) = 0.333; (b/d = side wall cost (Rs/$m^2$) ÷ base cost (Rs/$m^2$); and $AR^{2/3} = Qn/S^{1/2}$).

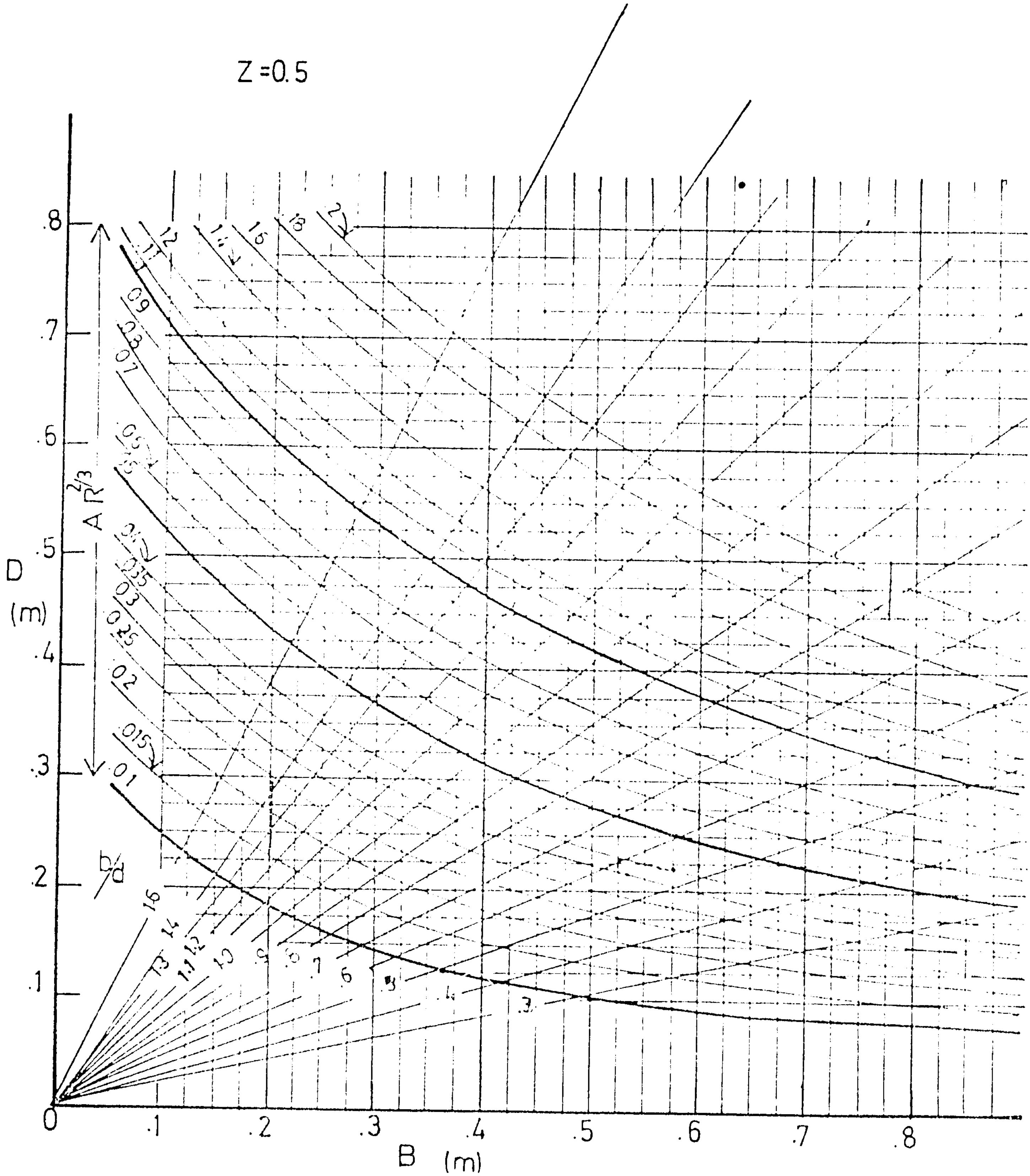



Figure 5. Nomograph for Determining Minimum Cost Dimensions of Small Lined Trapezoidal Channels with Side Slope (z) = 0.5; (b/d = side wall cost (Rs/$m^2$) ÷ base cost (Rs/$m^2$); and $AR^{2/3} = Qn/S^{1/2}$).

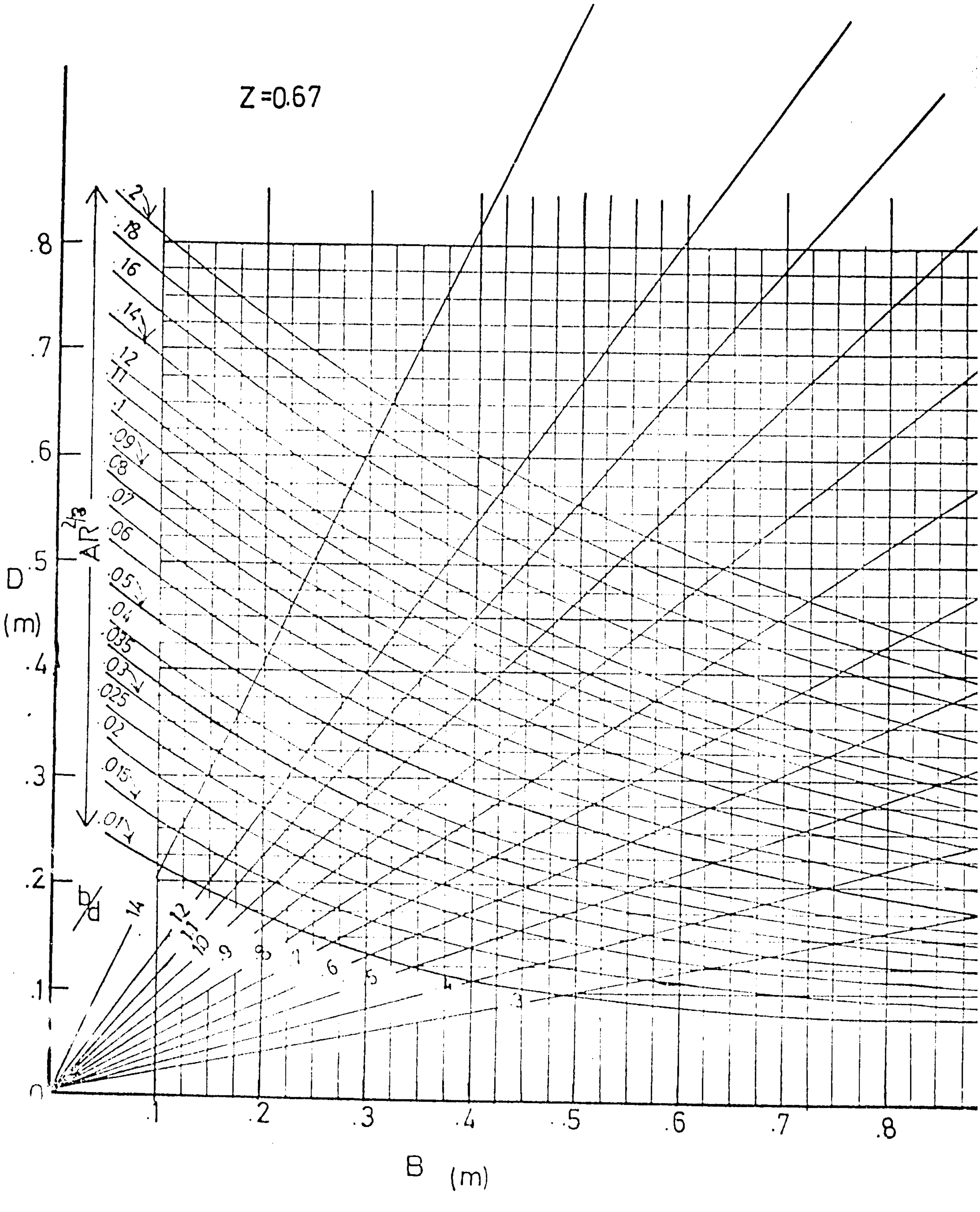



Figure 6. Nomograph for Determining Minimum Cost Dimensions of Small Lined Trapezoidal channels with Side Slope (z) = 0.67; (b/d = side wall cost ($Rs/m^2$) $\div$ base cost ($Rs/m^2$); and $AR^{2/3} = Qn/S^{1/2}$).

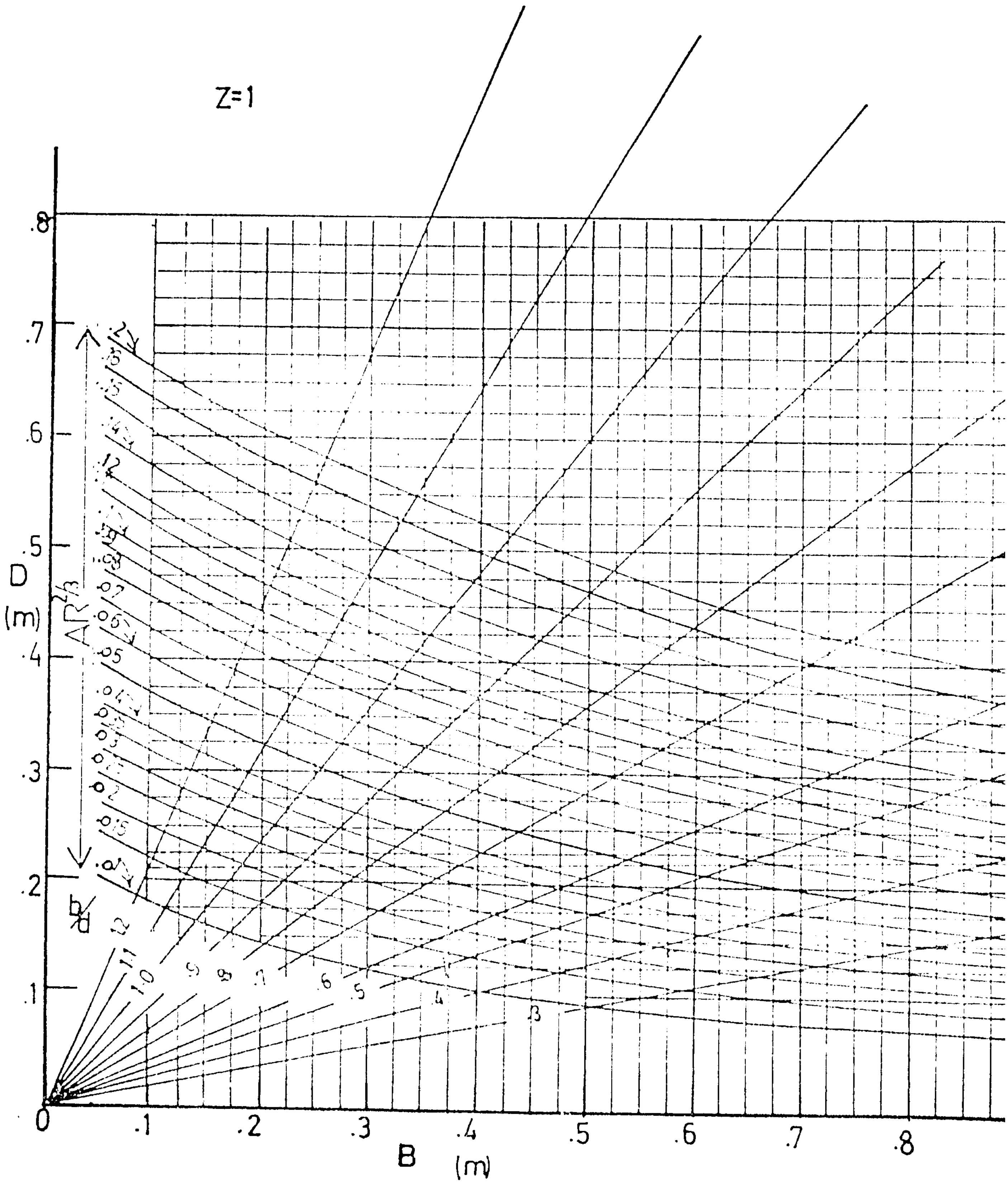



Figure 7. Nomograph for Determining Minimum Cost Dimensions of Small Lined Trapezoidal Channels with Side Slope (z) = 1; (b/d = side wall cost ($Rs/m^2$) ÷ base cost ($Rs/m^2$); and $AR^{2/3} = Qn/S^{1/2}$).

The cross sectional shape with the smallest wetted perimeter is the semicircle. This shape can be made by RCC pipe manufacturers at a price of about Rs. 75 per meter diameter per meter length at the factory. Our channel requires a depth of:

$$D = 1.00 \left(\frac{Qn}{S^{\frac{1}{2}}}\right)^{3/8} = .33\text{m}$$

or a diameter of 0.66 m, and would cost Rs. 50 per meter. Freeboard requirements (15 cm) would increase the cost, and would be difficult to install. Transport would further increase the price.

If section lengths were sufficiently long, the concrete pipe making machine could be moved to the field, eliminating the need for reinforcement and reducing transport costs. Material costs could be reduced to about Rs. 28/m with 6 cm thick 1:1½:3 concrete and 15 cm freeboard (which would be attached later). Labor costs would be relatively high.

The next lowest wetted perimeter alternative is the trapezoidal section given in Table 2. The required dimensions would be B=.37m, z=.58, and D=.48m including 0.15m freeboard. Material costs of a 8 cm thick 1:2:4 poured in place concrete lining would be about Rs 35/m. The form costs would be extra, but forms could be reused for other sections. Labor costs will depend upon the process and equipment utilized and supervision.

The commonly used lining material in Pakistan is brick masonry both in one and two brick (11 and 23 cm respectively) wall thickness. Although brick masonry bottoms are commonly used, a rigid base such as poured concrete, will greatly add to the strength and stability of the section, especially in fill areas where compaction will be a problem. Material cost parameters for such sections would be:

| 11 cm wall thickness | 23 cm wall thickness |
|---|---|
| b = Rs 24/m$^2$* | b = Rs 24/m$^2$* |
| d = Rs 26/m$^2$ | d = Rs 52/m$^2$ |
| k = Rs 17/m** | k = Rs 30/m** |

*1:2:4 concrete 8 cm thick

**z = 0 (rectangular section)

for $z \neq 0$: $k = \text{Rs } 9.4 + 7.8(\sqrt{z^2+1})$ for 11 cm walls and

$k = \text{Rs } 14.9 + 15.5(\sqrt{z^2+1})$ for 23 cm walls.

Because vertical side walls are easier to construct, it was decided to first calculate the minimum costs of a rectangular section. The optimum dimensions and costs are determined from Figure 3 and/or Equations 11, 12 and 4 to be:

| 11 cm wall thickness | 23 cm wall thickness |
|---|---|
| B = .62 m | B = .83 m |
| D = .29 m | D = .22 m |
| C = Rs. 47/m | C = Rs. 73/m |

In order to check how much the costs can be reduced by utilizing sloping sides, Equations 9, 10, and 4 were iteratively solved for varying z values. It was found that, with 11 cm walls, the minimum cost side slope is with z = .35 and costs are reduced by Rs. 1.5/m or about 3%. With 23 cm walls, the minimum cost side slope is at z = .2 and costs are reduced by Rs. 0.5/m or less than 1%. The reduction in material costs for both cases was deemed insufficient to outweigh the extra labor and supervisory costs that would be involved in making sloping sides.

There is an advantage to sloping side walls which will, under some conditions increase their economy. The weight of sloping side walls opposes the back pressure from the soil outside the watercourse. Thin-walled linings will fail most often as a result of this back pressure, especially if they are built in cut areas or adjacent to roadways and/or the surrounding soil is often saturated. If the side walls are sloping, less strength is required in the walls to oppose this force, and thinner, lower cost wall materials can be used.

Since the lined section is passing through a heavily trafficked area, it is desirable to keep the bottom width as narrow as possible so that crossing is easier and so that animals will be less likely to enter and damage the watercourse.

The costs associated with other than optimum dimensions were calculated and are shown in Figure 8. It can be seen from this figure or from studying Figure 3, that costs increase slowly at first, and then more and more rapidly as the dimensions vary from the optimum. Decreasing B from 0.62 m to 0.40 m would increase costs by 9% with 11 cm wall thickness lining. Decreasing from 0.62 to 0.5 m would involve only 2% additional costs. With 23 cm lining, decreasing B from 0.83 m to 0.40 m increases cost by 22% and to B = 0.5, by 9%.

If culverts would eliminate most of the inconvenience created by a wider section, it would be cheaper to install a reinforced concrete slab walking culvert (which would cost less than Rs. 100) each 50 meters than to reduce the bottom width of a 11 cm lining from B = 0.5 m to B = 0.4 m.

Again, the back pressure must be considered when determining the dimensions. As depth increases, the back pressure force on the walls increases and a stronger, thicker wall must be designed. So, depth should be maintained as small as is practical. It should be remembered that 0.15 m of

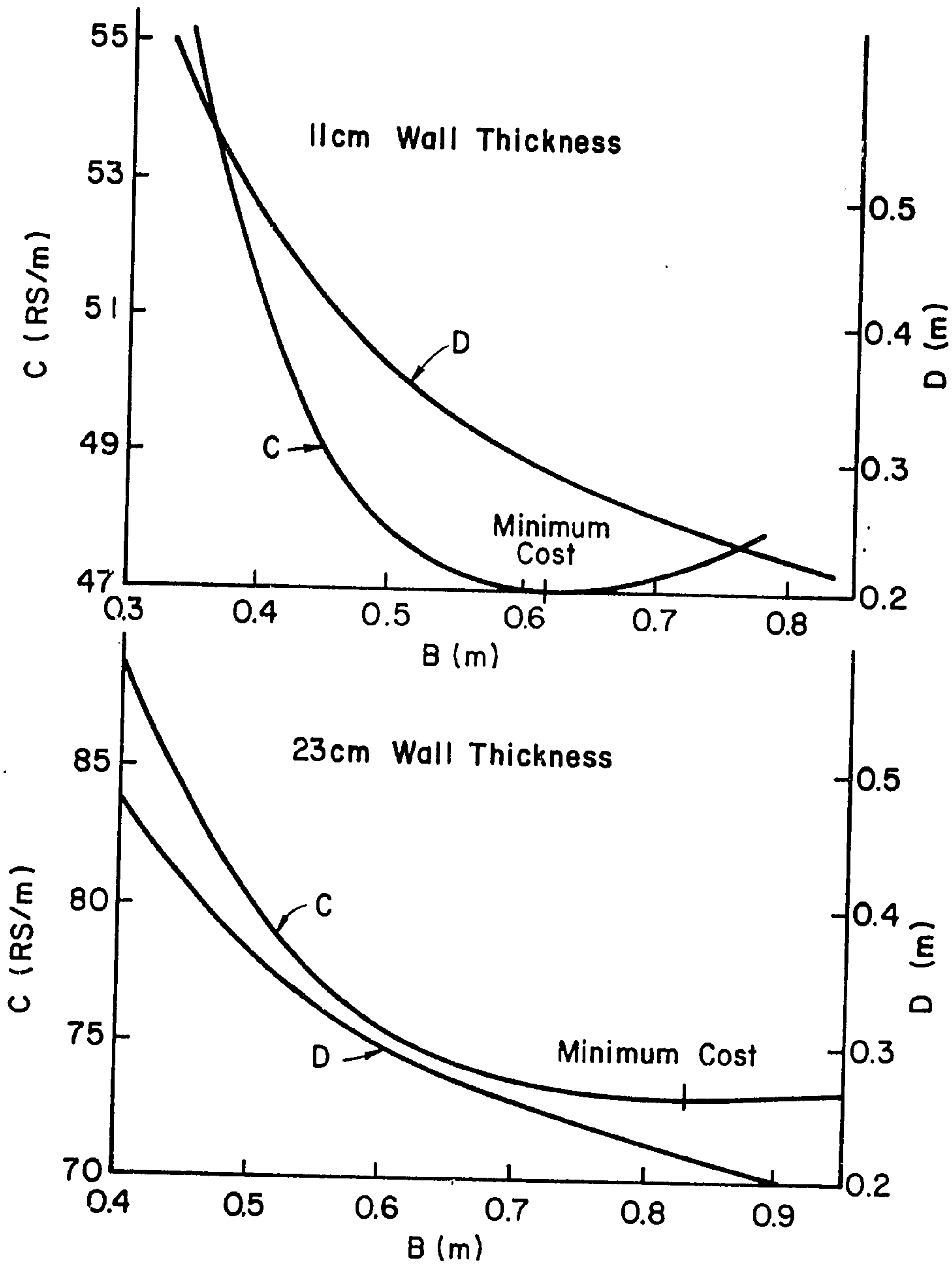



Figure 8. Cost (C) vs. Bed Width (B) for 11 cm and 23 cm Wall Thickness Rectangular Channel for the Practice Example Watercourse.

freeboard is added to the calculated depth (D) to get actual wall height.

In light of this analysis this designer would recommend rectangular cross sections with a 11 cm wall thickness through most of the lined section, and a 23 cm wall thickness through a portion where a roadway runs beside the watercourse. The dimensions and costs of both sections would be:

| 11 cm wall thickness | 23 cm wall thickness |
|---|---|
| B = 0.5 m | B = 0.6 m |
| D = 0.36 m | D = 0.30 m |
| C = Rs 48/m | C = Rs 76/m |

## CONCLUSIONS

1. Designing lined channels, utilizing the cost minimization techniques given can significantly reduce material costs with a small investment of the designer's time.

2. Even if the minimum cost design is not desirable, the additional costs involved in other cross sections can be determined and used to evaluate alternatives.

3. Under most cost conditions, the cost reduction involved in building sloping side walls on trapezoidal channels rather than rectangular cross sections will be small.

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APPENDIX 1. DERIVATION OF MINIMUM WETTED PERIMETER DIMENSIONS FOR VARIOUS SHAPES

1. Semi Circle (where radius = D):

$$\frac{Qn}{S^{\frac{1}{2}}} = AR^{2/3} = \frac{\pi D^2}{2}\left(\frac{\pi D^2/2}{\pi D}\right)^{2/3} = \frac{\pi D^2}{2}(D/2)^{2/3} = \frac{\pi}{2^{5/3}} D^{8/3}$$

$$D = \frac{2^{5/3}}{\pi}\frac{Qn}{S^{\frac{1}{2}}}^{3/8} = 1.00\left(\frac{Qn}{S^{\frac{1}{2}}}\right)^{3/8}$$

2. Rectangle (D = B/2):

$$\frac{Qn}{S^{\frac{1}{2}}} = AR^{2/3} = \frac{(BD)^{5/3}}{(B + 2D)^{2/3}} = \frac{(B(B/2))^{5/3}}{(B + B)^{2/3}} = \frac{(1/2)^{5/3}B^{10/3}}{2^{2/3}B^{2/3}} =$$

$$\frac{B^{8/3}}{2^{2/3}} \qquad B = 2^{7/8}\left(\frac{Qn}{S^{\frac{1}{2}}}\right)^{3/8} = 1.83\left(\frac{Qn}{S^{\frac{1}{2}}}\right)^{3/8}$$

3. Trapezoid ($D = \sqrt{3}/2B$ and $Z = 1/\sqrt{3}$):

$$\frac{Qn}{S^{\frac{1}{2}}} = AR^{2/3} = \frac{(BD + zD^2)^{5/3}}{(B + 2D\sqrt{z^2+1})^{2/3}} = \frac{((\sqrt{3}/2)B^2 + 1/\sqrt{3}(\sqrt{3}/2)^2B^2)^{5/3}}{(B + 2(\sqrt{3}/2)B\sqrt{(1/\sqrt{3})2} +1)^{2/3}}$$

$$= \frac{(\sqrt{3}/2 + \sqrt{3}/4)^{5/3}B^{10/3}}{(1 + 2(\sqrt{3}/2)(2/\sqrt{3}))^{2/3}B^{2/3}} = \frac{(3\sqrt{3}/4)^{5/3}}{3^{2/3}}B^{8/3} = \frac{3^{11/6}}{4^{5/3}}B^{8/3}$$

$$B = \left(\frac{4^{5/3}}{3^{11/6}}\frac{Qn}{S^{\frac{1}{2}}}\right)^{3/8} = 1.12\left(\frac{Qn}{S^{\frac{1}{2}}}\right)^{3/8}$$

APPENDIX 2. DERIVATION OF EQUATIONS 9 AND 10

For a trapezoidal channel:

$$AR^{2/3} = \frac{A^{5/3}}{WP^{2/3}} = \frac{(BD + ZD^2)^{5/3}}{(B + 2D\sqrt{z^2+1})^{2/3}} \tag{7}$$

and $C = bB + 2D\sqrt{z^2+1} + k$ (4)

The optimum is found where the ratio of the marginal outputs equals the ratio of the marginal costs, or where:

$$\frac{\dfrac{\partial(AR^{2/3})}{\partial B}}{\dfrac{\partial(AR^{2/3})}{\partial D}} = \frac{\dfrac{\partial C}{\partial B}}{\dfrac{\partial C}{\partial D}} \tag{8}$$

$$\frac{\partial(AR^{2/3})}{\partial B} = \frac{(5/3)DA^{2/3}WP^{2/3} - (2/3)A^{5/3}WP^{-1/3}}{WP^{4/3}} = (A/WP)^{2/3}$$

$$[(5/3)D-(2/3)(A/WP)]\,\frac{\partial(AR^{2/3})}{\partial D}$$

$$= \frac{(5/3)(2zD + B)A^{2/3} - (2/3)(2\sqrt{z^2+1})A^{5/3}WP^{-1/3}}{WP^{4/3}}$$

$$= (A/WP)^{2/3}[(5/3)(2zD + B) - (4/3)\sqrt{z^2+1}\ (A/WP)]$$

$$\frac{\partial C}{\partial B} = b$$

$$\frac{\partial C}{\partial D} = 2d\sqrt{z^2+1}$$

Plugging into (8) above:

$$\frac{(A/WP)^{2/3}[(5/3)D - (2/3)(A/WP)]}{(A/WP)^{2/3}[(5/3)(2zD + B) - (4/3)\sqrt{z^2+1}\ (A/WP)]} = \frac{b}{2\sqrt{z^2+1}\ d}$$

$$10\sqrt{z^2+1}(D) - 4\sqrt{z^2+1}(A/WP) = 10z(b/d)D + 5(b/d)B - 4\sqrt{z^2+1}(b/d)(A/WP)$$

$$[10\sqrt{z^2+1} - 10z(b/d)]D + [4\sqrt{z^2+1}(b/d) - 4\sqrt{z^2+1}](A/WP) - 5(b/d)B = 0$$

Insert the equations for A and WP and multiply by WP:

$$10\sqrt{z^2+1}(BD) + 20(z^2+1)D^2 - 10z(b/a)BD - 20z\sqrt{z^2+1}\ (b/a)D^2 + 4\sqrt{z^2+1}(b/d)BD + 4z\sqrt{z^2+1}(b/a)D^2 - 4\sqrt{z^2+1}(BD) - 4z\sqrt{z^2+1}(D^2) - 5(b/d)B^2 - 10\sqrt{z^2+1}\ (b/d)BD = 0$$

Grouping terms:

$$[20(z^2+1) - 4z\sqrt{z^2+1} - 16z\sqrt{z^2+1}(b/d)]D^2 + [6\sqrt{z^2+1} - 6\sqrt{z^2+1}(b/d) - 10z(b/d)]BD - 5(b/d)B^2 = 0$$

When all terms are divided by $B^2$, the equation becomes quadratic of the form:

$$a(D^2/B^2) + e(D/B) + c = 0$$

whose solution is:

$$D/B = \frac{-e\pm\sqrt{e^2 - 4ac}}{2a}$$

Plugging the terms into this equation gives:

$$D/B = \frac{[6\sqrt{z^2+1}(b/d-1) + 10z(b/d)] + \sqrt{[6\sqrt{z^2+1}(1-(b/d)) - 10z(b/d)]^2 + 20(b/d)[20(z^2+1) - 4z\sqrt{z^2+1}(1+4(b/d)]}}{8[5(z^2+1) - z\sqrt{z^2+1}\ (1 + 4(b/d))]} \qquad (10)$$

The second equation required to find the unique solution is the formula for the hydraulic section:

$$\frac{Qn}{S^{\frac{1}{2}}} = AR^{2/3} = \frac{A^{5/3}}{WP^{2/3}} = \frac{(BD + zD^2)^{5/3}}{(B + 2D\sqrt{z^2+1})^{2/3}}$$

This can be converted to:

$$\frac{Qn}{S^{\frac{1}{2}}} = \frac{[(D/B)B^2+z(D/B)^2B^2]^{5/3}}{[B + 2(D/B)\sqrt{z^2+1}(B)]^{2/3}} = \frac{[(D/B) + z(D/B)^2]^{5/3}}{[1 + 2\sqrt{z^2+1}(D/B)]^{2/3}}\ B^{8/3}$$

or

$$B = \left[\frac{[1+2\sqrt{z^2+1}(D/B)]^2}{[(D/B) + z(D/B)^2]^5}\ \frac{Qn}{S^{\frac{1}{2}}}^{3}\right]^{1/8} \qquad (9)$$

# APPENDIX 16

# ROUGHNESS COEFFICIENTS FOR WATERCOURSE DESIGN

Tom Trout, Zahid Saeed Khan, Hayat Ullah Khan,

and Abdul Khaliq[1/]

## INTRODUCTION

The most widely used water channel design equation where siltation and scouring are not the primary considerations, is the empirically derived Manning's Equation. This equation, shown below, is being utilized to design watercourses in Pakistan.

$$Q = \frac{1}{n} AR^{2/3}S^{1/2}, \tag{1}$$

where:

$Q$ = flow rate ($m^3$/sec),

$n$ = Manning's roughness coefficient,

$A$ = cross sectional flow area ($m^2$),

$R$ = hydraulic radius = $A/WP$ (m),

$WP$ = wetted perimeter (m),

$S$ = slope of the water surface (m/m),

The roughness coefficient in this equation, termed "Manning's n", has been calibrated in many western countries for various watercourse conditions, and values are readily available in the literature. Values vary according to the condition of the wetted perimeter (i.e., whether it is smooth or rough, the density and length of grasses, the presence of aquatic weeds, the uniformity of the cross section, etc.) Chow (1959) lists values of 0.011 to 0.020 for smooth concrete lined channels, from 0.018 to 0.025 for straight uniform clean earthen channels, from 0.025 to 0.040 for earthen channels with some weeds and grasses, and as high as 0.10 for unmaintained earthen channels with dense weeds and grasses.

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[1/] Colorado State University Water Management Research Project Agricultural Engineers. The work was supported by USAID Contract No. AID/ta-C-1411. The opinions expressed herein are those of the authors and not necessarily held by CSU or USAID.

The objective of this study was to determine whether the roughness coefficient values of Indus Basin watercourses were in the same range of values available in the literature and to determine how changes in watercourse vegetation affected the roughness coefficient, channel geometric flow parameters, such as depth and cross sectional area, and water loss rates.

PROCEDURE

Sixteen watercourse sections were studied in newly-built and aged, cleaned and uncleaned conditions. On each test section of length between 300 and 600 meters, the watercourse geometric parameters which are utilized in Manning's Equation were measured at 30 meter intervals while the watercourse was flowing at steady state. The data collection sheet utilized in this study is shown in Figure 1.

Flow rate was determined immediately upstream of the test section during the measurement period with a Cutthroat flume. After completion of the geometric measurements, a second flume was installed just below the section to determine the loss rate and average flow rate in the section. The downstream flume was not installed until after completion of the other readings because the headloss it creates and the resulting backwater effects perturbs the flow depth in the test section.

The water surface elevation was measured with a surveyor's level with the rod placed at the water surface at each 30 meter station. A graph of elevation versus distance was used to determine the slope of the water surface.

Cross sectional flow area was determined by graphically integrating (with a planimeter) five measurements equally spaced across the top width. Figure 2 shows a sample of the resulting cross sectional graph.

Wetted perimeter was determined by pressing a flexible metal measuring tape against the watercourse perimeter from one water surface to the other and measuring the wetted perimeter length directly.

Cross sectional area and wetted perimeter data were combined at each station into $AR^{2/3}$, called the hydraulic section. The hydraulic section value was then plotted vs. distance, along with the water surface elevation values. A sample of this graph is shown in Figure 3. The roughness coefficient was determined by solving Manning's equation for n.

$$n = \frac{(AR^{2/3})(S^{1/2})}{Q} \qquad (2)$$

Figure 1. DATA SHEET FOR DETERMINING MANNING'S N

Date________________

Experimenter________________

1. Choose a long (1500' - 2000') straight section with no major obstructions such as culverts.

   Location of W/C ________________

   Location of test section________________

2. Flow rate at head and tail of section. Remove downstream flume before taking other data.

Inflow

| Time | $h_a$ | $h_b$ | Q |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Outflow

| Time | $h_a$ | $h_b$ | Q |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

3. Measure wetted perimeter and cross sectional area at about 100 ft. (½ ac. intervals). WP is measured directly with tape. Area is calculated from top width of water surface and five equally spaced with depth measurements.

| Distance from start (units) | Wetted Perimeter | Top Width | Depth 1 | 2 | 3 | 4 | 5 | Area | $AR^{2/3}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Figure 1. (Cont'd)

4. Determine the FSL elevation at each 100 ft. (½ ac. interval) location. Only FSL rod readings and turning point readings are required.

| Distance from start (units) | BS | FS | IS (FSL) | RL (FSL) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |

5. Fully describe the condition of the W/C with respect to uniformity, location of obstructions or constructions, type, length and density of grasses and other types of vegetation, and any recent cleaning activities.

________________________________________

________________________________________

________________________________________

Often the slope and/or hydraulic section varied significantly within the test sections, so they were divided into subsections for which a value of the roughness coefficient was calculated.

For each studied section, a visual assessment of the condition of the watercourse wetted perimeter including cross sectional shape, uniformity, grass length and density, water weed density, and the presence of bushes was made. Bends or major obstructions, where they couldn't be avoided, were also noted, as were flow conditions downstream of the section to insure that the section was flowing uniformly and at the hydraulic normal depth.

RESULTS

The derived Manning's roughness coefficients along with a brief description of each test watercourse section is given in Table 1. The sections are listed generally by increasing amount of vegetation and roughness. Listed with the roughness coefficient is the range of values calculated within each subsection resulting from variations in slope and hydraulic section.

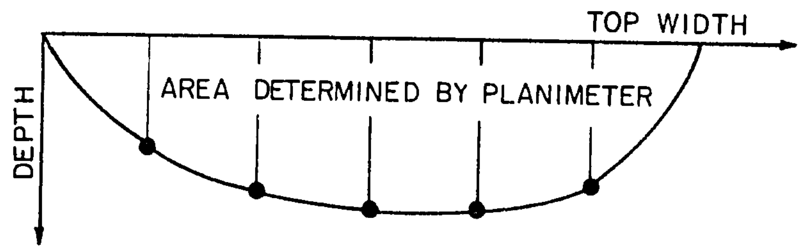


Figure 2. Graphical cross-sectional flow area determination.

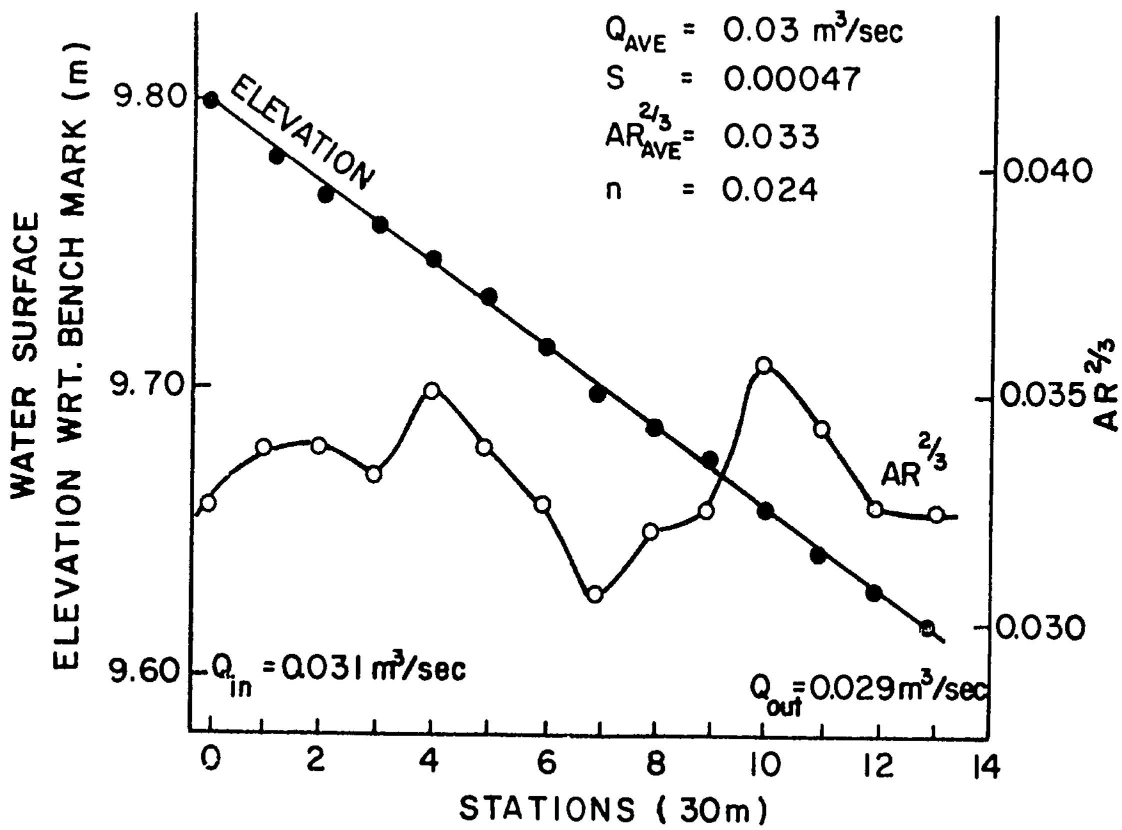


Figure 3. Graphical presentation of channel hydraulic parameters.

Table 1. Derived Manning's "n" Values for the Studied Watercourse Sections

| | Section Location | Wetted Perimeter Description | Sub Section | Average n value and range |
|---|---|---|---|---|
| 1. | Mona TW 78 Main Channel from below TW | Unif. rect., plastered brick masonry lined, with some silt on bed, algae on sides | | .018 ± .002 |
| 2. | Mona TW 56-R Main below bend | Unif., newly built, very clean (same section - 1 month interval) | a | .020 ± .003 |
| | | | a | .017 ± .003 |
| 3. | Tikriwala #1, Branch A | Unif. recently built, recently cleaned, no grass | a | .030 ± .005 |
| | | | b | .030 ± .002 |
| | | | c | .032 ± .006 |
| 4. | Tikriwala #1, Branch M | Unif., recently built, recently cleaned, no grass | a | .020 ± .005 |
| | | | b | .018 ± .005 |
| | | | c | .027 ± .005 |
| 5. | Tikriwala #1, Branch D | Unif., recently built, recently cleaned, no grass | a | .018 ± .004 |
| | | | b | .022 ± .005 |
| | | | c | .018 ± .006 |
| 6. | Samundri, Chak 474 Main channel from mogha | Winding, aged; clean, smooth W.P. with few grasses at upper edge | | .026 ± .004 |
| 7. | Mianwali (MP W/C #6), Main channel | Uniform, aged; clean smooth W.P. | a | .026 ± .005 |
| | | | b | .014 ± .004 |
| 8. | Moro (MP W/C #52), Main below mogha | Winding, non-unif., aged, fairly clean with little vegetation | a | .040 ± .004 |
| | | | b | .028 ± .008 |
| 9. | Mona TW 56-L, G Branch from Nawaz Dhera | Unif., recently built, recently cleaned, short (3 cm) grasses on W.P. | a | .018 ± .004 |
| | | | b | .035 ± .006 |
| | | | c | .031 ± .005 |
| 10. | Mona TW 56-R, Main below mogha | Unif., recently built, recently cleaned, few floating aquatic weeds | a | .050 ± .005 |
| | | | b | .030 ± .004 |
| 11. | Tikriwala #1, Branch B | Non-unif., aged, clean bottom and grassy (3-6 cm) sides | a | .040 ± .004 |
| | | | b | .035 ± .003 |
| 12. | Mona TW 440, Branch E Near mogha | Non-unif., wide and sandy, aged, clean bottom and grassy sides | a | .041 ± .006 |
| | | | b | .053 ± .006 |
| 13. | Faisalabad Chak 4 (Ram Diwali), Main below mogha | Fairly Unif., aged, clean bottom and grassy (10 to 15 cm) sides | | .062 ± .015 |
| 14. | Mona, TW 140, Branch G | Non-unif., sandy, aged, clean bottom some grass on sides | | .097 ± .010 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 15. | Mona TW 77, Main channel from mogha | Fairly unif., aged, very grassy (15 cm) in most placed, aquatic plants in some areas | | .042 | ± | .005 |
| 16. | Mona TW 56-R Main below mogha | Unif., recently built, grass on sides and very extensive anchored floating aquatic plants throughout | a<br>b | .35<br>.18 | ±<br>± | .08<br>.04 |

The first watercourse section listed in Table 1 is a rectangular section lined with plaster brick masonry with some silt deposits on the bottom and algae growth on the sides. The derived n value is 0.018. This is a little higher than average values given in the literature, but well within published ranges.

The next four test sections, numbers 2 through 5, were recently renovated earthen watercourses in very clean and uniform condition. Roughness coefficient values vary from 0.017 to 0.032 with an average of 0.023. This again is slightly higher than average values given in Chow (1959), but well within the listed ranges.

The following two listed watercourse sections are old, but clean with very little vegetation on the wetted perimeter, and fairly uniform. One n value derived was very low (0.014) while the other two were both 0.026.

The unimproved and irregular Moro watercourse section had little vegetation. Roughness values for two subsections were 0.028 and 0.040.

The following two sections listed, numbers 9 and 10, are recently rebuilt sections which had been cleaned 2 to 4 weeks prior to the measurements and had short grasses on the wetted perimeter. The n values varied widely from 0.018 to 0.05. The high value could have been caused by a few floating water weeds left in the watercourse after cleaning. Three of the five values fall between 0.030 and 0.035. This is again in the higher range of values listed in Chow (1959) for similar conditions.

Four aged watercourses with clean bottoms but grassy (7-15 cm length) sides had roughness coefficients measured between 0.035 and a very high 0.097. The high value was in a steep sloping section that appeared no worse than the others and the finding is suspect. The average of the remaining five values is 0.046. This is significantly higher than the range of values listed by Chow (1959) which are 0.025 to 0.033 for "winding and sluggish channels with grass and weeds."

Tubewell 77 watercourse, which was unimproved and the uniform; and improved TW 56-R section (this is the same section measured twice before in newly constructed and very clean, and somewhat clean conditions) were measured while in very poor condition. The grasses, especially in TW 77 watercourse, were thick and about 15 cm long, and the anchored floating aquatic weeds, especially in TW 56-R watercourse, were very extensive. The n value derived for the first section was 0.042. In the two sub-sections of the second watercourse the values were found to be 0.18 and 0.35. These last two values are very high, much higher than is listed for the worst possible conditions in Chow (1959). Small measurement errors could not explain such high values. During the week following the measurements, the watercourse was cleaned, and although the inflow increased from 20 l/sec to 100 l/sec, the flow depth was about the same. This indicates that the n value must have decreased to about one-fifth its previous value. One measurement does not verify that such high values are valid, but it does introduce the possibility.

As part of the measurement procedure, channel cross sectional shapes were also determined. It is interesting to note the variations in average depths (D), top widths (TW), and shapes. In unimproved channels, ratios of top width to maximum depth varied from 1.4 to 5.4 and averaged about 3. The ratio was smaller in larger channels, as depths increased more than top width with larger capacity channels. Table 2 lists the average values for the hydraulic and geometric parameters for each watercourse section.

The common cross sectional shapes varied from circular to trapezoidal. The best generalized formula found to model the various cross sectional shapes is a power curve of the form:

$$y = w\,x^{p} \tag{3}$$

Where

x and y are the two coordinate directions associated with width and depth, and

w and p are determined to best fit the physical model.

Figure 4 depicts a sample of this model for w = 2.5 and p = 3. The slopes of the wetted perimeter at the water surface averaged a little less than 1:1, but are highly variable.

## DISCUSSION OF THE FINDINGS

Manning's roughness coefficient values empirically measured in this study in Pakistan watercourses were generally higher than those reported in the literature (generally measured in the U.S.A.). In the lower value ranges, the difference

Table 2. Average Hydraulic and Geometric Parameters of the Studied Watercourse Sections

| | Section Location | S (m/1000m) | Q ($m^3$/sec) | A ($m^2$) | TW (m) | $D_{max}$ (m) | V (m/sec) | WP (m) | $AR^{2/3}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Mona TW 78 Main Channel from below TW | 0.34 | 0.040 | 0.14 | 051 | 0.26 | 0.29 | 1.01 | .030 |
| 2a. | Mona TW 56-R | 0.15 | 0.088 | 0.44 | 1.50 | 0.40 | 0.20 | 1.75 | .14 |
| a. | Main below bend | 0.15 | 0.072 | 0.35 | 1.40 | 0.32 | 0.21 | 1.60 | .10 |
| 3a. | Tikriwala #1, Branch A | 0.58 | 0.035 | 0.15 | 0.85 | 0.24 | 0.23 | 0.95 | .043 |
| b. | | 0.47 | 0.034 | 0.16 | 0.75 | 0.26 | 0.21 | 0.94 | .047 |
| c. | | 0.91 | 0.032 | 0.13 | 0.72 | 0.24 | 0.25 | 0.84 | .037 |
| 4a. | Tikriwala #1, Branch M | 0.83 | 0.042 | 0.12 | 0.78 | 0.25 | 0.35 | 1.04 | .030 |
| b. | | 1.08 | 0.044 | 0.11 | 0.84 | 0.23 | 0.40 | 1.00 | .025 |
| c. | | 1.00 | 0.045 | 0.14 | 0.89 | 0.39 | 0.32 | 1.10 | .038 |
| 5a. | Tikriwala #1, Branch D | 0.91 | 0.044 | 0.13 | 0.87 | 0.18 | 0.33 | 1.00 | .027 |
| b. | | 1.40 | 0.040 | 0.12 | 0.83 | 0.21 | 0.33 | 0.96 | .023 |
| c. | | 0.40 | 0.037 | 0.13 | 0.85 | 0.23 | 0.28 | 1.00 | .033 |
| 6a. | Samundri, Chak 474 Main from Mogha | 0.77 | 0.054 | 0.18 | 0.83 | 0.30 | 0.30 | 1.14 | .050 |
| 7a. | Mianwali (MP W/C #6) | 0.61 | 0.060 | 0.21 | 0.90 | 0.33 | 0.28 | 1.25 | .062 |
| b. | Main Channel | 0.21 | 0.056 | 0.17 | 0.85 | 0.33 | 0.33 | 1.20 | .050 |
| 8a. | Moro (MP W/C #52) | 1.40 | 0.033 | 0.28 | 0.84 | 0.21 | 0.12 | 1.02 | .035 |
| b. | Main below Mogha | 0.36 | 0.031 | 0.40 | 0.96 | 0.30 | 0.08 | 1.14 | .045 |
| 9a. | Mona TW 56-L | 0.3[illegible] | 0.110 | 0.35 | 0.87 | 0.34 | 0.31 | 1.75 | .105 |
| b. | G Branch | 0.60 | 0.106 | 0.40 | 1.02 | 0.38 | 0.27 | 1.90 | .150 |
| c. | from Nawaz Dhera | 0.63 | 0.103 | 0.38 | 1.05 | 0.38 | 0.27 | 1.86 | .130 |
| 10a. | Mona TW 56-R | 1.10 | 0.101 | 0.41 | 1.60 | 0.45 | 0.25 | 1.85 | .17 |
| b. | Main below mogha | 0.53 | 0.099 | 0.33 | 1.60 | 0.47 | 0.30 | 1.75 | .12 |
| 11a. | Tikriwala #1 | 0.95 | 0.043 | 0.23 | 1.16 | 0.34 | 0.19 | 1.35 | .060 |
| b. | Branch B | 1.45 | 0.039 | 0.15 | 1.00 | 0.26 | 0.27 | 1.10 | .035 |
| 12a. | Mona TW 140, Branch E | 1.10 | 0.078 | 0.33 | 1.70 | 0.34 | 0.24 | 2.20 | .09 |
| b. | Near Mogha | 0.40 | 0.065 | 0.48 | 1.80 | 0.50 | 0.14 | 2.10 | .17 |
| 13. | Faizalabad Chak 4 (Ram Diwali) Main Below Mogha | 1.50 | 0.055 | 0.27 | 0.84 | 0.59 | 0.21 | 1.40 | .09 |
| 14. | Mona TW 140, Branch G Near Mogha | 3.80 | 0.076 | 0.30 | 1.25 | 0.23 | 0.25 | 1.15 | .105 |
| 15. | Mona TW 77, Main Channel from mogha | 0.29 | 0.028 | 0.21 | 1.02 | 0.31 | 0.13 | 1.24 | .07 |
| 16a. | Mona TW 56-R, | 1.60 | 0.021 | 0.40 | 1.70 | 0.48 | 0.05 | 2.50 | .10 |
| b. | Main below mogha | 1.90 | 0.017 | 0.30 | 1.40 | 0.36 | 0.06 | 1.60 | .06 |

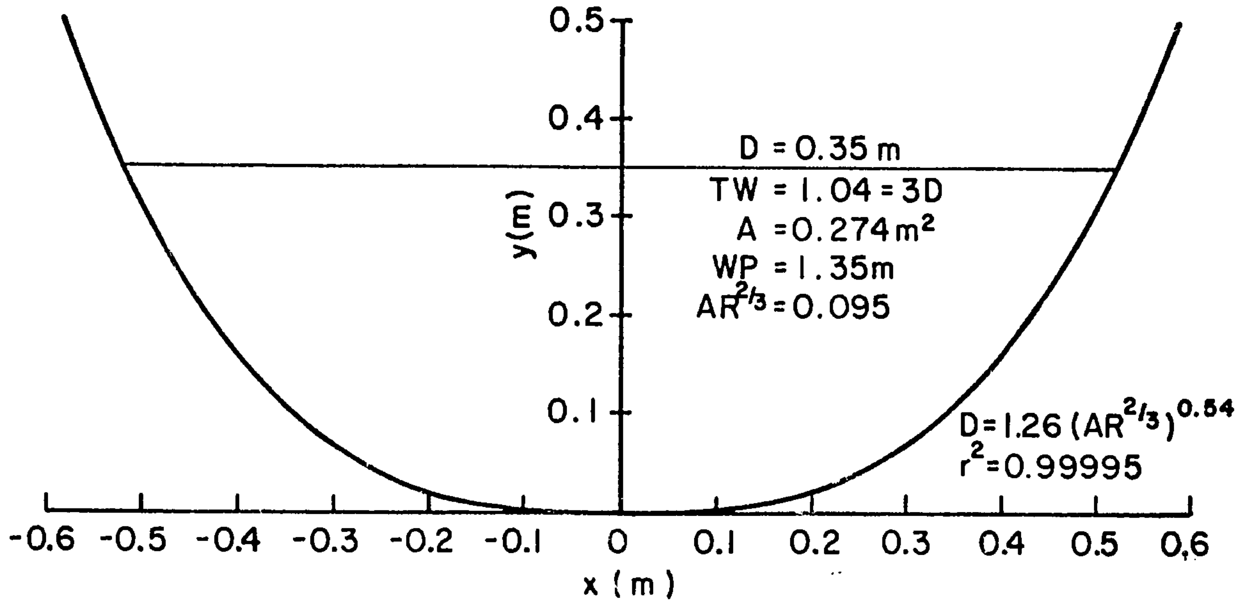


Figure 4. Watercourse cross-sectional shape model defined by Equation 3, with 2 = 2.5 and p = 3.

was not great, but at high values, the differences were large. Table 3 gives a comparison of values given in Chow with those measured in this study.

Table 3. Manning's n values for various channel conditions from Chow and derived in this study.

| Channel Condition | Manning's n Values | |
|---|---|---|
| | From Chow (1959) | Derived for Pakistan Watercourses |
| lined with brick masonry | .011-.015 | .018 |
| earthen, newly built, uniform, clean | .016-.020 | .017-.032 |
| earthen, winding, with no vegetation | .022-.033 | .030-.035 |
| earthen, uniform, with short grasses | .023-.030 | .026 |
| earthen, winding, with grass and some weeds | .025-.033 | .035-.055 |
| earthen with dense weeds | .050-0.12 | .042, .18, .35 |

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... because of
nonuniform ... found in
water... long
sections ... depth was not
affected ... variability in
measured ... channels indicate
that the ... uniform
for Manning ...

IMPLICATIONS ... LOSS RATES

It can ... that as the rough-
ness coeffic... of a channel for
carrying water ... the flow depth of
a channel ... increase. The amount
of depth increase ... increase cannot,
for all but ... shapes, be explicitly
determined; but, ... shapes and sizes of water-
courses which ... relationship tends to be of
the form:

$$D = a\left(\frac{Qn}{S}\right) \qquad (4)$$

where:

$D$ = depth of flow (m),

$a$ = an empirical constant,

$e$ = an empirical exponent, and

$\frac{Qn}{\sqrt{S}}$ = channel hydraulic section (= $AR^{2/3}$).

The constants a and b vary with channel shapes and sizes, but a tends to vary from 1.1 to 1.4 and c from 0.45 to 0.55 for the watercourses considered. If flow rate (Q) and slope (S) remain constant, the change in depth with a change in roughness coefficient becomes:

$$\frac{dD}{dn} = \left[baQ^{b}S^{-b/2}\right]n^{b-1} \qquad (5)$$

where all the values in the brackets are constant. Figure 5 depicts the change in flow depth with roughness (Eq. 4) for different values of Q and S when a = 1.2 and c = 0.5. From Figure 4 it can be seen that the flow depth in a small watercourse will increase by about 7 to 11 cm as a result of grass and weed growth that increases the roughness coefficient from 0.03 to 0.05. In a study of watercourse cleaning conducted by Akram et al. (1978), it was observed that the normal flow depth in watercourse sections decreased by about 10 to 11 cm as a result of cleaning out the grasses and weeds plus some silt removal. This observation agrees with the above analysis.

A study of the causes of watercourse water losses utilizing the ponding method for measuring losses conducted in over 100 watercourse sections (Trout, et al., 1978) determined that loss rates are very sensitive to the depth of flow relative to the usually occurring flow depth. The empirically derived relationship has the following exponential form:

$$K = K_o e^{b(\Delta D)} \qquad (6)$$

where:

$K$ = water loss rate ($m^3$/sec/100m)

$K_o$ = loss rate at the usual with flow depth ($D_o$) ($m^3$/sec/100m)

$e$ = base of the natural log

$b$ = an empirically derived exponent ($m^{-1}$)

$\Delta d$ = flow depth relative to the usual flow depth ($\Delta d = D-D_o$) (m)

Both constants, $K_1$ and B, varied widely from channel to channel. The average value for B was about 15 which implies that the loss rate doubles for each 4 to 5 cm increase in flow depth. From Figure 5 (or Eq. 5) it can be seen that a change in roughness coefficient of only 0.010 or 0.015 can cause such a depth change and consequently cause watercourse loss rates to double. Figure 6 utilizes both Equations 4 and 6 to predict the increase in the loss rate at a given roughness coefficient to the loss rate at a "clean" roughness value, taken to be 0.03. The other parameters and constants are the same as those used in Figure 5 and mentioned above.

Figure 6 indicates an extreme sensitivity of loss rate to the roughness coefficient and consequently to the condition of the watercourse. It should be noted that this analysis and the resulting figure will tend to overstate the effects because it assumes a "normal" flow depth when the watercourse is clean, when in reality the more "normal" condition would be with some grasses and weeds present on the watercourse wetted perimeter. But regardless of the adjustment made, the effect is still the same--cleaned watercourses will have lower roughness coefficient, lower flow depths, and significantly lower loss rates. Support for this finding is given in the same previously mentioned cleaning study (Akram et. al., 1978) where measured loss rates in the studied sections were about four times higher before cleaning than they were after cleaning, even though the infiltration rates into the cleaned banks would be expected to be higher due to the consequent silt removal.

## CONCLUSIONS AND RECOMMENDATIONS

1. Manning's roughness coefficients for Pakistan watercourses tend to be somewhat higher than values given in Western literature.

2. Roughness coefficients above 0.10 can be attained in watercourses with extensive floating water weeds.

3. Although "clean" watercourses will have n values around 0.03, a more conservative value of 0.04 should be used in watercourse design. This will result in an extra freeboard of 3 to 5 cm.

4. A freeboard of at least 15 cm, especially in larger, flat watercourses, should be given to allow for increased depths that will result from increasing roughness.

5. Installing outlet structures such that they will be overtopped if the water surface level exceeds design by 6 to 8 cm might be tried as a mechanism to force farmers to clean and maintain their water conveyance system.

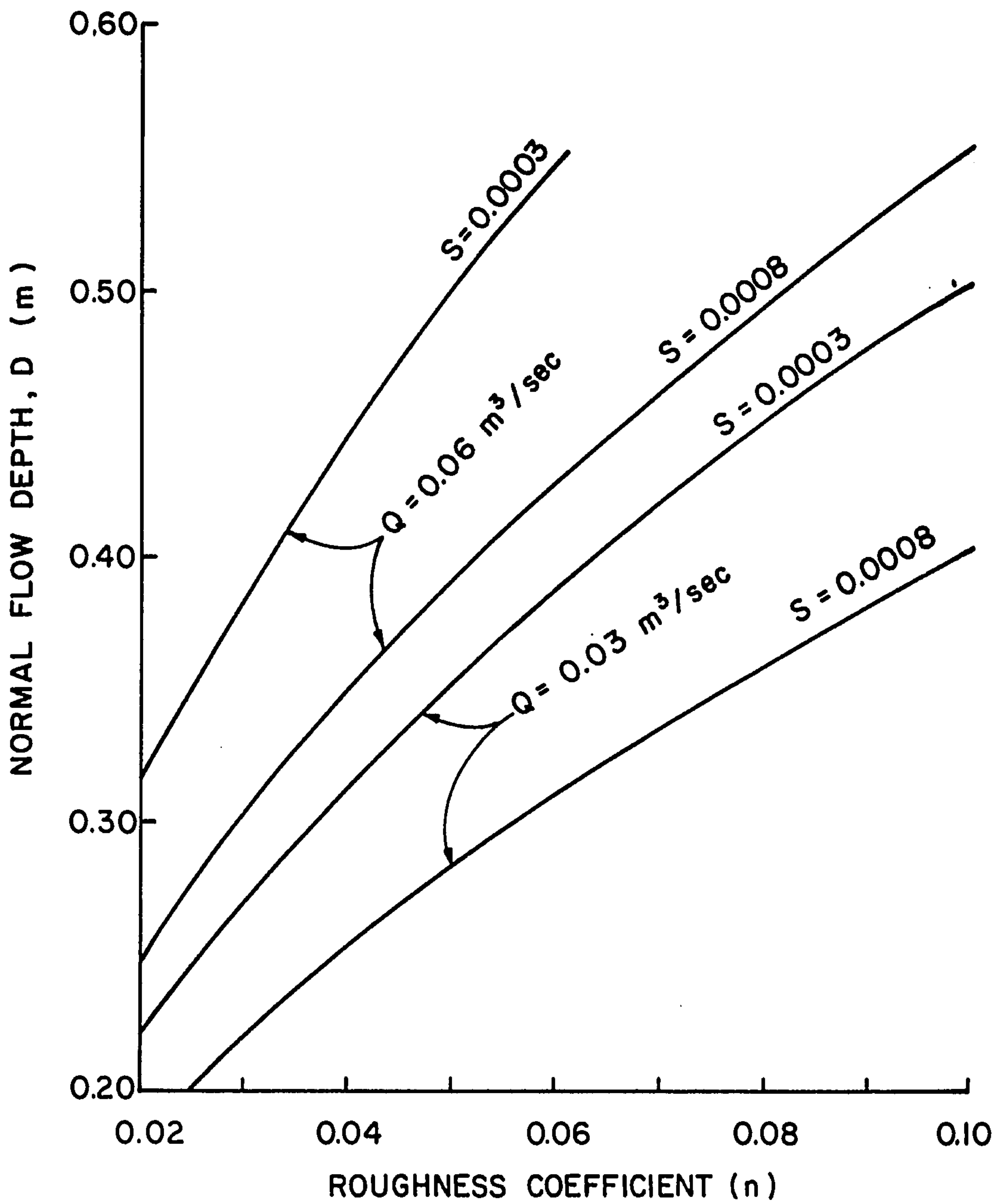


Figure 5. Variation of normal flow depth with changing roughness coefficient (from Equation 4 with a = 1.2 and c = 0.5).

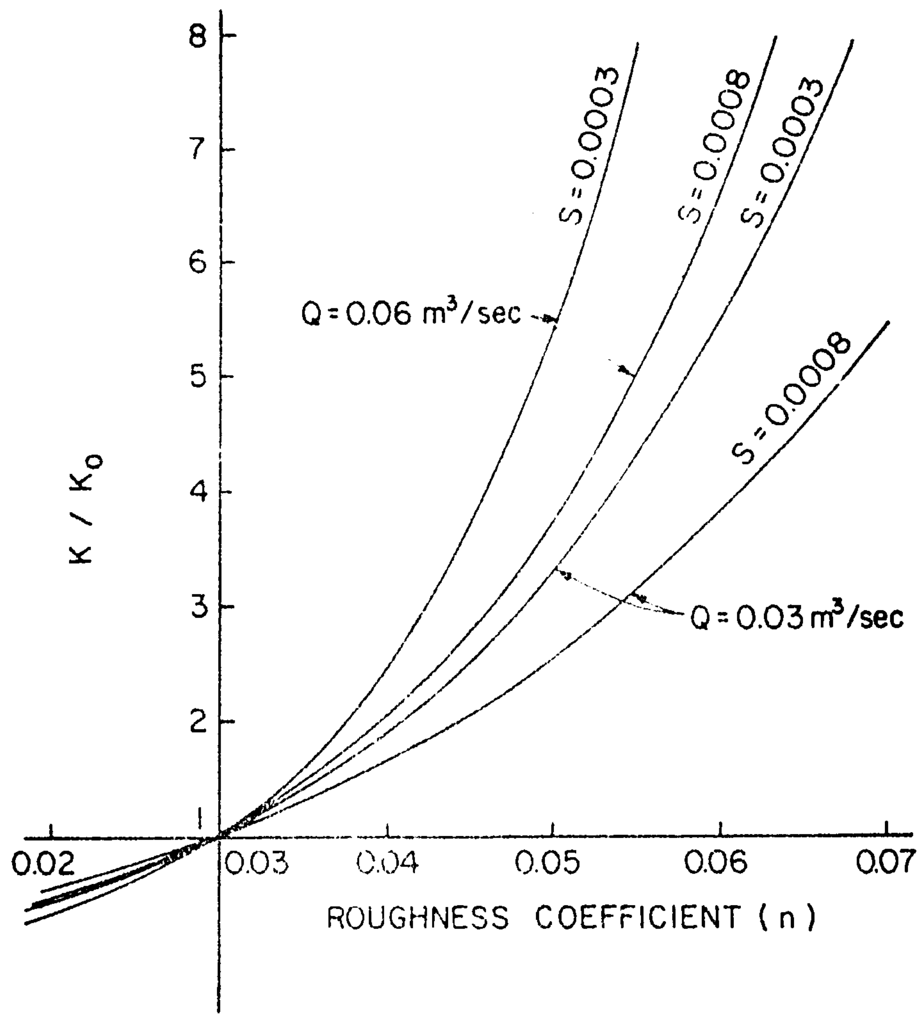


Figure 6. Relative change in loss rates ($K/K_o$) with changes in roughness coefficient (n) (from Equation 4 and 6).

6. Both flow depths and water loss rates increase rapidly with increasing channel roughness and only cleaning should reduce watercourse losses in weedy, grassy channels to a fraction of their initial values.

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# APPENDIX 17

# LOW COST FARM IRRIGATION CONTROL STRUCTURES FOR PAKISTAN[1]

Mohammad [illegible], [illegible] and Tom Trout[2]

Farm irrigation control structures are devices utilized to regulate, direct, and control irrigation water in the watercourse conveyance system. There is a need for such structures to give the farmer better control over his irrigation water, to make the job of irrigation easier, and to reduce conveyance losses in watercourses.

The control structures presently existing on nearly all of Pakistan's 2 million kilometers of watercourses in 78,000 command areas are temporary ones constructed from earth. In order to divert the water from one channel into another, the irrigator cuts a hole through the bank and then attempts to stop the flow in the original direction by building an earthen dam across the channel.

The effects of this practice are everywhere evident. Watercourse banks are weak, porous, and irregular from the many cuts. Adjoining crops are sometimes poor due to excessive water leakage. Junctions are often very much enlarged as a result of borrowing soil from inside the channel to build the dams, or crops are spoiled from the borrow pits outside the banks. Banks are thin and weak in the junction area, and water is often trickling into side branches through the porous dams which will quickly wash out. Kemper and Akram (1975) found that 45% of the losses from one leaky watercourse were from the junction area. Also, the soil which has eroded away in the process of building and breaking these dams is often partially filling the watercourse downstream from the junctions.

An additional result of the traditional water control method is the temporarily exhausted farmer who has just finished spending 10 or 15 minutes building a dam to stop and divert his water. He will wait at the junction for a while to stop any leaks in his newly built dam, and then will walk upstream to patrol the watercourse banks for leakage through previously made outlet cuts.

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1/Joint Contribution of Mona Reclamation Experimental Project and Colorado State University Water Management Research Project prepared for the International Seminar on Low Cost Structures, University of Peshawar, February 27-March 4, 1978.

2/Mona Project Director, Mona Senior Hydrologist and Agricultural Engineer, Colorado State University, respectively.

Attempts were begun at Mona Reclamation Experimental Project in cooperation with Colorado State University Water Management Research Project in 1974 to find some alternative to this traditional water control technique. This paper is a report on the structures developed during the past three years to meet this need.

BRIEF DESCRIPTION OF THE WATERCOURSE CONVEYANCE SYSTEM

The size and layout of watercourses in the Indus Basin vary widely. The "average" watercourse serves around 160 hectares of land farmed by about 40 cultivators in level bunded units less than 0.3 ha. in size. With such small holding and plot sizes, the watercourse system is necessarily extensive, often about 60 m length per commanded acre. Of that total length, about 15% is government laid out and authorized primary channels (sarkari khal) used jointly by the cultivators. The remainder are the small branches which connect the sarkari khal to a single or small group of farmers' fields. Although the length is only about 15% of the total, 80% of the channel used to convey water from the watercourse head to the field is sarkari khal. Consequently, practically all cooperative watercourse improvement programs involve only the sarkari khal.

Water is usually rotated through the watercourse system on a weekly turn rotation which begins at the watercourse head and moves through each cultivator to the last one at the tail. A farmer's irrigation time allowance is based on his land holding size. Water moves through the entire system and to each cultivator each week.

By the original design, there were usually only outlets (nuccas) from the sarkari khal about every 300 m (one square length). As land was subdivided, the need for additional nuccas grew, until there were often farmers branches leaving the sarkari khal every 60 to 120 m. Many farmers also cut the banks of the sarkari khal to allow water to run directly onto their adjoining fields.

Another important factor on most watercourses is the flat topography. There is usually less than .0006 m/m slope available to convey water through the system, and sometimes less than .0003. This means that any permanent structure through which water flows should create as little head loss as possible, so that the available slope is not wasted pushing water through structures.

A designer who wishes to install structures in a watercourse is consequently faced with a system composed of perhaps 4,000 m of sarkari khal with about 50 outlets to farmers' branches most of which are used weekly, additional unauthorized cuts directly to farmers' fields; and 20,000 m of farmers' branches with perhaps 1500 cuts leading to the fields.

TYPES OF CONTROL STRUCTURES

There are basically two types of control structures needed on most Indus Basin watercourses, outlets and checks. A third type, drop structures (energy dissipation devices), which control flow velocity, are normally not required because of the small slopes encountered. When a drop is needed, it can usually be accomplished with a small sized or properly elevated check structure and sufficient erosion control downstream.

The control structures discussed here are essentially gates for water. The objective is that when open, they do not obstruct the flow, and when closed, they do not leak. They should be low cost and made from locally available materials. They should be durable and have a long life. This implies not only strength, but also that the alternative uses or scrap value of the structure is minimal so that it is not stolen. And they should be easy for the farmer to use.

Nuccas are the gates which allow water to pass through the bank into branch watercourses or onto the field. Since those outlets into branch watercourses are the ones most extensively used, and are the only authorized outlets from the sarkari khal, field outlets will not be considered. The same structures could be used on farmers' branches as field outlets, but because of the large number required and their intermittant use, they would prove to be more expensive.

Check structures are the gates which stop the flow in the main channel to force it to flow through the nucca into the branch watercourse. They are placed across the watercourse downstream of the nucca.

Since water flowing to most fields must flow past many closed nuccas and through only one nucca, minimizing leakage is a primary consideration in nucca design. However, water will flow through several open check structures and past only one closed check, so head loss is of primary importance in check design, and leakage of secondary importance.

At junctions from which two or three major branches begin, the gates act as both checks and nuccas, and both factors are important. This combination structure is called a diversion box.

All structures discussed here are permanent. Temporary checks such as canvas dams, and temporary outlets such as siphon tubes, have wide usage in many countries. However, under the local conditions where land holdings are small, structures are jointly utilized, diversions are made from the same location on a weekly basis, only diversions into branches are considered, and available head is small, permanent structures have thus far proven more economical. If field outlets are desired, temporary structures should be considered.

Irrigation structures for use other than controlling water, such as culverts, buffalo wallows, and clothes washing stations, and low cost linings have also been developed at Mona, but will not be discussed in this paper.

## CONSTRUCTION MATERIALS

Several factors must be considered in choosing materials to be used in farm irrigation control structures. The first, of course, is that it can be fabricated into a product that can fulfill the design requirements. It must produce an effective water gate, which is durable, has a long life and is simple and easy to use. It is desirable that the material is locally available and can be utilized by local or at least regional fabricators. In this way, the growth of small local industries would be encouraged, and farmers would have ready access to replacements.

The product should also be as low cost as possible. This would reduce the cost of watercourse improvement programs, or alternately increase the number of structures which could be installed on a given budget. Also, a structure that is sufficiently inexpensive that a small farmer would purchase it for his own use would be desirable.

Table 1 lists materials which have been used in the construction of irrigation control structures. The list is divided into materials used primarily to fabricate the actual gate (frame and lid), and those used for installation of the device in the watercourse. The materials are then compared as to their relevant characteristics. Costs of frame and lid materials are calculated on the basis of the material costs of fabricating a panel 0.6 m x 0.6 m that is sufficiently strong to be utilized as a nucca lid. Installation material costs are calculated on a volumetric basis, and on the material cost of a typical nucca installation.

Each of the lid and frame materials have drawbacks. Steel is expensive and has high scrap value. Wood has a short life and high reuse value as fuel. Concrete is heavy, and unless of good quality, subject to chipping and breakage. Fiberglass is relatively expensive, and not locally available.

The choice of installation material depends primarily upon the local conditions and costs.

## FARM IRRIGATION CONTROL STRUCTURE DEVELOPMENT AT MONA

On the realization that a significant portion of Pakistan's water resource was being lost from the farm level conveyance system, work was begun at Mona to develop techniques to improve watercourse conveyance efficiencies. It was immediately recognized that improved water control structures must be an integral part of this program.

Table 1. Materials for use in watercourse water control structures.

STRUCTURE FRAME AND LID MATERIALS

| Material | Material Cost of 0.6 m x 0.6 m Panel (1) | Durability | Life | Lid Weight | Local Availability | Reuse Value |
|---|---|---|---|---|---|---|
| Mild Steel | Rs. 80 | Good | Medium | Medium | Good | High |
| Wood | Rs. 30 | Poor | Short | Light | Good | High |
| Concrete (1:1:1½ mix) | Rs. 30 | Poor to Good | Long | Heavy | Adequate | None |
| Fiberglass | Rs. 60 | Good | Long | Light | Not Available | Unknown |

INSTALLATION MATERIALS

| Material | Material Cost Rs. | Life | Local Availability | Material Cost of Typical Nucca Installation | Installation Labor Cost |
|---|---|---|---|---|---|
| Precast Concrete (1:1½:3 mix) | Rs. 400 | Long | Good | Rs. 100 (2) | Rs. 10 |
| Poured Concrete (1:2:4 mix) | Rs. 300 | Long | Good | Rs. 120 (3) | Rs. 15 |
| Brick Masonry | Rs. 220 | Long | Good | Rs. 110 | Rs. 20 |
| Soil Cement | Rs. 190 | Medium | Good | Rs. 90 (4) | Rs. 20 |

(1) Material thickness and reinforcement as required.
(2) Includes Rs. 10 casting labor charge, but not transport charges.
(3) Includes Rs. 10 form costs.
(4) Includes Rs. 20 labor charge for making blocks.
Note: Costs vary with distance from supply point.

The first structures installed in 1974 were sliding metal gates, patterned after designs which had been used in Turkey. Because of sometimes poor fabrication and installation, and rusting due to poor maintenance, many of the structures were difficult to use and leaked badly. The structures were also very costly, with the frames and gate costing Rs. 500. In light of the high cost and poor performance, alternatives better adapted to the local conditions were sought.

Concrete, being relatively cheap and durable, locally available, and familiar to regional fabricators, was the next material tested. A round shaped lid fitting into a panel was chosen, since forms for round lids could be machined on local lathes. The structure was termed circular orifice panel nuccas. The panels were installed in the watercourse in a backwards slope from 30° to 45° from vertical. The first nuccas had square shaped sealing surfaces and were made from wooden forms.

It soon became apparent that the wood forms which had been used would not maintain a constant shape during wetting and drying, and the nucca lids and panels did not seal well. So metal forms were made, and a better product produced.

Several hundred such nuccas were produced and tested in the field. Primary problems experienced were leakage and chipping and breakage of the sealing surface.

Although the casting forms were precision made, there was still not a perfect fit between the lid and panel, and small leakage occurred. Leakage through 11 such nuccas was measured about one year after they had been installed. Sixty percent leaked less than 0.1 liters per second (lps), 30% between 0.1 - 1.0 lps, and 10% greater than 1 lps. Two additional nuccas were chipped or broken and had been covered with soil.

Soft rubber strips were attached to the lids of some nuccas. Although the leakage was completely stopped when the strips were intact, they were often pulled loose or removed by passing boys. Nuccas with damaged rubber seals leaked badly.

Farmers are accustomed to stopping leakage with mud, so slots were left in the front of the panel around the lid for applying mud. Many farmers utilized this technique, although the mud often washes out after two or three days and must be replaced. Leakage through nuccas to which mud had been applied was less than half the leakage measured through nuccas without mud.

In order to evaluate structures, costs of leakage must be determined. Johnson (1977) determined that the value of supplemental water varied between Rs. 1200 and 2000 per hectare-meter (ha-m) at the root zone. We will choose a value at the nucca of Rs. 1200 per ha-m. Water flows past the average closed nucca about 30% of the time. If it leaks at 0.1 lps, about Rs. 100 worth of water per year is leaking past the nucca and being lost. A farmer near the tail of a watercourse which is flowing 50 lps would be losing 4% of his water if the water is flowing past 20 closed nuccas which are each leaking about 0.1 lps. Economically, more investment can be added to nucca development and fabrication until their marginal cost exceeds the value of the water that is saved. Practically, if nucca losses can be reduced to less than perhaps 2 or 3% of the watercourse inflow, additional work should be concentrated on other aspects of watercourse conveyance losses.

In order to reduce chipping and leakage, a curved sealing surface was tested, as shown in Figure 1. With this design, there were no sharp edges to chip, the impact force during closing was distributed evenly over a larger surface, and there was a larger surface contact area between the lid and panel to reduce leakage.

Another development made possible by the new design, was the capability of casting the panel from a metal form, and later casting the lid in the greased panel so that a perfect fit is insured. When both parts are cured, the wetted lid is rapidly rotated in the panel which slightly wears away and smoothes the sealing surface, making removal easy.

Field testing has shown that the new design is an improvement over the old one. Breakage is less if quality of fabrication is good. Leakage, although not measured, is observed to be smaller than that with the previous design, even without the application of mud.

This design is presently the one being installed in the field. Table 2 lists the number of orifice panel nuccas sold by the manufacturer (New Hassnain RCC Products, Sargoda) since 1974. Most of those supplied since 1976 have been of the last design. Additional concrete manufacturers are now attempting to produce similar products. The present cost of such panel orifice nuccas is Rs. 55 for the 50 cm diameter size, and Rs. 45 for the 38 cm diameter size.

A variation of the circular orifice nucca which was tested utilized the rim of worn out car and truck tires as the panel sealing surface. It was hoped that the flexibility of the rubber would eliminate breakage and leakage. Although the former was achieved, the rubber was sufficiently hard and sealed sufficiently imperfect, that leakage occurred. It was not determined that the concept could not work, only that it didn't work in the samples prepared.

One problem with the circular design is that it must be opened against the hydraulic pressure of the water, usually

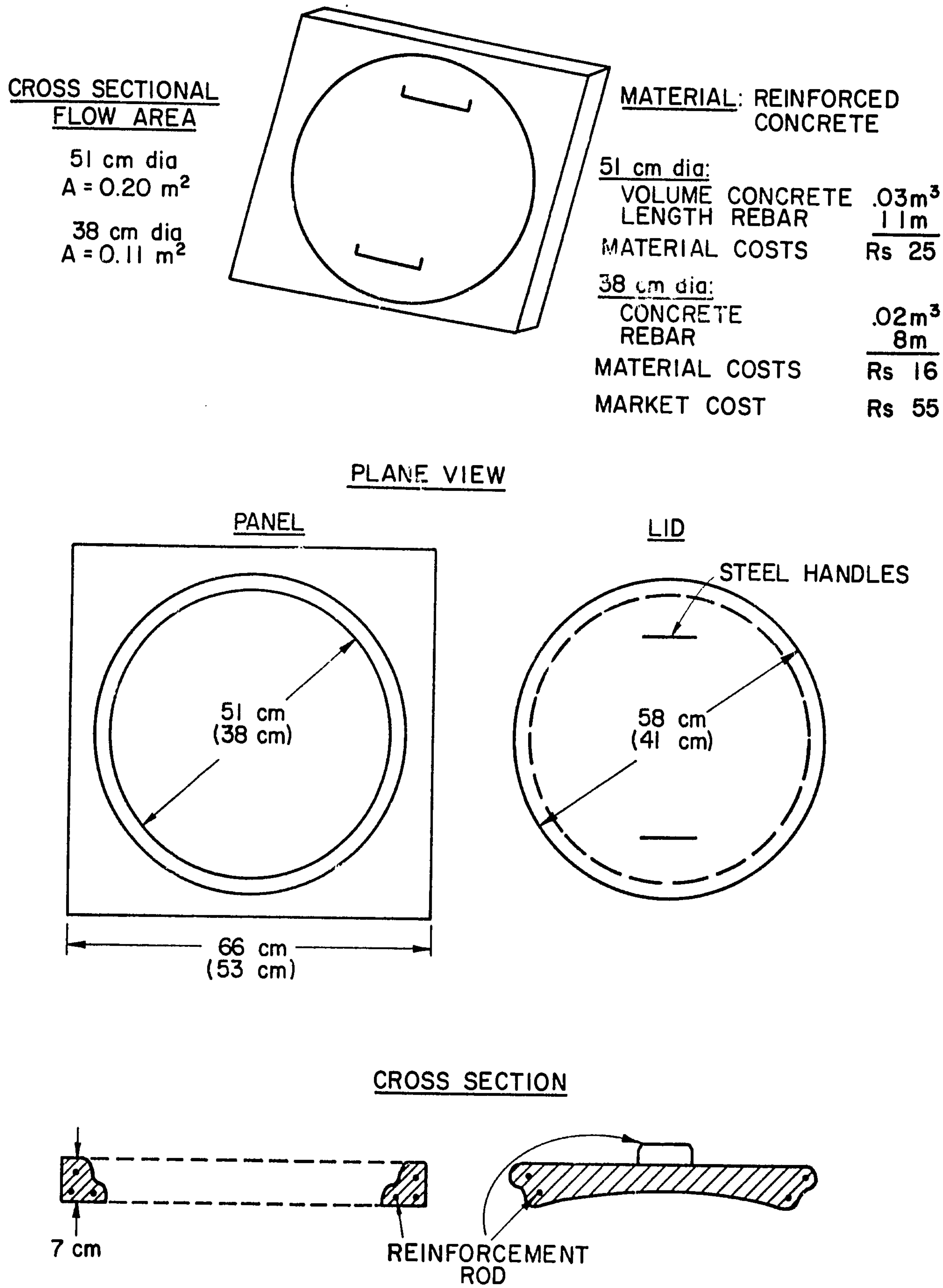


Figure 1. Circular orifice panel nucca (51 cm and 38 cm diameter)
(38 cm nucca dimensions in parentheses)

Table 2. Round orifice nuccas sold by Sargoda manufacturer since 1974

| Year | Number Sold |
|---|---|
| 1974 | 135 |
| 1975 | 313 |
| 1976 | 835 |
| 1977 | 1571 |
| 1978 | 3500 |
| Total | 6354 |

from inside the watercourse. On a 50 cm diameter lid which is nearly submerged, just hydraulic pressure will add about 20 kg to the force needed to open it.

It was consequently desired to design a lid that could be removed from above. First attempts to this end were on rectangular sliding nuccas. The nuccas were very easy to use, but leaked badly. After several attempts, it was determined that it was very difficult to produce a large flat plate and frame that was perfectly flat, and the slightest warp produced a large leak.

The next attempt was a trapezoidal shape shown in Figure 2, where the edge of the lid also served as a sealing surface, so that exact flatness was not as important. The design also allowed the lid to be cast in the panel, or in this case, the panel to be prepared around the precast lid, to insure a perfect fit. Since the lid cannot be spun in the panel, as was the case with the circular shape, the smooth sealing surface is more difficult to achieve. Very good quality casting is required. Also, the forms, which cannot be made on a lathe, are more costly and less precise. Sharp edges were again avoided wherever concrete-on-concrete contact would be made. This nucca is still in the testing stages. It can stop leakage as well as the orifice nucca. But sediment which deposits on the bottom panel lip is tedious to remove completely and causes incomplete closure and large leakage. In the circular design, a spin of the lid would smooth out and distribute this silt around the sealing surface.

Another disadvantage of the trapezoidal shape is that the lid area must include sufficient freeboard to prevent overtopping, which increases the weight of the lid.

It is hoped that, on smaller capacity watercourses (less than 50 lps) this trapezoidal lid can be a viable alternative to the circular orifice.

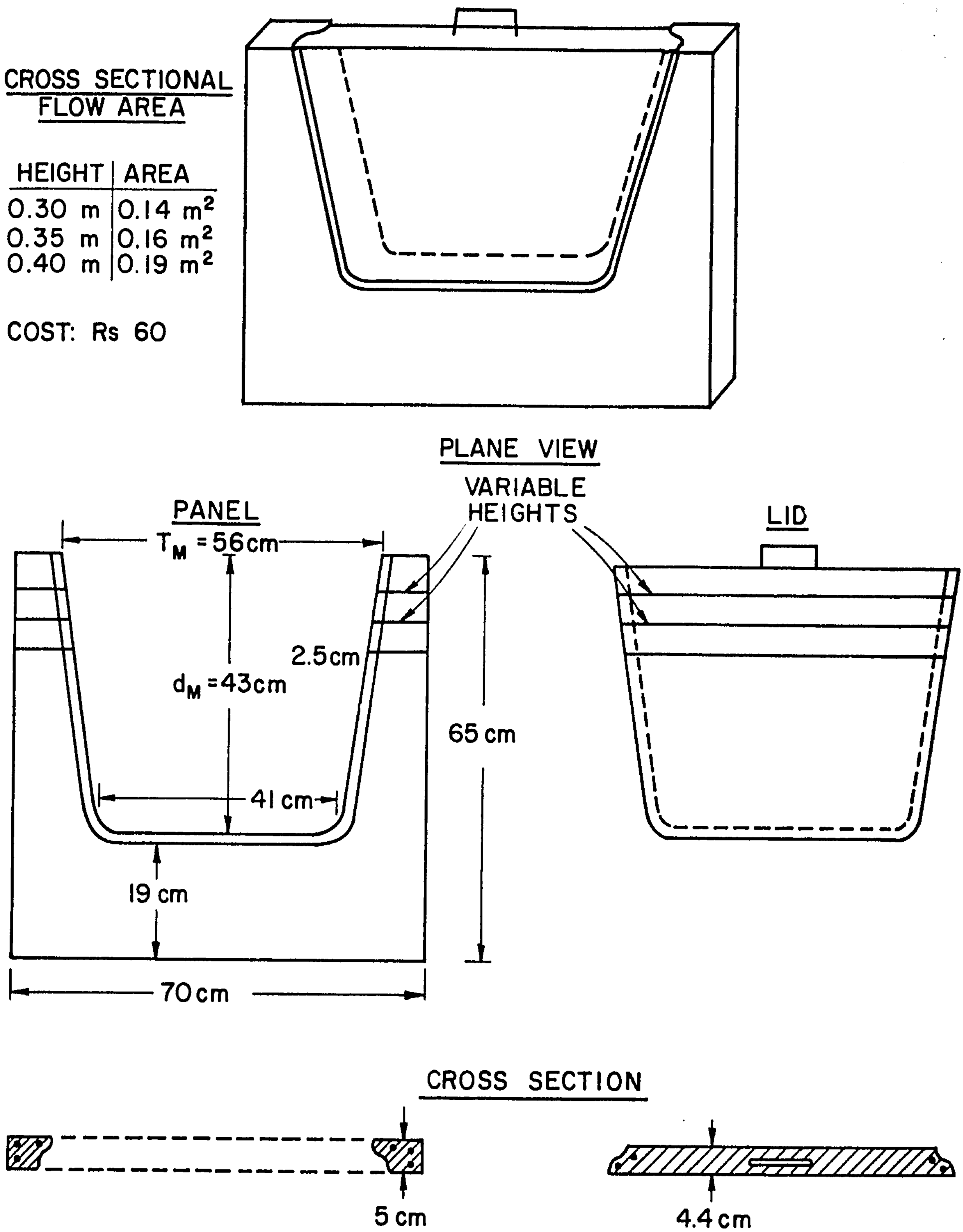


Figure 2. Trapezoidal panel nucca.

For watercourses where the flow rate is small (< 50 lps) or slope is large and head loss through structures is not important, the previously described nuccas can also be used as check structures. However, on large volume watercourses, as is often found in public tubewell supplemented areas, and where slopes are small, too much head loss is consumed in the smaller sized structures. Structures with larger openings are required (head loss is approximately inversely related to the square root of the opening area). Large size concrete lids become very heavy and difficult to handle.

There are three possible solutions. One is to place two regular nuccas side by side. This nearly doubles the cost, the work of the farmer, and the leakage, but reduces the head loss by 75%.

A second is to design a large lid which rotates or slides on the panel, so that its entire weight need not be lifted. Sliding lids in rectangular frames, such as previously mentioned, have been used for this purpose. A second design which has been tested is composed of a panel with a rectangular hole upon which lies a flat lid which is larger than the hole. The lid is pinned to the panel on a top corner and swivels around the pin, sliding on the surface of the panel. Both designs allow a large opening size in a concrete structure. Both leak significantly more than the nucca designs previously mentioned.

Since only one check is closed at one time, the leakage is not additive, and higher leakage can be suffered. A check which leaks .5 lps and is used 10 hrs per week will leak Rs. 100 worth of water per year, and lose 1% of the flow on a 50 lps watercourse. If the structures are designed for mud application, most leakage still can be eliminated.

The third possible solution to the large check problem is to use light weight lid materials. Fiberglass is one material being tested. Precision fiberglass lids and slides which are later cast into a concrete panel can be fabricated. Steel can also be used, if a proper seal can be developed.

Additional work and development needs to be done on large size check structures.

All structures discussed thus far are panels and lids. They can be directly installed into lined watercourses. In earthen watercourses, where nearly all are presently being utilized, a special installation must be made. The purpose of the installation is to support the panel, prevent leakage around the panel, and prevent erosion of the banks.

Some alternative installation materials are listed in Table 1. The most commonly used is brick masonry. Materials and masons are available in every village. A common installation is shown in Figure 3. The cost of this installation is about Rs. 110 for materials plus Rs. 20 for the labor. So a complete orifice nucca would cost about Rs. 185.

The importance of the cutoff wall should be pointed out. Local masons and laborers (and often engineers) are usually not aware of the importance of compaction required to stop leakage around structures. The cutoff walls do not eliminate the need for compaction, but they do decrease the degree required.

Alternative building materials for this type of installation include precast concrete blocks, where aggregate is inexpensive, or soil cement, where material costs must be minimized. Soil cement block will reduce total costs by about 10% and material costs by 25%. The life of well made, plastered soil cement is not yet fully known, but thus far appears to be comparable to bricks.

Much supervisory time is required to install nuccas with masonry. Often two months is consumed only installing structures on a watercourse. Also, in this time many cuts have already been made through the banks of the newly reconstructed watercourses. So it has been attempted to reduce this time factor through the use of precast installations. The primary advantages are of time saved and uniformity of quality. Thus far some difficulty has been experienced transporting the slabs to the site; and total costs, including transportation, is running higher than the masonry installations. Three types of precast installations are being tested. The first involves slotted wing walls into which the panels slide. The second, shown in Figure 4, utilizes precast sides and base which support an enlarged front panel from behind. The third is a pipe installation in which a 4 foot length of reinforced concrete pipe cut at the proper angle, is attached to the rear of the panel and then buried in the watercourse bank.

Where aggregate is inexpensive, cast-in-place concrete installations are a durable alternative. They have not been tested at Mona.

## RECOMMENDATIONS

On the basis of the practical experience of developing, installing and testing of different low cost irrigation control structures, the following recommendations are made:

1. Precast reinforced concrete is a recommended material for fabricating nuccas. It has many advantages including cost, life, and availability. Recommended installation materials will depend upon the local conditions.

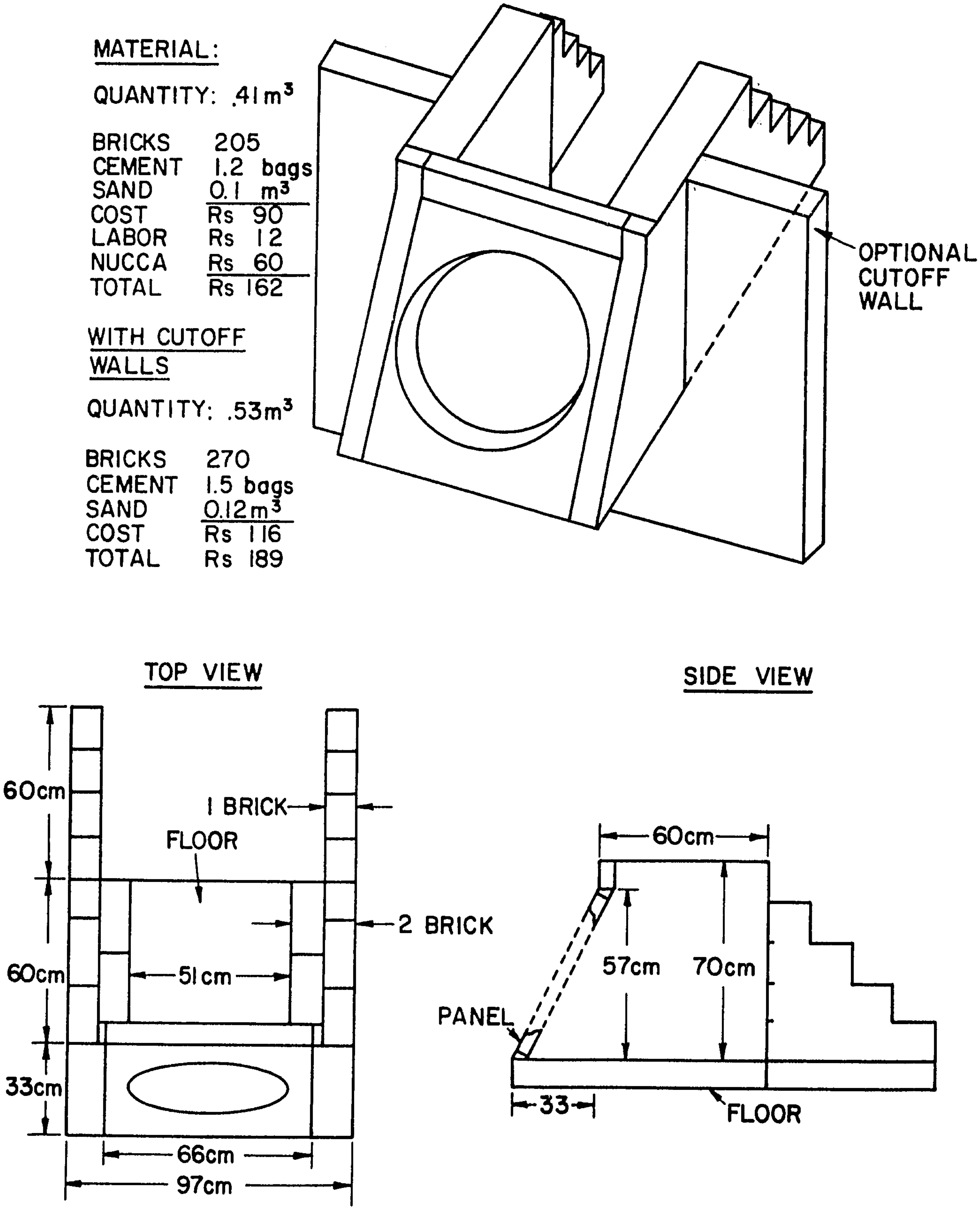


Figure 3. Standard brick masonry installation for the circular orifice nucca.

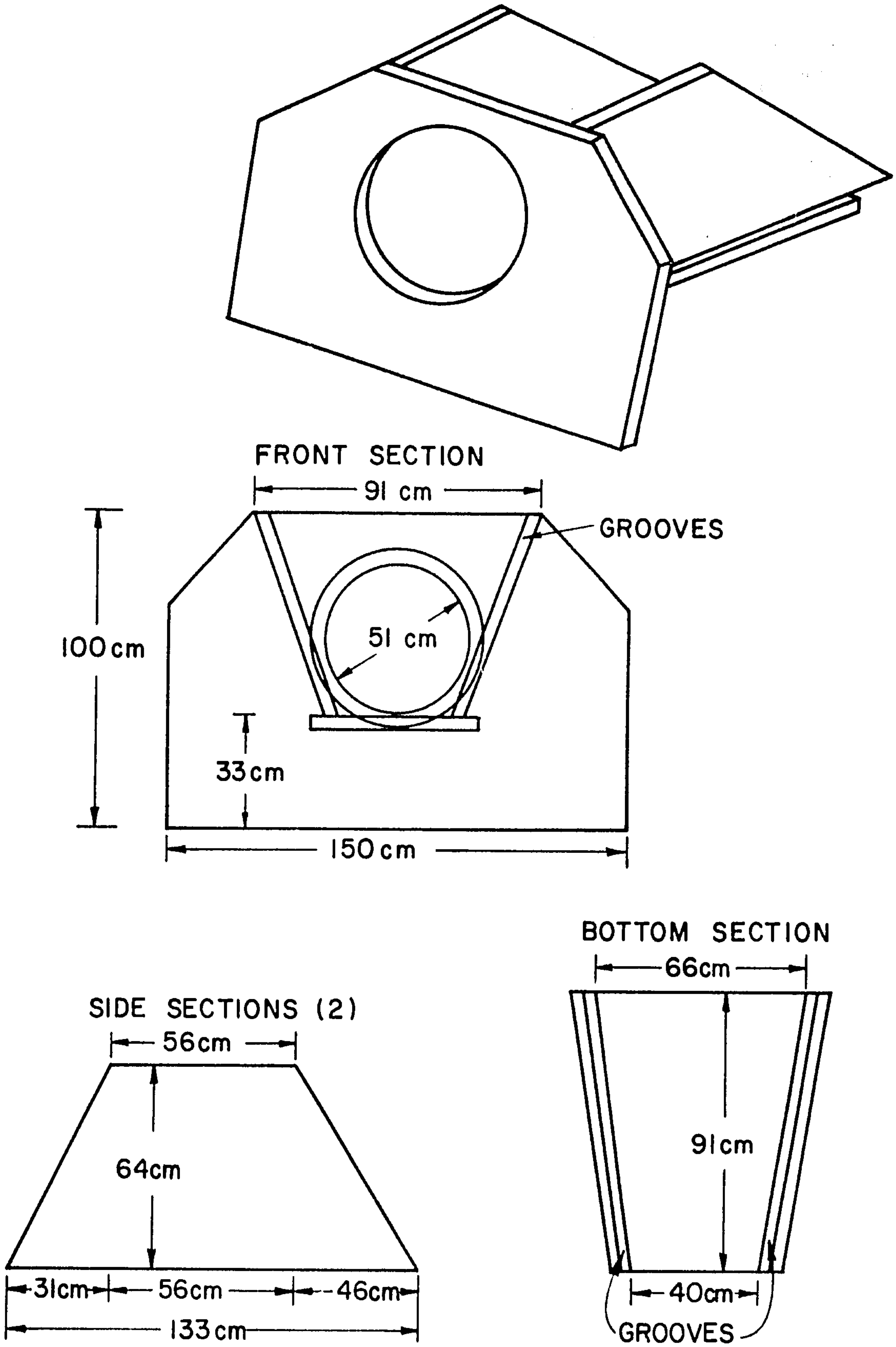


Figure 4. Concrete slap pre-cast installation for the circular orifice nucca. Cost (complete with nucca) Rs. 200.

2. Circular orifice panel nuccas with a curved sealing surface, are easy to fabricate, simple to use, and allow less leakage than other tested materials.

3. Additional work must be done to develop easy to use larger size check structures where leakage is small.

4. Small drops in watercourse levels can be accomplished by judiciously sized and located check structures.

# APPENDIX 18

## EVALUATION OF PUCCA NUCCAS IN WATERCOURSE IMPROVEMENT

Tom Trout, Abdul Khaliq and Zahid Saeed Khan[1]

An integral part of the On-Farm Water Management (OFWM) watercourse improvement program is the installation of concrete checks and outlet structures (pucca nuccas). The type presently being installed are precast concrete panel orifices and lids installed in a brick masonry structure. (For a complete description, see "Low Cost Farm Irrigation Control Structures for Pakistan," by Moh'd Munir, Siddique Shafique and Tom Trout.) The latest design has evolved during three years of experimentation. This particular nucca is being produced by New Hassnain RCC Products, Sargodha. About 4,000 of these structures have been installed in Pakistan.

An initial evaluation of the nuccas, installed from 6 to 18 months prior to inspection, by On-Farm Water Management personnel on watercourses was undertaken in this study. Chipping, breakage and overall functioning of the structure was checked and, where possible, leakage was measured. The results of this evaluation are given in Table 1.

From the table it can be seen that the lids of 3 percent of the 69 evaluated structures are ruined and should be replaced. Twenty-six percent of the lids and 6 percent of the panels are broken or have badly chipped edges but are still serviceable. Nine percent of the lids and 1 percent of the panels are slightly chipped but are working well. Twelve percent of the masonry installations have cracks but are functioning properly. The remainder of the structures are in good condition.

It should also be noted that, where panels are chipped or broken, it was always at the top edge of the orifice where the lid hits the panel hardest upon closing. Also, there was practically no chipping or breakage of check structures. This may indicate that a major cause of breakage is the striking of the lid on the panel by the irrigator when the flowing nucca, with full hydrostatic force, is being closed. Checks are normally closed before the water arrives.

Water was flowing through [illegible] to 12 closed nuccas per watercourse where water leakage was large enough to be measured. Fifty-seven percent of the nuccas had no leakage, 11 percent had up to 0.05 l/sec (0.0018 cusecs) leakage, 19 percent from 0.05 to 0.10 l/sec (.0035 cusec), and 14 percent had greater than 0.10 l/sec. leakage. The maximum leakage

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1/Agricultural Engineer and Assistant Agricultural Engineers, Colorado State University, respectively.

Table 1. Performance of pucca nuccas on four selected OFWM watercourses.

| Watercourse | Age (mo) | Lid condition | | | | Panel condition | | | | Structure condition | | | | Total (cusec) | Leakage (l/sec) | | | | Average (l/sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | G | F | P | R | G | F | P | R | G | F | P | R | | 0-.05 | | .05-.1 | >.1 | |
| Ram Diwali | 12 | 15 | 3 | 3 | 2 | 21 | 0 | 2 | 0 | 19 | 4 | 0 | 0 | 0.02 | 3 | 3 | 2 | 2 | .056 |
| Thikriwala | 18 | 6 | 0 | 5 | 0 | 11 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0.006 | 4 | 1 | 2 | 0 | .023 |
| Bhodriwala | 6 | 12 | 2 | 2 | 0 | 15 | 1 | 0 | 0 | 13 | 3 | 0 | 0 | 0.003 | 7 | 0 | 1 | 0 | .011 |
| Jaranwala | 6 | 10 | 1 | 8 | 0 | 17 | 0 | 2 | 0 | 18 | 1 | 0 | 0 | 0.019 | 7 | 0 | 2 | 3 | .045 |
| Total No. | | 43 | 6 | 18 | 2 | 64 | 1 | 4 | 0 | 61 | 8 | 0 | 0 | 0.048 | 21 | 4 | 7 | 5 | -- |
| Total % | | 62 | 9 | 26 | 3 | 93 | 1 | 6 | 0 | 88 | 12 | 0 | 0 | -- | 57 | 11 | 19 | 14 | .036 |

G - good
F - fair
P - poor
R - ruined

recorded was 0.2 l/sec (.0075 cusec) on two nuccas with badly damaged lids.

The average total loss per watercourse through the pucca nuccas was 0.337 l/sec (.012 cusec). This is less than 1 percent of the inflow to most watercourses. A farmer at the tail of the watercourse would probably suffer leakage from about twice as many nuccas, or about 2 percent of his water would be lost.

The materials cost of the OFWM nuccas are about Rs. 180. Mason costs are about Rs 20 and unskilled labor about Rs. 10 per structure, for a total cost of Rs 210 per nucca. With an expected nucca life of 7 years, the undiscounted cost is about Rs. 0.63 per week of use. The benefits derived would be in the form of water savings, labor savings and better water control. Farmer pride is also increased. If water is worth Rs. 800 per ha-cm (Rs. 100/AF), reducing leakage by only .013 l/sec (.00045 cusec) in 10 nuccas or .0013 l/sec per nucca would return the cost of the nucca. On three watercourses with exceptionally leaky earthen (katcha) nuccas and junction areas, from 5 to 10 times this amount of leakage was measured. Nucca washouts occur frequently and only four 20-minute nucca washouts each week would cost the same in water loss as would pucca nuccas.

Farmers on the Thikriwala watercourse were observed to reduce the irrigation labor utilized by 20 man-hours per week after watercourse improvement. At least 50% of this reduction is likely due to the pucca nuccas. This is worth Rs. 20/week (Rs. 1/hr labor costs) which, by itself, would repay the pucca nucca costs.

To put an economic value on the additional benefits is difficult. It is known that pucca nuccas are one of the prime factors which motivate the farmers to invest the labor required to undertake watercourse earthen improvements.

## CONCLUSIONS

1. The precast orifice nuccas, when in good condition, had practically no leakage. Average losses were about 1 percent of the mogha inflow after one year of field use.
2. Breakage of nuccas is still a problem and the quality of the structures must be improved. A nucca replacement rate of 10-20 percent per year might be expected with the present nuccas.
3. Water and/or labor savings will repay the cost of pucca nuccas. Extra benefits are improved water control, more irrigation time and farmer pride.

# APPENDIX 19

## AIDS AND SUGGESTIONS FOR THE SUCCESSFUL MANUFACTURE OF CONCRETE NUCCAS

Norman Illsley and Azeem Cheema[1]

Water losses in irrigation systems have been appreciably decreased by using improved structures at control points along watercourses.[2] These control points serve any of three functions: to divert the water into the desired watercourse; to drop the elevation of the watercourse slope; and to terminate the flow of water down the watercourse when irrigation is being done above that point. Traditionally these functions have been served by simple earthen fills that are weak and leaky.

Several structural designs and various materials were tested in field conditions and resulted in the development of a concrete structure that is giving good service. This design is described by Trout, et al.[3] and resembles a concrete manhole inclined at a 45$^{o}$ angle in a watercourse. However, when some contractors have tried to duplicate these nuccas they have had difficulty in achieving the performance of the nuccas manufactured by the original contractor, Hasnain RCC, Sargodha. Failures of nuccas have been generally due to poor quality control in the concrete and in achieving a watertight seal between the lid and the panel. It is obvious that there are no short cuts in making quality concrete structures; however, there are some tools and techniques that will facilitate achieving quality.

## QUALITY CONCRETE

For concrete to achieve its potential strength it must be made with good quality materials. The cement is of uniformly good quality when manufactured but, if left open or stored for long periods of time, it may deteriorate by picking up moisture from the air. In this case it will become hard and lumpy. If too much moisture has been picked up the strength of the concrete will be impaired.

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1/Colorado State University Agricultural Engineer and Assistant Agricultural Engineer, respectively.

2/Evaluation of Pucca Nuccas in Watercourse Improvement by Tom Trout, Abdul Khaliq and Zahid Saeed Khan. August 1978. Unpublished Colorado State University Water Management Research Project in Pakistan.

3/Low Cost Farm Irrigation Control Structures for Pakistan by Mohammad Munir, M. S. Shafique, and Tom Trout, 1978. Presented at the International Seminar on Low Cost Structures, Peshawar, February 27-March 4, 1978. Research was funded in part by USAID grant.

The most important single factor controlling the strength of concrete is the water/cement ratio (see Figure 1). A ratio of 0.36 (1 kg water to 2.75 kg cement) should produce a concrete of about 4,000 psi/strength (281 K/cm$^2$) if made with reasonable quality aggregate, sand and water.

Reasonable quality aggregate means that the parent rock should be strong and free from any harmful elements such as sulfur which attacks cement. Sand should again come from good quality rock and be free from fine silt and clay. Clay, in particular, interacts with the cement particles and prevents the cement from bonding properly. Water should be clear and free from any chemicals such as sulphur or salt that adversely affect cement. All materials should be free from organic matter. This includes sticks or grass in the sand, as well as algae or slime in the water.

Concrete must be thoroughly and properly mixed. A mechanical mixer is the only sure way of properly mixing concrete. Mixing with a shovel in a pile will not assure consistent quality from batch to batch. When using a power mixer the batch should be mixed at least two minutes after the last ingredient was added. All concrete should be in the forms and in place within 1/2 hour after adding water to the mix.

The temperature of the concrete during mixing and placement will effect the ultimate strength of the concrete. The cooler the temperature the stronger the concrete so long as it remains above freezing (see Figure 2). However, the lower the temperature the slower the curing process. Once the concrete is placed and has taken its initial set, the temperature may be raised. Where forms are to be stripped as soon as possible, it is desirable to use steam for curing. This allows removing forms in a matter of hours.

Finally, concrete must be properly cured. Once the concrete is hard and movable it is best to place cast pieces under water in a large tank and allow them to remain there for at least one week. The longer concrete remains exposed to water the harder it will get. The hardening process slows down but never stops (see Figure 3).

PLACING CONCRETE

If a proper water/cement ratio is used, the resulting concrete should be stiff enough so that vibration will be necessary to achieve proper compaction. Two methods of vibration are available, the first is with the small size portable vibrator shafts that are inserted and moved around in the concrete. The second is to construct a vibrating table on which the forms are filled and vibrated. The hand portable vibrator is more versatile, but usually slower than

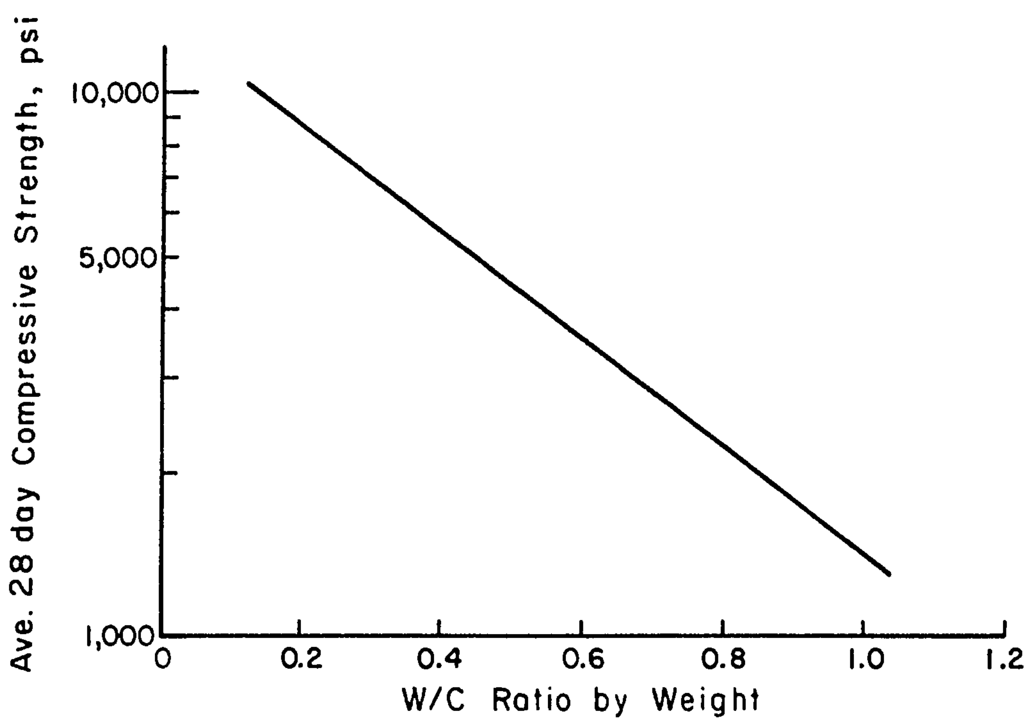



Figure 1. Effect of water/cement ratio on strength of concrete.

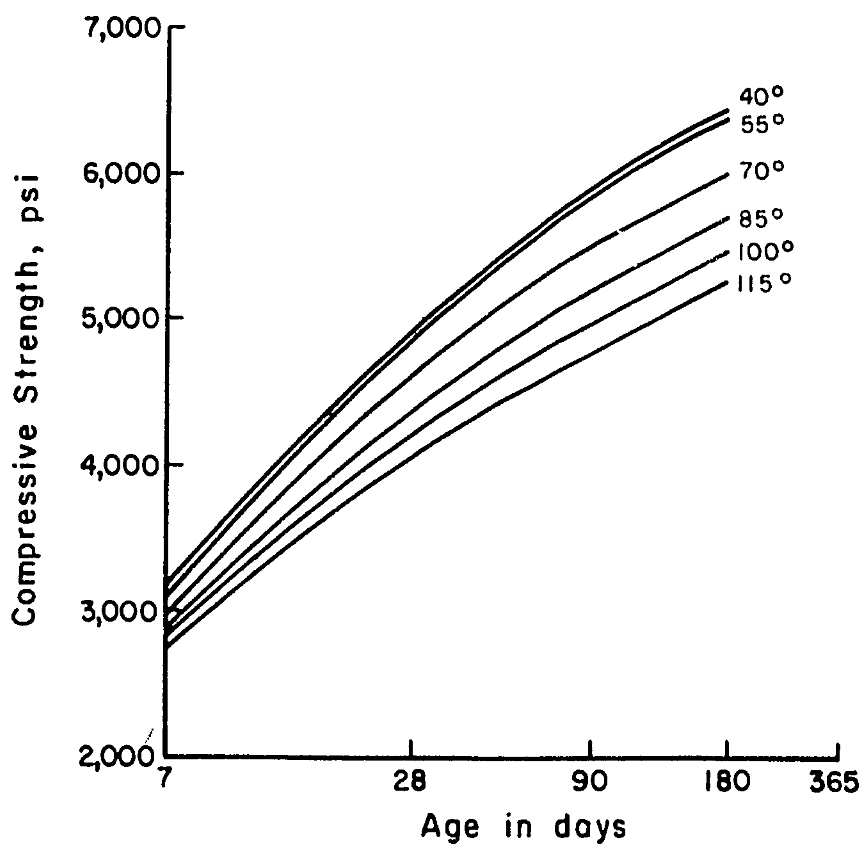



Figure 2. Factors affecting concrete strength.

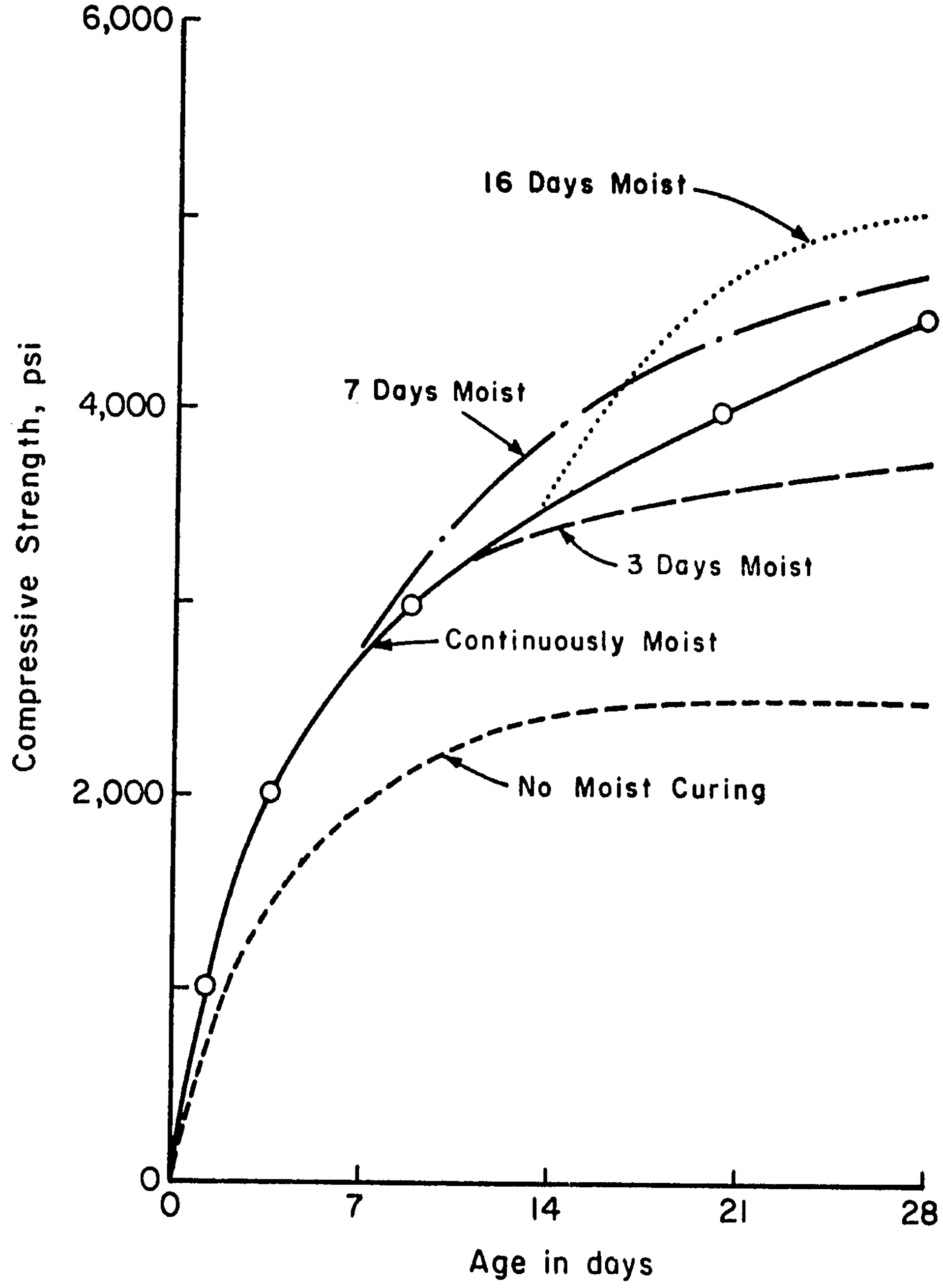



Figure 3. Effect of moist curing on strength of concrete.

the vibrating table. But vibration is essential first for proper compaction which effects strength, and second to work the aggregate away from the forms leaving a smooth grout paste on the surface. In the case of casting nuccas, any air bubbles on the surface of the form where the lid is to seal would cause leaks. It is essential to vibrate this portion of the concrete sufficiently to remove all entrapped air bubbles in both the nucca panel and lid. Vibrators should not be allowed to contact reinforcing steel for any extended time. If the steel is vibrating it will force back the aggregate and gather water next to the steel bar. The result will be a poor bond between the concrete and the steel.

## FORMS AND MOLDS

Forms for portions of concrete that do not have critical dimensions can be made of wood, but surfaces, such as the sealing portion of the nucca panel, must be cast against a hard, rigid material, such as machined cast iron or accurately finished concrete. Wherever possible, edges and corners should be rounded to reduce chipping. The sealing surfaces of the concrete should have a smooth, uniform texture with no large pieces of aggregate showing. A grout paste of sand and cement with no aggregate is used for this portion of the castings. In making the panel, regular concrete is first used between the outside form and an inner ring form that is about 10 cm larger in diameter than the lid. This ring is slightly tapered so that it can be easily removed as soon as the concrete is in place and vibrated, after the ring is removed the cast iron form is placed in the panel and the remaining space is filled with grout. This is again vibrated to assure no air pockets remain that will cause leaks.

By using the cast iron ring for the sealing surface of the panel, the lid can be cast directly into the panel. After the panel has cured enough to work with, a convex disc is placed in the panel so that the center thickness of the lid will be reduced by about 50%. The sealing surface of the panel is liberally coated with light grease to act as a releasing agent when the concrete of the lid has cured and is to be removed. The reinforcing steel and lid handles are positioned and the concrete for the lid is placed. Here again, to assure a fine smooth texture, a sand-cement grout is placed on the sealing portion of the panel first. This grout is about five to ten centimeters thick to assure no aggregate from the remaining concrete emerging. Finally, good vibration is essential for strength and to ensure that no air bubbles are on the sealing surface.

## FINISHING

After the panel and lid have cured sufficiently (a few days) the lid is ground or lapped into the panel. This is done by rotating the lid in the panel much the same as engine valves are ground into their seats. Water is used as a lubricant and for flushing out the ground away material. This can be done by hand but requires about 20 minutes of hard work per panel. The starting torque on an unground panel and lid is of the order of 250 ft lbs. The running torque is about 1/4 of this. A special machine has been designed for this purpose and has resulted in a much better quality surface on the seal with much less physical work. It is described in detail below.

CURING

Proper curing of concrete is essential for strength (see Figure 3). Steam is fast but requires special equipment. A simple pond that the concrete pieces can be stored in is adequate. Hasnain RCC found that storing under water for one month gave appreciably harder nuccas than the usual storage time of one week. Where time and facilities permit, this is good practice.

GRINDING MACHINE

The most difficult problem is making nuccas, whether concrete or any other material, is to get a tight seal. The "S" shape seat developed by Trout and the grinding technique used by Hasnain showed the greatest promise of a good seal. However, the labor involved in the grinding process meant that only the most diligent manufacturer would produce a "tight" nucca. Therefore, a machine was designed and built to lap the lids to their seats in the panel mechanically.

This machine must:

1. have sufficient torque to rotate the lids (over 250 ft lb.),
2. be made of locally available material with local shop facilities,
3. be flexibile enough that it could grind any anticipated shape of nucca,
4. be reasonable in cost, and
5. be portable and simple.

In evaluating these constraints the following observations were noted. A mechanics torque wrench was used on a new nucca and indicated a starting torque of 200 ft lbs. Local shops generally have good welding facilities and a variety of lathes, shapers and milling machines. Foundries are familiar with sand casting of common metals, and are reasonable in their charges. Mild steel is available in the common shapes such as angle, channel, pipe, and plate. A large market exists in used ball and roller bearings which have been salvaged from old machinery and automobiles.

Electric motors, both single and three phase, are locally made, and old automobile wheels are available in the used market.

An electric motor was used for power because of its simplicity, cheapness and low maintenance. This imposed one constraint, namely that the power for the machine would be delivered at 1,500 rpm. Since a final turning speed of one half revolution per second is adequate, a 1/4 hp motor has sufficient power. This requires a 50:1 speed reduction. To keep pulleys and sprockets reasonable in size, this speed reduction was done in three steps. The first step from the motor to the first step down pulley is 4:1 using 4" and 16" pulleys. This phase also changes the axis of rotation from horizontal at the motor to vertical at the first pulley. An auxiliary guide pulley is needed here to align the belt on the slack side from the motor to the pulley. This guide pulley is on a movable arm so that it can slack off the belt and act as a clutch. As the torque is lowest here, this is the best location for a clutch mechanism, and the guide pulley serves the purpose well. The second or intermediate phase is from a 4" pulley cast integrally with the first 16" pulley, to a second 16" pulley giving an additional 4:1 reduction. The second 16" pulley has a 3" sprocket mounted on it to make the final drive to a 12" sprocket on the drive shaft. The total reduction is therefore 64:1. This is greater than the required 50:1 and resulted from what was locally available in sprockets and the torque and tension can be calculated in reverse order. Given a maximum torque of 250 ft. lbs, the tension on the final drive chain would be 500 lb on a 12" (6" radius) sprocket. The torque on the humb of the 3" sprocket would be 62.5 ft. lbs. This gives a tension of the intermediate belt of 93 lbs. The torque on the hub of the first step down pulley would be 15.6 ft lbs. The tension on the first belt would then be 23.4 lbs, giving a torque on the motor shaft of 3.9 ft lbs. These figures start with an arbitrary value and do not account for fricitional inputs. They indicate that the sizes selected are capable of carrying the loads imposed.

All of the pulleys and shafts are mounted on ball bearings with provision for occasional lubrication.

Tension adjustment of the first belt is done with the clutch pulley as well as by moving the motor on its mount. The second belt and the final drive chain are adjusted simultaneously by rotating the shaft for the second 16" pulley and sprocket on the eccentric plates that hold the shaft in position. By rotating the two plates the shaft can be positioned anywhere within a 6" circle so that both belt and chain may be set at the desired tension.

The final drive sprocket is mounted on an automobile rear axle flange. The axle then extends through two ball bearings and has an automobile universal joint pinned on the lower end. A steel drive arm is bolted to the unversal joint flange, and studs on which to attach drag chains are welded to the trailing edges of the drive arm. Short drag chains attach to the appropriate studs and hook onto the handles cast into tne nucca lids. By changing the studs to which the chains hook, different diameter lids can be accommodated.

The frame is made of 3" channel iron with the wheel axle held by "U" bolts. This allows the axle to be moved to change the balance of the machine, thus varying the load on the lid being ground. A handle is mounted on the front of the machine for moving the machine into position and also for lifting the machine and lid while starting, to reduce the starting torque.

It was initially intended to put a spring load on the clutch pulley to hold tension on the first belt. However, this was found unnecessary. The pulley has very little force on it because it rides on the slack run of the belt. Secondly, the mount for the pulley has sufficient friction in it to hold any position. This is because the arm is welded onto a tube that was machined to a sliding fit on a 1 1/2" machined shaft. When the welding was done with the unit assembled, the shrinkage from welding warped the tube enough to make it a tight fit on the shaft. A spring may have to be added at a later date but, thus far, the friction on the 4" tube is adequate and has not changed perceptibly.

What was formerly done in 20 minutes of hard physical work can now be done better in three minutes. By using the grinding machine described, the new nuccas are virtually water tight and it is expected that they will remain so. Nuccas that were hand ground to less than this degree of tightness have not deteriorated in the past.

Concrete can be a good material for making these control structures provided it is used and finished properly.

# APPENDIX 20

## TRAPEZOIDAL PLATES WITH CIRCULAR ORIFICES FOR MEASURING FLOW RATES AND WATER LOSS IN WATERCOURSE

W. D. Kemper, Dwayne Konrad,
Norman Illsley, and Tom Trout[1]/

### DESCRIPTION OF PLATES AND THEIR ORIFICES

A set of these plates with 4", 6" and 8" orifices was made with the base of the trapezoid being twice the diameter of the orifice, the bottom of the orifice at a distance of one diameter from the bottom of the plate the side slopes of the orifice at two units vertical to one unit horizontal and the distance from the top of the orifice to the top of the plate was about 0.5 ft. as indicated in Figure 1a.

The bottom and side edges of these orifices should be sharpened to about a 60° angle as indicated in Figure 1b.

The plates were cut from 1/4" thick sheet plastic. If this sheet is clear or translucent, it allows the reader to see the level of water on the front side of the plate when viewing from the back side and thereby facilitates and increases the accuracy of the head loss measurement.

The orifice edges were flat as indicated in Figure 2.

The profile view of the general measurement conditions is shown in Figure 2 for submerged flow conditions.

### CALIBRATION AND CONSISTENCY OF MEASUREMENTS

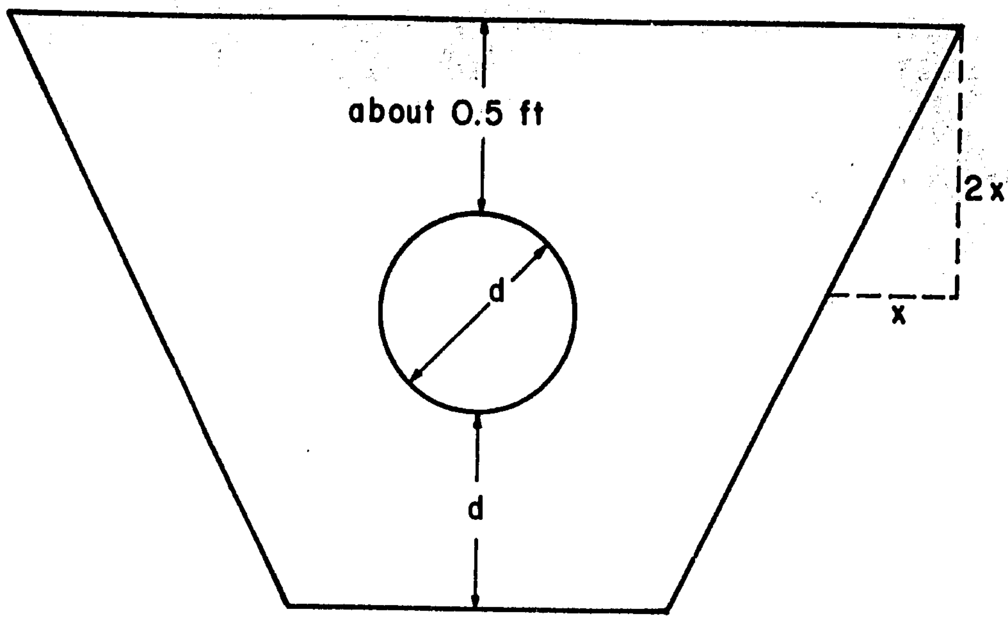
Table 1 shows the flows associated with head losses through 2", 3", 4", 6", 8", 10", 12" and 16" diameter circular orifices. This table was calculated from the equation.

$$Q = 0.65\ A\ (2g\Delta H)^{1/2}$$

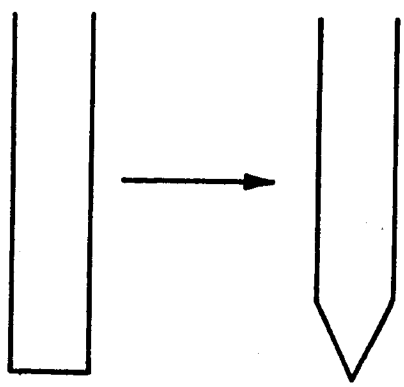
where Q is the flow rate in cubic feet/second, A is the area of the opening in square feet, g is the acceleration of gravity (32.2 ft/sec$^2$) and $\Delta H$ is the difference in elevation of the water surface in front of and behind the orifice. The coefficient of 0.65 was selected on the basis of past calibrations.

1/Agricultural Engineer, Extension Engineer, and Agricultural Engineers, Colorado State University, Fort Collins, Colorado, respectively.

Figure 1. Orifice plate.




a. Front View.



b. Sharpening of edges to
be forced into the soil.

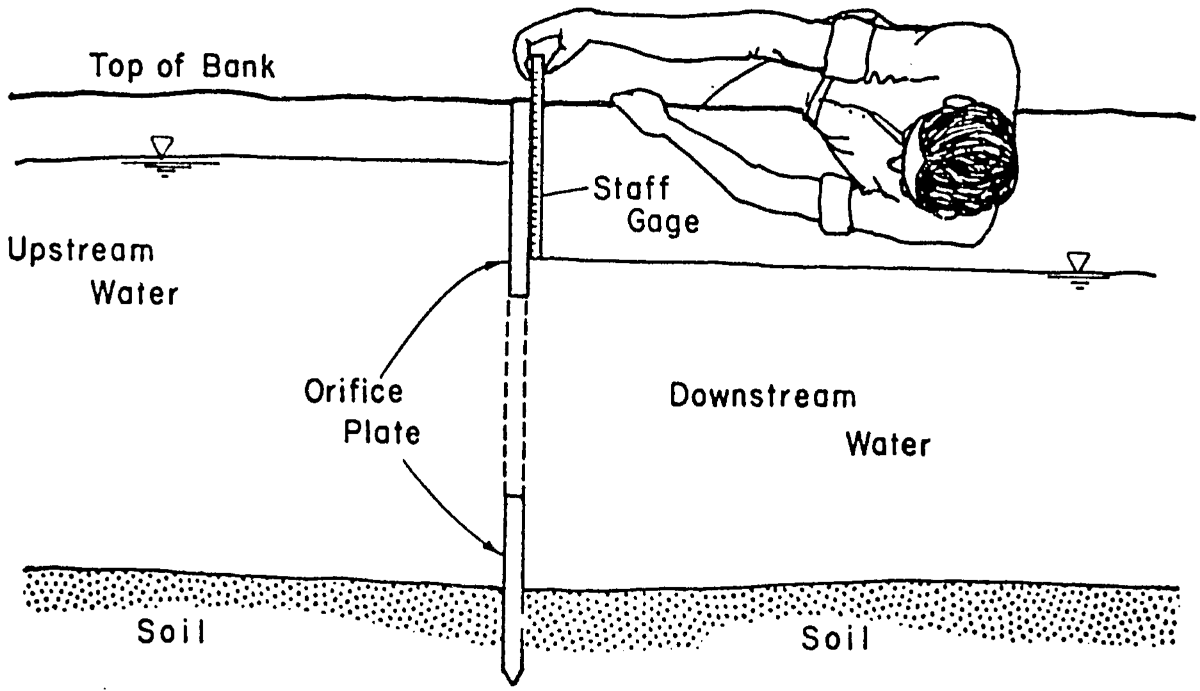



Figure 2. Side View of Installation Condition

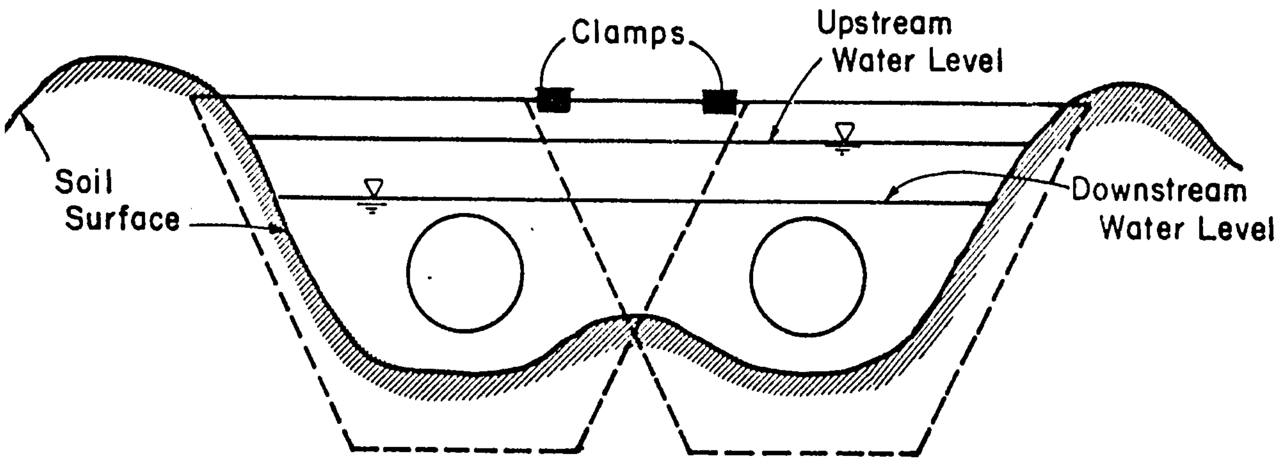



Figure 3. Double Orifice Installation; View from Downstream

Consistency was tested for the 4" and 6" orifices, by installing a 6" orifice, allowing time for steady state and measuring the head loss across the 6" orifice in a channel and then placing a 4" orifice directly in front of the 6" orifice, allowing time for steady heads to develop, measuring the head loss again and then comparing the flow rates using Table 1.

In one channel, the head loss with the 6" orifice was measured at 0.10 feet and then the 4" orifice was inserted, the steady state head loss was 0.50 feet. Using Table 1, these translated to 0.304 and 0.302 cusecs respectively.

On another channel the head loss through a 6" orifice was 0.09 ft. and the head loss through a 4" orifice was 0.43 feet. Using Table 1, these translated to 0.288 and 0.281 cusecs respectively.

Since turbulence on the water surface (particularly on the downstream side) prevents reading the elevation difference to closer than plus or minus 0.005 feet, consistency of measurements using these two sizes of orifices is within the limits of observational accuracy.

In several cases, before 8" orifices were available, flows between 1.0 and 1.2 cusecs needed to be measured. Two of the 6" orifice plates were placed side by side as indicated in Figure 3 and flows in this range were measured. To obtain an indication of whether two orifices placed this close together would disturb eachother's flow rates and calibration, the following measurements were taken. After a head loss of 0.48 feet had been measured across a single 6" diameter orifice (indicating 0.666 cusecs flow) at one location with a free flow drop about 30' upstream, two orifices were installed as indicated in Figure 3. The head loss measured across the double orifice was 0.12 feet, which using Table 1 and assuming half of the 0.666 of flow through each of the submerged orifices was exactly consistent.

In all of these measurements the level of water on the downstream side was raised to about 0.04 feet or more above the top of the orifice by placing of rocks or shovels in the channel to achieve submerged conditions.

In several other cases where streams joined together or split, the measured combined flows were equal to the sum of the separate flows within observational limitations.

When measuring flows with flumes at successive positions along watercourses where losses are extremely low, great care must be taken, or downstream readings occasionally exceed upstream readings due to improper leveling of the flume, bouncing of water levels, etc. Using orifice plates it is soon apparent that they yield more consistent results in the

Table 1. Flow rates (cubic ft/second) indicated by the head loss (cm) according to $q = .65\ A\sqrt{2g\Delta H}$, where $A = \pi D2/4$, $g = 32.2\ ft/sec^2$

| Head Loss ft. | Diameter of Circular Orifices (feet) .167 | .25 | .333 | .50 | .667 | .835 | 1.0 | 1.33 |
|---|---|---|---|---|---|---|---|---|
| 0.01 | .011 | .026 | .046 | .102 | .182 | .284 | .410 | .725 |
| 0.02 | .016 | .036 | .064 | .145 | .258 | .402 | .579 | 1.03 |
| 0.04 | .023 | .051 | .092 | .205 | .364 | .569 | .819 | 1.45 |
| 0.06 | .028 | .063 | .112 | .250 | .446 | .696 | 1.00 | 1.78 |
| 0.08 | .032 | .072 | .129 | .290 | .515 | .804 | 1.16 | 2.05 |
| 0.10 | .036 | .081 | .144 | .324 | .575 | .899 | 1.30 | 2.29 |
| 0.12 | .040 | .089 | .158 | .355 | .631 | .985 | 1.42 | 2.51 |
| 0.14 | .043 | .096 | .170 | .384 | .681 | 1.06 | 1.53 | 2.71 |
| 0.16 | .046 | .102 | .182 | .409 | .729 | 1.13 | 1.64 | 2.90 |
| 0.18 | .048 | .109 | .193 | .435 | .773 | 1.20 | 1.74 | 3.08 |
| 0.20 | .051 | .115 | .204 | .458 | .814 | 1.27 | 1.83 | 3.24 |
| 0.22 | .054 | .120 | .213 | .481 | .854 | 1.33 | 1.92 | 3.40 |
| 0.24 | .056 | .125 | .223 | .502 | .892 | 1.39 | 2.01 | 3.55 |
| 0.26 | .058 | .131 | .232 | .522 | .928 | 1.45 | 2.09 | 3.70 |
| 0.28 | .060 | .135 | .241 | .542 | .963 | 1.50 | 2.17 | 3.84 |
| 0.30 | .063 | .140 | .249 | .560 | .997 | 1.56 | 2.24 | 3.97 |
| 0.32 | .065 | .145 | .258 | .580 | 1.03 | 1.61 | 2.32 | 4.10 |
| 0.34 | .067 | .149 | .265 | .597 | 1.06 | 1.65 | 2.39 | 4.23 |
| 0.36 | .069 | .154 | .273 | .615 | 1.09 | 1.70 | 2.46 | 4.35 |
| 0.38 | .070 | .158 | .280 | .631 | 1.12 | 1.75 | 2.53 | 4.47 |
| 0.40 | .072 | .162 | .288 | .648 | 1.15 | 1.79 | 2.59 | 4.58 |
| 0.42 | .074 | .166 | .295 | .664 | 1.18 | 1.84 | 2.66 | 4.70 |
| 0.44 | .076 | .170 | .303 | .679 | 1.21 | 1.88 | 2.72 | 4.81 |
| 0.46 | .078 | .174 | .309 | .695 | 1.23 | 1.93 | 2.78 | 4.92 |
| 0.48 | .079 | .177 | .315 | .710 | 1.26 | 1.97 | 2.84 | 5.02 |
| 0.50 | .081 | .181 | .322 | .725 | 1.29 | 2.01 | 2.90 | 5.12 |
| 0.55 | .085 | .190 | .337 | .760 | 1.35 | 2.11 | 3.04 | 5.37 |
| 0.60 | .089 | .198 | .352 | .793 | 1.41 | 2.20 | 3.17 | 5.61 |

hands of the common operator than do the flumes. Reasons for the consistency of the orifice readings include three obvious factors.

1. Orifices do not require precise leveling to assure that the upstream and downstream gauge readings are with respect to the same datum.

2. When the orifice is submerged, actual depths of the water on the upstream and downstream are not necessary and only the difference in head, which is easily measured across the clear plastic orifice plates is needed.

3. Head difference is a squared function of the flow rate through orifices (i.e., square both sides of equation 1) and consequently is a more sensitive measure of flow rate than is the flow in a flume which varies with about the two-thirds power of the head.

As an illustration of the latter point consider that a flow rate of 0.608 cusecs is occurring in a watercourse and that 2000 feet downstream 10% of the water has been lost so that 0.549 cusecs of water is flowing at that point. The head loss readings across the 6" diameter orifice plates would be 0.40 feet and about 0.32 feet at the two successive points.

On the other hand if 4" width cutthroat flumes were used, under free flow conditions at the two successive points, the upstream staff gauge readings would be about 0.62 and 0.58 feet at the two successive points.

The difference in gauge readings between the first and second stations would be two times as great for the orifice plates as for flumes and consequently the orifice plates allow more accurate measures of loss between the measuring stations on the watercourse. When the orifices can be used under conditions of considerable head loss, the precision is magnified by the squared relationship between head loss and flow, so it is relatively easy to detect losses of only a few percent. However, when the head loss must be kept small, larger orifices must be used which cannot benefit from this magnification in their accuracy.

## INSTALLATION OF ORIFICE PLATES IN EARTHEN CHANNELS

In some earthen channels with size and shape similar to the orifice plates, it is possible to simply force the plates into the channel at right angles to the flow and wait for the head to build up on the upstream side. Submergence of the orifice on the downstream side should be achieved by fixing a shovel (or stones) in the bed about 10' downstream from the orifice plate.

If the channel bed is too hard to allow the plastic plate to penetrate, or if grass and roots or dry soil on the side prevent the plate from extending into the banks, a shovel can be used to cut through these obstructions and open the way for the plate to enter the bottom and sides of the channel to the point where the orifice will become submerged as indicated in Figure 2.

If the channel is wider than the plates it will be necessary to build partial bunds on one or both sides of the channel which will support the orifice plate in its vertical position and prevent passage of water around the plate. In such cases, and for the larger orifice plates in particular, it may be necessary to drive a couple of metal stakes firmly into the bed of the watercourse just behind and to each side of the orifice to help support the plate in a vertical position and prevent it from bowing excessively.

Remove any soil or grass from at least three orifice diameters in front of the plate to three orifice diameters behind the plate which is in direct line with the orifice and the cylinder which extends at least an inch beyond the orifice.

Time required to achieve steady head conditions can be as little as one or two minutes where there is free flow over an upstream structure close to the orifice plate, or there is a steep gradient of the channel bed. However, the time required for steady head conditions to develop increases as the slope of the channel decreases and the head drop across the imposed orifice plate increases and it may be as long as 30 or 40 minutes. Consequently readings of head loss should be táken at 5 or 10 minute intervals until they are constant before the observed head loss is used as a measure of the flow rate.

STANDARDIZED CONDITIONS FOR OPTIMUM REPRODUCIBILITY

The head loss accompanying a specific rate of flow through the orifice is dependent, to some extent, on the approach and departure conditions. For instance, if the approach conditions consisted of a pipe with an inside diameter equal to that of the orifice, there would be negligible head loss in the orifice. The energy balance for the conversion of hydraulic head energy ($V\Delta H$) to kinetic energy ($1/2MV^2$) is the basis for the general form of equation (1). The numerical coefficient in the equation is determined by several hydraulic factors, including the approach velocity. The numerical coefficient will remain reasonably constant if the approach and departure conditions are reasonably the same.

For this reason it is suggested that the level of water on the departure side always be about 0.04 ft. above the top of the orifice and that the approach channel should have a cross section at least five times that of the orifice. This latter condition can be achieved by excavating the channel on the approach side if it does not already have this dimension. However, the channel should be returned to its original condition when the measurement is completed to maintain good relations with the farmers.

## GENERAL COMMENTS

Orifice plates can generally be made at less cost than other flow measuring devices. They are also easy to transport in passenger vehicles and easy to carry to the field. Although they are simple, they can be an accurate tool for measuring water flow rates and rates of loss in watercourses.

Since the country is converting from English to metric units, a calibration chart for metric units is given in Table 2 for round orifices with diameters approximately equal to those in Table 1.

Table 2. Flow rates (in liters/second) indicated by the head loss (cm) according to the equation $q = .65A\sqrt{2g\Delta H}$.*

| Head loss $\Delta H$ (cm) | Orifice Diameter (cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5 | 7 | 10 | 15 | 20 | 25 | 30 | 40 |
| .2 | .25ℓ/sec. | .50 | 1.01 | 2.27 | 4.04 | 6.32 | 9.09 | 16.2 |
| .4 | .36 | .70 | 1.43 | 3.21 | 5.71 | 8.93 | 12.9 | 22.8 |
| .6 | .44 | .86 | 1.75 | 3.94 | 7.00 | 10.9 | 15.7 | 28.0 |
| 1.0 | .56 | 1.11 | 2.26 | 5.09 | 9.04 | 14.1 | 20.3 | 36.1 |
| 1.5 | .69 | 1.36 | 2.76 | 6.22 | 11.0 | 17.3 | 24.9 | 44.2 |
| 2.0 | .80 | 1.57 | 3.19 | 7.19 | 12.8 | 20.0 | 28.7 | 51.1 |
| 2.5 | .88 | 1.75 | 3.57 | 8.04 | 14.3 | 22.3 | 32.1 | 57.1 |
| 3.0 | .97 | 1.92 | 3.91 | 8.81 | 15.6 | 24.5 | 35.2 | 62.6 |
| 3.5 | 1.05 | 2.07 | 4.22 | 9.51 | 16.9 | 26.4 | 38.0 | 67.6 |
| 4.0 | 1.12 | 2.21 | 4.51 | 10.2 | 18.1 | 28.2 | 40.6 | 72.2 |
| 4.5 | 1.19 | 2.35 | 4.79 | 10.8 | 19.2 | 30.0 | 43.1 | 76.6 |
| 5.0 | 1.26 | 2.48 | 5.05 | 11.4 | 20.2 | 31.6 | 45.4 | 80.8 |
| 5.5 | 1.32 | 2.60 | 5.30 | 11.9 | 21.2 | 33.2 | 47.7 | 84.9 |
| 6.0 | 1.37 | 2.70 | 5.51 | 12.4 | 22.0 | 34.5 | 49.6 | 88.1 |
| 6.5 | 1.44 | 2.83 | 5.76 | 13.0 | 23.0 | 36.1 | 51.9 | 92.2 |
| 7.0 | 1.49 | 2.93 | 5.97 | 13.4 | 23.9 | 37.3 | 53.7 | 95.5 |
| 7.5 | 1.54 | 3.03 | 6.17 | 13.9 | 24.9 | 38.6 | 55.5 | 98.7 |
| 8.0 | 1.59 | 3.13 | 6.38 | 14.4 | 25.5 | 39.9 | 57.4 | 102 |
| 8.5 | 1.64 | 3.23 | 6.58 | 14.8 | 25.8 | 41.2 | 59.2 | 105 |
| 9.0 | 1.69 | 3.33 | 6.78 | 15.3 | 27.1 | 42.4 | 61.0 | 108 |
| 9.5 | 1.73 | 3.40 | 6.94 | 15.6 | 27.7 | 43.4 | 62.4 | 111 |
| 10 | 1.78 | 3.50 | 7.14 | 16.1 | 28.6 | 44.7 | 64.3 | 114 |
| 11 | 1.87 | 3.68 | 7.50 | 16.9 | 30.0 | 46.9 | 66.6 | 120 |
| 12 | 1.94 | 3.83 | 7.80 | 17.6 | 31.2 | 48.8 | 70.2 | 125 |
| 13 | 2.03 | 4.00 | 8.16 | 18.4 | 32.6 | 51.0 | 73.4 | 131 |
| 14 | 2.11 | 4.15 | 8.47 | 19.1 | 33.9 | 53.0 | 76.2 | 135 |
| 15 | 2.17 | 4.28 | 8.72 | 19.6 | 34.9 | 54.5 | 78.5 | 140 |
| 16 | 2.25 | 4.43 | 9.03 | 20.3 | 36.1 | 56.5 | 81.2 | 144 |

*Where A is the area of the orifice in $cm^2$, q the flow rate in $cm^3$/sec, g is 980 dynes/gm and $\Delta H$ is in cm.

# APPENDIX 21

## TUBEWELL JUNCTION JET PUMP

M. S. Shafique and D. E. Konrad1/

### INTRODUCTION

A common problem for irrigation farmers in the Mona Project area is that their full authorized discharge is not provided at the outlet (mogha) to their watercourse. The moghas are either modular (flume type) or non-modular (pipe orifice). The modular moghas are designed to discharge the full supply at an unsubmerged condition. Because of flat watercourse gradients, along with silt deposits, vegetative growth, and elevated fields, the water is usually backed over the mogha.

Where tubewells exist near the mogha, it is possible to use excess water horsepower or energy at the tubewell to raise the level of the water in the watercourse. This was done successfully in two locations in the Mona Project area. The first jet pump utilized a long discharge pipe from the tubewell to the watercourse and from there a horizontal steel jet pipe and nozzle. The other jet pump involved bringing the watercourse to the tubewell to save piping cost. The existing concrete discharge box was heightened to allow full use of the relatively high discharge elevation of the tubewell. In both cases, the previously submerged mogha was freed to allow full supply flow. Also, the jet pump allows the complete mixing of the canal water with the more saline groundwater.

### BACKGROUND

Watercourses MN-60 and MN-62 are just across from each other on the same distributary. Their problems were alike. Both watercourses had access to a public tubewell built under the Salinity Control and Reclamation Project (SCARP-II) to lower the water table and augment the irrigation water supply. However, in both cases, the mogha was submerged even without the tubewell in use. When the tubewell for each watercourse was activated, the mogha became more submerged so that the water through the mogha ceased flowing altogether. In that case, the farmers were essentially paying for tubewell water only and giving their higher quality canal water back to the distributary. This completely defeated the purpose of the SCARP tubewells since it neither

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augmented these two water supplies nor did it provide reasonable quality mixed water to these farmers. In fact, the farmers were actually being charged for water that they did not prefer.

Watercourse MN-60, for example, should receive 2.83 cusecs through the mogha as authorized supply. The tubewell is capable of pumping 3.6 cusecs. When the tubewell was actually turned on, total flow through that watercourse section became 3.5 cusecs. In effect the total supply was coming from the tubewell.

Farmers at MN-60 could not recall having received the authorized flow of water in 13 years. More recently, they had organized to improve or rehabilitate their watercourse to increase the supply. Even when that hard labor was finished, the mogha was still submerged. In effect, the farmers could not see the immediate benefits of earthen improvement. The situation at watercourse MN-62 was much the same. Since MN-60 and MN-62 are moghas opposite each other on the distributary, any effect on one mogha would surely affect the other mogha.

Submergence of the modular type mogha is such that, once the flow is unsubmerged, maximum flow exists unless the distributary water level is increased. There are also submerged pipe moghas in the Mona Project area. Where these pipes exist, the effect of reducing submergence can have a potentially greater effect on flow to the watercourse than with the flume type mogha. Flow through the pipe depends upon net head between distributary and watercourse. In reality, flows greater than authorized could be caused by unsubmerging to extreme.

## PRINCIPLE OF JET PUMP

A jet pump operates with the principle of taking a low capacity but high velocity stream of water and transferring that energy to another stream of low velocity water to increase the head or water level of the combined streams. This was convenient to do at Mona Project without adding a cost of energy because the SCARP tubewell discharges are constructed with discharge pipes from 4 to 5 feet above the watercourse level. A worthwhile feature of the jet pump is that it has no moving parts and is relatively simple to fabricate. All materials could be manufactured in Pakistan and near the place of use. In some cases, the jet pump could also be seen to eliminate the expensive animal driven jalar or water wheel.

## RESEARCH FINDINGS

The first type of jet pump or energy principle pump was proposed by CSU and built on watercourse MN-51 in 1977

(Figure 1). Obviously too much energy was dissipated before the tubewell water reached the canal supply and only a small lift was realized.

Aust did further research on jet pumps in 1977-78. Research pointed out that theoretical efficiencies up to 50% could be attained by hydraulic jet pumps. With the knowledge that even a 25% efficient pump would be satisfactory for the Pakistan situation, a jet pump was designed and constructed for testing at the Engineering Research Center, Foothills Campus, Colorado State University. Results of testing a model such as Figure 2 showed an efficiency of 42%. Lowest efficiency attained was 19%. Critical parts of design were the nozzle size and distance of nozzle to mixing chamber. Total cost of installation for Pakistan was estimated at Rs. 1,600.

## MONA TUBEWELL JUNCTION JET PUMP INSTALLATION

Figure 2 shows the installation setup type at MN-60 for the first designed tubewell junction jet pump (JJP). Particular dimensions of the pump mechanism are given in Figure 3. This installation required the purchase of 8-inch steel pipe from the pump discharge to the nozzle. The nozzle was also made of steel. The mixing chamber, inlet section and diffuser were made of brick and concrete masonry. Total cost was Rs. 12,000 ($1,212), well above the estimated cost by CSU. The tubewell is located about 700 feet below the mogha. Input energy to the tubewell was not increased by adding the jet pump device.

Costs were decreased greatly at MN-62 by bringing the watercourse to the tubewell and by employing the existing discharge box although the box walls did require heightening. A concrete mixer and nozzle were used initially but the nozzle was later changed to metal so that clearance between nozzle and intake would be adequate to pass trash from the watercourse and to decrease head loss in that section. The cost of this final installation was just under Rs. 1,000 ($101). The tubewell is located about 150 feet below the mogha.

## RESULTS OF TUBEWELL JUNCTION JET PUMP TESTS

Discharges, flow depths, jet pump features and jet pump efficiencies are given in Table 1. In all cases, the operation of the JJP cause the mogha to be unsubmerged at the inlet to the watercourse. The water level in the distributary was below normal so that the full authorized flow was not achieved for MN-62. Later into the irrigation season, full supply is expected.

Output of the jet pump can be expressed in terms of either foot-pounds per second or water-horsepower. Since

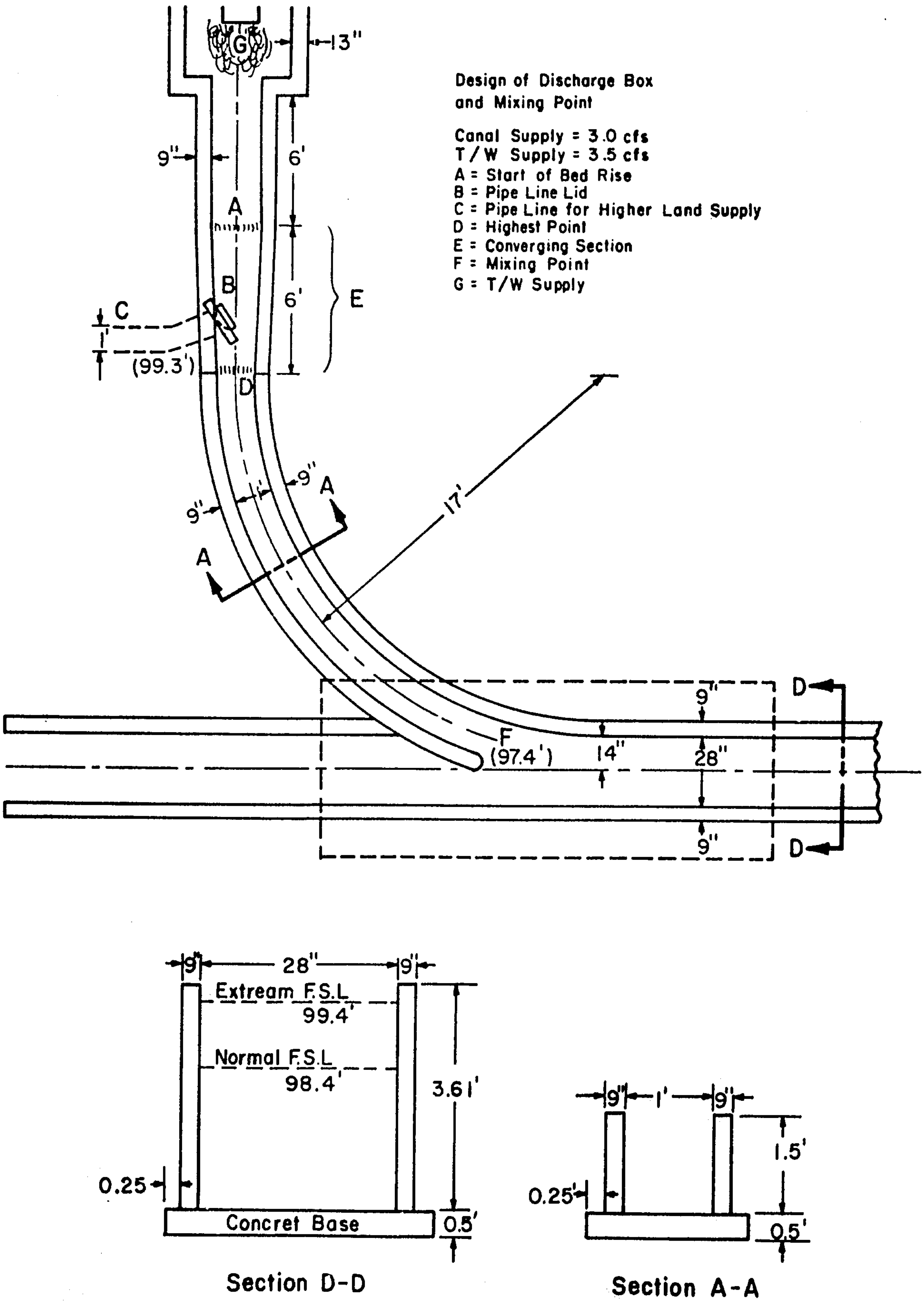


Figure 1. Layout of first junction jet pump arrangement at MN-51.

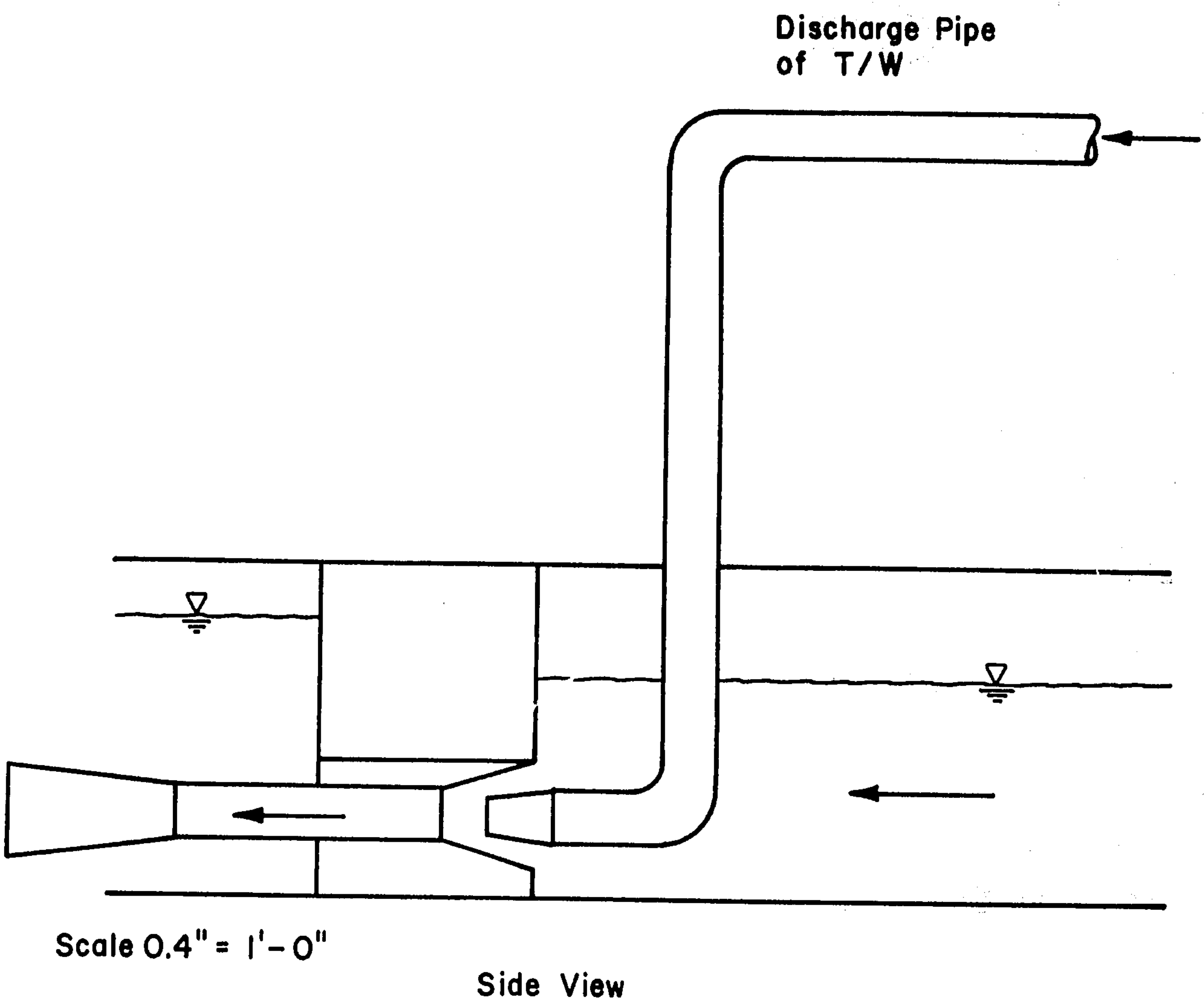


Figure 2. Tubewell junction jet pump installation at MN-60, Mona.

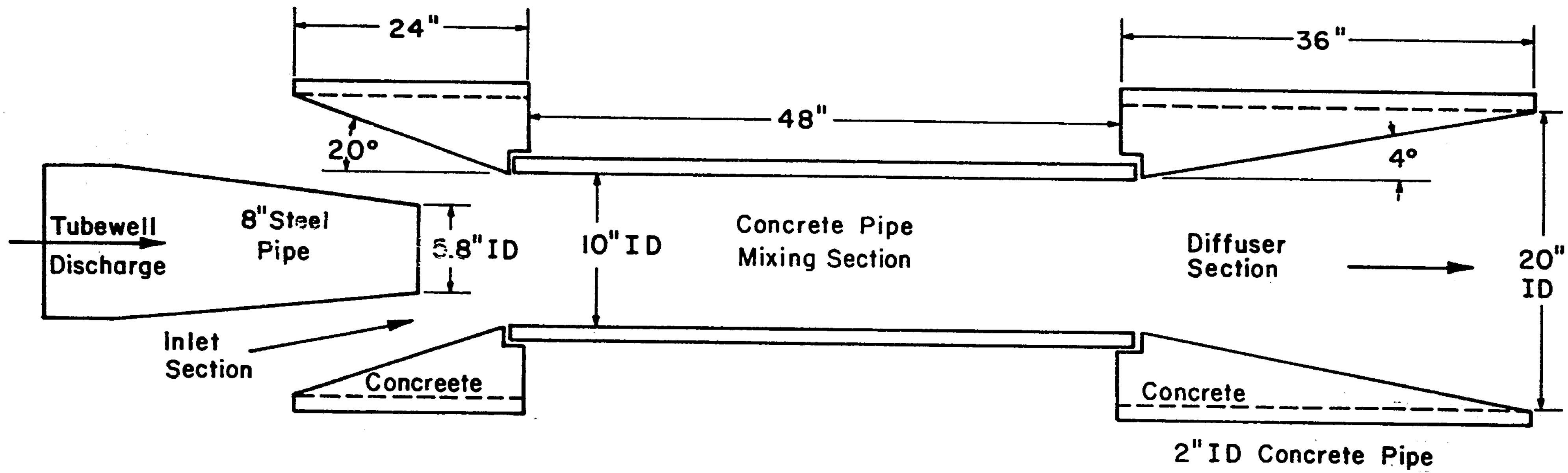


Figure 3. Hydraulic junction jet pump device installed and tested at MN-60, Mona. (Similar to MN-62)

Table 1. Results of tubewell junction jet pump tests and design dimension.

| | TW MN-60 (5.8" Nozzle) | TW MN-62 (5.25" Nozzle) | TW MN-62 (5.5" Nozzle) |
|---|---|---|---|
| Watercourse Flow, $Q_W$ | 2.14 cusecs | 1.20 cusecs | 0.66 cusecs |
| Tubewell Flow, $Q_P$ | 3.60 cusecs | 2.75 cusecs | 2.75 cusecs |
| Total Flow, $Q_T$ | 5.74 | 3.95 cusecs | 3.41 cusecs |
| Nozzle Velocity, V | 20.0 fps | 18.3 fps | 17.2 fps |
| Net head at tubewell, $H_P$ | 5.0 ft | 4.39 ft | 4.07 ft |
| Net lift produced, by jet pump, $H_T$ | 1.15 ft | 0.88 ft | 0.82 ft |
| Water horsepower input | 2.04 HP | 1.37 HP | 1.27 HP |
| Water horsepower output | 0.75 HP | 0.62 HP | 0.32 HP |
| Efficiency (Power) $E_P$ | 36.7% | 28.9% | 25.1% |
| Efficiency (Momentum) EM | 17.8% | 10.8% | 6.1% |

horsepower is a term generally associated with pumps, this term was chosen. Water horsepower is determined by the formula:

$$WHP = 0.114QH$$

where 'Q' is in cusecs and 'H' is in feet.

Input horsepower is determined from tubewell discharge and distance from center lines of discharge pipe to jet nozzle. Output horsepower is determined from total discharge and the height that the total supply is lifted. In the cases at Mona, it is seen in Table 1 that efficiencies of 25.1 to 36.7% were reached without great refinement of the jet pump.

The test at MN-62, indicating an efficiency of only 25%, was run under conditions such that watercourse flow was only 0.66 cusecs and the accomplished lift was 0.82 feet. Also, the nozzle size used was 5.5 inches, resulting in a nozzle velocity of 17.2 fps. It was quite possible that, in this case and due to low watercourse flows, the nozzle may have been slightly unsubmerged so that energy was lost in that section. The diffuser section was also deleted at MN-62 (Figure 4). The earlier test, using a 5.25 inch nozzle and watercourse flow of 1.2 cusecs, resulted in a pump efficiency of 28.9%. Nozzle velocity appears to be a critical parameter to efficiency.

As noted in the table, the jet pump input is in a relatively low horsepower range. At the same time, where this horsepower (1.27 - 2.04) cannot be utilized, one could question the practice of constructing a tubewell with the high relative elevation of the discharge pipe.

Efficiency of the junction jet pump can also be expressed in terms of momentum lost vs. momentum gained by the water through the pump. In that case, we see relatively low efficiencies of 6.1 to 17.8%. The efficiency is determined by the formula,

$$E_M = \frac{(Q_T - Q_P)\ H_T \ X\ 100}{Q_P\ (H_P - H_T)}$$

Salinity of the tubewell water at MN-62 was measured as 802 ppm. The canal water salinity is 166 ppm. With the installation and operation of the junction jet pump, the salinity of the mixed supply is 611 ppm. This is close to what would be expected with this mixture.

## CONCLUSIONS

Standard efficiency can be attained for the type of low head jet pump built at the Mona Project on watercourse MN-60 and MN-62. Where the tubewell is situated so that it is near the mogha and near the watercourse it serves, design and cost of installation present no difficulty. It is anticipated that most junction jet pumps could be designed and built much like MN-62. At this cost (Rs. 1,000) and with an increased flow rate of about 1.2 cusecs (30%) farmers at MN-62 should recover that cost in only 9 days of pumping, (water valued at Rs. 50/ac ft). Claiming this benefit may cause question since, in reality, the water that is now coming from the mogha previously went to another mogha. The fact

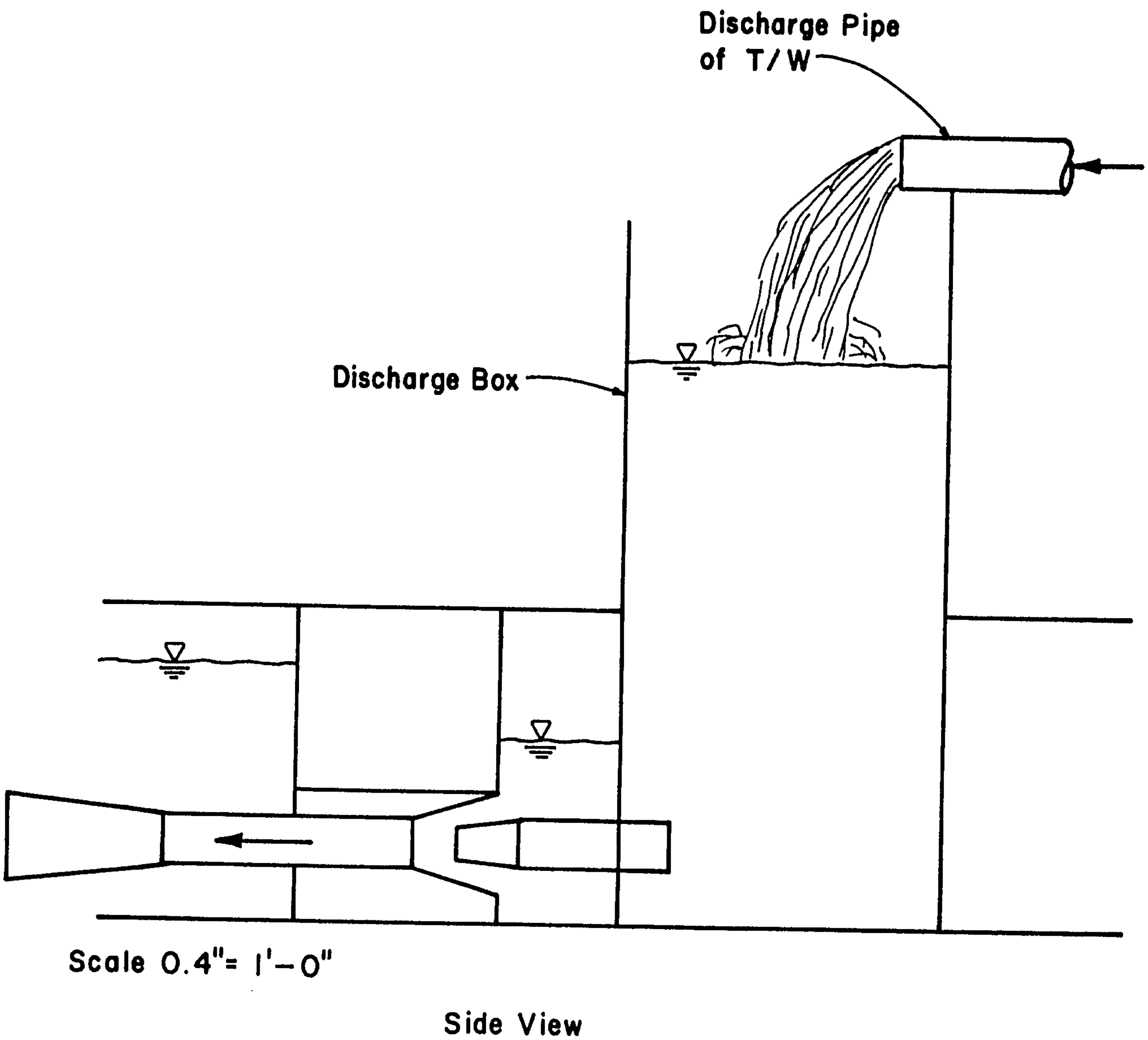


Figure 4. Tubewell junction jet pump installation at MN-62, Mona.

is that, without the JJP, there was no incentive for MN-60 and MN-62 farmers to pump at all. In that respect, the jet pump results in the tubewell water being the supplement for which it was intended. Another direct benefit of the JJP is that it does result in a mixed water supply that, in most cases, will meet the water standards for salinity.

The increased water supply caused by the installation of the junction jet pumps caused farmers on both watercourses to begin further watercourse improvement programs. The Mona Project staff briefed them on the fact that they would need an improved and enlarged watercourse to make use of the full supply that they hadn't seen in 13 years. The jet pumps at MN-60 and MN-62 were provided from Mona Project Research funds and the farmers were willing to put in many man-hours of earth work in expectation of the results. None were disappointed when the job was completed.

RECOMMENDATIONS

1. Test junction jet pump devices at more difficult locations (i.e., where tubewell water must be bifurcated between watercourses). This will require careful bifurcation of the total mixed supply as well as special agreement between farmers on the watercourses.

2. Work to further lower the cost of JJP installations so they can become more readily available.

3. Provide a basic design of JJP that will accommodate certain flows and specific conditions so that only simple field adjustments need be made. Put these designs in printed form.

4. Inventory of the Mona Project area to determine the potential use of JJP devices.

5. Continue to monitor JJP's at MN-60 and MN-62 to determine how well they perform over a three-year period.

# APPENDIX 22

## POST-IMPROVEMENT STUDY ON THE WATERCOURSE AT CHAK-2J.B. RAM DEVALI

by

M. Iqbal Niazi[1/]

### OBSERVATIONS

Pacca Section: Head

1. 20/25 newly planted plants very close to the left bank near mogha.

2. At the end of the pacca section, a farmer having his land adjacent on both sides of the watercourse, has cut down earth from both the banks, leaving it hardly 6" wide with the brick walls. (He could not be resisted by other farmers.)

Katcha Improved Portion: Middle

A 25-foot long portion of the right edge of the watercourse looks damaged a lot, being cut in six places. A two kanal plot of potatoes is comparatively low and looks quite wet. During the last rains in January and February, it got filled several times and was emptied each time with buckets to save the potato crop. This practice weakened and cut the watercourse bank. However, some of the farmers told me that the respective farmer is a cooperative type of man and he will soon repair it. So far, there has been no need of irrigation water. The watercourse has no water flowing in it because the mogha was closed by the farmers to save their lands from flooding.

Tail

1. A 40-foot long portion of the right edge of the watercourse has been narrowed by the respective farmer. He cut earth clods from the edge-side and put them on its top uncompacted.

2. In the field adjacent to the first half of the tail, the crops look very weak i.e., yellowish/brownish, uneven and having several empty spots because of the recent rains.

3. In the fields on the second half of the tail, the crops look almost destroyed with standing rain water, still 4" to 12" deep.

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## The Mogha

The mogha was closed by the farmers during the last rains, to save their land from flooding. According to the rules this is forbidden as it causes an increase in the pressure on the edges of the distributary which may break out anytime. But there is no drain on the tail of the watercourse and when no one is irrigating lands, the water overflows the edges at the tail and spreads about in the adjacent lands, causing loss to the crops and land.

## COMMON PROBLEMS

### Waterlogging

The difference between the elevation of the mogha and the land at the tail is six to seven feet. Water table has been continuously rising day by day in the area all around. With the continuous flow of the watercourse and/or rains, the tail land get flooded and hence the crops wasted. There is neither an outlet drain at the tail of the watercourse nor any tubewell to lower the water table. It appears that the land will change to wastelands within a few years.

### Rats

Rats are increasing all around in the area and wasting land, edges of the watercourses and crops. I observed countless rat holes along the Katcha improved portion of the watercourse and in the fields with or without standing crops. I could not see any open hole; all were blocked, indicating that the kind of rat in that area is most probably, 'NESOKIA'. The farmers say the above two problems are common throughout this area on both the improved and unimproved watercourses.

## PROGRESS IN FARMING
(Prior to the installation of the tubewells)

### Before 1963

It was a common practice that the farmers cropped turn by turn one-third and two-thirds of their land in Kharif and Rabi season, respectively, because of a shortage of irrigation water. Cotton was the most common crop in Kharif which yielded above 20 mds/acre, at that time. The thefts of irrigation water and conflicts over theft were a routine. All the farmers had to watch all along the watercourse while irrigating his land. In short, irrigation water was never enough for anyone's lands.

**1963-1977 (Installation of the Tubewells to the Improvement of the W/C)**

With the installation of a tubewell on each of the three watercourses in the village, the problem of water shortage was solved to a large extent. The farmers began to crop 75 percent to 100 percent of their lands per season. They began to sow sugarcane, vegetables, maize, fodder, newly-introduced varieties of wheat and increased the cotton area. But in the early 1970's, cotton began to be wasted by insects and diseases, particularly the insect which causes the cotton bolls to drop before ripening. These diseases increased year by year with the result that the farmers lost interest in growing cotton.

Chemical fertilizers were introduced in the 1960's. In the first 5 to 6 years, most of the farmers did not wish to apply it on their crops. They thought that fertilizer is harmful to their crops i.e., would burn the crops, etc. By the beginning of the 1970's, hardly one-third of the farmers had begun to apply chemical fertilizers to some crops, especially wheat, sugarcane, and vegetables. By the middle of the decade (1975-76), almost all the farmers began the practice on some and most of them on all of the crops. It was experienced by the farmers that after applying chemical fertilizer to a crop, the field proved very poor to grow the next crop without the application of chemical fertilizer again, so the farmers became bound to apply chemical fertilizer to every crop. Replacing old varieties of crops, especially wheat, with the new high yielding ones became a usual practice. Irrigation water thefts and conflicts became very rare, but not given up. Formerly, it was not possible for most of the farmers to cultivate all of their land with the bullock plows. Thus tractors were also an important factor in the increase in the cropped area.

The major problem with the watercourse was that it was flowing through the village pond. Formerly it flowed beside the pond's bank but due to leakage of water, the pond expanded to its other side, too. Hence the edges of the watercourse being over-wet, got weak enough to break often by themselves or from animal stepping. This way most of its water got wasted in the pond and the farmers had to watch and repair the edges for watering their fields. Then there were many other weak sections downstream and to avoid thefts of water, another person had to guard it all along. This irrigation process was very difficult.

Second, the paths on the bank used to be muddy even in the dry season and hence difficult to walk along. A katcha road leading to a neighboring village, Dhotanwala (Chak No. 111 J.B.), also passed by the same pond. While passing, many times the residents of that village, stuck in or slipped on the mud especially in the dark night and they used to curse these villagers. To get rid of their continuous insult, these villagers repaired the path many times but it deteriorated again within a few days. The villagers of this village told me that it was really a continuous shame for them.

1977 and Onward (After the Improvement of the Watercourse)

1. The section near the pond is now pacca-lined, so there is no mud and leaking around the ponds. This is the biggest benefit of the improvement of the watercourse.

2. One person can easily divert water to his field on his turn, whereas prior to the improvement three to four persons were needed, two or three for watching the channel upstream and one for diverting water. The farmers at the middle of the watercourse could irrigate their lands with fewer persons than the farmers at the tail did before improvement; now one is sufficient even at the tail.

3. All the farmers get an even amount of water, whether at head, middle or tail.

4. There is no possibility for water theft along the pacca section. There is some possibility of the same along the katcha section but this practice has been reduced to being negligible, because all of the farmers can get enough water for their requirements on their respective turns.

5. The farmers now lend their turns of water to each other according to their needs. This was not even thought about before the improvement.

6. The farmers now sow crops within even a week after harvesting the previous crop. Formerly they had to wait for sufficient water and hence sowed the new crops at least three or four weeks after the harvest of the previous crops. This way they are able to sow early and keep their lands under different crops with very small intervals of time, and hence they grow more crops.

7. The cropped area per season was already 90 percent to 100 percent so no change was possible here.

8. Cotton has almost been excluded from the list of the major crops at this chak. It covered hardly four acres of land on this watercourse in the last Kharif season (1978). This is because of the insects and diseases.

9. Sugarcane, wheat and fodder are in almost the same position, as they were before the improvement.

10. A trend of growing vegetables, especially potato, has been in progress for the last five to six years.

11. In the last Kharif season (1978), for the first time, the Department of Reclamation issued permits to the farmers for planting rice on their saline land. Rice planting will be continued for two more Kharif seasons, at least, to reduce salinity in the lands.

12. Sometimes water leaking is caused by rats only, otherwise there is none.

13. Finally, it is notable that the watercourse committee has not been active or effective since improvement.

APPENDIX 23

# TREE REMOVAL AND WATERCOURSE IMPROVEMENT: A PRELIMINARY STUDY

by

Iqbal Niazi, Muhammad Yasin, Douglas Merrey and Helmer Holje[1]

## INTRODUCTION

Pakistan is predominantly an agricultural country and its agriculture is primarily dependent on irrigation. In spite of having one of the world's largest conveyance systems which contains over 85,000 watercourse command areas, the average crop yield is one of the lowest in the world. This is due in large part to the inefficient delivery system. These inefficiencies are found mainly in the watercourse (sarkari khal) of the command area and in the farmer's branches which lead from the sarkari khal to the individual fields.

In order to alleviate the water losses in the sarkari khal an intensive research program was undertaken by the Mona Reclamation Experimental Project with advisory help provided by Colorado State University funded under a program of USAID. The initial effort was directed at determining the most feasible system of watercourse improvement. Various pucca lining experiments were conducted along with a simple earthen improvement program, but with the installation of pucca control structures.

As a result of this experimentation, it was found that the earthen improvement program with pucca structures was the most feasible from an economic point of view in terms of costs and benefits as well as providing an opportunity to improve the many watercourses of Pakistan on a massive scale. It is primarily a labor oriented development with limited capital investments. Also, the labor is provided by the farmers for the most part with technical assistance provided by the GOP and USAID. Thus, it was felt that with a well organized and managed government institution that the watercourse improvement program throughout the entire country could be implemented and proceed at a fairly rapid pace. As a result, the On-Farm Water Management (OFWM) program was created. This program has been underway for some time and is making rapid progress in watercourse improvement. The research and development programs in watercourse improvement are also continuing at the Mona Reclamation Experimental Project to develop new and better methods for the watercourse improvement program.

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1/PSC, Social Scientist; PSC, Agr. Engineer; CSU, Anthropologist; CSU, Economist, respectively.

In order to proceed with the improvement work on a particular watercourse the farmers are required to remove all of the trees on the sarkari khal before any technical or monetary assistance is provided. Since trees are a valuable resource, both to the individual owner and to the Nation, this requirement has raised a number of questions about the necessity and utility of removing these trees. At present there are very little data available on the number and value of the trees removed, or farmers' attitudes and perceptions toward removing their trees as part of the watercourse improvement program. Therefore, it seemed most important to obtain some preliminary data concerning this problem to determine whether additional research was needed which could be used to develop policy measures by the GOP in regard to the tree removal regulation.

As a result, two surveys were conducted. One was carried out in conjunction with the Water Users Association study. A questionnaire was prepared and a random sample of farmers was selected from five villages. These farmers are all located on watercourses that have been improved. The second survey was undertaken on four watercourses that had not as yet been improved, but were to be improved at an early date. The thought was to get the opinions and attitudes of the farmers on a 'before' and 'after' situation. Unfortunately, these watercourses are still awaiting improvement although the farmers have removed the trees in most cases. Thus, a number of the answers given to the questions asked in the survey are opinions, or observations, of these farmers before experiencing the results of the watercourse improvement work. These answers, however, will be helpful in understanding the attitudes and feelings of the farmers, particularly when correlated with the answers obtained in the survey of the farmers in the five villages.

The first section of this paper contains the data obtained from the farmers in the five villages. The second section provides the information received from the farmers on the unimproved watercourses and this will be followed by some general observations and conclusions of the analysts.

Table 1 presents basic background data on the five villages surveyed. Two were in Sahiwal District two in Faisalabad, and one in Multan. Therefore a variety of cropping regions are represented in the sample. The sample was a random sample, stratified by position on the watercourse.

## Number and Types of Trees Removed According to Sample Farmers

Sample farmers were asked to estimate the total number and types of trees removed by them during the watercourse improvement project. These data are presented in Table 2.

TABLE 1

| Sr. No. | Village Number | Village Name | District | Tehsil | W/C Length (Meters) Total | W/C Length (Meters) Improved | Commanded area (acres) | No. Farmers Total | No. Farmers Sample | No. Farmers with trees on W/C |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 45/12-L | Firdous | Sahiwal | Chichan-watni | 4290 | 4290 | 400 | 31 | 16 | 11 |
| 2. | 103/10-L | Dinpur | Sahiwal | Sahiwal | 2218 | 2218 | 300 | 21 | 16 | 8 |
| 3. | 216 RB | Muham-madwala | Faisala-bad | Jaranwala | 5250 | 4140 | 375 | 56 | 11 | 8 |
| 4. | 136/16-L | Chak 36 | Multan | Khanewal | 5413 | 4490 | 492 | 46 | 13 | 5 |
| 5. | 475 GB | Giddar Pindi | Faisala-bad | Smundari | 7260 | 990 | 757 | 99 | 16 | 8 |
| | | | | | Total | | | 253 | 72 | 40 |

TABLE 2

Number and Kinds of Trees Removed*

| Village No. | Number of trees** | | | | |
|---|---|---|---|---|---|
| | Shisham | Kikar | Shisham and Kikar | Other | Total |
| 1 | 877 | 9 | - | 5 | 891 |
| 2 | 515 | 30 | 30 | - | 575 |
| 3 | 1459 | 67 | - | 22 | 1548 |
| 4 | 1027 | 302 | - | - | 1329 |
| 5 | 587 | - | - | - | 587 |
| TOTALS | 4465 | 408 | 30 | 27 | 4930 |
| PERCENT | 91 | 8.0 | 0.6 | 0.4 | 100 |

* Based on sample farmers' reporting
**Shisham is Dalbergia sisso; kikar is Acacia arabica; "other" includes mulberry, Dharek or Bakain (Melia azadarach); and Albizzia Lebbek.

The totals include both mature and immature trees, and are estimates made after completion of improvement.

Ninety-one percent of the total number of trees reported as removed from the five watercourses were Shisham. Shisham trees are quite abundant in most districts of Punjab. The weakest branches are commonly used as fuel, while the wood is especially valuable for making good quality roof beams and furniture, and is thus quite expensive. The next most common tree reported cut was Kikar (Acacia), accounting for eight percent of the total. Three-fourths of the total Kikar trees in the sample were removed from the Multan watercourse. This tree is found everywhere in Punjab, but is especially abundant in southern Punjab and Sind, where the soils are more sandy. Kikar wood is used mostly for fuel and cheap roofing and furnishing purposes. Shisham and Kikar together account for 99.6 percent of the total number of trees removed according to the sampled farmers.

Table 3 shows that among those farmers who had some trees on the watercourse. There is a very wide range in average numbers of trees per farmer. Assuming the sample as a whole is representative, the estimated total of trees per watercourse varies between 756 and 7896, while the total number removed from the five watercourses is estimated at over 18000. These figures combine mature and immature trees and are farmer's estimates, not actual counts. Nevertheless, they suggest that the farmers have sacrificed a large number of trees in order to obtain more irrigation water, and perhaps are a rough indication of the value farmers place on improving their watercourses.

## Number of Trees Not Removed from Improved Watercourse Sections

In the two villages of District Sahiwal, all the trees were removed during watercourse improvement. However, in the two District Faisalabad villages nine and two farmers, respectively, did not agree to remove them; they insisted on retaining their trees for shade during the hot summers for their cattle and themselves, and for fruit. In the District Multan village, of three trees not removed, one is owned by a farmer who refused to cooperate while the other two are claimed to be the property of the Government. These two could not legally be removed by the farmers. Therefore, with these few exceptions, the farmers did remove their trees as part of the improvement process.

## Means of Removal: Labor Organization

Table 4 shows that 68 percent of the sampled farmers having trees on the watercourse removed the trees themselves, or did it themselves with some help from hired labor. Thirty two percent had them removed by hired laborers.

TABLE 3

Average Number of Trees Reported per Farmer*

| Village No. | No. farmers w/c total | No. farmers Sample total | No. farmers Sample Having trees | Total No. Trees | Average No. Trees those having trees | Average No. Trees total sample farmers | Estimated** w/c total trees | Length of sarkari khal (meters) | Average No. trees/100 meters |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 31 | 16 | 11 | 891 | 81 | 56 | 1736 | 4290 | 40 |
| 2 | 21 | 16 | 8 | 575 | 72 | 36 | 756 | 2218 | 34 |
| 3 | 56 | 11 | 8 | 1548 | 194 | 141 | 7896 | 5250 | 150 |
| 4 | 46 | 13 | 5 | 1329 | 266 | 83 | 3818 | 5413 | 71 |
| 5 | 99 | 16 | 8 | 587 | 73 | 45 | 4455 | 7260 | 61 |
| TOTAL | 253 | 72 | 40 | 4930 | 686 | 361 | 18661 | 24431 | - |
| MEAN | 51 | 14 | 8 | 986 | 137 | 72 | 3732 | 4886 | 76 |

* The range in number of trees reported per farmer is from 3 to 1200; the figures from village number four include one farmer having 1200; similarly one farmer in village number three had 799.

**Average number of trees per farmer for total sample multiplied by number of farmers on the watercourse.

TABLE 4

Tree Removing Labor

| Labor Type | Number | Percent | |
|---|---|---|---|
| self (individual farmer) | 10 | 25 | 68 |
| self and hired labor | 17 | 43 | |
| hired labor only | 13 | 32 | |
| TOTAL | 40* | 100 | |

*40 is the number of sampled farmers actually removing trees.

## Opinions Concerning Ownership of Trees on the Sarkari Khal

Some questions have been raised as to whether the farmers or the government own the trees along the watercourse. Over 90 percent of the farmers in our sample believe that the trees along the watercourse are the property of the owners of the land adjacent to the watercourse. Most of them are, in fact, planted and harvested by these farmers.

## Official Objections to Removing Trees

There was no official objection to removing the trees on four of the five sampled watercourses, but on the fifth, in village number 5, Tehsil Samundari, the Revenue Department objected. As a punishment, and to recover its alleged loss, the Revenue Officials fined nine out of the thirteen sampled farmers.[2/] The farmers, under the rules, should have appealed to the Assistant Commissioner through proper channels, that is, On Farm Water Management. However, not knowing the official procedures, they went directly to the A.C., who referred them to OFWM for help. The OFWM officials assured the farmers verbally that they would discuss the matter with the Revenue Department and they would get their fines remitted. As of December, 1978, only one of the farmers had had his fine refunded. Another farmer's fine was excused before he had deposited it. The remaining seven farmers said they expected to have their fines remitted soon.

## Disposal of Trees Removed from the Watercourse

Table 5 shows that of the total forty farmers who removed some trees, twenty (50 percent), used the wood for fuel, while eleven (28 percent), used some for fuel and sold the rest. Only one sampled farmer sold all of his trees for lumber. The remaining eight farmers used their wood for various purposes, including fuel, building materials, and furniture; and three farmers had some agricultural implements made, including a cart. Also the leaves are frequently used as fodder, especially for goats.

## Income from the Trees

Annual Income Before Removal. Farmers were reluctant to indicate how much they earned from their trees annually before their removal. Table 6 shows that only thirteen farmers responded to this question. However, despite the limited data, some idea can be formed about the annual income from the trees before watercourse improvement.

2/Presumably this means that a much larger total number of farmers were fined. Only one sampled farmer indicated the amount of his fine--Rs.330.

TABLE 5

Uses of the Trees Removed

| Mode of Use | Village Number (No. and percent farmers)* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | | | |
| | no. | % | no. | % | no. | % | no. | % | no. | % | Tot-al** | % |
| Sale only | - | - | 1 | 13 | - | - | - | - | - | - | 1 | 2 |
| Own fuel only | 6 | 55 | 2 | 25 | 5** | 63 | 1 | 20 | 6 | 75 | 20 | 50 |
| Fuel and sale | 3 | 27 | 2 | 25 | 3 | 38 | 3 | 60 | - | - | 11 | 28 |
| Fuel & Building | 1 | 9 | 3 | 38 | - | - | - | - | - | - | 4 | 10 |
| Fuel & Agric. Imp. | 1*** | 9 | - | - | - | - | - | - | 2 | 25 | 3 | 8 |
| Fuel & Furniture | - | - | - | - | - | - | 1 | 20 | - | - | 1 | 2 |
| TOTAL | 11 | 100 | 8 | 101 | 8 | 101 | 5 | 100 | 8 | 100 | 40 | 100 |

* Percentages are rounded off.

** One farmer has stocked the wood at his dera and has been using part of it as fuel, but has not yet decided on further uses.

***This farmer had a plow and a cart made from wood.

## TABLE 6

Estimated Average Annual Income from Trees Before Removal

| Village No. | No. of farmers | | No. of Trees | | Average Annual Income (Rupees) | |
|---|---|---|---|---|---|---|
| | Removing Trees | Responded to question | Removed on w/c | Owned by respondents | Per farmer | Per Tree |
| 1 | 11 | 3 | 891 | 510 | 233 | 1.37 |
| 2 | 8 | 3 | 575 | 379 | 1167 | 3.08 |
| 3 | 8 | 3 | 1548 | 1000 | 1333 | 1.33 |
| 4 | 5 | 2 | 1329 | 1252 | 2500 | 2.00 |
| 5 | 8 | 2 | 587 | 61 | 500 | 16.40 |
| TOTAL | 40 | 13 | 4930 | 3202 | - | - |
| MEAN | 8 | 3 | 986 | 640 | 1147 | 4.84 |

Table 6 shows that each farmer used to earn about Rs.1147 per year from his standing trees. The average annual income per tree was Rs.4.84. Regardless of the exact reliability of these figures, it was obvious that standing trees are not only a means of saving for farmers, but are also a source of regular income, analagous to a savings account in a bank. "Closing the account" by removing the trees is likely only if farmers feel the potential benefits are greater than the annual income from their trees, and the need to have a source of ready cash for emergencies.

Estimated Income from Removal of Trees. Table 7 shows that for this question, too, the number of responses is rather limited. This table shows a wide variation in claimed income per tree from tree removal, ranging from Rs.6.18 to Rs.12.38. The average income per tree for all watercourses is under Rs.9.00. This figure is rather low, perhaps reflecting the inclusion of immature trees in the total sample. Farmers may also have understated their incomes. The total income claimed per farmer ranged from Rs.450 on one watercourse, to Rs.7,750 per farmer on the District Multan watercourse. The average amount earned per farmer was Rs.2,214.00. The estimated average total income from the removal of trees on a per farmer as well as per tree basis is almost double the annual income from the trees before removal.

## Farmers Willingness to Cut Trees Again, if Asked

The farmers were asked if they would still cut their trees as part of the watercourse improvement work if asked to do so again. Forty farmers--the number who actually cut trees--responded to this question. Table 8 shows that thirty-six (90 percent), of the respondents expressed satisfaction with the results of cutting their trees, and said they would cut their trees again. Only four farmers (10 percent), said they would not cut their trees again. This suggests that most farmers perceive the benefits of trees removal as being greater than the loss of their trees.3/

In the second survey, four unimproved watercourses were selected for study. The initial objective was to determine the number, type and size of the trees that were located on the sarkari khal, farmer's branches and in the fields of the watercourse command area. Two of the watercourses were located on the Mona Reclamation Experimental Project. They are W.C. 94, a perennial watercourse and supplemented previously by a public tubewell which has been shut down because of brackish water. However, there are four private tubewells in operation on this watercourse at the present time. The

3/Nevertheless, the authors have observed that farmers often replant new trees on improved watercourses after completion of the improvement.

TABLE 7

Estimated Income from Removal of Trees

| Village No. | No. of removing trees | Farmers responded to quest | No. of trees removed by respondents | Estimated Income (Rupees) Per Farmer | Per Tree |
|---|---|---|---|---|---|
| 1 | 11 | 3 | 510 | 1050 | 6.18 |
| 2 | 8 | 3 | 198 | 450 | 6.82 |
| 3 | 8 | 3 | 336 | 900 | 8.04 |
| 4 | 5 | 2 | 1252 | 7750 | 12.38 |
| 5 | 8 | 7 | 581 | 921 | 11.10 |
| TOTAL | 40 | 18 | 2877 | - | - |
| MEAN | 8 | 4 | 575 | 2214 | 8.90 |

TABLE 8

Willingness to Cut Trees Again

| Response | Village Number 1 | 2 | 3 | 4 | 5 | Total number | Total percent (of respondents) |
|---|---|---|---|---|---|---|---|
| Yes | 9 | 7 | 7 | 5 | 8 | 36 | 90 |
| No | 2 | 1 | 1 | - | - | 4 | 10 |
| No Response | 5 | 8 | 3 | 11 | 5 | 32 | - |
| TOTAL | 16 | 16 | 11 | 16 | 13 | 72 | 100 |

*Nevertheless, the authors have observed that farmers often replant new trees on improved watercourses after completion of the improvement.

other watercourse at Mona is 140 which is uncommanded, but has one public tubewell, which is operating, as well as four private tubewells. The two watercourses selected at Faisalabad are at Chak No. 52 and Chak No. 61. Both of these are perennial and without public tubewell water, but each have two private tubewells in operation.

When these watercourses were selected, it was understood that the trees would be removed during the winter and that the watercourses would be improved in early February. It was then thought that it would be desirable to interview a few selected farmers at Mona to ascertain their attitudes and feelings about the watercourse improvement program. A questionnaire was developed for this purpose. Unfortunately, the watercourse improvement work did not proceed as scheduled, so the farmers are still awaiting the improvement of their watercourses. However, it was felt that some informed opinions could be gleaned from the farmers, so ten farmers at each watercourse were interviewed. They, of course, had observed what had happened, and is happening, on previously improved watercourses at Mona, and they were in a position to make some worthwhile observations about their own situation.

Number, Location and Size of Trees Removed

Watercourse 94 has a command area of 700 acres and has a total of 23,936 trees. Out of these, 6665 are on the sarkari khal, 5894 on the farmers' branches and 11,377 in the command area. This means that over 50 percent of these trees are either on the sarkari khal, or on the farmers' branches. It was found that 58 percent of these trees are shisham, 19 percent bari, 16 percent kikar and the remaining 7 percent in a variety of species. In terms of size, about 60 percent of these trees are 8 inches or less in diameter.

There are 7537 trees at Watercourse 140 which has a command area of 455 acres. The sarkari khal contained 919, the farmers' branches 1750 and 4868 are in the command area. In this case, only 12 percent of the trees are on the sarkari khal and 23 percent on the farmers' branches. Also, kikar is the most common as 56 percent of the trees are in this species, followed by shisham with 22 percent, bari, 9 percent, and all others 13 percent. The trees on this watercourse are smaller in size than on W.C. 94 as 84 percent are less than 8 inches in diameter.

At Chak 52 and Chak 61 only the trees were counted. No tabulation was made of the species, or size, as this type of information was obtained in the first survey. At Chak 52, a command area of 500 acres, 916 trees were counted on the sarkari khal, 1457 on the farmers' branches and 1370 in the command area. The watercourse at Chak 61 is relatively small having only 275 acres. Here 112 trees were counted on the sarkari khal, 855 on the farmer's branches and 536 in the command area.

When one compares the number of trees by location and per acre at each of the watercourses a considerable difference is found. Watercourse 94 has 28 percent of its trees on the sarkari khal, W.C. 140, 12 percent, Chak 52, 24 percent and Chak 61 only 7 percent. However, at Chak 61, 57 percent of the trees are on the farmers' branches while at Chak 52, 39 percent are on farmers' branches, at W.C. 140, 23 percent and at W.C. 94, 25 percent. In the command areas, one finds 47 percent of the trees at W.C. 94, 65 percent at W.C. 140, 37 percent at Chak 52 and 36 percent at Chak 61. On a per acre basis there are 34 at W.C. 94, 17 at W.C. 17, 7 at Chak 52 and 5 at Chak 61. It is fairly obvious that the density of trees is much greater in the Mona area.

As indicated previously, the plan to interview the farmers on the two watercourses at Mona didn't materialize as expected because the watercourse improvement work has not yet been completed. However, 10 farmers at each watercourse were interviewed to get their attitudes and reaction to the program. All but two of the farmers felt that the improvement program would increase their water supplies which would enable them to increase their cropping intensity and acres cultivated, thereby increasing their overall production. They felt that this increased production would more than compensate them for the loss of trees. Twelve of the twenty farmers said they planned to plant new trees, but not on the sarkari khal or the farm branches.

All but two of the farmers interviewed felt that the trees on the sarkari khal belong to the farmers whose land it borders. There was no interference from government agencies and 18 of the 20 farms removed the trees themselves with the help of hired labor in a few cases.

When asked why the trees had not been removed before when the general feeling seems to be that it would greatly increase their water supply the most prevalent answers were: 1) ignorance; 2) lack of technical assistance; 3) lack of cooperation among the farmers; 4) there had been sufficient water and 5) the trees are a valuable asset and could not be replaced.

Only one-half of the farmers were willing to state how much they had received in income from the trees removed. The mean income was Rs. 885, but there was a great variance among the respondents. If a more sophisticated study is initiated it would be advisable to determine the return on a linear foot basis of the sarkari khal. However, the general income question asked, both at Faisalabad and Mona, does indicate that the trees removed have a substantial value and could provide much of the money needed for the pucca structures on the improved watercourses.

General Observations and Conclusions

1. Trees, without question, are a valuable resource to the farmers. They are used for many purposes such as implements, building materials, furniture, fuel, fodder, shade, boundary lines, wind breakers and have great aesthetic value. They also serve many farmers as a source of income for emergency and other purposes.

2. Unfortunately, trees can also be a serious detriment to the farmer operations, particularly when they are located in improper places. Those located on the sarkari khal or farmers' branches often impede the full flow of water and provide opportunities for trash to accumulate which further restricts the flow of water. Likewise, the trees located on the banks of the watercourse makes them porous and enables rodents and insects to greatly increase the seepage losses. The trees themselves also consume large quantities of water which otherwise could be used for crop production. Also, many of the trees are an ideal haven for destructive birds.

3. It was estimated that 26,612 trees were removed from the sarkari khal on the nine watercourses included in this survey. Almost all of these were removed by the farmers and represents a lot of hard work. In most cases, no definite plans have been made to replace these trees. Obviously, most of them were not planted, but are a result of natural propagation. It would be desirable to develop a tree replacement policy. Desirable species could be selected and planted in strategic locations, thereby maintaining the free flow of water in the watercourses and as time goes on in the farmers' branches as well.

4. Almost all of the farmers believe that the trees on the sarkari khal belong to the farmers whose land it borders. This is a legal question that hasn't been resolved in the courts, but the government thus far has adopted a lenient policy regarding their removal and will probably do so in the future. The general feeling being that the tree removal program is essential to the watercourse improvement work which in turn is most beneficial to increasing agricultural production.

5. Over 95 percent of the farmers interviewed feel that the tree removal requirement is desirable and that the increased water supplies more than offset the loss suffered from the removal of the trees.

6. Finally, it seems apparent from this brief survey that a much more intensive study of this matter is warranted. It appears that if the proper programs and policies are developed that the removal of the trees would not only enhance the water supply, but with a well designed tree planting program the benefits from the trees themselves could be increased, too.

## APPENDIX 1

### Tree Survey

Questions to be asked of sample farmers on Improved Watercourse

1. A. Were all the trees along the improved section of the watercourse removed? Yes ______ No ______
   B. Who removed them?
   C. If all were not removed, whose trees were not removed and why?
2. A. Who is the real owner of the trees on the watercourse, in your opinion? a) individual farmers ______;
   b) Government ______; c) Other ______ (specify)
3. A. Were there any objections from Government Departments (such as Revenue, Forestry) to your removing the trees?
   Yes ______ No ______
   B. If yes, then which Department objected? ______
   C. What action, if any, did this Department take, and with what result?
   D. If any action was taken, did the On Farm Water Management personnel help you? Yes ______ No ______
   E. What is the present position in regard to the action taken (e.g., appeals, no further action, etc.)?

(NOTE: Even if the respondent claims the Government owns the trees, he undoubtedly feels he has some rights in them and was making use of them. Therefore, ask the following questions from all farmers unless he had no trees; if none, write none in question 4.)

4. Please estimate how many of your trees were removed, the kinds of trees, their value, and what was done with them.

| Kind of tree | No. of use trees | made before cutting | annual earning before cutting | how disposed of if sold, give price |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| Total | | | | |

5. Do you know why OFWM asked you to remove the trees?
   Yes ______ No ______ If yes, why ______
6. Do you regret having removed these trees? That is, is the value of the improvement greater than the value of the trees

lost? (This will have to be explained clearly and carefully in simple language), Yes______ No________ Why____________
7. Would you cut your trees again if asked to for watercourse improvement? Yes__________ No__________

## APPENDIX 2

### TREE SURVEY OF FARMERS ON WATERCOURSES TO BE IMPROVED

1. What are your feelings about removing the trees from the watercourse?

   a. Has it helped to increase your water supply? Yes__________ No__________
   b. Has it helped to straighten and strengthen the watercourse? Yes________ No________
   c. Has it helped to increase the acres cropped? Yes________ No________
   d. Has it helped to increase your cropping intensity? Yes________ No________
   e. Were all of the trees removed from the watercourse? Yes________ No________
   f. Who removed the trees? Yourself____ Hired Labor_____ Contractor________
   g. What use has been made of the removed trees?________

2. Who do you feel is the real owner of the trees?________

3. Were there any objections from Government Departments (such as Revenue, Forestry, Irrigation, etc.)? Yes_____ No_____ If so, what was the objection and how was it resolved?________________

4. Do you feel that all of the farmers in the watercourse command area should share in the money received from the removal of the trees on the sarkari khal? __________
   Are you located on the sarkari khal?______________

5. What was the value of the trees removed?____________

6. Was this sufficient money to pay for the structures needed in the watercourse improvement work? Yes____ No________

7. Would you participate in the tree removal program again? Yes___________ No_____________

8. Did you grow these trees intentionally? Yes____ No_____

9. If yes, why did you plant them on the watercourse?_____

10. Do you plan to plant new trees? Yes_______ No________

11. If so, where do you plan to plant the new trees? ________

12. Is the income from the sale of trees necessary for your family living expenses? Yes______ No________

13. Do you feel that the tree removal and watercourse improvement work is helpful to you and that the increased returns from crop production more than compensates you for the loss of the trees? Yes______ No______

14. If you feel that the tree removal and watercourse improvement work is helpful to you why do you think so many farmers have not done this type of work in the past? ________________________________________

15. Are you planning to remove any trees from your field branches? Yes__________ No__________

APPENDIX 24

# A STUDY INTO THE MARKETING PROBLEMS OF CITRUS GROWERS IN THE MONA PROJECT AREA

Mohammad Aslam, Mohammad Siddique, Abdul Rauf and Helmer Holje[1/]

## CHAPTER ONE

## ORIGIN AND IMPORTANCE OF CITRUS

Weber (1948) in his book, "The Citrus Industry," is of the view that an important species of citrus, namely sweet orange, had been grown for many centuries in China much before the birth of Christ. Similarly, traces of citrus have been found in the Middle East, in the area of Mesopotamia and Southern Babylonia in the period B.C.

With an ever-increasing demand for balanced food supplies, fruit has become an important part of our diets. Almost all fruits are very nutritious and contain valuable vitamins and calories. Fruit raising is thus proving to be a significant and profitable enterprise, as well as a potential source of foreign exchange. Rapid economic growth, resulting in increased per capita incomes, will further enhance the demand for this quality food to meet the requirements of a balanced diet.

### IMPORTANCE

The economic progress of Pakistan is directly linked with the development of the agricultural sector. This, in turn, pivots around the development of techniques for increasing production, finding better and high-yielding crop varieties, improved processing and storage of farm produce and the development of an efficient marketing system.

In view of the foregoing, the fruit industry in Pakistan has ample stimulus for an accelerated development. Pakistan's future strategy for agricultural development should increase its focus on an enhanced supply of fruit and its by-products, both for domestic consumption as well as for export.

From the consumer's point of view, fruit constitutes a vital component of daily consumption as they contain essential calories, minerals and vitamins for his diet. Expectation of increased demand of processed fruits gives rise to the need for prompt promotion of fruit raising, processing and an efficient marketing system.

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Fruit raising in general, and citrus growing in particular, yields a higher income per acre when compared to other agricultural crops. Citrus, thus, holds a very important economic position in the fruit industry of Pakistan on both an acreage and total value basis.

Pakistan is one of the major citrus growing countries in the world. The others are the U.S.A., U.S.S.R., France, China, and India. Citrus contributes as much as 7% of the entire food production in Pakistan, of which the Punjab alone contributes about 89 percent. The other provinces, like Baluchistan, NWFP, and Sind, contribute 8.07 percent, 4.82 percent and 0.19 percent, respectively. 2/

The major citrus growing areas of Pakistan are Sargodha, Multan, Lahore, Peshawar, Hyderabad, Rawalpindi and Bahawalpur Divisions. Distribution of acreage and production of citrus in various divisions of the Punjab during 1976-77 is as follows: 3/

| | Division | Acreage | Production (Tons) | % Share |
|---|---|---|---|---|
| 1. | Sargodha | 83502 | 366368 | 56 |
| 2. | Multan | 37782 | 148929 | 23 |
| 3. | Bahawalpur | 32149 | 82163 | 13 |
| 4. | Rawalpindi | 9408 | 27413 | 4 |
| 5. | Lahore | 8811 | 27448 | 4 |
| | T O T A L | 171652 | 652321 | 100.00 |

The reasons for the phenomenal growth of citrus production in Pakistan is due to the favorable climate, fertile soils, and the availability of adequate irrigation water. Citrus has not only registered a quantitative increase but also its quality has been improved a great deal. These factors, coupled with good prices in most years, has created an ever-increasing interest in the citrus industry.

Rapidly increasing acreage under citrus will pose many problems, particularly in the field of marketing. Moreover, the enhanced production has brightened the chances of export of fresh fruit and this also requires a well established and efficient marketing system. On the other hand, the farmers usually complain that they are not receiving their share of the consumers rupees and during the surplus production years their produce is not properly marketed. In view of these

2/The Yearbook of Agricultural Statistics 1971-72 and Development Statistics of Sind, 1973.
3/Agri. Statistics of Pakistan-1977

circumstances, a scientific and well planned study is imperative to isolate the nature and extent of the various problems faced in the disposal of citrus fruit at various trade levels.

The Mona Reclamation Experimental Project was initiated with the aim to carry out research in the field of agriculture for the general economic uplift of the area. This study has been undertaken to examine the existing marketing system and the major bottlenecks in the way of establishing an efficient marketing system for citrus and to determine the extent of export possibilities for future programming and planning.

## CHAPTER TWO

## METHODOLOGY

### SELECTION OF AREA

The Punjab accounts for about 89 percent of the total acreage and 90-97 percent of the total production of citrus in Pakistan. The citrus production belt of the province comprises the districts of Sargodha, Faisalabad, Sahiwal, Lahore, Sheikhpura and Multan. Sargodha in general and Tehsil Bhalwal in particular, is the major citrus producing area - contributing the major share for home consumption and export. The project area, comprising mainly Tehsil Bhalwal, was thus selected for the analysis of marketing problems faced by the entrepreneurs in the industry.

### SELECTION OF GARDENS

A list of 137 citrus gardens, located at various locations was prepared by a preliminary survey of the area. Data from the sampled gardens relating to their location, distribution of variety, acreage in each orchard, type of approach road, means of transportation, type of losses, cost of transportation and selling practices were taken from the growers and handlers.

### DRAWING OF SAMPLE

After preparing a list of citrus orchards from a preliminary survey, the growers were stratified into three categories on the following criteria:

| Size of Gardens | Extent of Acreage |
|---|---|
| i) Small | 0 - 6.25 |
| ii) Medium | 6.25 - 12.50 |
| iii) Large | 12.50 - and above |

In order to give equal weight to each strata, a 40 percent random sample was taken from each. As a result, the following classification was used for the study.

| | |
|---|---|
| No. of small orchard holders | =18 |
| No. of medium orchard holders | =18 |
| No. of large orchard holders | =19 |
| TOTAL | =55 |

PROBLEMS OF MARKET ANALYSIS

Growers problems. Every effort was made to obtain the unbiased views of the growers concerning their marketing problems. Incidentally only two out of the 55 cases turned out to be growers who marketed their citrus themselves.

Contractors' problems. Generally, the pre-harvest contractors market the citrus at their own risk. Unlike the growers who were contacted on their farms for the interview, the pre-harvest contractors were approached in the orchards, at the markets where they carry on their business and even at their residences, creating great difficulty in making these contacts.

COLLECTION OF DATA

The sampled gardens were regularly visited and the information was collected from the garden owner, or the contractor, or whoever was found managing the garden.

Likewise, the markets were visited to contact the pre-harvest contractors, middlemen and arhtis to determine the cost of picking, packing, loading, unloading, transportation, and the commission rate paid to the middlemen and arhtis for handling the business.

PROBLEMS FACED IN THE COLLECTION OF THE DATA

Inaccessibility to the respondents. Much difficulty was faced in contacting the respondents. In the case of the orchard owners, the job was a bit easier as they could be approached on their farms. The main difficulties arose when the pre-harvest contractors were involved, who greatly outnumbered the growers. Generally a contractor was managing more than one orchard and hence not easily accessible.

Hesitation in providing the information. The respondents were usually suspicious of the interviewers and reluctant to reply. The field staff was, however, fully apprised of the importance of the study and were accordingly trained to obtain unbiased information.

Lack of written records. Besides the reluctance of the respondents to respond, the lack of written records was another hinderance. In most cases the memory of the respondents had to be relied upon. However, every effort was made to secure reliable information.

## CHAPTER THREE

## RESULTS AND DISCUSSION

Training in gardening. In order to assess the technical knowledge in gardening, the growers were asked to indicate their training. In line with the general standard of literacy in the country, however, only 20 percent of the growers claimed to be trained and even those "informally." This reflects the backwardness of the growers in this important industry. This is not a good sign for the healthy development of this industry. Moreover it also indicates the inadequacy of the existing training facilities in the country.

Distance from the local market. The local market is an important place for determining the profit prospects. The approach roads and routes from the place of production to the local market area, therefore, are very important. An efficient network of roads is a prerequisite for safe and quick transportation. The sampled orchards in this study have 61.39 percent pucca roads and 38.61 percent katcha roads at their command.

Area under different citrus varieties. According to the sample, kinno is commanding the largest acreage of the total area under citrus orchards. Feutrell early, malta and mussami follow by order of relative importance. The overall percentage is 73.87, 11.48, 8.16 and 6.50, respectively. However, young gardens are almost entirely in kinnos. The following table provides the data breakdown by variety, size of orchards and whether the gardens are young or mature.

Table 1 shows that among the large gardens young kinno commands the largest percentage of the area under citrus. No young gardens have been reported under feutrell, early or mussami in the large gardens. In the medium category there are no young gardens of malta and mussami, and in the small category there are no young gardens in mussami.

In the case of mature gardens, after kinno, the largest percentage of the area comes under feutrell and next comes malta. Mussami is the tail-ender. This indicates a trend towards the demand of more juicy citrus fruit.

Table-1 PROPORTIONAL AREA UNDER DIFFERENT CITRUS VARIETIES

| Size of garden | Kinno YG % | Kinno Mature % | Feutrell YG % | Feutrell Mature % | Malta YG % | Malta Mature % | Musammi YG % | Musammi Mature % |
|---|---|---|---|---|---|---|---|---|
| Small | 96.38 | 75.42 | 1.45 | 9.32 | 2.71 | 6.78 | - | 8.47 |
| Medium | 98.44 | 71.77 | 1.56 | 11.90 | - | 12.59 | - | 3.74 |
| Large | 99.10 | 74.34 | - | 11.62 | 0.90 | 6.91 | - | 7.13 |
| Overall | 98.53 | 73.87 | 0.63 | 11.48 | 0.84 | 8.16 | - | 6.50 |

Fruit-bearing behavior. There is no uniform age for fruit-bearing of citrus plants. The age varies depending on climate, quality of the soil and variety of the plant. The majority of the respondents agreed that 4-5 years was the normal fruit bearing maturation age.

The prime age for fruit-bearing was from the 6th through the 8th year.

There is considerable difference of opinion as to when the trees become unproductive. The majority of respondents thinks it starts in the 11th year, whereas some thought it commences in the 12th, 13th, 14th and even the 15th year of the plant's life.

Cost of production. Net income equals gross income minus the costs of production. A glance at Table 2 reveals that the cost of production per acre increases with the increase in the size of the garden. This is mainly due to the disguised family labor on the smaller gardens, higher costs of plant replacement, bigger doses of fertilizer and more plant protection measures adopted in the larger orchards.

Fertilizer constitutes the biggest part of the total variable cost of production. This is followed by labor cost of replacement, F.Y.M., land revenue, transportation and spraying.

The cost of production per acre in the small category is Rs. 365. In the medium category it amounts to Rs. 405 and in the large category it totals Rs. 434. The increasing cost of production per acre with the increase in size of the gardens points out the presence of disguised labor in the case of the smaller categories as the owners rarely hire labor outside their family.

Table-2

COST OF PRODUCTION (AVERAGE)
(Rs)

| Size of garden | Replacement Cost | F.Y.M. | Fertilizer | Labour | Spraying | Transportation | Land Revenue | Average peracre |
|---|---|---|---|---|---|---|---|---|
| Small | 372.00 | 344.44 | 305.27 | 585.77 | 145.00 | - | 337.61 | 365.20 |
| Medium | 1267.67 | 851.00 | 1145.00 | 1185.00 | 550.00 | - | 841.17 | 405.06 |
| Large | 2077.00 | 2240.00 | 4165.50 | 3545.45 | 1375.00 | 1000 | 2472.00 | 433.72 |
| Overall | 1496.77 | 1215.81 | 2122.28 | 1719.56 | 861.25 | 1000 | 1239.75 | 421.25 |

<u>Rate of fruit-bearing per plant</u>. In view of the increased demand for kinno, more attention is being paid to this variety. It is not only the highest yielding variety, but is also very tasty. Malta feutrell early and mussami follow in order of merit. The following table indicates the yields by variety and garden size.

Table-3 TOTAL PRODUCTION FRUIT BEARING PER PLANT (Number)

| Size of garden | Kinno | Feutrell early | Malta | Mussammi |
|---|---|---|---|---|
| Small | 681 | 623 | 667 | 310 |
| Medium | 743 | 590 | 638 | 490 |
| Large | 979 | 718 | 780 | 840 |
| Overall | 900 | 673 | 732 | 736 |

<u>Reason for selling gardens at premature stage</u>. The selling of one's product at a premature stage shows the vulnerability of the producer to the current market structure. It seriously reduces the chances of the farmers to improve his bargaining power and ultimately his net income.

Out of the 55 cases selected for this study, only two growers do their own marketing. The rest sell their gardens at a premature stage to the contractors.

On inquiry, it was revealed that th urgent need of money was the primary reason for selling their gardens at this stage. The lack of market information, business experience, timidity to take risk and convenience were other factors contributing to this practice. Some other factors include the nonavailability of labor and means of transportation at the appropriate time. Table 4 classifies the importance of each of these factors on a percentage basis.

<u>Mode of payment</u>. As has already been stated, out of the 55 cases selected for survey, 53 turned out to be preharvest contractors, who do not make the payment in lump sum but is made in installments. The other two cases fall in the category of owner-cum-preharvest contractors. On inquiry it was revealed that 42 respondents paid 1/4th of the total amount at the time of the contract and the remaining 3/4th at the time of harvest. Six respondents paid 1/4th at the time of contract, 1/2 at the

start of the picking and the remaining 1/4th at harvest. The other 6 respondents paid 1/4th at the time of the contract, another 1/4th at the middle of the picking and the remaining 1/2 at the end.

Losses incurred. In 1970 the FAO reported: "Nobody knows how much food men labor every year to produce only to see it.....spoiled in a hundred different ways. The figures and estimates fly around 10 percent here, 50 percent there, 20 percent in the world as a whole and almost every figure has its firm supporters and its equally resolute opponents. About the only thing that is generally agreed upon is that losses are enormous.....".

Pakistan, being a developing country, can ill-afford the wastage of even a small quantity of its agricultural produce.

Since in the surveyed area the pre-harvest contractors purchased the orchards much before maturity, they have to bear all such losses taking place due to kera in addition to those occuring during the picking, packing and transportation. Almost 50 percent of the total losses are due to kera. This is a standing fruit loss and is mainly due to poor soil conditions and climatic factors. Birds and parasites damage about 30 percent and 3 percent is pilferage.

Picking usually starts when the fruit is almost mature. At the pre-harvest contractors level, picking is performed by the contractors themselves or by hired labor. In the surveyed area, the small contractors participated in picking but the large contractors used hired labor. That is why picking losses in medium and large gardens are higher than in small gardens. Of the total loss the loss due to picking is about 5 percent.

After picking the fruit, it is packed for hauling to the market. Grading is also done before the commodity is packed. The grading is performed on the basis of color, size and taste. However, the majority of the contractors disposed of their produce without grading. This was mainly to save time and the cost of labor as there does not exist any standard for grading. Packing losses were 3 percent of the total losses. However, since the small contractors market their produce loose, the loss is negligible.

Transportation moves the commodity from the place of production to the buyers. It is, therefore, a crucial step in the marketing process. Transportation is carried out in the surveyed area by trucks, trolleys and bull-carts. On an average, the total loss reported for transportation is about 10 percent.

Details of the losses incurred is given in Table 5.

Table-4

## REASONS FOR SELLING GARDEN AT PRE-MATURE STAGE
(Percentage)

| Size of garden | Lack of | | | | Urgent need of money | To avoid | |
|---|---|---|---|---|---|---|---|
| | Labour | Transportation | Market Information | Business Experience | | Risk | Inconvenience |
| Small | 5.56 | 9.26 | 12.96 | 16.67 | 20.37 | 18.52 | 16.67 |
| Medium | 7.14 | 4.76 | 16.67 | 19 05 | 26.19 | 9.52 | 16.67 |
| Large | 2.44 | 4.88 | 21.95 | 12.20 | 19.51 | 19.51 | 19.51 |
| Overall | 5.11 | 6.57 | 16.79 | 16.60 | 21.90 | 16.06 | 17.52 |

Table-5

LOSSES INCURRED
(Percent)

| Size of garden | Birds | Kera | Stealing | During picking | During Packing | During Transportation |
|---|---|---|---|---|---|---|
| Small | 31.25 | 53.75 | 1.57 | 3.40 | 0.94 | 9.07 |
| Medium | 38.00 | 34.67 | 6.00 | 6.34 | 3.67 | 11.33 |
| Large | 19.23 | 60.38 | - | 6.92 | 4.62 | 8.85 |
| Overall | 29.50 | 49.60 | 2.61 | 5.45 | 3.07 | 9.77 |

Yield of the trees. Yield has a direct correlation with production. A study of the factors leading to enhanced yield was made. Likewise, factors hindering yields were also analyzed. The trees of the sampled orchards which did not yield fruit were studied and the reasons given by the growers were recorded. It was found that 32 percent of the sterility was caused by disease. Lack of irrigation water, fertilizer and improper soil also decreased the fruitition of the trees by 16.8, 10.7 and 12.2 percent, respectively.

Other factors responsible for low yields are: lack of care, immaturity of trees, hazardous sub-soil and water, nonavailability of good varieties, lack of plant protection measures and waterlogging.

Table 6 gives the reasons for the low yields of trees.

Price behavior. Generally, commodity prices move together. Like the prices of most other goods the trend in citrus during the period 1975-78 has been upward. The growers and contractors were asked as to what the price structure had been during this three-year period.

A look at Table 7 makes it clear that the last three years have witnessed a price boom in the citrus industry. The main reason being a tremendous increase in its demand, both at home and abroad.

It is noteworthy that the increase in the price of citrus per acre was greater during 1977-78 than in 1976-77. On an average, an acre of citrus was worth Rs. 1992 in 1975-76, Rs. 2229 in 1976-77, but shot up to Rs. 3749 in 1977-79. This was due to the increased demand for citrus without a corresponding increase in supply.

Table-6 REASONS FOR TREES NOT YIELDING FRUIT (Percentage)

| Size of garden | Lack of | | | | Immaturity | Hazardous sub-soil water | Disease attacks | Non-availability of good fruit tree varieties | Water-logging | Lack of P.P. measures |
|---|---|---|---|---|---|---|---|---|---|---|
| | Irrigation supply | Proper soil | Proper care | Fertilizar | | | | | | |
| Small | 16.22 | 15.51 | 2.70 | 10.81 | - | 5.41 | 29.73 | - | 18.92 | 2.70 |
| Medium | 12.50 | 15.00 | 15.00 | 15.00 | 5.00 | - | 30.00 | 2.50 | 2.50 | 2.50 |
| Large | 20.37 | 9.26 | 5.56 | 7.41 | 3.70 | 1.85 | 35.19 | 5.56 | 3.70 | 7.40 |
| Overall | 16.79 | 12.21 | 7.65 | 10.69 | 3.05 | 2.29 | 32.06 | 3.05 | 7.65 | 4.58 |

Table-7 PRICE BEHAVIOUR OF CITRUS (PER ACRE) DURING THE LAST THREE YEARS(1975-78) (Rs)

| Size of garden | 1975-76 | 1976-77 | 1977-78 |
|---|---|---|---|
| Small | 1693.22 | 1977.97 | 3261.02 |
| Medium | 2786.39 | 2952.72 | 3466.00 |
| Large | 1774.12 | 2189.69 | 3902.69 |
| Overall | 1991.69 | 2229.23 | 3748.53 |

During 1977-78, there was a slump in the citrus market for a short while as markets swelled with the exportable surplus, but with the easing of import restrictions by Iran the citrus market recovered rapidly.

An interesting fact revealed by Table 7 is that generally the smaller orchard growers received lower prices than the larger ones. This indicates a lack of bargaining power of the small growers with the contractors.

Picking practices. Picking practices are important reasons for the price fluctuations in citrus during the season. Citrus fruit is a highly perishable commodity. A slump in its trade may be due to gutted markets which in turn quickly lowers its price. As a matter of fact, picking of the citrus usually starts with a rush and ends abruptly.

In the surveyor area, 47 respondents picked their produce early, five picked timely and three picked the fruit late. A more uniform rate of picking would be highly desirable.

Transportation. Marketing depends to a large extent on transportation. Efficient transportation is a prerequisite to an efficient marketing system.

As already pointed out, only a few growers market their produce themselves. Marketing is in most cases a contractor's problem. The marketing problems faced by the contractors are enumerated in Table 8.

High cost is the largest obstacle in hiring transport. This is simply due to its shortage as compared with its demand during the peak season. Even if transport is available,

Table-8 PROBLEMS OF TRANSPORTATION
(percentage)

| Size of garden | Non-availability of means | High Cost | Losses during transit | Inaccess-ability |
|---|---|---|---|---|
| Small | 27.59 | 58.62 | 6.90 | 6.90 |
| Medium | 32.00 | 60.00 | - | 8.00 |
| Large | 25.00 | 56.25 | 9.38 | 9.38 |
| Overall | 27.91 | 58.14 | 5.81 | 8.41 |

many orchards are inaccessible. It may also be noted that additional losses occur during transit.

Cost of marketing citrus. Marketing is much more important today than a short while ago. The function of a good marketing system is to get the product to the consumer at the proper place, at the proper time, in the proper form and at an acceptable price.

Marketing costs are relatively inflexible because many of them are based on volume rather than the value of the product. This is particularly true in the citrus industry. Whatever the price of citrus, marketing costs remain more or less fixed.

However, marketing costs do differ on account of:

i) Amount of perishability: The higher the rate of perishability, the higher the cost of marketing.

ii) Bulkiness relative to value: Marketing costs also increase with the bulkiness of the product.

In the sampled area, only two means of transportation were used. These are truck and rehra. The former is used for packed transportation to the relatively distant markets and the latter for the local market, i.e. Bhalwal. A look at Table 9 shows that with an increase in the acreage of orchards the share of transportation done by rehra decreases. In other words, small contractors and growers content themselves with selling their produce in the local market.

Table-9

| Size of garden | Mode of transport (percent) | |
|---|---|---|
| Small | Rehra | 41.12% |
| | Truck | 58.88% |
| Medium | Rehra | 29.41% |
| | Truck | 70.59% |
| Large | Rehra | 10.53% |
| | Truck | 89.47% |
| Overall | Rehra | 26.42% |
| | Truck | 73.58% |

Table 10 depicts the cost of handling and transporting citrus by truck. It may be seen that the nearer the market, the higher the cost of marketing per mile. In economic terms it may be said that the marginal cost of transportation decreases with every added mile of distance. An interesting factor is that only 1/7th of the total costs of marketing are the commission costs. If these could be reduced the price to the consumer could be lowered substantially.

As already pointed out, when the distance is short the citrus may be transported in loose form because of the minimum climatic hazards during transit. Thus, the rehra is a feasible means of transport for the local markets.

However, for the more distant markets truck transportation becomes necessary and the marketing costs are increased greatly. These data are presented in Table 11. Though export transportation costs were not analyzed in this study, the costs there would be even greater because of the greater distance and the need for more careful handling.

Cost of picking and packing of fruit on per truck basis:

On an average, picking and packing a truck with 400 (12x12x18) crates per truck costs about Rs. 2870. The breakdown of the total cost is as follows:

Table-10

COST OF MARKETING OF PACKED FRUITS PER HUNDRED AND PER MILE FROM ORCHARD TO DIFFERENT MARKETS

| From Orchard to..... | Mode of trans-port | Cost of hiring trans-port | Cost of handling the fruits | | | | | | | | Cost during tran-sit | | | Cost/ hund-red | Cost per hundred per mile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Watch and ward | Raw material | | | | Pick-ing | Pack-ing | Unlo-ading | | | | | |
| | | | | Bas-kets | Kut-ar | News paper | Nails | | | | Oct. | Toll tax | Comm-ission | | |
| Peshawar | Truck | 1200 | 150 | 1400 | 1800 | 500 | 30 | 500 | 200 | 225 | 250 | 50 | 875 | 8.00 | 0.03 |
| Hyderabad | -do- | 1750 | 150 | 1300 | 1200 | 300 | 30 | 325 | 200 | 225 | 250 | 50 | 980 | 9.00 | 0.01 |
| Karachi | -do- | 2050 | 150 | 1350 | 1200 | 280 | 30 | 325 | 200 | 250 | 250 | 50 | 1000 | 10.00 | 0.01 |
| Quetta | -do- | 1800 | 150 | 1400 | 1200 | 315 | 30 | 315 | 200 | 250 | 250 | 50 | 900 | 9.00 | 0.01 |
| Lahore | -do- | 670 | 150 | 1325 | 1100 | 310 | 30 | 300 | 225 | 250 | 250 | 50 | 445 | 8.00 | 0.05 |

Table-11

COST OF MARKETINGS OF UNPACKED FRUIT PER HUNDRED AND PER HUNDRED MILES FROM ORCHARD TO DIFFERENT MARKETS

| From orchard to...... | Mode of Transport | Cost of hiring transport | Cost of handling | | | Cost during transit | | | Cost/100 | Cost/100 mile |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Watch and ward | Picking and loading | Unloading | Oct. | Toll tax | Commission | | |
| Bhalwal | Rehra | 35.00 | 10.00 | 50.00 | 3.00 | 15 | - | 12.50 | 2.34 | 0.24 |
| Sargodha | Truck | 233.00 | 140.00 | 300.00 | 200.00 | 250 | 50 | 280.00 | 3.20 | 0.11 |
| Faisalabad | -do- | 550.00 | 150.00 | 300.00 | 250.00 | 250 | 50 | 350.00 | 4.20 | 0.04 |
| Lahore | -do- | 670.00 | 150.00 | 300.00 | 200.00 | 250. | 50 | 300.00 | 4.30 | 0.03 |

| | | |
|---|---|---|
| 1. | Cost of labor for picking (32 laborers @ Rs. 10/laborer) | Rs. 320.00 |
| 2. | Packing (18 laborers @ Rs. 10/laborer) | = Rs. 180.00 |
| 3. | Cost of 400 crates Rs. 350/crate | = Rs.1400.00 |
| 4. | Nails | = Rs. 30.00 |
| 5. | Waste paper (paper cuttings Rs. 300+waste (paper Rs. 640) | = Rs. 940.00 |
| | TOTAL | Rs.2870.00 |

The rehra is the other type of transportation used in the area surveyed. They haul the produce to the local market in loose form. The cost of picking and packing in the case of the rehra is negligible when compared with that of a truck.

Labor for marketing. Out of the 55 respondents, 53 hired casual labor while the remaining 2 managed the marketing themselves with the help of family members.

Total production. In the surveyed area, total production of citrus was 56,196,000 units. Of this, kinno production was 44,119,500 for a total percentage of 78.51. Feutrell early ranked second with 5,651,500 units for a percentage of 10. Malta and Mussammi varieties ranked third and fourth with 3,295,000 and 3,130,000 units, respectively. The percentage share of these two varieties comes to 5.86 and 5.56 (see Table 12).

As is evident from the above, kinno is by far the most popular variety with consumers. Mussammi and malta are decreasing in demand and Feutrell early is barely holding its own with the consumer.

MARKETABLE CITRUS

Production minus home consumption determines the amount of marketable citrus. All that is produced is not marketed. A negligible part of it is taken away by the hawkers for door-to-door selling in the vicinity of the garden. Moreover, when striking a bargain, the owner also demands a part of the produce at the time of harvest. This may be in the terms of the number of plants or the amount of fruit.

Table-12

TOTAL PRODUCTION
(NOS)

| Size of garden | Kinno | Feutrell early | Malta | Mussammi | Total |
|---|---|---|---|---|---|
| Small | 3098000 | 342500 | 200000 | 155000 | 3795500 |
| Medium | 7840000 | 1504000 | 670000 | 245000 | 10259000 |
| Large | 33181500 | 3805000 | 2425000 | 2730000 | 42141500 |
| G. Total | 44119500 | 5651500 | 3295000 | 3130000 | 56196000 |
| Percentage | 78.51 | 10 | 5.86 | 5.56 | 100 |

It was revealed that this share ranged between one percent to 12 percent of the total produced. Out of the 561,96,000 units of citrus produced about 409,500 units were used by the producers for home consumption. This is about .73 percent of the total produced. Therefore, unlike many other crops grown in Pakistan, almost all of the citrus was sold in the market.

## CONCLUSION AND SUGGESTIONS

The marketing problem facing a farmer involves when, where and how to sell his produce. When to sell involves many factors such as price, storage facilities and deciding at what stage of maturity the produce should be sold. This is particularly important for fruit and vegetables where perishability is a major problem. Where to sell involves the selection of a buyer. Should it be sold to a market agency at a terminal, or in the local market? How to sell concerns whether the product should be graded before it is sold, whether the farmer should transport the product to the buying agency, or have it picked up and finally the type of contract that should be used.

The grower labors under a distinct disadvantage in his attempt to market the citrus. He has frequently neither the time, the merchandizing ability, nor the information necessary to market his produce successfully.

Since effective production calls for a high degree of specialized knowledge most farmers are unable to become specialists in marketing as well. They consequently have insufficient knowledge of marketing methods, of market conditions and possess little, or no information as to the price of their produce. Marketing, then becomes the role of the middleman unless the growers are able to organize themselves in an orderly and efficient manner.

In order to assess the bottlenecks in the way of a smooth and economical system of marketing, citrus growers, as well as the contractors, were encouraged to suggest methods to improve the marketing structure. These are summarized below:

<u>Citrus processing industry</u>. Doubtlessly, the establishment of an organized processing industry would be a significant step towards the development of an efficient marketing system. A large portion of the produce is not required for immediate consumption. This surplus could be processed, or stored for domestic consumption, as well as export. Unfortunately, due to high cost of these plants, this industry has not attracted much attention of the GOP, or private business firms.

In Bhalwal, a private enterprise, "Pak Citrus Industry", carries on a limited amount of this business, but is quite inadequate in view of the citrus produced in the area. More processing units are required to make efficient use of the mature surplus citrus.

Credit problems. Although a vast amount of money is being spent by the GOP and lending agencies for the increased production of fresh fruit, there is practically no allocation of credit for marketing the produce after it is produced. The establishment of marketing agencies that can supply a rapid, controlled type of credit for harvesting, packing, and transportation will go a long way in solving these problems.

Transportation. Transportation appears to be the most serious of all the problems and is one of the most expensive to solve.

Access roads are deficient. Most of those traveled are so rough that damage from bruising is very high, even for a short distance. During the peak season, the shortage of trucks or other means of rapid transportation has been noted. Railroads are not being used in the marketing of citrus. As a result, transportation costs are very high. The following steps are recommended to help solve these problems:

i) Improve and construct garden-to-market roads.

ii) Facilitate the development of more rapid transportation and refrigerated vehicles by credit allocation and the reduction of import duties and customs.

iii) Conveyance should be made more efficient and speedy by special trains on a priority schedule.

iv) Regulations should be established for trucks requiring insurance on the fruit they haul.

Storage problems. Losses due to the absence of cold storage facilities are enormous. Dehydration causes both spoilage and weight loss. As such, dry storage should be built. Moreover, as storage rates are very high--especially short term storage--steps should be taken to lower this cost.

Market place problems. A main problem is the lack of a citrus market place in many areas. This results in increased handling costs, unsanitary conditions and lack of space for additional marketing people and organizations. This reduces competition and helps keep marketing costs high. These problems can be partially overcome by:

i) Expansion of the present market site, or the construction of new sites.

ii) Improve the sanitation facilities.

iii) Provide storage cover.

iv) Provide better access to the market for a better flow of produce to and from the market place.

Export policy. The problems of exporting citrus are somewhat the same as the domestic problems of marketing regarding packing, transportation and financing. However, the development and maintenance of foreign markets requires much more expertise by both private and government personnel. The slump witnessed in the citrus market during 1977-78 was due mainly to the fact that the blockage imposed by Iran on citrus imports could not be coped with. As citrus production continues to expand, these foreign markets become ever more important. The GOP, with cooperation from private growers, needs to examine this problem immediately and develop export plans and policies that will expedite citrus exports. There is, without question, a great potential to increase citrus exports which will provide a greater market for the citrus growers and increased foreign exchange earnings for Pakistan.

# APPENDIX 25

## IMPACT OF MONA RECLAMATION EXPERIMENTAL PROJECT ON THE FARM ECONOMY OF THE PROJECT AREA

by

Mohammad Aslam, Mohammad Siddique, Abdul Rauf and Helmer Holje[1/]

## CHAPTER ONE

### INTRODUCTION

The Mona Reclamation Experimental Project comprises the northwestern part of SCARP II and spreads over an area of about 110,000 acres. The project was initiated in 1965 with a view to finding out the ways and means for overcoming the factors limiting agricultural development in the area, such as water-logging, salinity and the lack and timeliness of irrigation water. These research activities were designed to make better use of the limited farm resources in order to improve their efficiency and net farm incomes. The following lines of action were planned:

1. The development of methods and procedures to achieve effective use of water and land.

2. The reclamation of saline land.

3. Detailed ground water and hydrologic studies to determine the effect of ground water management, quality changes and tubewell performance.

4. Tubewell operation, maintenance, rehabilitation, and replacement.

5. Efficient management of water supplies.

6. Determining optimum economic input-output relationships.

7. The transfer of technical assistance and farm technology to the farmers through the extension program.

The project, already in operation, must be evaluated from time to time to determine its progress and pinpoint those areas that are retarding development. Evaluation helps to avoid pitfalls of the past and furnishes data to minimize costs and

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maximize returns in the years to come. Since the inception of the project many changes have taken place in the agricultural economy of the area. The implementation of the project encouraged adoption of improved cultural practices, high-yielding varieties, chemical fertilizers and plant protection measures. Improvement in the value of land, increased economic activity, enhanced employment opportunities and a change in the distribution of income are other benefits of the project though they are not analyzed in this study.

An evaluation study was made in 1970-71 of the Project area to determine the progress made since the benchmark study of 1965-66. However, in the period since 1971-72 many changes have occurred in the project. This was due largely to the following factors:

1. The adoption of new technology and modern inputs.
2. Watercourse remodeling, cleaning and maintenance.
3. Precision land leveling.
4. Improved and increased agricultural extension activities.

Intensive research and extension activities of the project have induced farmers to adopt many new scientific and improved innovations. More attention was paid to the remodeling and maintenance of watercourses. This resulted in reducing the conveyance losses and thereby enhancing the supply of irrigation water and lessening the time to irrigate. Through an effective extension service, precision land leveling was popularized and has proven quite helpful in optimizing the use of the available water supplies and reclaiming saline lands. As a result many tangible benefits have been realized by the farmers throughout the project area.

An evaluation of the project will help to assess the activities of the project and to locate the major causes of failure or success of these development endeavors. It, therefore, is important to undertake an economic evaluation study to measure the progress made since the Project's inception so that steps may be suggested to accelerate the role of development in the area. Changes brought about by the project activities in the agricultural sector up to 1976-77 have been calculated. Every effort has been made to present a lucid, comprehensive and comparative picture of the magnitude and direction of change in land utilization, cropping patterns and intensities, farm costs, use of farm inputs and gross net income. In order to portray net benefits of the project, annual costs of the project have been compared with annual benefits, thereby establishing a cost-benefit ratio.

# CHAPTER II

## METHODOLOGY

An economic appraisal was made of the Mona Project activities in 1970-71. The present study was designed to evaluate the progress that has been achieved since that time. Cost-benefit analysis has been used to analyze the 'with' and 'without' situation. However, only the primary benefits (benefits to the farmers) have been assessed. It is well recognized that many secondary benefits have occurred as a result of this project, such as enhanced employment opportunities, increased tax base, rising land values and, generally, increased economic activity. However, to make an evaluation of these secondary costs and benefits is beyond the scope of this study though they are very important from a regional and national point of view. The following criteria have been assumed:

1. Primary benefits are considered in calculating the cost-benefit ratio. The project's primary benefits represent the difference of net income under with and without project conditions. Public tubewell development signifies the "with" project situation and its absence represents the "without" condition.

2. Current prices have been used for agricultural inputs and outputs to give a vivid picture of the present situation. Net incomes have been computed according to the total cost method.

3. A 25 year life span has been assumed for the project installations, whereas 12 years is used for the life of the tubewells. No salvage value was considered.

4. A 10 percent discount rate was used in the cost-benefit analysis.

## SAMPLE SELECTIONS

<u>Villages</u>. Almost the same villages as taken in 1970-71 were selected for the with project comparison. They are:

| | |
|---|---|
| Perennial: | Chak No. 10-ML, 15-NB, Sidowal, Old Phullarwan and Jagatpura. |
| Nonperennial: | Kot Momyana, Jahanpur Dahr and Chak Sahib Khan. |
| Uncommanded: | Gurmukh singh wala, Jahanpur. |

To facilitate the comparison, the following non-project villages, in close proximity to the project area, were selected:

Perennial: Chaks 19 NB, 21 NB, 23 NB, 16 NB and 17 NB. Turtipur, Chak Sheikh da Lok, Kolian, Sigh Bala, Sigh Zaireen.

Uncommanded: Chak Nizam, Boolary Bala, Boolay Zaireen, Mid Parghana Miani.

Farms. Due to the shortage of time and other constraints, only 20 percent of the farmers enumerated in the benchmark survey could be selected at random for detailed study. In a strata where the number of respondents was extremely small their number was increased to maintain statistical significance. The distribution of the sample by farm size, tenure and irrigation type are presented in Tables 1 (A,B,C).

Table 1(A)

NUMBER OF RESPONDENTS BY SIZE OF FARM

| Size of farm (Acres) | 1965-66 Base year | 1970-71 With Project | 1970-71 Without Project | 1976-77 With Project | 1976-77 Without Project |
|---|---|---|---|---|---|
| 0-6.25 | 97 | 42 | 50 | 57 | 33 |
| 6.25-12.50 | 219 | 70 | 86 | 91 | 43 |
| 12.50-18.75 | 121 | 50 | 49 | 52 | 27 |
| 18.75-25.00 | 50 | 37 | 36 | 41 | 31 |
| Over-25 | 70 | 49 | 41 | 45 | 25 |
| Total | 557 | 248 | 262 | 286 | 159 |

Table 1(B)

NUMBER OF RESPONDENTS BY SIZE AND TENURE SYSTEM

| Size of farm (acres) | Base year | | | With Project 1976-77 | | | Without Project 1976-77 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Owner operators | Owner cum tenants | Tenants | Owners | Owner cum tenants | Tenants | Owner | Owner cum tenants | Tenants |
| 0-6.25 | 50 | 22 | 25 | 35 | 15 | 9 | 16 | 8 | 9 |
| 6.25-12.50 | 77 | 58 | 84 | 35 | 20 | 36 | 20 | 11 | 12 |
| 12.50-18.75 | 51 | 23 | 47 | 22 | 11 | 19 | 10 | 9 | 8 |
| 18.75-25.00 | 24 | 8 | 18 | 22 | 7 | 12 | 13 | 9 | 9 |
| Over-25 | 36 | 4 | 30 | 27 | 9 | 9 | 9 | 9 | 7 |
| Total | 238 | 115 | 204 | 141 | 60 | 85 | 68 | 46 | 45 |

TABLE 1(C)

NUMBER OF RESPONDENTS BY SIZE AND IRRIGATION TYPE

| Size of farm (acres) | Base year | | | 1976-77 With Project | | | 1976-77 Without Project | | |
|---|---|---|---|---|---|---|---|---|---|
| | Perennial | Non-perennial | Uncommanded | Perennial | Non-perennial | Uncommanded | Perennial | Non-perennial | Uncommanded |
| 0-6.25 | 53 | 5 | 39 | 33 | 15 | 9 | 9 | 13 | 11 |
| 6.25-12.50 | 110 | 34 | 75 | 51 | 18 | 22 | 11 | 19 | 13 |
| 12.50-18.75 | 73 | 11 | 37 | 21 | 19 | 12 | 8 | 10 | 9 |
| 18.75-25.00 | 22 | 5 | 23 | 15 | 15 | 7 | 11 | 9 | 11 |
| Over-25 | 38 | 14 | 18 | 19 | 12 | 14 | 9 | 8 | 8 |
| Total | 296 | 69 | 192 | 143 | 79 | 64 | 48 | 59 | 52 |

It should also be noted that the farmers selected for this study are not the same as those sampled in 1970-71. This was due to the fact that many changes have occurred in tenancy, ownership, and fragmentation.

Questionnaire. The questionnaire developed for the Benchmark Survey was used in this study. The enumerators were duly trained in the art of interviewing and filling the questionnaires. The field operations were supervised by the Head of the Agricultural Economics Section of the Mona Reclamation Project.

Limitations. The survey team was conscious of serious deficiencies in the research data and every effort was made to collect and analyze these data as objectively as possible. However, certain factors were beyond their control. They are:

1. The labor force supplied by the farm family and the time spent by each member, especially women on cultivation, was difficult to estimate accurately.

2. Many commodities like milk, feed, fodder and manure are not weighed or measured by the farmers and their true value is difficult to estimate.

3. The system of weighing commodities, especially grains, are done on a volumetric and unstandardized basis in most villages. This makes it difficult to convert weights into standard maunds accurately.

4. In the majority of the villages selected to represent the uncommanded conditions, some of the farmers had installed private tubewells for irrigation water supplies. Therefore, true uncommanded conditions do not exist on such farms. The final estimates of cropping patterns, intensities, yield rates and the resultant gross and net returns for these uncommanded areas would tend to be on the highside for this reason.

5. The respondents were usually suspicious of the interviewers and often reluctant to reply. This made the job of the interviewers most difficult and the data obtained in those cases is subject to question.

6. Besides the reluctance of the respondents to respond, the lack of written records was another hinderance. The memory of the respondents had to be relied upon. However, every effort was made to secure reliable information.

## CHAPTER THREE

### LAND UTILIZATION AND CROPPING PATTERNS

At the inception of the project, 138 tubewells were installed in the project area. However 18 tubewells have been closed down due to poor quality water. As a result, the net additional water supplied by the tubewells decreased from 2 AF/acre to 1.25 AF/acre. This reduced the total supply of water in the commanded area from 3.6 AF/acre to 2.85 AF/acre. The cultivated area decreased from 98.54 percent and 97.45 percent in 1970-71 to 96.80 and 94.52 percent in 1976-77 under with and without project conditions, respectively. However, culturable waste and the area not available for cultivation disappeared under with project conditions, whereas these increased significantly under without project conditions during 1976-77. Table 2 below gives the details of the land use pattern:

Table 2

LAND UTILIZATION

| | 1965-66 | 1970-71 | | 1976-77 | |
|---|---|---|---|---|---|
| | Base year | With Project | Without Project | With Project | Without Project |
| Farm area (acres)* | 14.00 | 14.40 | 15.60 | 17.10 | 18.07 |
| Percentage of Farm area | | | | | |
| Cultivated area | 97.10 | 98.54 | 97.45 | 96.80 | 94.52 |
| Uncultivated area | 2.90 | 1.46 | 2.55 | 3.20 | 5.48 |
| Forest | 0.20 | - | - | - | - |
| Culturable waste | 1.90 | 0.48 | 1.23 | - | 4.10 |
| Not available for cultivation | 0.80 | 0.98 | 1.32 | - | 1.38 |
| Percentage of cultivated area: | | | | | |
| Cropped area | 110.80 | 128.35 | 113.72 | 131.52 | 111.44 |
| Net cropped area | 96.80 | 98.57 | 97.95 | 99.51 | 95.73 |
| Area sown more than once | 14.00 | 29.78 | 15.77 | 32.01 | 15.71 |
| Fallow | 3.20 | 1.43 | 2.05 | 0.46 | 4.27 |

*Appendix 1.

The cropping intensity, however, increased from 128.35 percent in 1970-71 to 131.52 percent in the with project area. The increased intensity was a result of a 2.3 percent increase in double cropping and a reduction in fallow land. This illustrates the awareness of the farmers in making more efficient use of the available water resources, coupled with the adoption of the on-farm water management program, the introduction of short-period crops, the use of modern techniques and cultural practices and a high rate of fertilizer application.

In the without project area, the cropping intensity fell from 113.72 percent to 111.47 percent. This was mainly due to an increase in culturable waste and fallow land and the lack of adopting modern technology provided by the project.

A comparison of tubewell utilization and the intensities achieved is presented in Table 3.

Table 3

TUBEWELL UTILIZATION AND INTENSITIES

| Year | Rate of tubewell utilization | | Annual pumpage | | Cropping intensities | |
|---|---|---|---|---|---|---|
| | Percent | Index | A.F. | Index | Actual | Index |
| 1971-72 | 44.65 | 100.00 | 143158 | 100.00 | 128.35 | 100.00 |
| 1972-73 | 36.77 | 82.35 | 117576 | 82.13 | 124.60 | 98.97 |
| 1973-74 | 39.92 | 89.41 | 122245 | 85.39 | 124.20 | 98.65 |
| 1974-75 | 48.21 | 107.97 | 134583 | 94.01 | 126.20 | 100.24 |
| 1975-76 | 40.66 | 91.06 | 111708 | 78.03 | 126.70 | 100.64 |
| 1976-77 | 47.18 | 105.67 | 126186 | 88.14 | 131.52 | 102.78 |
| | Project cultivated area: | | | 102030 | | |

From the above, it is evident that the rate of tubewell utilization has no consistent relationship with the cropping intensities. During 1975-76 and 1976-77 the pumpage declined as compared with 1974-75, but the intensities increased. This is largely due to the decline in the water table, amelioration in the physical and chemical conditions of the soil, an increase in water use efficiency supported by doublecropping and short-period crops, use of modern inputs and the improvement in the technical assistance extended by the Mona Project personnel.

Cropping pattern. Proper land utilization and the judicious allocation of scarce water resources from public tubewells have had a marked impact upon the cropping patterns which are given in Table 4. A look at the table reveals

Table 4.

CROPPING PATTERN
(Percentage)

| | 1965-66 | | 1970-71 | | | | 1976-77 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cultivated | Cropped | Without Project | | With Project | | Without Project | | With Project | |
| | | | Culti-vated | Cropped | Culti-vated | Cropped | Culti-vated | Cropped | Culti-vated | Cropped |
| Food Grains: | | | | | | | | | | |
| Wheat | 35.86 | 31.7 | 40.79 | 35.87 | 42.54 | 33.14 | 39.31 | 35.27 | 37.82 | 28.76 |
| Bajra | 1.85 | 2.0 | 3.52 | 3.10 | 1.75 | 1.36 | - | - | 0.11 | 0.08 |
| Rice | 1.39 | 1.9 | 3.26 | 2.87 | 4.48 | 3.49 | 15.65 | 14.05 | 9.86 | 7.50 |
| Maize | 0.88 | 0.7 | 2.90 | 2.55 | 6.92 | 5.39 | 1.75 | 1.56 | 0.06 | 0.04 |
| Total | 39.98 | 36.3 | 50.47 | 44.39 | 55.69 | 43.38 | 56.71 | 50.88 | 47.85 | 36.38 |
| Cash Crops: | | | | | | | | | | |
| Cotton | 22.92 | 20.8 | 9.28 | 8.16 | 9.98 | 7.78 | 5.29 | 4.75 | 9.68 | 7.36 |
| Sugarcane | 4.24 | 3.8 | 8.07 | 7.10 | 8.10 | 6.78 | 12.09 | 10.85 | 10.98 | 8.35 |
| Garden | 4.20 | 3.9 | 6.83 | 6.00 | 8.67 | 6.75 | 3.83 | 3.43 | 13.38 | 10.18 |
| Mehndi | 0.67 | 0.6 | 0.89 | 0.78 | 1.37 | 1.07 | 0.37 | 0.33 | 12.58 | 9.56 |
| Others | 0.47 | 0.4 | 0.84 | 0.76 | 1.80 | 1.40 | 0.57 | 0.50 | 0.13 | 0.10 |
| Total | 32.50 | 29.3 | 25.91 | 22.78 | 30.52 | 23.78 | 22.15 | 19.86 | 46.75 | 35.55 |
| Pulses: | | | | | | | | | | |
| Grams | 0.31 | 0.3 | 0.74 | 0.65 | 0.59 | 0.46 | 0.09 | 0.08 | 0.70 | 0.52 |
| Other pulses | 0.30 | 0.3 | 0.24 | 0.21 | 0.26 | 0.20 | 0.04 | 0.03 | - | - |
| Total | 0.61 | 0.6 | 0.98 | 0.86 | 0.85 | 0.66 | 0.13 | 0.11 | 0.70 | 0.52 |
| Fodders: | | | | | | | | | | |
| Kharif F. | 21.21 | 19.1 | 18.99 | 15.27 | 24.62 | 19.18 | 16.22 | 14.56 | 18.88 | 14.36 |
| Rabi F. | 16.51 | 14.7 | 17.37 | 16.70 | 16.69 | 13.00 | 16.26 | 14.59 | 17.35 | 13.19 |
| Total | 37.72 | 33.8 | 36.36 | 31.97 | 41.31 | 32.18 | 32.48 | 29.15 | 36.23 | 27.55 |
| Annual Total | 110.81 | 100.0 | 113.72 | 100.00 | 128.38 | 100.00 | 111.47 | 100.00 | 131.53 | 100.00 |

that a substantial increase has taken place in the cash crops due to the introduction of improved seeds, application of fertilizers and a greater and ensured supply of irrigation water. A change in the cropping pattern has also occurred under without project conditions. One of the factors for this has been the establishment of the Noon Sugar Mill.

Food crops. The behavior of individual food crops has been somewhat erratic. The cultivated area under wheat decreased from 43 percent to 38 percent in 1976-77 under with project conditions. This decrease was offset by an increase in the area under rice which moved up from 4.48 percent to 9.86 percent. The acreage under rice in the non-project area increased nearly five-fold over 1970-71. This tremendous increase in the area under rice during the last six years has been a result of better prices and increased yields due to the abundant rainfall.

There has been a marked decrease in the cultivated area under maize in both the with and without project areas when compared with 1970-71. This is attributed to the heavy rains during the last five years. The cultivation of bajra has been abandoned in the without project area whereas in the project area it has become a minor crop. This indicates a more rational allocation of water resources and a move to the production of cash crops.

Cash crops. Cash crops have registered a declining trend during the study period in the without project area, but they increased rapidly in the with project area. During 1970-71, 26 percent and 31 percent of the cultivated acreage was put under cash crops in the without and with project area, respectively. In 1976-77 only 22 percent of the cultivated area in the without project area was used for cash crops production. However, 47 percent of the with project area was in cash crops in 1976-77.

The decreased percentage in cultivated acreage of cash crops (except sugarcane) in the without project area has been due primarily to a slump in cotton sowing which was a result of the depressed yields due to adverse climatic factors and unsuitable soil conditions aggravated by an unstable supply of water.

In the with project area, the percentage of cultivated area under sugarcane, gardens and mehndi increased from 8 to 10.9, 8.70 to 13.40 and 1.40 to 12.60, respectively. The sugar mill has provided a strong impetus for the increased production of sugarcane and the enhanced demand for citrus fruit has brought more area under gardens, particularly in those areas having a good and stable water supply. Similarly mehndi, being a short-period crop and a big source of income, attracted more area when compared with previous years.

<u>Crop varieties</u>. The area under improved crop varieties showed a marked improvement in sugarcane and rice, both in the with and without project area over the year 1970-71. Cotton did not attract improved varieties due to the poor crops during the last few years. The adoption of improved varieties of wheat remained relatively constant in the project area, but dropped significantly in the without project area. See Table 5 for specific data on the adoption of improved varieties.

# CHAPTER IV

## FARM COSTS

The costs of farm inputs have been calculated at the current rates of payments. The methodology practiced in the benchmark survey of 1965-66 was also used in this study.

### METHODOLOGY

The farm costs were estimated on the assumption that all the factors of production were hired.

1. Land: The actual rent was taken as the cost of land for tenants. For owners, the average rent prevalent in the areas was used.

2. Manual Labor: This comprised family and permanent hired labor. The labor units were arrived at by considering any male over 15 years as one unit and below 15 as one half unit. Similarly, women above 15 years were treated as a half unit and below that as a quarter unit. The wages were valued in money terms. Family labor was charged on the basis of the average rate for permanent hired labor. The casual labor employed was also taken into account.

3. An annual inventory of draught power was prepared at the beginning and end of the year. These were depreciated at 12 percent and 10 percent rates of interest. The variable costs were added to compute the total costs of the work animals.

4. Seed, manure, fertilizer and plant protection: The home grown seed was valued at the harvest price. Purchased seed was priced at the average village rate. Farmyard manure, chemical fertilizers and pesticides were valued at their purchase price.

Table 5. ADOPTION OF IMPROVED VARIETIES
(Percentage)

| | Base year 1965-66 | Without Project 1970-71 | With Project 1970-71 | With Project 1976-77 | Without Project 1976-77 |
|---|---|---|---|---|---|
| COTTON | | | | | |
| A.C. 134 | - | 11.00 | 25.00 | 61.88 | 35.58 |
| L.S.S. | 86.20 | 70.00 | 56.00 | 19.50 | 30.71 |
| Other improved | 6.00 | 20.00 | 3.00 | 0.44 | 7.12 |
| Unspecified | 7.80 | 10.00 | 12.00 | 18.00 | 26.59 |
| SUGARCANE | | | | | |
| C-312 | 17.90 | 12.00 | 16.00 | - | - |
| L-54 | 33.10 | 61.00 | 57.00 | 95.84 | 87.57 |
| L-29 | 0.90 | 23.00 | 10.00 | - | - |
| BL-4 | - | - | - | 2.82 | 4.80 |
| Other improved | 5.70 | 1.00 | 3.00 | 0.73 | 0.30 |
| Unspecified | 42.40 | 10.00 | 9.00 | 0.55 | 7.34 |
| RICE | | | | | |
| Basmatti | 39.50 | 77.00 | 72.00 | 74.39 | 54.60 |
| Jhona | 17.00 | 8.00 | 4.00 | - | - |
| Irripak | - | 7.00 | 12.00 | 5.17 | 4.44 |
| Kernal | - | - | - | 19.85 | 23.46 |
| Other improved | 12.00 | 2.00 | 5.00 | - | - |
| Unspecified | 31.50 | 6.00 | 7.00 | 0.54 | 17.50 |
| WHEAT | | | | | |
| C-591 | 37.20 | 11.00 | 6.00 | - | - |
| Maxi-pak | 0.10 | 76.00 | 87.00 | 64.01 | 34.65 |
| Drick | 26.00 | 4.00 | 2.00 | - | - |
| Ch. 70 | - | - | - | 9.74 | 10.45 |
| Yakora | - | - | - | 23.35 | 41.30 |
| Unspecified | 30.10 | 7.00 | 2.00 | 2.90 | 13.60 |
| Other improved | 6.60 | 2,00 | 3.00 | - | - |

5. Implements and tools: These were depreciated at various rates depending on their length of life. The repair costs whether in kind or in cash have been accounted for.

6. Miscellaneous charges like water rates, land revenue, transportation, including octrol charges, were direct cost items and posed no problems in evaluation.

FARM INPUTS AND THEIR COST

Livestock. Livestock constitutes a sizeable segment of the farm industry in the project area. It included both draught and milch animals.

Numberwise, the bullock force decreased by 35 percent and 13 percent per acre in the with and without project areas, respectively, during 1976-77 when compared with 1970-71. Of the total cost, livestock constituted 30 percent and 36 percent in the with and without project areas during 1976-77 compared to 42 percent and 40 percent during 1970-71. All of this points to a lesser dependence on livestock and an increasing trend towards a mechanized rural economy.

Rent. Rent has a positive relation with production. After livestock, it is the second largest cost item. It was 20 percent and 23 percent of the total cost during 1970-71, but increased to 29 percent and 28 percent in the with and without project areas, respectively, during 1976-77.

Farm labor. The labor force of a farm consists of family, permanent-hired and casual-hired labor. Total labor costs are less than rent, but they are an important component of total costs. There has not been a significant change in family and permanent hired labor during the study period. However, casual hired labor, which was practically nonexistent earlier has become an important part of the farm labor costs in both the with and without project areas, but more so in the project area. This suggests a more progressive and market oriented type of farming using the help of local manpower. It also indicates the increased employment opportunities provided by the project development.

Seed. During 1970-71 the expenditure on seed was somewhat identical in both the with and without project areas. It was 3.41 percent with the project and 3.56% without the project. This pattern again prevailed during 1976-77 constituting 3.64 percent and 3.62 percent of the total cost in the with and without project areas, respectively.

F.Y.M. The expenditures on farmyard manure have actually decreased slightly during the study period. This is primarily due to the adoption of chemical fertilizers which are easier to apply and now more readily available.

Fertilizer. With the advent of intensive farming, the application of chemical fertilizer has increased substantially. As a result, fertilizer has become a crucial input.

a. Fertilized area under different crops: In the project area vegetables, wheat and sugarcane received the largest amount of fertilizer. Percentage wise the area fertilized under these crops was 100, 76 and 72 percent respectively; rice, gardens, rabi fodder, cotton and kharif fodder follow. On a total cropped acre basis, the fertilizer application was 41 percent.

   The without project application of fertilizer was primarily in sugarcane, rice and wheat. The percentage of the total area fertilized under these crops was about 65 for each. Gardens, maize, rabi fodder, kharif fodder received the same fertilizer. As in the case of the with project area, 2.78 percent of the cotton area received fertilizer. This was due to the poor cotton yields because of untimely heavy rains and the attack of pests and disease. Table 6 shows the use of fertilizer by crop and type during 1976-77.

b. Type of fertilizer: In the with project area, 2165 bags of urea and 866 bags of D.A.P. were applied by the sampled respondents. Every cultivated acre received 35.66 lbs. (Nitrogen 26.51 lbs. Phos: 9:14 lbs.) as compared to 24 lbs. per acre during 1970-71. In the without project area 876 bags of urea and 401 bags of D.A.P. were consumed by the sampled respondents. This means an acre average of 26.46 lbs. during 1976-77, compared with 15 lbs. during 1970-71. The percentage share of this input in cost was 2.82 percent and 1.82 percent in the with and without project areas, respectively during 1970-71. It increased to 3.12 percent and 3.10 percent during 1976-77. The cultivation of mehndi comes under fertilizer application, but since the preharvest contractors are responsible for its cultural operations it has not been included in the analysis.

   The foregoing depicts an encouraging trend in the application of fertilizer and most significantly in the project area. This is due primarily to the enhanced and ensured water supply and the help of the technical and extension service of the Mona Staff.

Table 6. USE OF FERTILIZER

| Crops | Without Project 1976-77 | | | | | | With Project 1976-77 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cropped Acres | Ferti-lized acres | Unfer-tilized acres | No. of Bags Applied: Urea | DAP | Total | Cropped acres | Ferti-lized acres | Unfer-tilized acres | No. of Bags Applied: Urea | DAP | Total |
| Sugarcane | 328.37 | 216.75 | 111.62 | 170.16 | 85.33 | 255.50 | 519.13 | 376.25 | 143.68 | 342.25 | 156.00 | 498.25 |
| Cotton | 143.75 | 4.00 | 139.75 | 3.00 | – | 3.00 | 458.25 | 39.00 | 419.25 | 32.33 | 10.17 | 42.50 |
| Rice | 425.00 | 275.50 | 149.50 | 199.00 | 99.50 | 298.50 | 466.87 | 186.50 | 280.37 | 138.00 | 69.00 | 207.00 |
| K. Fodder | 440.50 | 9.00 | 431.50 | 8.00 | – | 8.00 | 894.10 | 30.50 | 863.60 | 25.00 | 4.75 | 29.75 |
| Garden | 104.00 | 22.00 | 82.00 | 17.84 | 8.92 | 26.75 | 633.75 | 167.50 | 466.25 | 200.00 | 110.00 | 310.00 |
| Wheat | 1067.25 | 683.25 | 384.00 | 462.00 | 207.00 | 669.00 | 1790.87 | 1374.88 | 415.99 | 1304.76 | 514.08 | 1818.84 |
| R. Fodder | 441.50 | 12.50 | 429.00 | 11.50 | – | 11.50 | 821.42 | 102.50 | 718.92 | 112.25 | – | 112.25 |
| Maize | 47.50 | 4.50 | 43.00 | 4.50 | – | 4.50 | 2.75 | – | 2.75 | – | – | – |
| Grams | 2.50 | – | 2.50 | – | – | – | 33.25 | – | 33.25 | – | – | – |
| Oil Seed | 1.00 | – | 1.00 | – | – | – | 1.00 | – | 1.00 | – | – | – |
| Vegetables | – | – | – | – | – | – | 5.00 | 5.00 | – | 10.00 | 2.00 | 12.00 |
| Total | 3001.37 | 1227.50 | 1773.87 | 876.00 | 400.75 | 1276.75 | 5627.19 | 2282.13 | 3345.06 | 2164.59 | 866.00 | 3030.59 |

In the without project area, aside from the demonstration affect, the persistent rains during the study period made it possible to increase the application of fertilizer.

7. Tractors and implements: No inventory was made regarding the number of tractors and implements in the previous surveys. At this time, there were 15 tractors among the project respondents and 10 in the without project area. A similar situation existed in other implements such as cultivators, threshers, trolleys, karahs, ploughs and other field implements. It is very evident that with increasing yields and incomes that the farmers are adopting modern technology. Without question, this trend will continue at an increasing pace in future years.

8. Hand tools and artisans: As a result of mechanization, the expenditure on this item decreased during 1976-77. It was only 1.83 percent in the project area and 1.88 percent in the without project area compared to 3.25 percent and 3.78 percent in 1970-71.

9. Tubewells and irrigation water: Private tubewells did not exist in the project area in 1970-71. However, in 1976-77 there were a number of private tubewells and their share of total costs was 1.29 percent. In the without project area, private tubewell costs decreased from 2.70 percent in 1970-71 to 2.19 percent in 1976-77.

   In addition to the 1.60 AF/acre of canal supplies, the Project supplied 1.25 AF/acre of tubewell water during 1976-77, compared with 2.0 AF during 1970-71. The closure of a number of tubewells due to bad quality water was the reason.

10. Plant protection measures: The expenditure on plant protection measures indicates an increasing awareness of the farmer for healthy crops. In 1970-71 an average expenditure of Rs. 1.40 and Rs. 0.46/acre in the with and without project areas, respectively, was made. In 1976-77 these expenditures had increased to Rs. 3.21 and Rs. 0.63/acre under project and without project conditions, respectively.

11. Land revenue: Land revenue is a source of income for the government and has in general a positive relation with production. However, land revenue costs actually decreased during the study period because of the exemption of payment by the GOP on land holdings of less than 12 acres.

12. During 1970-71, marketing charges constituted a negligible percentage of the cost. However, in 1976-77 the marketing charges increased substantially. This suggests a movement of the farmer away from the traditional pattern of selling his commodity at the farm gate.

    The details of physical inputs are given in Table 7 and Table 8 depicts the cost per holding and per cultivated acre and the relative importance of each input.

# CHAPTER FIVE

## GROSS AND NET FARM INCOME

Gross farm income is a function of acreage, yields and prices. The acreage under each crop was discussed earlier under cropping patterns, while the number of livestock is given in Table 9. Yields of crops and livestock production are presented in Table 10. Current prices have been used in the analysis.

## METHODOLOGY

1. The total cropped area included the area which was sold or fed green, the matured crops and partly greenfed and saved for seed production. The crops used as green fodder were evaluated at their sale or purchase price if consumed at the farm. The total production of the matured and harvested crops was considered in computing farm incomes. For the commodities that were consumed on the farm, or paid in kind to the artisans, harvest prices were used.

2. The income from animals and their by-products, such as milk, wool, FYM, meat and skins, etc., were evaluated using current prices. The average village rates were used for the products consumed at the farm. Whenever the draught power was hired out the returns were included in their income. The gross income of milch animals was based on the quantity of milk produced during the year. Milk

Table 7.

PHYSICAL QUANTITIES OF FARM INPUTS (PER ACRE)

| Items | Unit | Base year 1965-66 | 1970-71 | | 1976-77 | |
|---|---|---|---|---|---|---|
| | | | Without Project | With Project | Without Project | With Project |
| Family and permanent hired labor | Adult man | 0.16 | 0.14 | 0.16 | 0.15 | 0.17 |
| C. H. Labor | Rs. | - | - | - | 16.50 | 29.01 |
| Bullocks | Working units | 0.14 | 0.16 | 0.23 | 0.14 | 0.15 |
| Fertilizer (nutrients) | Lbs. | 1.70 | 15.00 | 24.00 | 26.46 | 35.66 |
| Irrigation Water: | | | | | | |
| a) Canal | A.F. | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 |
| b) Tubewell | A.F. | - | - | 2.00 | - | 1.25 |
| Total | | 1.60 | 1.60 | 3.60 | 1.60 | 2.85 |
| Plant protection | Rs. | - | 0.46 | 1.40 | 0.63 | 3.21 |

Table 8. COST OF FARM INPUTS AND THEIR RELATIVE IMPORTANCE

| | | Items | Total cost | Rent of land | Labor | Livestock | | Seed | F.Y.M. | Fertilizer | Tools imple-ments and arti-sans | T/well and T/well water purch-ased | P.P. | Land revenue | Tractor and Tractor hiring | Market-ing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Draught | Milch-others | | | | | | | | | |
| Base year 1965 | (i) | Cost per holding | 4987.00 | 1135.00 | 943.00 | 767.00 | 1371.00 | 161.00 | 98.00 | 13.00 | 140.00 | 121.00 | - | 235.00 | - | 3.00 |
| | (ii) | Cost/culti-vated acre | 367.00 | 83.53 | 69.39 | 56.44 | 101.10 | 11.85 | 7.21 | 0.96 | 10.30 | 8.90 | - | 17.29 | - | 0.02 |
| | (iii) | Relative importance | 100.00 | 22.76 | 18.91 | 15.37 | 27.50 | 3.23 | 1.96 | 0.26 | 2.82 | 2.43 | - | 4.71 | - | 0.05 |
| Without Project 1970-71 | (i) | Cost per holding | 5481.00 | 1263.00 | 940.00 | 789.00 | 1413.00 | 195.00 | 83.00 | 100.00 | 207.00 | 148.00 | 7.00 | 318.00 | - | 18.00 |
| | (ii) | Cost/culti-vated acre | 360.60 | 81.10 | 61.80 | 52.00 | 93.00 | 12.80 | 5.50 | 6.60 | 13.60 | 9.70 | 0.50 | 20.90 | - | 1.00 |
| | (iii) | Relative importance | 100.00 | 23.03 | 17.15 | 14.39 | 25.77 | 3.56 | 1.51 | 1.82 | 3.78 | 2.70 | 0.13 | 5.83 | - | 0.33 |
| With Project 1970-71 | (i) | Cost per holding | 5960.00 | 1166.00 | 1140.00 | 925.00 | 1585.00 | 203.00 | 115.00 | 168.00 | 194.00 | - | 20.00 | 428.00 | - | 16.00 |
| | (ii) | Cost/culti-vated acre | 419.80 | 82.10 | 80.30 | 65.10 | 111.60 | 14.30 | 8.10 | 11.80 | 13.70 | - | 1.40 | 30.10 | - | 1.20 |
| | (iii) | Relative importance | 100.00 | 19.56 | 19.13 | 15.52 | 26.59 | 3.41 | 1.93 | 2.82 | 3.25 | - | 0.30 | 7.18 | - | 0.30 |
| Without Project 1976-77 | (i) | Cost per holding | 17597.62 | 4952.12 | 3611.63 | 2092.83 | 4283.41 | 637.62 | 204.91 | 545.75 | 331.79 | 386.77 | 10.75 | 211.91 | 211.74 | 116.28 |
| | (ii) | Cost/culti-vated acre | 1030.53 | 290.00 | 211.50 | 122.56 | 250.84 | 37.34 | 12.00 | 31.96 | 19.43 | 22.65 | 0.63 | 12.41 | 12.40 | 6.81 |
| | (iii) | Relative importance | 100.00 | 28.14 | 20.52 | 11.89 | 24.34 | 3.62 | 1.16 | 3.10 | 1.88 | 2.19 | 0.06 | 1.20 | 1.20 | 0.66 |
| With Project 1976-77 | (i) | Cost per holding | 22935.62 | 6622.57 | 5546.40 | 2311.77 | 4619.24 | 840.23 | 298.01 | 716.72 | 420.86 | 298.01 | 53.14 | 573.34 | 308.11 | 327.15 |
| | (ii) | Cost/culti-vated acre | 1395.30 | 410.00 | 335.00 | 139.63 | 279.00 | 50.75 | 18.00 | 43.52 | 25.42 | 18.00 | 3.21 | 34.63 | 18.61 | 18.74 |
| | (iii) | Relative importance | 100.00 | 29.28 | 24.01 | 10.01 | 20.00 | 3.64 | 1.29 | 3.12 | 1.83 | 1.29 | 0.23 | 2.48 | 1.33 | 1.41 |

*Base year's prices have been used for the year 1970-71, whereas current prices have been used for 1976-77.

Table 9. LIVESTOCK STRENGTH/FARM

| Project Conditions | Draft Animals | Buffaloes | | | | Cows | | | | Others | | | | G. Total adult units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Wet | Dry | Young stock | Total adult units | Wet | Dry | Young stock | Total adult units | Donkeys | Horses | Sheep Goats | Total adult units | |
| Base year 1965-66 | 2.70 | 1.92 | 1.38 | 1.70 | 4.00 | 0.30 | 0.20 | 0.30 | 0.60 | 0.20 | 0.40 | - | 0.60 | 7.90 |
| With Project 1970-71 | 3.20 | 2.30 | 1.69 | 1.09 | 4.35 | 0.18 | 0.12 | 0.07 | 0.33 | 0.41 | 0.13 | 0.01 | 0.26 | 8.15 |
| Without Project 1970-71 | 2.73 | 1.75 | 2.10 | 0.93 | 4.17 | 0.17 | 0.11 | 0.05 | 0.29 | 0.48 | 0.12 | 0.04 | 0.29 | 7.85 |
| With Project 1976-77 | 2.50 | 2.52 | 1.40 | 1.78 | 4.51 | 0.77 | 0.56 | 0.67 | 1.55 | 0.62 | 0.21 | 2.05 | 1.10 | 9.66 |
| Without Project 1976-77 | 2.38 | 2.43 | 1.23 | 1.99 | 4.32 | 0.81 | 0.44 | 0.75 | 1.50 | 0.64 | 0.21 | 2.68 | 1.32 | 9.52 |

Table 10. YIELDS FROM CROPS AND LIVESTOCK

| Crops | Base year | 1970-71 | | Price Rs./ maund | 1976-77 | | Price Rs./ maund |
|---|---|---|---|---|---|---|---|
| | | Without Project | With Project | | Without Project | With Project | |
| Sugarcane | 238.00 | 352.00 | 409.00 | 2.25 | 325.00 | 368.00 | 5.65 |
| Cotton | 4.10 | 5.30 | 7.70 | 38.00 | 4.29 | 4.00 | 124.00 |
| Rice | 13.70 | 13.70 | 15.70 | 18.70 | 18.75 | 21.25 | 49.00 |
| Maize | 9.50 | 9.50 | 13.70 | 14.70 | 14.20 | 15.00 | 44.00 |
| Bajra | 10.70 | 10.70 | 10.20 | 8.30 | - | 8.00 | 50.00 |
| Mehndi | 325.00 (Rs) | 325.00 | 350.00 | - | 800.00 (Rs) | 1000.00 (Rs) | - |
| Garden | 517.00 (Rs) | 550.00 | 600.00 | - | 2000.00 (Rs) | 2230.00 (Rs) | - |
| Vegetables and others | 325.00 (Rs) | 325.00 | 330.00 | - | 3000.00 (Rs) | 4000.00 (Rs) | - |
| K. Fodder | 149.00 (Rs) | 180.00 | 200.00 | - | 350.00 (Rs) | 400.00 (Rs) | - |
| Others | - | - | - | - | - | - | - |
| Wheat | 12.30 | 15.60 | 20.00 | 15.00 | 18.30 | 22.00 | 41.00 |
| Oil seed | 6.50 | 9.90 | 10.1 | 35.00 | 8.20 | 10.25 | 70.00 |
| Gram | 8.00 | 8.00 | 7.00 | 15.00 | 7.50 | 8.00 | 49.00 |
| R. Fodder | 278.00 (Rs) | 300.00 | 350.00 | - | 700.00 (Rs) | 800.00 (Rs) | - |
| Others pulses | 260.00 | 260.00 | 250.00 | - | - | - | - |
| Crops by-products | | | | | | | |
| Cotton | 25.00 | 25.00 | 30.00 | - | 50.00 | 50.00 | |
| Rice | 15.00 | 15.00 | 20.00 | - | 40.00 | 50.00 | |
| Maize | 30.00 | 30.00 | 35.00 | - | 47.50 | 60.00 | |
| Bajra | 30.00 | 30.00 | 35.00 | - | - | 60.00 | |
| Wheat | 12.30 | 15.60 | 20.00 | 2.50 | 18.30 | 22.00 | Rs. 7/md. |
| Livestock lbs./day | | | | | | | |
| Buffaloes | 9.30 | 12.50 | 13.10 | 22.00 | 11.67 | 14.00 | Rs. 55/md. |
| Cows | 5.30 | 8.50 | 9.00 | 16.00 | 8.77 | 9.51 | Rs. 55/md. |

NB: Base year's prices have been used for the year 1970-71, whereas current prices have been used for 1976-77.

in most cases was not sold as such. Part of it was consumed and the rest was converted into ghee which was partly consumed and partly marketed. Ghee was not considered in estimating the income from milch animals because its production, consumption and sale was entirely in the hands of womenfolk and the male interviewers knew little about it. Consequently, gross income from milk alone was estimated.

YIELD OF MAJOR CROPS AND LIVESTOCK

1. Crops: During the period 1972-73 to 1976-77 unseasonal weather conditions played havoc with agricultural production. The project area is prominent for sugarcane growing, but the uncertain and unfavorable weather conditions, coupled with the attack of pests and disease, reduced sugarcane yields from 409 maunds/acre in 1970-71 to 368 maunds/acre in 1976-77. Cotton met the same fate of uncertain weather and the attack of pests and disease. Untimely torrential rains destroyed most of the cotton crop before maturity. This reduced the yield of this important cash crop from 7.7 maunds/acre in 1970-71 to 4 maunds/acre in 1976-77.

   In the without project area, yields of sugarcane and cotton fell from 352 to 325 maunds/acre and from 5.30 to 4.29 maunds/acre, respectively, during 1976-77 compared with 1970-71.

   The rest of the crops, within and without the project showed yield increases, but more significantly in the project area. The heavy rains which proved fatal in the case of sugarcane and cotton proved a blessing for rice. Its yield increased from 18.70 and 15.90 mds/acre in 1970-71 to 21.25 and 18.75 mds/acre in 1976-77 with and without the project, respectively. The increased demand for citrus encouraged growers to bring more fertile area under gardens, thus increasing both their yields and acreage and ultimately their net income.

   Livestock: The yield from livestock maintained a steady rate of increase in the project area. Compared with 13.10 lbs/day in 1970-71, the milk yield from buffaloes went up to 14.00 lbs/day in 1976-77 in the project area. However, in the without project area it decreased from 12.50 lbs/day to 11.67 lbs/day during the same period.

The milk yield from cows increased from 9.0 lbs/day to 9.51 lbs/day in the project area and from 8.50 lbs/day to 8.77 lbs/day in the without project area in the period 1970-71 to 1976-77.

## GROSS AND NET INCOME

The gross income per cultivated acre was Rs. 1,979 and Rs. 1,422, with and without the project, respectively, during 1976-77. Using the base year's gross income index of 100, incomes under the project increased to 536 and in the without project area to 391. The cropped acreage index was 452 in the project area and 388 in the without project area during 1976-77.

The contribution of livestock to gross income in 1970-71 was 31 percent in both the with and without project area. However, in 1976-77 livestock's share of gross income dropped to 28 percent indicating a shift to cash crops.

A classification of gross income is represented in Table 11.

Table 11.

GROSS INCOME FROM CROPS AND LIVESTOCK (RS.)

| | Per holding | | | Per Acre | | Indices | |
|---|---|---|---|---|---|---|---|
| | Crops | Live-stock | Total | Culti-tivated | Crop-ped | Per cul-tivated acre | Per Crop-ped acre |
| Base year 1965-66 % | 3,666 (73) | 1,353 (27) | 5,019 (100) | 369 | 332 | 100 | 100 |
| Without Project 1970-71 % | 5,357 (69) | 2.461 (31) | 7,818 (100) | 514 | 452 | 140 | 136 |
| With Project 1970-71 % | 6,405 (69) | 2,851 (31) | 9,256 (100) | 652 | 509 | 179 | 153 |
| Without Project 1976-77 % | 17,553 (71) | 7,068 (29) | 24,622 (100) | 1,442 | 1,294 | 391 | 388 |
| With Project 1976-77 % | 23,753 (72) | 9,019 (28) | 32,772 (100) | 1,979 | 1,505 | 536 | 452 |

N.B. Evaluation for 1970-71 has been done on base year's prices whereas current prices have been used for 1976-77

In order to arrive at net income, all farm costs have to be subtracted from gross income. This is presented in Table 12 on a per holding, per cultivated and per cropped acre basis.

Table 12

NET INCOME FROM PRODUCTION (RS.)

| | Base year 1965 | 1970-71 | | | 1976-77 | | |
|---|---|---|---|---|---|---|---|
| | | Without Project | With Project | Benefits | Without Project | With Project | Benefits |
| Per Holding | 32.00 | 2,337.00 | 3,296.00 | 959.00 | 7023.00 | 9671.00 | 2648.00 |
| Per cultivated acre | 2.30 | 153.00 | 233.00 | 80.00 | 411.00 | 584.00 | 173.00 |
| Per Cropped acre | 2.10 | 126.00 | 184.00 | 58.00 | 369.00 | 444.00 | 75.00 |
| Total benefits of project on 102030 cultivated acre. | | | | | | | 17,634,865 |

COST BENEFIT ANALYSIS

Primary and secondary benefits have occurred, both in the area as well as to the nation at large, as a result of the development. However, only direct benefits have been considered and indirect benefits like improvement in the value of the land, increased economic activity leading to off farm business and employment opportunities, increased Government revenues and income distribution have not been accounted for in this study. The measurement of secondary costs and benefits is most complex and beyond the scope of this study. The cost benefit analysis presented here is concerned only with the direct costs and benefits.

Project benefits. Agricultural production has increased largely because of the enhanced irrigation supplies provided by tubewell development, more efficient use of the water, high-yielding crop varieties, fertilizer and better plant protection measures. Although the project water supply has declined from 2 AF/acre in 1970-71 to 1.25 AF/acre in 1976-77 due to the closure of a number of tubewells as a result of brackish water, more efficient water use has offset this water loss. The net income with and without project conditions are presented in Table 12. The difference between value added under with and without project conditions, represents the net benefits of the project. The project benefits amount to Rs. 17.6 million.

Project costs. The costs include the annual capital costs, operation and maintenance, project services, and a sinking fund for the tubewells. The detail of the project costs are given below:

| | | Amount (Rs) |
|---|---|---|
| A. | Capital costs | |
| | Installation of tubewells | 6,976,245 |
| | Operators, quarters and distribution network | 1,276,458 |
| | Construction of colony | 2,957,263 |
| | Electricication network | 3,605,442 |
| | Construction of link watercourses | 108,134 |
| | | 14,923,542 |
| | Amortized @ 10 percent taking project's life as 25 years. | 1,644,097 |
| B. | Operation and maintenance costs | |
| | Electricity charges | 1,595,034 |
| | Vehicles | 88,531 |
| | Workcharged staff | 4,011 |
| | Maintenance and repair of tubewells | 517,797 |
| | Repair of pump houses | 40,081 |
| | Total | 2,245,454 |
| | Cost of project services | 1,189,117 |
| | Grand Total | 3,434,571 |
| C. | Sinking fund for tubewells (Assuming 12 year life) @ 10% | 326,230 |
| | Total of capital operation and maintenance cost and replacement cost | 5,404,898 |

The annual project costs thus come to Rs. 5.4 million. It averages to Rs. 53 per cultivated acre or Rs. 42 per acre CCA, feet of water pumped.

<u>Cost benefit ratio</u>. Cost benefit ratio is simply a relationship depicting total benefits relative to total cost and is presented below:

| | |
|---|---|
| Annual costs | 5.4 million |
| Annual benefits | 17.6 million |
| Cost benefit ratio | 1:3:26 |

<u>Cost of and return from tubewell water</u>. The cost per acre foot of water in the project is generally lower than in the adjoining areas of the project where private tubewells are used.

During 1976-77 the project tubewells pumped out 126186 acre feet of water. As already pointed out the cost per acre foot is Rs. 42/CCA against a return of Rs. 140 per acre foot.

<u>Policy guidelines</u>. The main activities of the Mona Reclamation Experimental Project are:

1. Operation and management of the tubewells.

2. Research and investigation of modern technology.

3. Dissemination of this research to the farmers by the Extension Division.

A review of the project's past performance shows that it has met with success in its major objectives. However, it is felt that there is still a great opportunity to increase agricultural production beyond the present levels. The following guidelines are presented for this purpose.

a. First, and foremost, comes the coordination between the different disciplines of the project.

b. Surveys of the waterlogged and saline areas should be conducted at regular intervals to assess the success of the project.

c. Due to the installation of tubewells in the project area, there is a significant increase in the water supply, but all the farmers have not adjusted their farm plans accordingly. Optimum use of available water supplies, therefore, should be emphasized and carried out through the extension service.

d. It was found that the input levels applied by many farmers is less than required for optimum crop yields. Steps should be taken to ensure the supply of these critical inputs and to provide incentives for their use. Provision of credit, supported by technical knowledge and application, can go a long way in achieving this objective.

e. Due to the intensification of agriculture, the attack of pests and insects is on the increase. Plan protection services should be provided to the farmers at the appropriate time and place.

f. Farmers generally get a lower return from their farm products. The establishment of agro-based industries in the project area would improve this situation.

g. The dissemination of modern techniques and knowledge among the farming community has become an essential prerequisite for the adoption process. Personnel from each section should be deployed for this purpose.

SUMMARY

1. The culturable waste disappeared during 1976-77 in the project area, but increased to 4.10 percent outside the project.

2. Fallow land decreased from 1.48 percent in 1970-71 to .40 percent in 1976-77 in the project but doubled in the nonproject area.

3. The cropping intensity increased to 131.53 percent in the project but declined to 111.47 percent outside the project. It was 128.38 percent and 113.72 percent respectively during 1970-71.

4. The cropping pattern showed a favorable trend for rice, sugarcane, garden and mehndi, particularly in the project area.

5. The application of fertilizer per cropped acre increased to 35.66 lbs. and 26.46 lbs. under with and without project conditions, respectively. It was 24 and 15 lbs. per cropped acre, respectively, during 1970-71.

6. The expenditure on plant protection measures, which did not exist in 1965-66, and was Rs. 1.40 and 0.46 with and without the project during 1970-71 increased to Rs. 3.21 and 0.63 during 1976-77.

7. The yield per acre of almost all crops increased in both the project and nonproject areas, with the exception of sugarcane and cotton, with the largest gains in the project area.

8. The net income under with and without project conditions was Rs. 584 and 411/cultivated acre, respectively.

9. The annual benefits and costs were Rs. 17.6 million and 5.4 million, respectively, thus showing a cost-benefit ratio of 1:3:26.

# APPENDIX 26

# SIMULATING CROPPING PATTERN AND WATER MANAGEMENT ALTERNATIVES IN THE PUNJAB, PAKISTAN

## MODEL DEVELOPMENT

Wynn R. Walker, John O. Reuss and Naveed Ahmad[1]

## PART 1. MODELING OVERVIEW

### INTRODUCTION

A watercourse command area simulation model is planned as one of the current tasks within the USAID sponsored work of Colorado State University. The objectives outlined for the model are as follows:

(1) To establish the overall water balance on a watercourse command area as affected by canal diversions, tubewell pumping, watercourse condition, cropping patterns, and climatic variables; and

(2) To examine the viability of various cropping patterns systems and intensities in terms of water availability for planting and in-season water stress.

In order to accomplish these objectives, the model is initially being set up on a Hewlett-Packard HP 9825A computer.

The HP 9825A does not have sufficient internal memory (only about 23K bytes) to program in traditional methods. Large simulation exercises must be decomposed and handled as a series of overlay systems with the output from one set of computations being stored on tape and then being read into the memory of the next segment of the model. In the initial stages of the model development the transition from segment to segment is accomplished primarily in a manual manipulation of tape files by the user.

Because Dr. Walker initiated the programming while on TDY at Lahore, but could not program the complete model in so short a time, it is important that the work have sufficient continuity that substantial duplication be avoided. In this brief report, it is the intention of the writers to set forth the scope of the work as envisioned at the outset of the programming in order that further efforts might be undertaken with as little confusion regarding previous work as possible.

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## BASIC MODEL STRUCTURE

The simulation of the watercourse command area can be divided into four logical parts. The first submodel determines the basis for estimating evapotranspiration from land surfaces within the command area. Two primary models are utilized to calculate the potential evapotranspiration of a reference crop such that the effect of climatic and topographical variables within the hydrologic system are condensed into a single representation. These methods are the Penman Equation and the Jensen-Haise Equation, both of which seem to work well under Pakistani conditions. This model is completed and programmed in two versions, the principal one being a code to compute and record daily values of the reference potential evapotranspiration for use in subsequent segments of the model. The second version is a program to compute the evapotranspiration of various field crops and output these data onto tables.

The second submodel is a planting-irrigation scheduling program written to be an analysis of water management alternatives at the farm level rather than the more traditional simulation of real-time events prerequisite to recommendations on water application timing. Data from the potential evapotranspiration file along with precipitation, initial cropping and soil moisture conditions, and control parameters describing the priority for sequencing irrigations are input to the irrigation scheduling submodel. Data describing the timing and volume of the water supply at the boundary of the irrigated fields is necessary for the irrigation and planting scheduling. This latter information will come from the third submodel when formulated, but at the present an artificial data array must be defined a priori.

The irrigation scheduling submodel considers what is referred to as a "square," of about 25 acres of farmland, receiving a periodic supply of irrigation water from canal and/or tubewell sources. The frequency of the supply and its intended duration is referred to as the warabundi time. The spatial resolution of the square model is based on one-half acre units of fields which are intended to represent the field sizes typically encountered. A field of several acres is treated as several smaller fields.

The irrigation scheduling submodel is designed to determine the water balance within the square. Hydrologic output includes actual field evapotranspiration, the time distribution of soil moisture storage, and the deep percolation that may result from overirrigation. Of intrinsic interest, the model also provides information regarding the scheduling of irrigations and plantings, limitations on planting and growth due to stress and water shortage, and the impact of assuming different water management schemes at the farm and watercourse level.

A third submodel, a watercourse conveyance and water supply model, is not yet developed although the research into local hydrology has been most intensive during CSU research efforts in Pakistan. Dr. Walker omitted this model from coding during his TDY because it was felt this would be the most easily contributed phase of the modeling by other project personnel. The watercourse conveyance submodel needs to begin with the mogha diversions, tubewell pumping and watercourse physical conditions and predict the amount of seepage and evaporation losses expected along the length of the channel. This prediction allows an estimation of available water to a square anywhere along the watercourse. It is also envisioned that the impacts of linings, structural improvements, and management alternatives would be reflected in the output. The same model should also be able to evaluate seepage losses within the irrigated square itself in providing the net water supply data required by the scheduling program.

The final segment of the model is a groundwater simulation. Data from seepage predictions, deep percolation, and tubewell pumping will be used to estimate water table elevations. Several aspects of the model remain undefined so far as scope is concerned at the time of this writing. The chemistry of groundwater supplies is affected by the fact that the water table floats on a very saline groundwater basin. Research is currently underway to determine the best possible methods of pumping the shallow layer of relatively fresh water for reuse. In addition, it was originally intended to incorporate the contribution of a high water table to crop needs, but this does not seem realistic without doing so in conjunction with a groundwater model.

It is obvious that the hydrology within a watercourse command area is a large complex system. Use of the HP 9825A computer requires that the mathematical description of a system be decomposed with linkage among the parts accomplished via temporary data storage and overlaying the respective segments in the memory one at a time. A schematic view of how this is conceptualized by the writers is shown in Figure 1.

## PART 2. EVAPOTRANSPIRATION MODELS

### ESTIMATING POTENTIAL EVAPOTRANSPIRATION, $E_{tp}$

A key quantity in the daily water balance of an irrigated field is the evapotranspiration of the crop. The value of the evapotranspiration is dependent upon climatic conditions, crop variety, crop growth stage, moisture status of the soil, etc. In order to estimate field evapotranspiration, the water use of some standard reference crop growing as if water were not limiting is estimated. The estimate isolates climatic

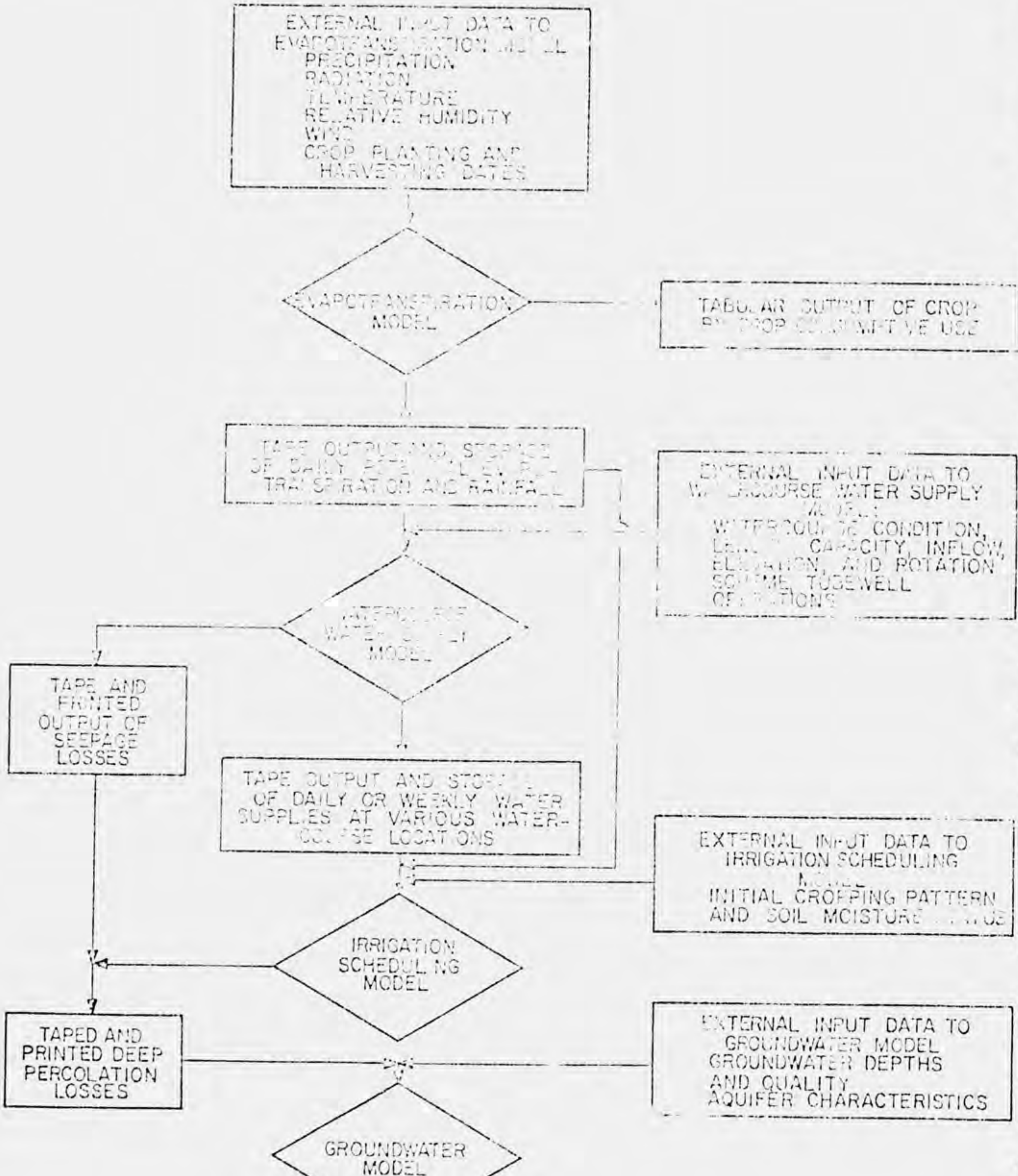


Figure 1. Schematic flow diagram of conceptualized watercourse command area simulation model.

factors from all others. The consumptive use under these conditions is called the potential evapotranspiration ($E_{tp}$). (Note that climatic factors do not enter into the definition, but that they determine the day-to-day variations in $E_{tp}$.) Common reference crops are alfalfa with 12 to 18 inches of growth, or grass, completely shading the soil.

There are a large number of methods for estimating $E_{tp}$ which are reviewed by Jensen (1973) and will not be detailed here. However, in the western United States and in Pakistan two approaches have been commonly employed: (1) The Penman Method; and (2) the Jensen-Haise Method.

The Penman Method

The Penman equation is a statement of the total energy available for evaporation and transpiration by the crop. The equation is called a "combination equation" because it includes both solar energy and advective energy (that made available due to air movement).

Penman (1948) first derived an equation for the evapotranspiration of a short, well-watered crop (generally assumed to be grass) based on a combination of energy balance at the crop surface and the heat-mass transfer processes due to air movements. The equation which resulted and is used today is written for a reference crop:

$$E_{tp} = \left[\frac{\Delta}{\Delta+\gamma} (R_n+G) + 15.36 \frac{\gamma}{\Delta+\gamma} (a + bU_2)(e_z°-e_z)\right] \tag{1}$$

in which

$E_{tp}$ = potential evapotranspiration, langleys/day;

$\Delta$ = slope of the saturation vapor pressure curve at a specified temperature, d(mb)/d(C);

$\gamma$ = psychrometric constant, mb/C;

$R_n$ = net radiant energy, langleys/day (ly/day);

G = soil heat flux, ly/day;

$U_2$ = wind run at a height of 2 meters, km/day;

a,b = empirical regression coefficients requiring local calibration; and

$e_z°-e_z$ = average daily vapor pressure deficit, mb.

In order to convert langleys/day to equivalent depth units, multiply by 0.0171 to obtain mm/day.

The Penman combination method requires data describing: (1) solar radiation, ($R_s$), (2) temperature; (3) wind; and (4) relative humidity. These data are then utilized in empirical functions to define the actual parameters given in Eq. 1. A summary of these functions and their origin is given in several literature sources, possibly the most complete being Jensen (1973).

Net radiation. The net radiation term, $R_n$, can be determined from relationships presented by both Jensen (1973) and Kincaid and Heermann (1974). Since the data actually describing solar radiation can be either measured values of solar radiation, hours of sunshine, or percent sunshine, the approaches utilized to arrive at $R_n$ are different. For the case when actual solar radiation values are recorded, the first step is to plot an envelope curve through the maximal values over a season. This curve defines the "clear day" solar radiation and is often expressed as an exponential function of the following form:

$$R_{so} = A \exp-\left[\frac{Day - B}{C}\right]^2 \qquad (2)$$

where,

$R_{so}$ = clear day solar radiation, ly/day;

Day = actual or modified Julian date;

A = seasonal peak value of $R_{so}$;

B = Julian date corresponding to A; and

C = empirical coefficient used to fit the shape of the curve

The coefficients in Eq. 2 vary with location and latitude, but can be estimated from Table 1 (by Jensen, 1973). A plot of Eq. 2 at the latitude of Lahore, Pakistan, is shown in Figure 2.

If the radiation data are reported in daily hours of sunshine, the approach involves first approximating $R_s$ by calculating the fraction of possible sunshine represented by the data. Utilizing a Julian date such that Day 1 = January 1st, the days of the year can be expressed in terms of the equivalent radians, ($\theta$), circumventing the earth's rotation about the sun:

$$\theta = \frac{2\pi}{365}(Day) - 1.377139376 \qquad (3)$$

The declination angle ($\Delta$) of the earth relative to the sun is determined by

$$\Delta = 0.40927971 \sin \theta \qquad (4)$$

where $\Delta$ is also expressed in radians. The possible number of sunshine hours per day depends not only on $\Delta$, but the latitude of the test site as well. Latitude is first converted to radians by multiplying by $2\pi/365$, thus:

Table 1. Mean solar radiation for cloudless skies (taken from Jensen, 1973) expressed in cal $cm^{-2}$ $day^{-1}$.

| Latitude °N | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 58 | 152 | 319 | 533 | 671 | 763 | 690 | 539 | 377 | 197 | 87 | 35 |
| 55 | 100 | 219 | 377 | 558 | 690 | 780 | 706 | 577 | 430 | 252 | 133 | 74 |
| 50 | 155 | 290 | 429 | 617 | 716 | 790 | 729 | 616 | 480 | 313 | 193 | 126 |
| 45 | 216 | 365 | 477 | 650 | 729 | 797 | 748 | 648 | 527 | 371 | 260 | 190 |
| 40 | 284 | 432 | 529 | 677 | 742 | 800 | 755 | 674 | 567 | 426 | 323 | 248 |
| 35 | 345 | 496 | 568 | 700 | 742 | 800 | 761 | 697 | 603 | 474 | 380 | 313 |
| 30 | 403 | 549 | 600 | 713 | 742 | 793 | 755 | 703 | 637 | 519 | 437 | 371 |
| 25 | 455 | 595 | 629 | 720 | 742 | 780 | 745 | 703 | 660 | 561 | 486 | 423 |
| 20 | 500 | 634 | 652 | 720 | 726 | 760 | 729 | 697 | 680 | 597 | 537 | 474 |
| 15 | 545 | 673 | 671 | 713 | 706 | 733 | 706 | 684 | 697 | 623 | 580 | 519 |
| 10 | 584 | 701 | 681 | 707 | 684 | 700 | 681 | 665 | 707 | 648 | 617 | 565 |
| 5 | 623 | 722 | 690 | 700 | 652 | 663 | 645 | 645 | 710 | 665 | 650 | 606 |
| 0 | 652 | 740 | 694 | 680 | 623 | 627 | 623 | 623 | 707 | 684 | 680 | 619 |

| Latitude °S | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 648 | 758 | 690 | 663 | 590 | 587 | 577 | 590 | 693 | 690 | 727 | 677 |
| 10 | 710 | 772 | 681 | 640 | 571 | 543 | 526 | 558 | 680 | 690 | 727 | 710 |
| 15 | 729 | 779 | 665 | 610 | 516 | 497 | 497 | 519 | 657 | 687 | 747 | 739 |
| 20 | 748 | 779 | 645 | 573 | 474 | 447 | 445 | 481 | 630 | 677 | 753 | 761 |
| 25 | 761 | 779 | 626 | 533 | 419 | 400 | 406 | 439 | 600 | 665 | 767 | 777 |
| 30 | 771 | 772 | 600 | 497 | 384 | 353 | 358 | 390 | 567 | 648 | 767 | 793 |
| 35 | 774 | 754 | 568 | 453 | 335 | 300 | 310 | 342 | 530 | 629 | 767 | 806 |
| 40 | 774 | 729 | 529 | 407 | 281 | 243 | 261 | 290 | 477 | 603 | 760 | 813 |
| 45 | 774 | 704 | 490 | 357 | 229 | 183 | 203 | 235 | 447 | 571 | 747 | 813 |
| 50 | 761 | 669 | 445 | 307 | 174 | 127 | 148 | 177 | 400 | 535 | 727 | 806 |
| 55 | 748 | 630 | 397 | 250 | 123 | 77 | 97 | 123 | 343 | 497 | 707 | 794 |
| 60 | 729 | 588 | 348 | 187 | 77 | 33 | 52 | 74 | 283 | 455 | 700 | 787 |

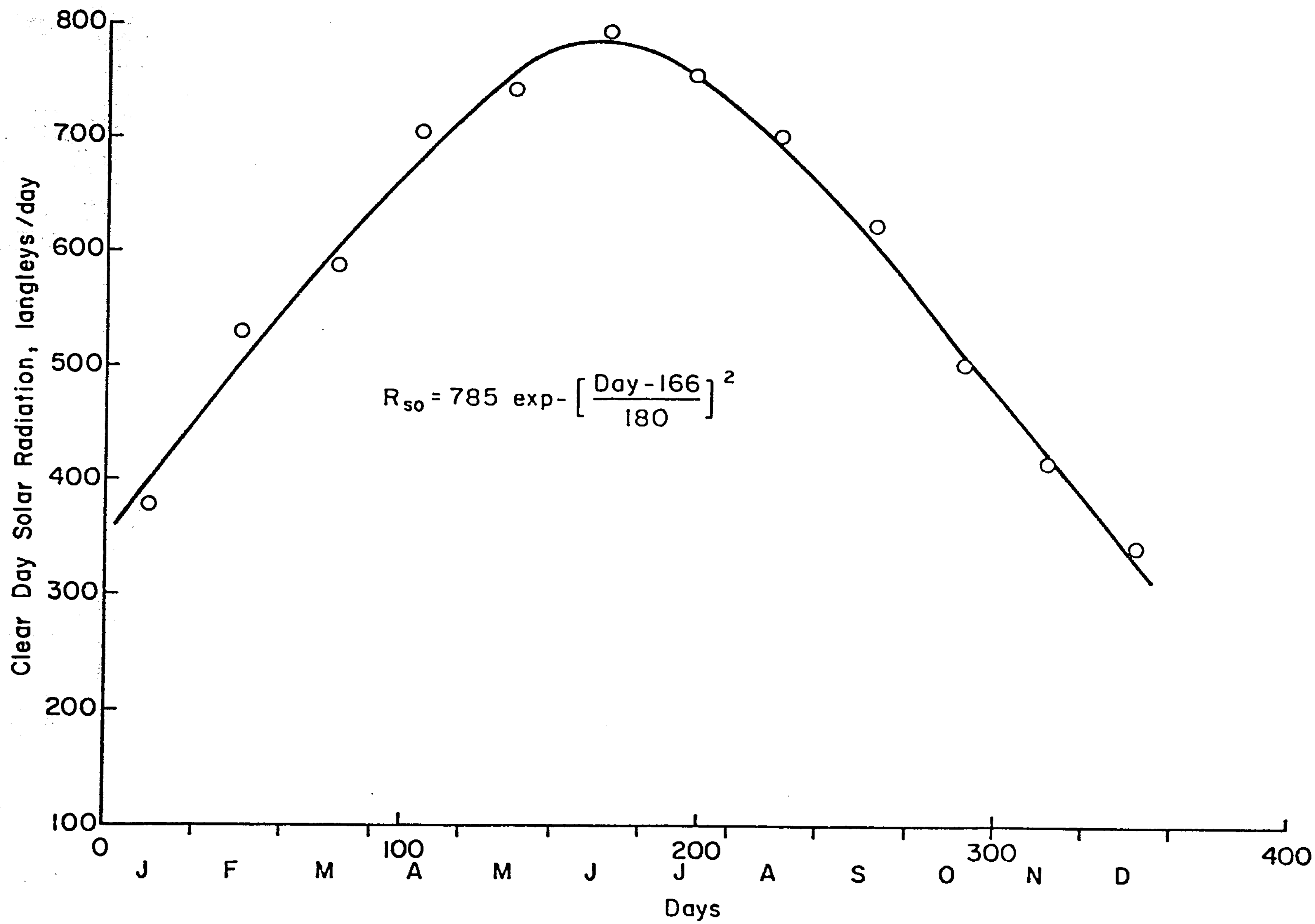


Fig. 2. Estimated yearly distribution of clear day solar radiation at Lahore, Pakistan.

$$\phi = \theta\pi/365 \text{ (Latitude in Degrees)} \tag{5}$$

Then the half day length in radians is:

$$\text{Half-Day} = \cos^{-1}(z) \tag{6}$$

in which

$$z = -\tan(\phi)\ \tan(\Delta) \tag{7}$$

The possible sunshine hours per day is defined as:

$$S_m = \frac{0.13333\ (\text{Half-Day})}{2\pi/365} \tag{8}$$

And finally, the fractional sunshine percentage, S, is computed as the ratio of actual measured values to $S_m$. Once given this value, solar radiation can be estimated from:

$$R_s = (0.35 + 0.61S)R_{so} \tag{9}$$

If S is given as data, solar radiation can be calculated directly from Eq. 9.

The next step is to define the clear day net outgoing longwave radiation:

$$R_{bo} = \varepsilon'\sigma T_k^{\ 4} \tag{10}$$

where,

$R_{bo}$ = net clear day outgoing longwave radiation, ly/day;

$$\varepsilon' = -0.02 + 0.261 \exp\left[-7.77 \times 10^{-4}(273 - T_k)^2\right] \tag{11}$$

$T_k$ = temperature in degrees Kelvin (°C + 273)

$\sigma$ = Stefan-Boltzmann constant = $11.71 \times 10^{-8}$ ly/°K.

Based on Eqs. 2 and 10, the longwave radiation occurring on a particular day equals:

$$R_b = \left[1.2\ \frac{R_s}{R_{so}} - 0.2\right] R_{bo} \tag{12}$$

and

$$R_n = (1 - \alpha)R_s - R_b \tag{13}$$

in which $\alpha$ = crop albedo (generally taken to be 0.23). The values 1.2 and -0.2 in Eq. 12 are suggested values for arid areas and will be different in more humid climates.

Soil heat flux. The exchange in heat from the soil is based on two assumptions: (1) the soil temperature to a depth of 2 meters varies approximately with average air temperature; and (2) the volumetric heat capacity of the soil is 0.5 cal $cm^{-3}$ $°C^{-1}$. The soil heat flux, G, is then written as (Jensen, 1973):

$$G = \frac{\bar{T}_{i-1} - \bar{T}_{i+1}}{\Delta t} \times 100 \tag{14}$$

where,

$G$ = soil heat flux, ly/day;

$\bar{T}_{i-1}$ = mean temperature for the previous period, °C;

$\bar{T}_{i+1}$ = mean temperature for the following period, °C, and

$\Delta t$ = days between the preceding and following period (twice the period interval).

Calculations of constants. Kincaid and Heermann (1974) present convenient expressions for determining $\Delta/\Delta+\gamma$, $\gamma/\Delta+\gamma$, and saturation vapor pressure. These expressions are as follows:

$$\gamma/\Delta+\gamma = 0.60543 - 0.01728T + 0.00014697^2 \tag{15}$$

$$\Delta/\Delta+\gamma = 1 - \gamma/\Delta+\gamma \tag{16}$$

and

$$e° = 6.328 + 0.424T + 0.01085T^2 + 0.000519T^3 \tag{17}$$

when T represents the daily value of temperature in °C being used in the computations.

Vapor pressure deficit. The evaluation of the term $(e_z° - e_z)$ in the Penman equation can be made in several ways. For many purposes, the following expression can be used:

$$(e_z° - e_z) = \frac{e_2° + e_1°}{2} - e_1° \cdot rh \tag{18}$$

in which,

$e_2°, e_1°$ = saturation vapor pressure at maximum and minimum temperatures, mb; and

rh = maximum relative humidity (usually taken as the 6-8AM values) expressed as a fraction.

## The Modified Jensen-Haise Method

The Jensen-Haise procedure is a temperature and solar radiation equation adjusted for location and elevation by vapor pressure functions (Jensen and Haise, 1963):

$$E_{tp} = C_T(T - T_x)R_s \tag{19}$$

in which,

$E_{tp}$ = average daily potential evapotranspiration of a well-watered alfalfa crop having 30-50 cm of top growth, cm/day;

$T$ = mean daily temperature, °C;

$R_s$ = total daily solar radiation in langleys multiplied by 0.00171 to get cm/day;

$T_x$ = intercept of the temperature axis

$$= 2.5 - 0.14(e_2 - e_1)\ °C/mb - elev(m)/550 \tag{20}$$

$e_2$, $e_1$ = saturation vapor pressures at the mean maximum and mean minimum temperature, respectively, for the warmest month of the year, in mb;

$C_T$ = temperature coefficient

$$= \frac{1}{C_1 + C_2 C_H} \tag{21}$$

$$C_1 = 38 - (2°C \times elev(m)/305) \tag{22}$$

$$C_2 = 7.6°C \tag{23}$$

$$C_H = \frac{50\ mb}{(e_2 - e_1)} \tag{24}$$

This equation has been found to work well in the western United States. Its applicability in Pakistan has been described by Clyma and Chaudry (1975) and by Reuss et al. (1976). A summary of the coefficients $T_x$, and $C_T$ are given in Table 2 for the metric units (Gill, 1977). It should be noted that in areas of high humidity, such as the monsoon areas of Pakistan, evidence suggests that $C_T$ should be diminished substantially (Jensen, 1973). Consequently, one might consider reducing $C_T$ by 24% when the average relative humidity is 40 to 50%, by 36% when the relative humidity averages 50-60%, and by 41% when the relative humidity is greater than 60%.

Table 2. Geographic coefficients for Jensen-Haise Equation in Pakistan (after Gill, 1977)

| Location | $C_t$ | | $T_x$ | |
|---|---|---|---|---|
| | Karif 1/ | Rabi 2/ | Karif 1/ | Rabi 2/ |
| Lahore | 0.01926 | 0.02232 | -6.100 | -8.739 |
| Lyallpur | 0.01926 | 0.02196 | -6.122 | -8.511 |
| Sargodha | 0.02016 | 0.02250 | -6.711 | -9.183 |
| Multan | 0.01998 | 0.02214 | -6.544 | -8.883 |
| Peshawar | 0.02142 | 0.02232 | -6.622 | -8.544 |

1/ July - September

2/ October through June

## ESTIMATING ACTUAL FIELD EVAPOTRANSPIRATION

In contrast to potential evapotranspiration ($E_{tp}$) which occurs in a well-watered crop, at full cover, under a given set of climatic conditions, there is the field evapotranspiration $W_e$. This is a combination of the crop evapotranspiration $E_t$, which would normally occur, plus the excess evaporation from the soil and crop $E_{tr}$ caused by their being excessively wet. This usually occurs for a short period immediately following a rain or an irrigation. Thus:

$$W_e = E_t + E_{tr} \tag{25}$$

It should be emphasized that $E_t$ does include some evaporation from the soil, such as would occur normally under conditions when neither the soil nor the plant are excessively wet.

Crop evapotranspiration can be estimated from the following equation:

$$E_t = K_c E_{tp} \tag{26}$$

where $K_c$ is a coefficient accounting for crop maturity and the water stress under which the plant is growing. This coefficient is calculated from the following:

$$K_c = K_{co} K_s \tag{27}$$

where $K_{co}$ is the crop growth stage coefficient and $K_s$ is the water stress coefficient. The crop growth stage coefficient can be determined from some generalized functional relationships applicable to many semiarid regions (Jensen, 1969; Jensen et al., 1970; Jensen et al., 1971). For computer scheduling purposes it is convenient to use a polynomial estimating equation as follows:

$$K_{co} = Ar^3 + Br^2 + Cr + D \tag{28}$$

where r is either (a) the fraction of time which has elapsed from planting to effective cover, or (b) the number of days which have elapsed beyond effective cover. The constants A, B, C and D take on different values depending on the crop and whether condition (a) or (b) exists. Experimental data throughout Pakistan indicates that $K_{co}$ values published for the United States require modification. These will be covered in a separate section.

The stress coefficient is calculated from the following:

$$K_s = \frac{\ln\,[1 + 100(1 - (D_P/D_T)]}{\ln(101)} \tag{29}$$

where,

$D_p$ = actual soil moisture depletion, cm; and

$D_T$ = total available soil moisture (field capacity - wilting point), cm.

In order to compute the value of the stress coefficient, $K_s$, the values of soil moisture depletion must also be known. This involves two factors. First, as the roots grow in the early season, more and more available soil moisture is added to the system:

$$D_T(t) = (MC)\ [RD_i + (RD_m - RD_i)\cdot r] \tag{30}$$

in which,

$D_T(t)$ = field capacity of the root zone with time, cm;

MC = moisture content at field capacity, cm/m;

$RD_i$ = initial rooting depth, m (Table 3);

$RD_m$ = maximum rooting depth, m; and

r = interval of the planting date to present divided by the time between planting date and full crop cover. (Table 4)

The soil moisture depletion on a day i is written,

$$D_p(i) = D_p(i-1) + E_t - R_i \tag{31}$$

where,

$D_p(i)$ = soil moisture depletion, cm; and

$R_i$ = rainfall or irrigation on the day, cm.

The value of $D_p$ substituted into Eq. 29 for a day i is usually the value $D_p(i-1)$.

Effective precipitation--that which reduces irrigation water demand by a crop--is difficult to determine. All run-off must of course be eliminated when considering the contribution of rainfall, but that water which passes into the soil through the surface is potentially available for use. If this quantity exceeds the root zone storage capacity of the soil (at the time of the precipitation occurrence) plus that which is consumptively used during the time it passes through the root zone, this must be considered and the contribution is reduced. Small rainfall events, which wet the plant and the soil surface but which do not enter the plant

Table 3. Initial and maximum root depth of selected crops in Pakistan.

| Crop | Initial depth at planting (cm) | Depth after effective cover (cm) |
|---|---|---|
| Citrus w/c | 15 | 120 |
| Citrus wo/c | 150 | 150 |
| Cotton | 15 | 180 |
| Berseem | 15 | 120 |
| Maize | 15 | 120 |
| Rice | 15 | 90 |
| Sugarcane | 15 | 90 |
| Wheat | 15 | 120 |

Table 4. A guide for establishing the effective cover dates of selected crops in Pakistan.

| Crop | Days from planting or beginning of growth to effective cover |
|---|---|
| Citrus w/c | 30 days |
| Citrus wo/c | 0 days |
| Cotton | 120 days |
| Berseem | 30 days |
| Maize | 60 days |
| Rice | 70 days |
| Sugarcane | 130 days |
| Wheat | 60-85 days |

roots, effectively reduce the demand for irrigation water and should be considered in full.

Whenever a rain or an irrigation occurs, the actual evapotranspiration is actually increased somewhat due to free water at the crop and soil surface. To account for this, an additional quantity of evapotranspiration is added to $E_t$ as follows:

$$E_{tr} = \left[K_r(0.9 - K_{co}K_s)\right]E_{tp} \tag{32}$$

where,

$E_{tr}$ = added evapotranspiration due to rain or irrigation, cm/day;

$K_r$ = 0.8 for first day following rain or irrigation;

= 0.5 for second day;

= 0.3 for third day; and

= 0.0 for other days.

If the value of $K_{co} \cdot K_s$ is greater than 0.9, $E_{tr}$ is set equal to zero. Thus, the actual evapotranspiration of a given day is:

$$E_t = \left[K_{co}K_s + K_r(0.9 - K_{co}K_s)\right]E_{tp} \tag{33}$$

A note of caution must be exercised concerning the definition of $E_{tp}$. If heavy rains cover the area for several days, $K_r$ would remain at 0.8 until the water had infiltrated the soil. In addition, if the groundwater elevation is sufficiently close to the soil surface, water may be evaporating in excess of the estimated values. In this case, $K_r$ should be based on the nearness of the water table and would be held constant.

## SIMULATION OF CROP GROWTH STAGE COEFFICIENTS

Crop growth stage coefficients for citrus, cotton, fodder (alfalfa and berseem), maize, rice, sugarcane, and wheat have been developed in the Punjab area of Pakistan through a coordinated program of gravimetric soil moisture sampling. These data were utilized in formulating a series of mathematical expressions required for programming of the HP 9825A computer. A description of the subroutine "crop" summarizing the attempt at mathematical simulation is found in Appendix A.

## Citrus

Citrus groves in Pakistan can be divided into those having a fodder crop of alfalfa or berseem growing under the tree canopies during the late fall and early winter, and those cultivated to be clean. Data from local experiments are plotted in Figure 3 for the cultivated condition. In most cases only the young developing orchards include a cover crop. The crop growth stage curve does not vary widely over an annual cycle and can be approximated by an exponential relation of the form:

$$K_{co} = a \exp - \left(\frac{b-T_i}{c}\right)^2 \tag{34}$$

in which

- a = maximum value of $K_{co}$;
- b = number of days since planting or beginning of growth to when the maximum value of $K_{co}$ occurs;
- c = empirial fitting constant; and
- $T_i$ = current Julian date.

Coefficient values of a, b and c are respectively, 0.75, 180.0 and 400.0

For the case of the citrus with fodder crop, the $K_{co}$ function is defined as that of berseem fodder.

## Cotton

Cotton is generally planted in the Punjab between the first of March and the last of April, depending upon such factors as water availability as to the specific timing. The cotton $K_{co}$ data indicate a single curve as shown in Figure 4 offset by the planting delays. This curve is not representable by the exponential curve form of Eq. 34 so a step wise polynomial regression was determined. For the first six weeks after planting, $K_{co}$ for cotton is expressed as a linear function:

$$K_{co} = 0.20 + 0.002381\ (T_i-T_p) \tag{35}$$

in which $T_p$ is Julian date of planting.

Between 42 and 98 days of the planting, the curve is expressed as a third order polynomial:

$$K_{co} + a + b(T_i-T_p) + c(T_i-T_p)^2 + d(T_i-T_p)^3 \tag{36}$$

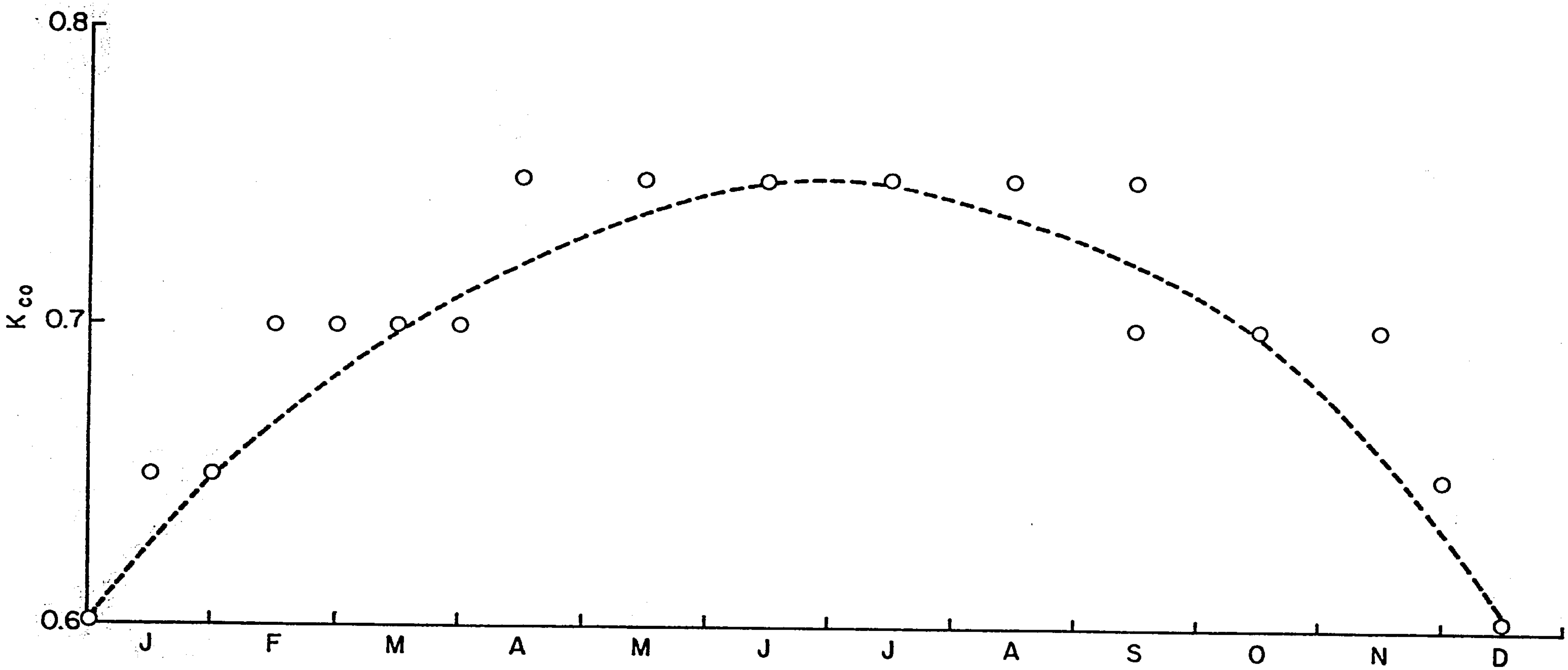


Figure 3. Crop growth stage coefficient curve for citrus without undercanopy cover crops.

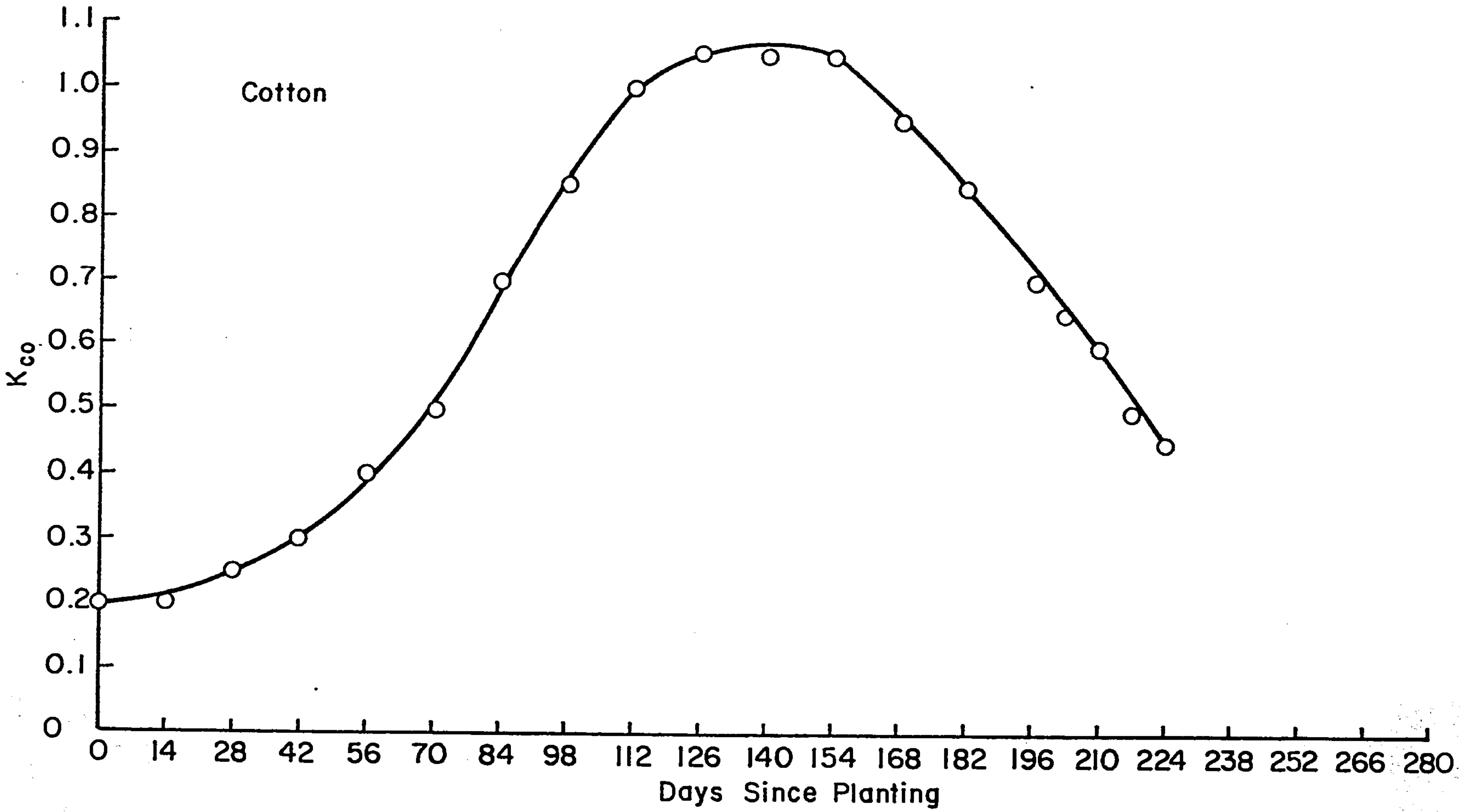


Figure 4. Growth stage coefficient, $K_{co}$, for cotton.

where,

$a = -6.942 \times 10^{-2}$

$b = 1.94799 \times 10^{-2}$

$c = -3.20859 \times 10^{-4}$

$d = 2.2544 \times 10^{-4}$

For the periods $98 \leq T_i \leq 140$ and $T_i > 140$, the $K_{co}$ relation is also described in the form of Eq. 36:

$a = 2.37505 \times 10^{-5}$

$b = -3.903237 \times 10^{-3}$

$c = 2.400357 \times 10^{-4}$ $\qquad 98 \leq T_i \leq 140$

$d = -1.128125 \times 10^{-6}$

and,

$a = 6.304 \times 10^{-5}$

$b = 2.17174 \times 10^{-2}$ $\qquad T_i > 140$

$c = -1.1893 \times 10^{-4}$

$d = 1.37862 \times 10^{-7}$

Fodder

Fodder crops of alfalfa and berseem planted in December and January would generally have relatively unique $K_{co}$ functions because these are the reference crops for estimating $E_{tp}$. For a period of about 30 days at the beginning of the growing season and for a period of about 20 days following a cutting, $K_{co}$ varies linearly from 0.5 to 1.0 (Kincaid and Heermann, 1974). In Pakistan, however, a fodder field is only partially harvested at any one time. In other words, a specific field is likely to exhibit a continuous range of conditions from freshly cut to the mature stand. Under these conditions, this model defines fodder $K_{co}$ values at 0.80 throughout the growing season.

Maize

Maize plantings range throughout July and August, but unlike cotton, the $K_{co}$ curve is affected by the date of planting as shown in Figure 5. In order to simulate the curves in Figure 5 for the full range of planting dates, the curve was divided into four segments. The first segment encompasses the period between planting and the next 6 weeks. This

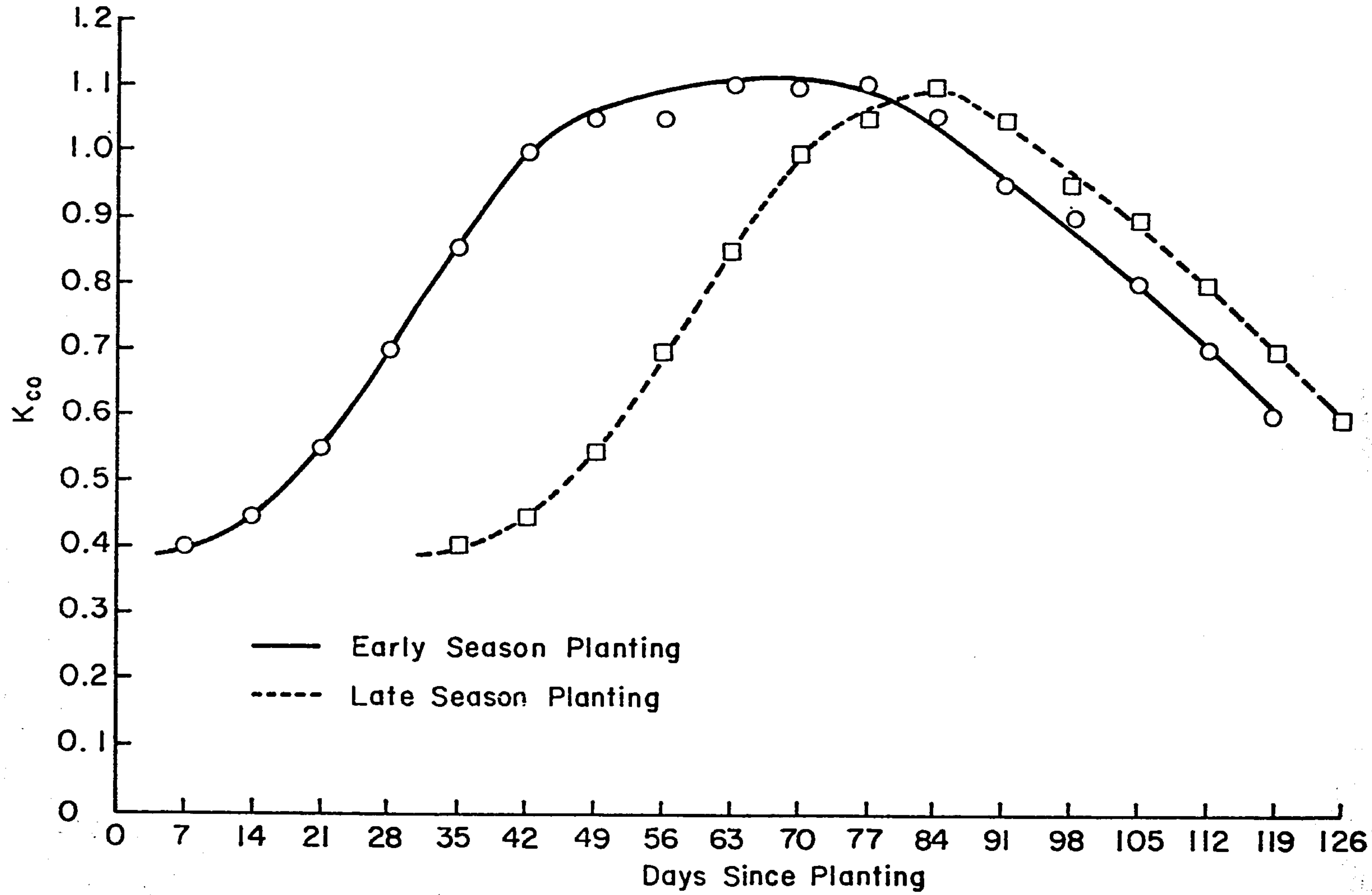


Figure 5. Crop growth stage curve for maize indicating the effect of early and late planting.

segment is the same regardless of planting date although offset in time. The expression used for this first 42 days is:

$$K_{co} = a + b(T_i - T_p) + c(T_i - T_p)^2 \qquad (37)$$

in which

$$a = 0.34$$

$$b = 5.2551 \times 10^{-3} \qquad T_i - T_p \leq 42$$

$$c = 2.551 \times 10^{-4}$$

For the next segment ($42 \leq T_i - T_p \leq 56$) which is also common for all planting dates, a linear function is utilized:

$$K_{co} = 0.70 + 0.00714286(T_i - T_p) \qquad (38)$$

The third segment of the curve is uniquely determined by the planting date. However, its development requires an explanation first of the fourth segment. It is assumed that maize will require at least 56 days (eight weeks) to reach full cover as modeled by Eqs. 37 and 38. A similar assumption is that six weeks or 42 days are required from the period of highest $K_{co}$ until harvest (refer to Figure 5). Thus, it is assumed that the growing season is at least 98 days as evaluated by the equations describing the first, second, and fourth segments. Any extra time of growth is given a $K_{co}$ value of 1.1. In other words, the effect of early planting is to extend the peak demand period. Mathematically, in this third period:

$$K_{co} = 1.1 \qquad 56 \leq T_i - T_p \leq T_h - 42 \qquad (39)$$

in which $T_h$ is the Julian date of harvest. The fourth segment function is an equation similar to Eq. 36 with:

$$a = 2.374 \times 10^{-5}$$

$$b = -3.903237 \times 10^{-3}$$

$$c = 2.400357 \times 10^{-4}$$

$$d = -1.128125 \times 10^{-6}$$

## Rice

Rice in the Punjab is usually planted between June 24th and July 23rd and then harvested in mid or late November. The $K_{co}$ curve for rice, assuming that the crop is transplanted rather than seeded, is shown in Figure 6. A single exponential curve of the type expressed by Eq. 36 fits the rice curve over its growth season:

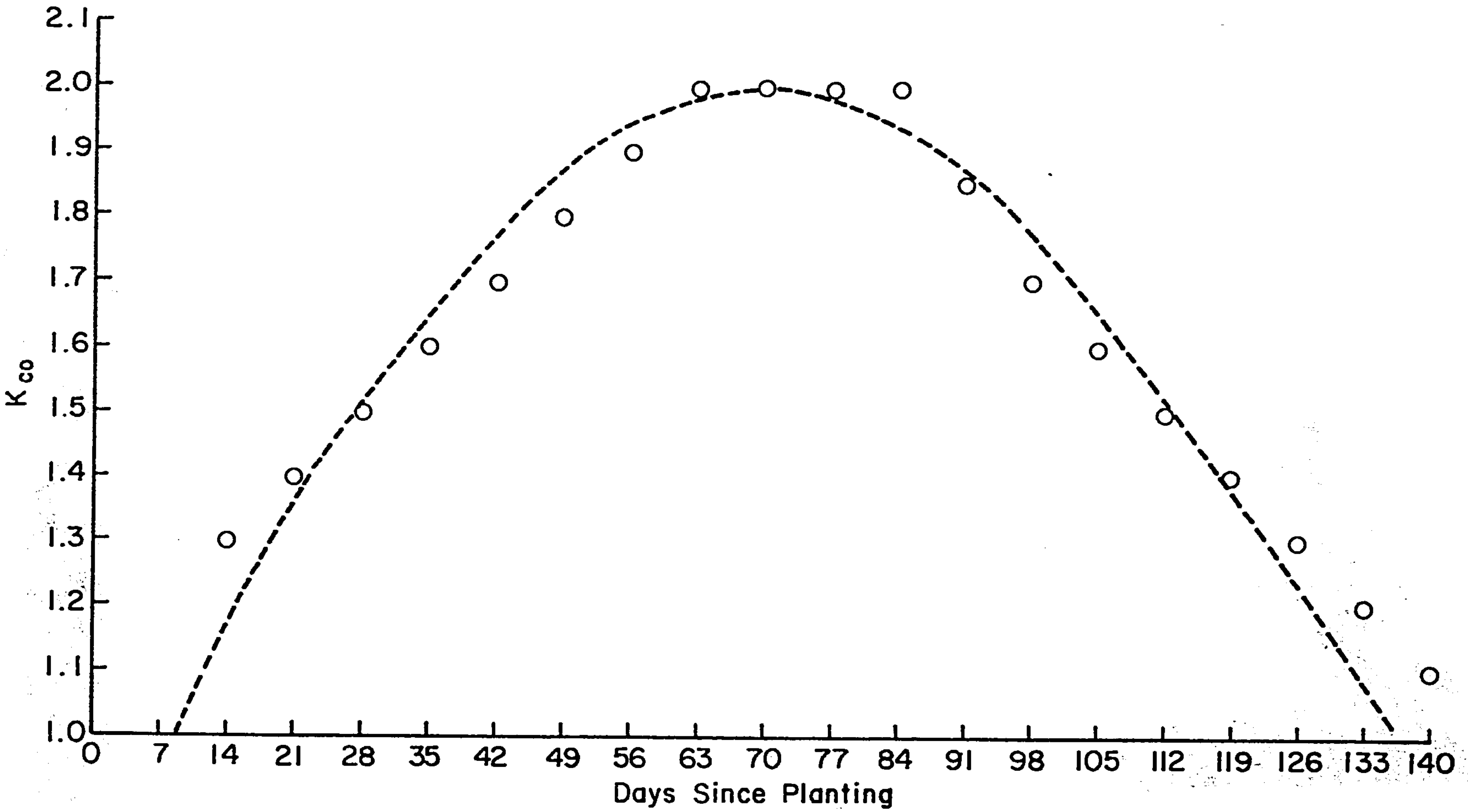


Figure 6. Growth stage coefficient curve for Rice.

$$K_{co} = 2.0 \text{ exp. } \left[\frac{77-(T_i-T_p)}{80}\right]^2 \quad (40)$$

Sugarcane

For the purpose of this model, it is assumed that sugarcane plantings occur during March or April and that harvest occurs near the end of December. The effect of ratooning is neglected. A plot of the $K_{co}$ relation for sugarcane is shown in Figure 7 again indicating some effect of delayed planting. Equations like Eq. 36 were fitted to the $K_{co}$ relation for both the increasing and decreasing segments. In order to shift the increasing segment in accordance with planting date, the Julian date and the coefficients b and c in Eq. 36 need to be modified as follows:

$$T_i' = T_i-69 \quad (41)$$

$$b = 133 + (T_p-69)/2.33 \quad (42)$$

$$c = 120-(T_p-69)/2.45 \quad (43)$$

$$K_{co} = 1.05 \text{ exp}-\left[\frac{b - T_i'}{c}\right]^2 \quad (44)$$

The decreasing segment is the same as Eq. 44 except that c is fixed at 175.

Wheat

The $K_{co}$ function for wheat in the Punjab is the most difficult to model. The crop can be planted from mid October to early December. Harvesting is near mid April. The complexity of the wheat $K_{co}$ curve is illustrated in Figure 8. Early season plantings exhibit a longer period to reach maximum $K_{co}$ than later plantings whereas the late season plantings tend to maximize at a lower $K_{co}$ value.

The increasing $K_{co}$ segment of the curve is modeled with an exponential form similar to Eq. 34 except the argument is cubed:

$$K_{co} = a \text{ exp } -\left[\frac{b - T_i'}{c}\right]^3 \quad (45)$$

The value of the maximum $K_{co}$ (a) is adjusted linearly as follows:

$$a = 1 - \frac{(T_p-288)}{980} \quad (46)$$

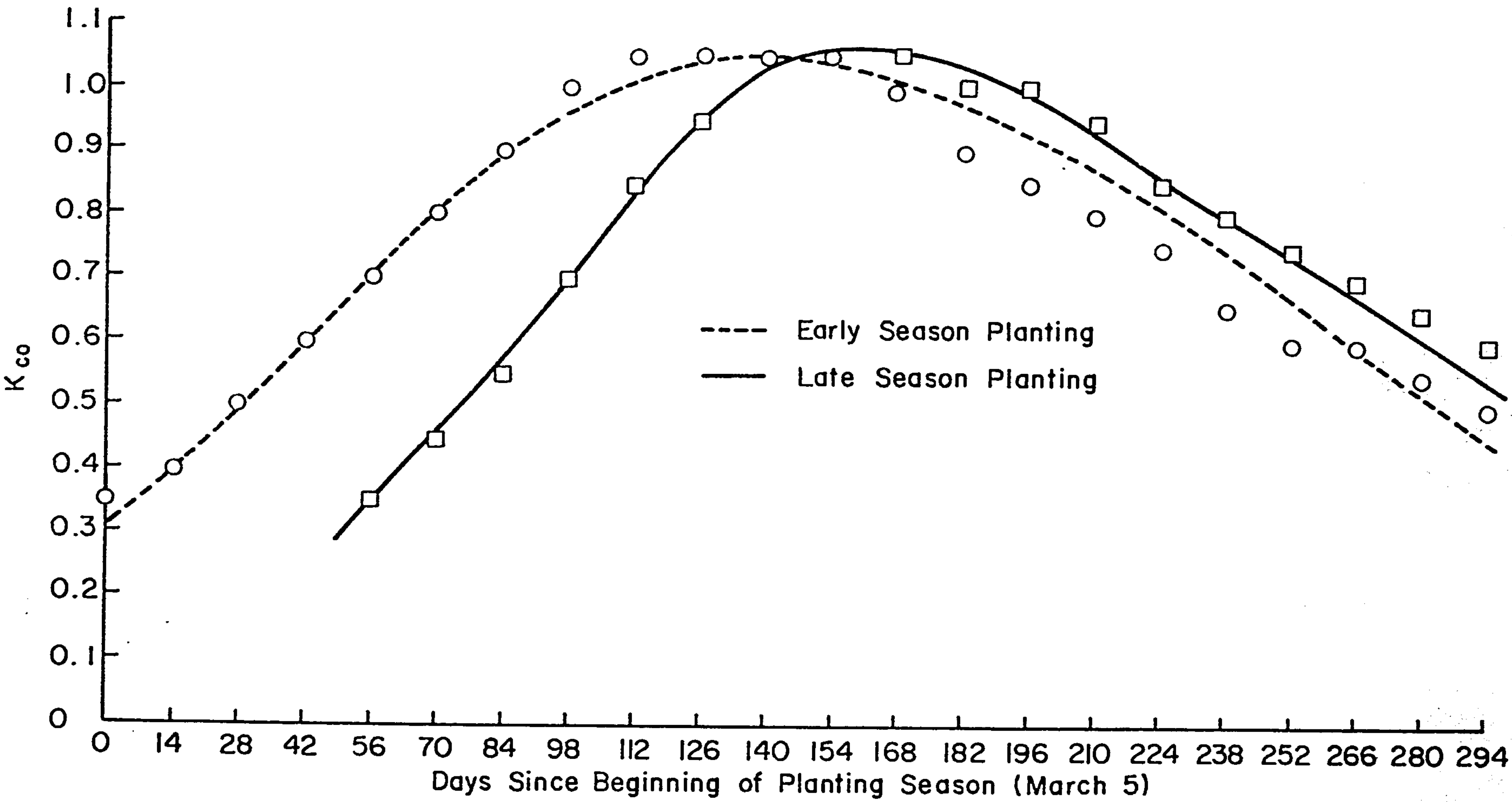


Figure 7. Crop growth stage coefficient for sugar cane.

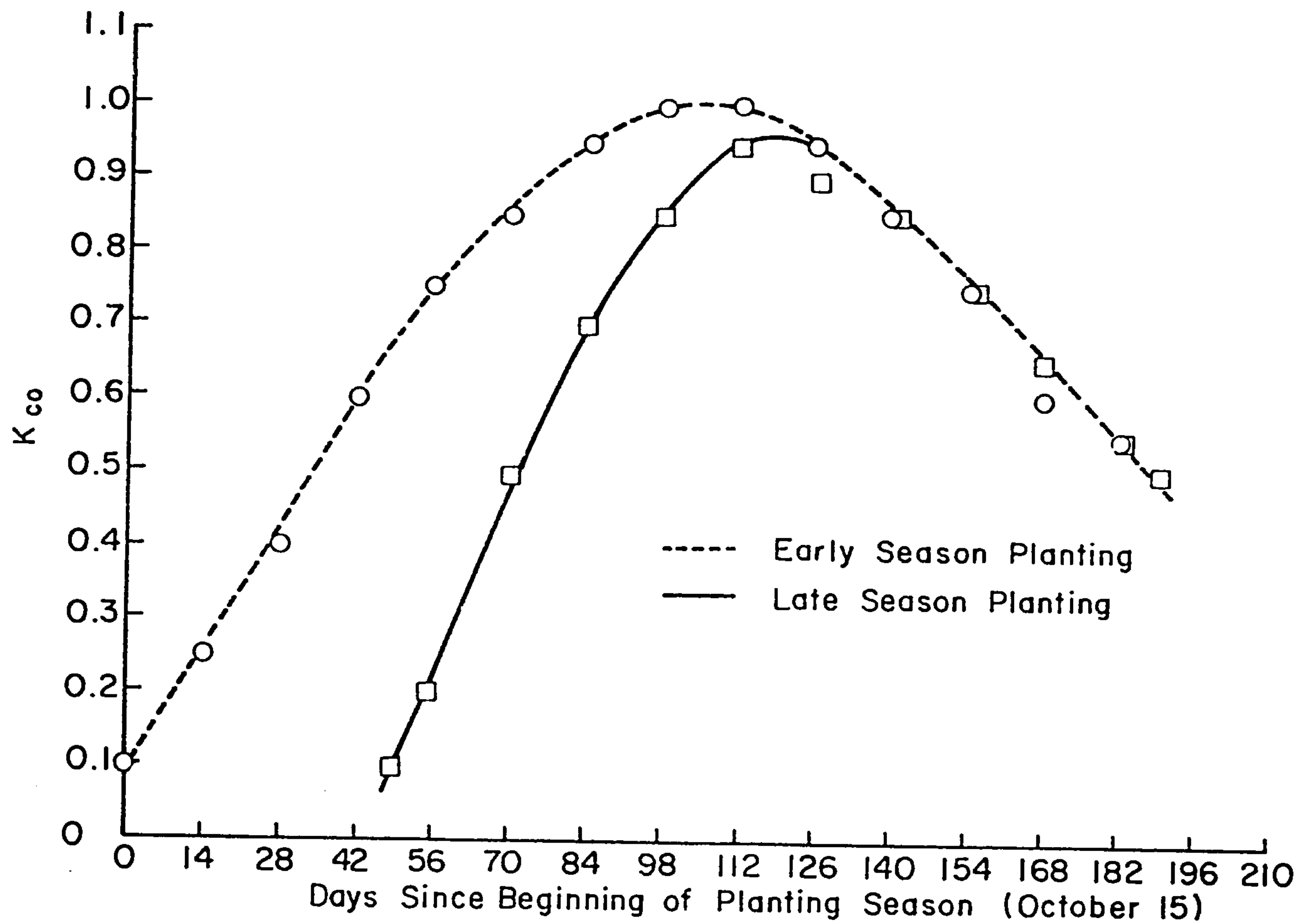


Figure 8. Crop growth stage curves for wheat indicating the effect of planting dates.

and the coefficients $T_i'$, b, and c similarly:

$$T_i' = T_i - 288 \tag{47}$$

$$b = 105 + (T_p - 288)/3.5 \tag{48}$$

$$c = 80 - (T_p - 288)/1.81 \tag{49}$$

The decreasing side of the curve is simulated with Eq. 34 with a, $T_i'$, and b as defined in Eqs. 47 and 49 and:

$$c = 100 - (T_p - 288)/2.45 \tag{50}$$

MODEL APPLICATION

The principle evapotranspiration model presented in this report is designed to calculate and tabulate values of $E_t$ for the eight Punjab crops listed previously. Documentation is given in Appendix A and a listing in Appendix B. A modified version which eliminates the printout, but stores the daily $E_{tp}$ values in taped arrays will be used to input estimated potential evapotranspiration requirements into the water management-irrigation scheduling model.

To test and verify the model, two sets of climatological data were recorded. Both data sets cover the period from October 1, 1974 to September 30, 1975. The only difference is that the first set includes radiation data as hours of sunshine per day while the second incorporates solar radiation in langleys/day (cal $cm^{-2}$ $day^{-1}$). The station of record is Sargodha, Pakistan. The data record includes the precipitation (mm), radiation or sunshine, maximum temperature (°C), minimum temperature (°C), maximum relative humidity (%), and daily wind run in miles.

Utilizing the first data set (hours of sunshine), the evapotranspiration of cotton and wheat were calculated on a daily basis using both the Penman and Jensen-Haise equations. The results are shown in Tables 5, 6, 7 and 8. The output is printed at various intervals and indicate the parameter value or rate on that date. The cumulative $E_t$ is summed for each day and printed at the selected intervals.

It is seen that the difference between the two methods of calculation is 13.7 mm (2.9 inches) for seasonal cotton $E_t$ which is an 8% average difference with the Penman method tending to estimate lower values of $E_t$ than the Jensen-Haise method. The wheat seasonal totals differed by 26.2 mm (1.03 inches) for an average disparity of 6.5%. In this case, however, the Penman approach produced the highest values. Both methods yield results within the range of values being measured in the Punjab.

Table 5. [illegible] 1975 [illegible]

| [illegible] Since Planting | [illegible] (cm) | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|
| [illegible] | 15 | [illegible] | [illegible] | 1.[illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | 1.[illegible] | [illegible] |
| 20 | [illegible]3 | [illegible] | [illegible] | [illegible].3 | [illegible] |
| 30 | [illegible] | [illegible].27 | [illegible] | [illegible] | [illegible].7 |
| [illegible] | 7[illegible] | .3[illegible] | [illegible] | [illegible].1 | [illegible] |
| 50 | [illegible]4 | [illegible].33 | 11.[illegible] | [illegible] | [illegible]1.[illegible] |
| 60 | [illegible] | [illegible].43 | [illegible] | 3.[illegible] | 1[illegible] |
| 70 | 111 | [illegible] | [illegible] | [illegible] | 1[illegible] |
| 80 | 12[illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 90 | 13[illegible] | 0.73 | [illegible] | [illegible] | [illegible].3 |
| 100 | 153 | [illegible] | [illegible] | [illegible] | 31[illegible] |
| 110 | 1[illegible]6 | .77 | [illegible].1 | [illegible] | [illegible] |
| 120 | [illegible] | 1.[illegible] | [illegible] | [illegible] | 41[illegible] |
| 130 | 1[illegible] | 1.[illegible]7 | [illegible] | [illegible] | [illegible]71.[illegible] |
| 140 | 180 | 1.0[illegible] | [illegible] | [illegible].2 | [illegible] |
| 150 | 1[illegible] | 1.[illegible] | [illegible] | [illegible].3 | [illegible] |
| 160 | 1[illegible] | [illegible] | [illegible] | [illegible].7 | [illegible] |
| 170 | 1[illegible] | [illegible] | [illegible].1 | [illegible].7 | [illegible].3 |
| 180 | 1[illegible] | [illegible] | [illegible] | [illegible] | 7[illegible] |
| 190 | 180 | [illegible].72 | 3.[illegible] | 3.1 | 75[illegible] |
| 200 | 1[illegible] | [illegible].69 | 2.[illegible] | 1.[illegible] | 7[illegible]3.[illegible] |
| 210 | 1[illegible]0 | [illegible].59 | 2.[illegible] | 1.5 | [illegible] |
| 220 | 1[illegible]0 | [illegible].4[illegible] | [illegible] | 1.7 | [illegible].1 |
| 223 | 1[illegible]0 | 0.46 | [illegible] | 1.1 | [illegible] |

Calcul. Use Penman [illegible] and Assume:
Planting Date of [illegible] April [illegible]
Harvest Date of [illegible] December [illegible]

Table 6. Estimated Et during 1975 for wheat

| Days Since Planting | Root Depth (cm) | Kco | Etp (mm/day) | Actual Et (mm/day) | Cumulative Et To Date (mm) |
|---|---|---|---|---|---|
| 0 | 15 | 0.10 | 4.0 | 0.4 | 0.4 |
| 5 | 22 | 0.11 | 3.8 | 0.5 | 2.9 |
| 10 | 29 | 0.20 | 3.3 | 0.6 | 5.0 |
| 15 | 36 | 0.26 | 3.3 | 0.9 | 9.9 |
| 20 | 43 | 0.33 | 2.6 | 0.9 | 14.5 |
| 25 | 50 | 0.41 | 3.0 | 1.2 | 20.1 |
| 30 | 57 | 0.50 | 2.[illegible] | 1.4 | 25.5 |
| 35 | 64 | 0.58 | [illegible].2 | 1.3 | 33.5 |
| 40 | 72 | 0.66 | 2.1 | 1.4 | 40.6 |
| 45 | 79 | .74 | 2.0 | 1.5 | 48.7 |
| 50 | 86 | [illegible] | 2.2 | 1.7 | 57.6 |
| 55 | [illegible]3 | 0.86 | 1.4 | 1.2 | 64.3 |
| 60 | 100 | 0.90 | 2.9 | 2.7 | 75.6 |
| 65 | 107 | [illegible].93 | 1.5 | 1.7 | 85.5 |
| 70 | 114 | [illegible].95 | 2.4 | 2.3 | 97.7 |
| 75 | 120 | [illegible].97 | [illegible] | [illegible] | 113.3 |
| 80 | 120 | [illegible] | 3.0 | 2.9 | 127.6 |
| 85 | 120 | [illegible] | [illegible] | 2.6 | 141.5 |
| [illegible] | [illegible] | [illegible] | 3.2 | 3.1 | 153.9 |
| [illegible] | 120 | [illegible] | 1.7 | 1.7 | [illegible] |
| [illegible] | [illegible] | [illegible].97 | [illegible] | [illegible] | 177.5 |
| [illegible] | [illegible] | [illegible] | [illegible].7 | [illegible].5 | 195.2 |
| 110 | [illegible] | [illegible] | [illegible] | [illegible].1 | 213.3 |
| 115 | [illegible] | [illegible].91 | 5.[illegible] | [illegible] | [illegible] |
| [illegible] | 120 | [illegible] | [illegible].1 | [illegible] | [illegible] |
| [illegible] | 120 | [illegible] | [illegible] | 3.7 | [illegible] |
| 13[illegible] | [illegible] | [illegible].91 | 5.[illegible] | [illegible] | [illegible] |
| [illegible] | 120 | .77 | [illegible].1 | [illegible].7 | 324.5 |
| [illegible] | [illegible] | [illegible] | 5.1 | 3.7 | 345.2 |
| [illegible] | [illegible] | [illegible] | [illegible].7 | [illegible] | 371.1 |
| [illegible] | [illegible] | [illegible] | 7.[illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible].1 | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

[illegible] 7. [illegible] 1975 for [illegible]

| [illegible] Since Planting | [illegible] (cm) | [illegible] | [illegible] | Actual [illegible] | Cumulative [illegible] |
|---|---|---|---|---|---|
| 0 | 15 | [illegible] | [illegible] | [illegible] | 1.7 |
| 10 | [illegible] | [illegible] | [illegible] | 1.[illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | .3 | [illegible] | [illegible] |
| [illegible] | [illegible] | .27 | [illegible] | [illegible] | [illegible] |
| [illegible] | 70 | .30 | [illegible] | .7 | [illegible] |
| [illegible] | [illegible] | [illegible] | 10.[illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | 1.[illegible] | [illegible].1 |
| 70 | 111 | [illegible] | 5.[illegible] | [illegible] | [illegible] |
| [illegible] | 12[illegible] | .50 | 7.[illegible] | [illegible].1 | [illegible] |
| 90 | 13[illegible] | 0.73 | 5.1 | [illegible].7 | [illegible]7.[illegible] |
| 100 | 153 | 0.8[illegible] | 7.1 | [illegible].3 | 317.5 |
| 110 | 156 | [illegible].[illegible]7 | [illegible] | [illegible].1 | 372.[illegible] |
| 120 | [illegible] | 1.[illegible] | 4.3 | 4.[illegible] | 424.4 |
| 130 | [illegible] | 1.07 | 5.[illegible] | [illegible] | [illegible] |
| 140 | [illegible] | 1.06 | [illegible].4 | [illegible].7 | [illegible] |
| 150 | [illegible] | 1.05 | 4.[illegible] | [illegible] | [illegible]1.3 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible]53.2 |
| 170 | [illegible] | [illegible] | 5.[illegible] | [illegible] | 70[illegible].2 |
| [illegible] | [illegible] | [illegible] | [illegible].7 | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible].7[illegible] | [illegible] | [illegible] | 7[illegible]7.3 |
| 200 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 210 | [illegible] | 0.5[illegible] | 2.[illegible] | 1.[illegible] | [illegible] |
| 220 | [illegible] | 0.4[illegible] | 2.[illegible] | 1.[illegible] | [illegible].1 |
| 223 | [illegible] | 0.[illegible] | 2.[illegible] | 1.[illegible] | [illegible].7 |

Calcul. Use Jensen-Haise [illegible] and Assume:
Planting date of [illegible] April 30
Harvest date of December 9

Table 8. Estimated Et during 1975 for Wheat

| Days Since Planting | Root Depth (cm) | Kco | Etp (mm/day) | Actual Et (mm/day) | Cumulative Et To Date (mm) |
|---|---|---|---|---|---|
| 0 | 15 | 0.10 | 3.6 | 0.4 | 0.4 |
| 5 | 22 | .14 | 3.9 | 0.6 | 3.0 |
| 10 | 29 | 0.20 | 3.5 | 0.7 | 6.1 |
| 15 | 36 | 0.25 | 3.3 | 0.9 | 10.6 |
| [illegible] | [illegible] | 0.33 | 2.8 | 0.9 | 14.7 |
| 25 | 50 | 0.41 | 2.5 | 1.1 | 20.2 |
| [illegible] | 57 | .50 | 2.5 | 1.3 | 25.7 |
| 35 | 64 | .53 | 2.2 | 1.3 | 32.8 |
| 40 | 72 | 0.56 | 2.1 | 1.4 | 40.5 |
| 45 | 79 | 0.74 | 2.5 | 1.9 | 49.1 |
| [illegible] | [illegible] | 0.80 | 1.9 | 1.5 | 57.4 |
| 55 | [illegible] | 0.86 | 2.6 | 2.2 | 65.9 |
| [illegible] | 100 | 0.90 | 2.8 | 2.5 | 75.9 |
| 65 | 107 | .93 | 2.5 | 2.4 | 87.9 |
| [illegible] | 114 | 0.95 | [illegible] | 2.3 | 101.4 |
| 75 | [illegible] | .97 | 1.9 | 1.3 | 115.9 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 129.4 |
| [illegible] | [illegible] | [illegible] | [illegible] | 1.5 | 141.1 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 150.5 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 171.8 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | .77 | [illegible] | 1.7 | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

[illegible]

Data describing radiation indirectly as hours of sunshine is usually a very poor substitute for radiation actually measured as langleys. Analysis of the second data set which incorporated the same data except radiation is summarized for the same conditions described previously in Tables 5, 6, 7 and 8. Comparison of the annual totals for cotton using the Penman method indicates that the actual radiation data produced a lower $E_t$ estimate by an average of 6.7%. The same trend was exhibited for the Jensen-Haise analysis although the difference increased 11.1%. Wheat differences diminished drastically. The Penman differences were less than 0.4% and the Jensen-Haise estimates reduced to 2.3%. Considering the range of values, differences in computational method and data input could amount to 15% for cotton but only 7% for wheat.

Too much evaluation of these tables is unwarranted and certainly do not indicate computational errors. The discussion of these estimating differences do, however, lead to three important conclusions. First, the form of radiation data, hours of sunshine or actual solar radiation probably does not create significant problems in using either the Jensen-Haise or the Penman approaches. Second, the choice of method is not too important at least at Sargodha although similar tests might be advisable at other locations. And third, both methods behave more uniformly during the cooler winter months when the radiation and vapor pressure influences are small.

A number of recommendations have also become apparent to the writer. The most significant being that the measurement of potential evapotranspiration for a reference crop should be undertaken in lysimeter studies. The current program of artificially establishing the empirical coefficients for the $E_{tp}$ model then using these figures to define $K_{co}$ is a poor approach because it creates too much of a "site calibration" mode of operation. It, therefore, tends to preclude any generalizing ability which would be important in evaluating various possible water management options.

## PART 3. IRRIGATION SCHEDULING MODEL

### INTRODUCTION

The purpose of this segment is to detail an irrigation scheduling model comprising the second phase of a much larger effort to simulation water management decisions along a watercourse in Pakistan. The scope of the model is a daily, but non-real time, simulation of the water balance within what is known as a watercourse square comprised of fifty one-half acre fields. In the second part dealing with evapotranspiration, the consumptive use simulation of citrus, cotton, alfalfa and berseem fodder, maize, rice, sugarcane, and wheat was discussed. Many of the same subprograms will be utilized in this model but not detailed again. The evaporation from fallow lands will be discussed in this report since it deals more directly with the simulation of planting schedules.

The water volume available to the croplands within a square is an important parameter in irrigation scheduling. Because of memory limitations, however, this information will be provided to the irrigation scheduling model as input data generated by an independent simulation of the watercourse conveyance system. Thus, the physical setting of this model is limited to the individual fields encompassed by a square. The computer program description and listings are given in Appendices D, E, F, and G.

## GENERAL OPERATION OF THE MODEL

The irrigation scheduling model consists of three models:

(1) A main program to control the order of calculations load input data and control parameters, and output results (Appendix E);

(2) A data preparation program to define control parameters and initial conditions if needed (this information can be stored on a tape file after initial definition (Appendix F); and

(3) A service program to calculate various coefficients such as irrigation priority, crop growth stage coefficients, and rooting depths (Appendix G).

This division is made solely for the purpose of meeting the computer's internal storage limitations which do not allow the simultaneous storage of both the data preparation and service program. The essential features of these latter two programs will be discussed in separate sections.

The main program includes three subroutines: (1) "DATE CONVERSION", described previously; (2) "INTERMEDIATE RESULTS" which is the principal output mechanism; and (3) "HARVEST DATES" which calculates the date a field will be harvested once it has been pre-irrigated and planted. With the exception of the third subroutine which will be described separately, the subroutines will not be described due to their straight forward operations.

## ELEMENTS OF THE MAIN PROGRAM

The main program section can be divided into five elements. In the section encompassing lines 14 through 43, the user responds to a series of questions which sets up the program's operation. For example, the generation of control parameters and initial conditions can be accomplished by either loading the appropriate tape files or attaching and executing the data preparation program. In addition, the evapotranspiration and water supply data files are identified and loaded.

From lines 44 to 60, the output headings on the external printer are programmed. Note that in this version, the write statements are listed as "wrt 701.1", whereas in the listings of the evapotranspiration model, the statement would have read, "wrt 6.1". The discrepancy involves the external printer select codes. The initial programming occurred in Pakistan with the impact printer which the irrigation scheduling model was completed in Fort Collins using a dot matrix printer. The proper select code must be utilized. Consequently, each write statement will need modification if the program is to run on other systems. These changes will be required throughout the program.

The third section of the program lies between program lines 61 and 95. This is the basic irrigation scheduling routine and will also be described separately.

Between lines 96 and 114 are the statements dealing with the irrigation of the individual fields in the square, and likewise will be described in another independent section.

## GENERAL OVERVIEW

The logic of the irrigation scheduling model is somewhat different than is inherent in traditional irrigation scheduling programs. This program simulates the planting, harvesting, and irrigation of fields within the subject area as opposed to calculating the suggested decisions regarding these operations for actual implementation. Consequently, the climatological and water supply inputs to the system are known one year in advance or more and the computations detail what would be expected to occur.

The program begins its daily cycle of calculations on October 1st by defining the initial state of each of 50 fields in the study area. On any given day thereafter, the fields are grouped into three classes with essentially the same analysis performed on each. The first class of fields includes those growing one of the eight crops. The program first calculates the crop rooting depth and growth stage coefficient, and then uses these data along with precipitation to update the soil moisture level in the crop root zone. For the second class, those fields which are idle or fallow, the "root zone" is defined to be 45 cm deep and then this depth of soil is also updated with respect to soil moisture. The evaporation from the fallow fields is set at 70% of the potential evapotranspiration. The third class of fields are a group of fields which have been preirrigated in preparation for planting. These fields are evaluated in the same manner as fallow fields except that when the soil profile dries to a prescribed level, the crop is planted automatically.

Once a crop has been planted, the harvest dates are computed. When the day by day analysis goes beyond this date, the crop is automatically harvested. A flow chart of the basic soil moisture updating analysis is shown in Figure 9.

After the soil moisture levels in each of the 50 fields have been updated, the program moves to the irrigation phase of the analysis. If irrigation water is available on the day in question, the water is distributed among the fields on the basis of a priority system to be discussed subsequently.

## PRIORITIES FOR SCHEDULING IRRIGATIONS

When water is the limiting factor in the agricultural production of an area, farmers face critical decisions regarding the allocation of the supply among the fields--a water management process better known as irrigation scheduling. Although the execution of irrigation scheduling is more likely to be based on the judgement of the farmer than any completely rational methodology, techniques based on computer simulation can be used. The nature of farmer decisions depends on the distance to the nogha, levelness of his fields, the season of the year, and the crops already growing or planned for planting. Since the complexities of these factors cannot be completely modeled, simulating irrigation schedules must be undertaken realizing the inherent limitations of the simplifying assumptions.

For the purposes of this model, irrigations will be scheduled according to a system of priorities incorporating several characteristics. First, the production of some crops like citrus and vegetables are more valuable than maize and fodder so a farmer will tend to protect these more profitable crops from stress. These factors are handled by way of a minimum fixed priority value for a specific crop. Second, effects of delayed irrigations, or stress, are less important in some crops than in others, but in all crops the effects of water shortage tend to reduce yields (cotton may be somewhat of an exception). Thus, a crop's priority for irrigation water must increase as the soil moisture reservoir in the soil diminishes beyond a critical point characteristic of the crop. And finally, a distinction must be made between the water demands of growing crops and the pre-plant irrigation utilized to initiate the season of other crops. Within the possible planting season, the priority must increase as the remaining planting opportunity declines.

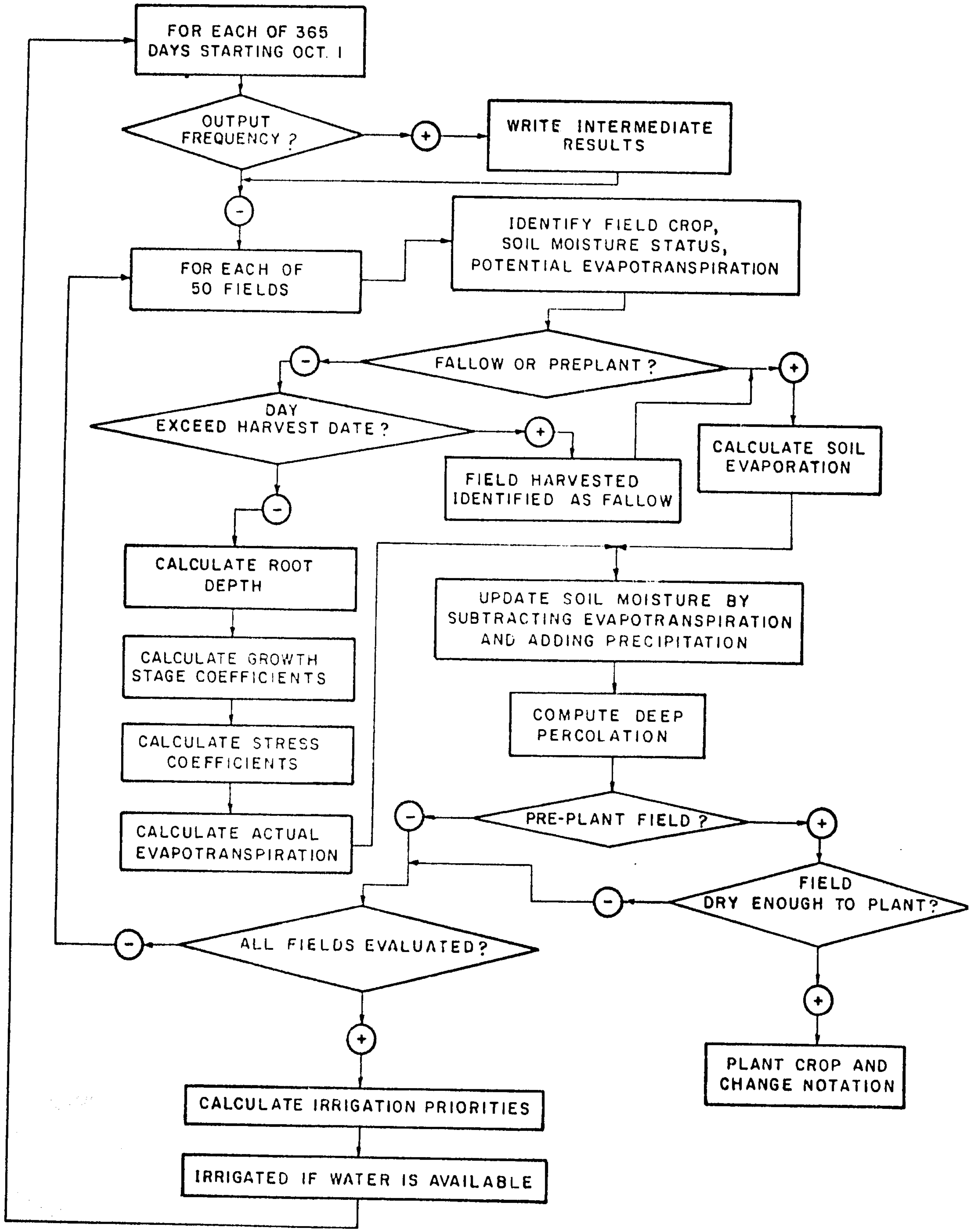


Fig. 9. Flowchart of basic soil moisture updating procedure.

The first component of the priority system might be called an "economic" priority. Of the nine land uses simulated by this model, the relative order of priority under existing production conditions is as follows: citrus (mature, fruit bearing trees), wheat, rice, berseem, citrus with fodder crop (immature trees), maize, sugarcane, cotton, and fallow. The relative differences among these crops dictate the relative differences in the economic portion of the priority.

The second priority component can be termed the "stress" priority since it is designed to be indicative of the relative impact on yield caused by soil moisture deficiencies greater than an optimum value. In other words, there is a soil moisture depletion below which the crops are not significantly affected because their roots can withdraw water from the soil at nearly the potential rate. Above this value, however, growth and production processes are hindered by the inability of rooting systems to satisfy water and nutrient requirements. At the wilting point, the stress is sufficient to essentially eliminate the plant from the production potential of the field. For the purposes of this model, it is assumed that the stress priority increases linearly with the depletion of moisture beyond the actual or optimal level. Mathematically, the first and second components of priority combine as follows:

$$P_j = 0; \text{ if } SMD < CSMD \tag{51}$$

$$P_j = P'_j + (100 - P'_j) X \left[\frac{SMD - CSMD}{100 - CSMD}\right] \tag{52}$$

in which,

$P_j$ = the irrigation priority of the j th crop;

$P'_j$ = minimum priority at optimal soil moisture depletion, also called the "economic" priority;

SMD = soil moisture depletion expressed as a percentage of the total available root zone water which has been withdrawn by the plant, in %;

CSMD = critical soil moisture depletion beyond which yields are expected to decline rapidly from the maximum due to water and nutrient stress, in %.

The third priority component is the "pre-plant" irrigation priority for the crop. Since this irrigation is in expectation of planting, it is mutually exclusive of the stress priority which would develop once the crop was planted. The pre-plant priority for water is intended to be indicative of farmer preferences in satisfying not only an expected economic return but also such factors as minimum acreages for animals and maintenance of crop rotations. The format of the preplanting priorities is similar to Eqs. 51 and 52 with the exception that the priority must increase as planting opportunity time passes. Mathematically,

$$\bar{P}_j = 0 \qquad T_i < T_j \tag{53}$$

$$P_j = P'_j + \frac{100 - P'_j}{\Delta T_j}\left(T_i - T_i\right) \tag{54}$$

where,

$\bar{P}_j$ = Preplant priority of the j th crop;

$T_i$ = Julian date of present time frame;

$T_j$ = Julian date of planting season's beginning; and

$\Delta T_j$ = duration of planting season, days

In as much as a single crop will have either a stress priority or a preplant priority, including in both cases the economic component, the priority for irrigating fields within the square at any time can be selected directly from comparison of relative priorities.

## IRRIGATION

Water available at the end of the field does not represent water available for storage in the crop root zone. In the Punjab where basin irrigation is used predominantly, a high potential application efficiency is possible if the field is well leveled and the depth of application equals the soil moisture depletion at the time of irrigation. Application efficiency, $E_a$, is the percentage of the flow into the field that is stored within the crop root zone.

Simulation of application efficiency ordinarily requires substantial field data describing the soil's infiltration characteristics, field levelness, and advance or filling times. At this stage of the research, these data are lacking and a simple approach is required. Two boundaries are imposed on water applications. The first is the minimum depth of application (Dmin), that can be achieved under existing irrigation practices and conditions. Similarly, a maximum depth of application (Dmax) is assumed to further restrict the model. Both of these boundary conditions will be part of the management scheme of the model itself.

While it is assumed that applied depths will always range within the limits of the minimums and maximums listed above, a further step must be taken to determine or estimate the actual applications. For these purposes, a series of admittedly simplistic assumptions are made. First, if the soil moisture deficit ranges between Dmin and Dmax, the soil reservoir is assumed to be completely refilled and 20% of the gross application results in deep percolation (Ea = 80%). Application efficiency can be specified at other values by the model user to reflect his judgment if field practices are more or less efficient. To express application efficiency mathematically, some relations between soil moisture variables and irrigation depths must be defined. The total available water per unit depth of soil is:

$$TAW = \frac{FC - PW}{100} \times P_s \qquad (55)$$

in which TAW = available moisture, mm/mm;

FC = soil moisture percentage at field capacity;

$P_s$ = bulk density of the soil, $gm/cm^3$.

The soil moisture depletion per unit depth is thus defined as

$$SMD = \frac{D_p}{TAW} \times 100 \qquad (56)$$

where $D_p$ = depth of water depleted from the unit of soil.

Usually, SMD is expressed over the depth of the root zone rather than at a specific point in the soil. For this case Eq. 56 is integrated over the root zone depth and averaged. If the root depth is represented as a time dependent variable RD (i), then the amount of water that can be stored by an irrigation is the irrigation requirement:

$$IR_i = \frac{TAW \times SMD_i \times RD(i)}{100} \qquad (57)$$

in which $IR_i$ = irrigation requirement on day i cm;

$SMD_i$ = soil moisture depletion on day i, in %, and

RD(i) = root depth on day i, in cm.

Now writing Ea mathematically:

$$Ea = \frac{Dmin}{IR_i \times 100} \quad \text{if } SMD_i < D \qquad (58)$$

$$Ea = 80.0\% \quad \text{if } D \leq SMD_i \leq D \qquad (59)$$

$$Ea = 100\% \quad \text{if } SMD_i > D \qquad (60)$$

It may not be obvious as to how the rainfall has been incorporated in this definition of application efficiency. The model adjusts $SMD_i$ each day to the precipitation received before the water applied through irrigation is added. It is possible that the rain could completely refill the root zone and result in some deep percolation loss as well.

It is necessary to make an adjustment to the application efficiency once irrigations of the various plots have been scheduled. Because the model deals with 25 acres in 50 uniformly sized fields, it does not allow irrigation of partial units. Therefore, the water available for only partial irrigation of a field will be spread back over the completely irrigated fields by adjusting the actual depths of application or application efficiencies. For the case where all fields requiring water have been irrigated and an excess exists, the applied depths are again adjusted. The only limitation in any of these adjustments is that the maximum irrigation depth, Dmax, is not exceeded.

The volume of water applied to each field under these assumptions is as follows: For the case where the $SMD_i < Dmin$, the applied depth would be Dmin. For $Dmin \leq SMD_i \leq Dmax$, the actual applied depth is $SMD_i/E_a$. When $SMD_i > Dmax$, the application depth is defined as equal to Dmax.

The volume of deep percolation from the fields is based on $E_a$ as follows:

$$DP = (1 - E_a)\ AD \tag{61}$$

where

DP = deep percolation in inches; and

AD = actually applied depth, inches.

Rainfalls are handled simply on a mass balance basis as stated above. If the amount exceeds $SMD_i$, the remainder is deep percolation and $SMD_i = 0$. If it is insufficient to raise $SMD_i$ to zero, no deep percolation occurs and $SMD_i$ is simply adjusted by the amount of rainfall.

## PLANTING AND HARVESTING DATES

All of the annual crops grown in the Punjab are planted over periods of several weeks. This planting schedule is affected in a number of ways. Preirrigation is an almost universal practice and consequently, the availability of water for preirrigation and the interval until the soil surface is dry enough to be worked are primary factors dictating the date of a field's planting. Occasionally, a rainfall will delay planting but this can be related directly to the wetness of the soil.

In the irrigation scheduling model, planting and harvest dates will be computationally selected. At the beginning of a crop's planting season, the model will identify available fallow fields, their soil moisture status, and their water demand priority in relation to crops already growing in the square. The individual fields will be irrigated and allowed to dry to a specified level before planting. Since the priority system was detailed in a previous section, two aspects of planting and harvest will be considered here: (1) definition of planting date; and (2) definition of harvest date.

Date of Planting

Consider a field which has just been immediately preirrigated. The moisture in the surface layers is near saturation and obviously prevents planting crops except rice. Drying of the first few centimeters of the soil occurs in three stages. The first stage is a drainage period of two to three days during which time the soil moisture level approaches field capacity. The second stage occurs simultaneously and is a period of wet surface evaporation. The rate of evaporation during this period (called constant rate evaporation) is approximately 90% of $E_{tp}$ and will proceed until 6 to 12 mm have evaporated (12 mm from a clay loam, 6 mm from a sandy soil). Then the third stage, or falling stage, begins. During this period, the evaporation rate varies with the square root of time since the second stage ended (Gardner and Hillel, 1962). Since the first stage of drying is simply a redistribution of the water, it will not affect the planting date and will be omitted from further consideration.

For the purposes of this model, the evaporation from the first 45 cm of the soil is assumed to occur at an average rate of 70% of $E_{tp}$. The date of planting thus occurs when the rate has depleted the soil moisture storage by 15-20%.

Harvest Date

Harvesting dates for the perennial crops like citrus are assumed to be unrelated to their water needs in the overall irrigation scheduling model since their needs exist throughout the year and must be irrigated when their root zones are sufficiently depleted. For fodder, sugarcane, cotton, wheat, rice and maize, however, the harvest dates are important because at that point they become fallow lands waiting for the next planting opportunity. Young citrus with a fodder cover crop will be treated as a fodder field during that season and as citrus during other times. A plot of growing season length versus the time between planting and the beginning of planting season is shown in Fig. 10. All of these curves can be represented by a function of the form:

$$T_g = T'_g - k\Delta T_p \tag{62}$$

in which $T_g$ = maximum growing season, days;

$k$ = slope of the relationship; and

$T_p$ = planting delay, in days.

For the crops shown, the following table summarizes the coefficients in Eq. 62:

| Crop | $T'_g$ | k | Maximum length of $\Delta T_p$ |
|---|---|---|---|
| Cotton | 233 | .54 | 42 |
| Berseem | 151 | 1.02 | 62 |
| Maize | 114 | .60 | 28 |
| Rice | 149 | .60 | 28 |
| Sugarcane | 292 | .60 | 49 |
| Wheat | 181 | .68 | 49 |

The date of harvest, therefore, is the date of planting plus the days determined by Eq. 62.

## MODEL EVALUATION

The irrigation scheduling program was developed and debugged using synthetic data over a one-year period. The evapotranspiration data were developed from the Sargodha climatological information utilized to evaluate the evapotranspiration models discussed earlier. The water supply file was set up to deliver a 35 ha-cm supply to the 50 fields every seven days. The remainder of the input, initial conductors and program control parameters, is summarized in Table 9.

The first version of the program works as intended and reproduces the basic features of the irrigation system. There are, however, several areas for improvement in subsequent versions. The first change that could be suggested is the consolidation of time steps. At present the program sequences through its varied steps on a daily basis. Since the water supply in Pakistan is generally provided on a rotating basis to each square, there is actually no advantage in daily time steps. Average 7-day conditions could be computed and then used in the scheduling process. This suggested improvement would vastly speed up the program's evaluation of a one-year period.

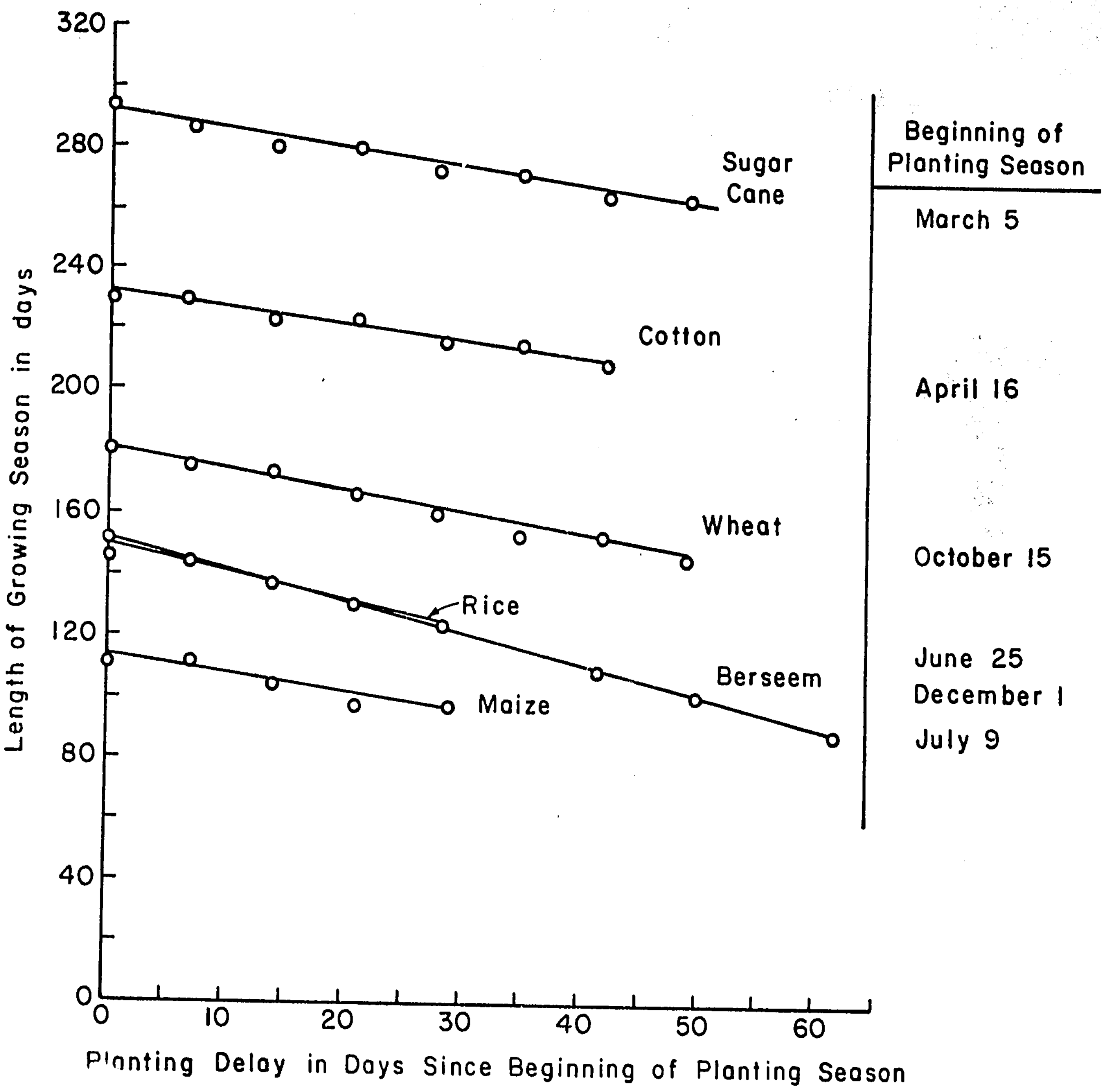


Fig. 10. Length of growing season as influenced by planting delays for selected crops in the Punjab, Pakistan.

Table 9. Definition of Irrigation Scheduling Control Parameters and Initial Conditions for Program Development Efforts.

| r-Variable | Description | Value |
|---|---|---|
| 1 | Max. Irr. Depth, Centimeters... | 15.00 |
| 2 | Min. Irr. Depth, Centimeters... | 5.00 |
| 3 | Econ. Priority:Citrus w/c...... | 25.00 |
| 4 | Citrus wo/c...... | 40.00 |
| 5 | Cotton.......... | 5.00 |
| 6 | Berseem.......... | 20.00 |
| 7 | Maize............ | 15.00 |
| 8 | Rice............. | 30.00 |
| 9 | Sugar Cane....... | 20.00 |
| 10 | Wheat............ | 30.00 |
| 11 | Critical SMD For:Citrus w/c.... | 50.00 |
| 12 | Citrus wo/c.... | 50.00 |
| 13 | Cotton......... | 70.00 |
| 14 | Berseem........ | 60.00 |
| 15 | Maize.......... | 60.00 |
| 16 | Rice........... | 20.00 |
| 17 | Sugar Cane..... | 50.00 |
| 18 | Wheat.......... | 60.00 |
| 19 | Soil Moisture Field Capacity,%. | 19.50 |
| 20 | Soil Moisture Wilting Point,%.. | 7.00 |
| 21 | Max. Acreag of Citrus w/c...... | 0.50 |
| 22 | Citrus wo/c...... | 0.50 |
| 23 | Cotton........... | 2.00 |
| 24 | Berseem.......... | 4.00 |
| 25 | Maize............ | 3.00 |
| 26 | Rice............. | 4.00 |
| 27 | Sugar Cane....... | 3.00 |
| 28 | Wheat............ | 8.00 |
| 29 | No. of Fields in:Citrus w/c.... | 1.00 |
| 30 | Citrus wo/c.... | 1.00 |
| 31 | Cotton......... | 4.00 |
| 32 | Berseem........ | 0.00 |
| 33 | Maize.......... | 6.00 |
| 34 | Rice........... | 8.00 |
| 35 | Sugar Cane..... | 6.00 |
| 36 | Wheat.......... | 0.00 |
| 37 | Fallow......... | 24.00 |

| Field No. | Field by Field Status Crop | Planting Date | SMD |
|---|---|---|---|
| 1 | Citrus w/c | January 1 | 0.10 |
| 2 | Citrus wo/c | January 1 | 0.10 |
| 3 | Cotton | April 16 | 0.10 |
| 4 | Cotton | April 16 | 0.10 |
| 5 | Cotton | April 16 | 0.10 |
| 6 | Cotton | April 16 | 0.10 |
| 7 | Maize | July 9 | 0.10 |
| 8 | Maize | July 9 | 0.10 |
| 9 | Maize | July 9 | 0.10 |
| 10 | Maize | July 9 | 0.10 |
| 11 | Maize | July 9 | 0.10 |
| 12 | Maize | July 9 | 0.10 |
| 13 | Rice | June 25 | 0.10 |
| 14 | Rice | June 25 | 0.10 |
| 15 | Rice | June 25 | 0.10 |
| 16 | Rice | June 25 | 0.10 |
| 17 | Rice | June 25 | 0.10 |
| 18 | Rice | June 25 | 0.10 |
| 19 | Rice | June 25 | 0.10 |
| 20 | Rice | June 25 | 0.10 |
| 21 | Sugar Cane | March 5 | 0.10 |
| 22 | Sugar Cane | March 5 | 0.10 |
| 23 | Sugar Cane | March 5 | 0.10 |
| 24 | Sugar Cane | March 5 | 0.10 |
| 25 | Sugar Cane | March 5 | 0.10 |
| 26 | Sugar Cane | March 5 | 0.10 |
| 27 | Fallow | 0 | 0.10 |
| 28 | Fallow | 0 | 0.10 |
| 29 | Fallow | 0 | 0.10 |
| 30 | Fallow | 0 | 0.10 |
| 31 | Fallow | 0 | 0.10 |
| 32 | Fallow | 0 | 0.1 |
| 33 | Fallow | 0 | 0.10 |
| 34 | Fallow | 0 | 0.10 |
| 35 | Fallow | 0 | 0.10 |
| 36 | Fallow | 0 | 0.10 |
| 37 | Fallow | 0 | 0.10 |
| 38 | Fallow | 0 | 0.10 |
| 39 | Fallow | 0 | 0.10 |
| 40 | Fallow | 0 | 0.10 |
| 41 | Fallow | 0 | 0.10 |
| 42 | Fallow | 0 | 0.10 |
| 43 | Fallow | 0 | 0.10 |
| 44 | Fallow | 0 | 0.10 |
| 45 | Fallow | 0 | 0.10 |
| 46 | Fallow | 0 | 0.10 |
| 47 | Fallow | 0 | 0.10 |
| 48 | Fallow | 0 | 0.10 |
| 49 | Fallow | 0 | 0.10 |
| 50 | Fallow | 0 | 0.10 |

A second possible improvement in the model lies in the simulation of soil drying after a pre-irrigation or rainfall. This process substantially affects planting and harvesting and would create more realistic simulations of those activities if a better soil evaporation equation were substituted in line 84 in the program.

The simulation of irrigation efficiency in lines 96-114 is very simplistic in comparison with the existing state-of-the-art in basin irrigation. As a result, the estimated values of irrigation efficiency and deep percolation are obviously rough and unreliable. These simplifying assumptions were made at the outset of the model development to keep the program within the calculator's core limitations, but could be added as revisions increase the efficiency of the program's storage allocations.

Any model of this scale can generate very valuable information to the irrigation planner and thus should be verified for one or more case studies. If squares along one or more watercourses could be studied intensively as a system, the validity of the model could be demonstrated and the results could yield beneficial information for model improvements.

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# APPENDIX A

## EVAPOTRANSPIRATION SIMULATION MODEL DESCRIPTION

The consumptive use model in this initial version is set up to compute and tabulate tables of $E_t$ values. A simple modification can be made to store the results in arrays which can be loaded as input to other parts of the water management model. A listing of this program is given in Appendix C.

The evapotranspiration model consists of a main program to control the order of input, calculations, and output in conjunction with six special purpose subroutines. The subroutines in brief are as follows:

| Subroutine | Purpose |
|---|---|
| "Date Conversion" | Convert calendar dates to Julian dates and vice versa |
| "Crop" | Calculations of crop growth stage coefficients, $K_{co}$ |
| "Root Depth" | Calculations of crop rooting depths |
| "Penman" | Calculation of potential evapotranspiration using the Penman equation |
| "Jensen-Haise" | Calculation of potential evapotranspiration using the Jensen-Haise equations |

A listing of the entire model (Appendix B) follows more explicit descriptions of these subroutines.

### Description of Date Conversion Subroutine

In order index arrays and maintain the order of time series calculations, time must be referenced as a Julian date rather than a calendar date. Input data describing important dates like planting, harvesting, etc., are more easily entered as calendar dates so a subroutine entitled, "Date Conversion" is provided to make the necessary transitions.

The "Date Conversion" can be appended to any program or subroutine and operated through a calling statement in the user routine. The call statement must have the following format:

call'Date Conversion (A, B, C)

in which the call parameters A, B, and C can be any variable, array element, or number. In the position of A, an output control parameter for the subroutine is defined. Specifying a 1 in the A position either numerically or by parameter will cause either the calendar date or Julian date to be printed on the HP 9825A internal tape printer. The B parameter specifies the direction of date conversion. B=0 is for Julian date to calendar date and B=1 is for calendar date to Julian date. The parameter C must be a variable name representing the day of the month or Julian date. It will enter in one form and emerge as the other in both directions.

Use of the date conversion subroutine also requires dimensioning of a string array, dim D$(10) in the calling program. An example of the use of "Date Conversion" is found in the evapotranspiration model, located in lines 67-98. An example call statement is found at line 12.

Description of Crop Growth Stage Coefficient Subroutine

The relationship between the evapotranspiration of a specific crop under well watered conditions (and well fertilized) and the reference $E_{tp}$ is the crop growth stage coefficient, $K_{co}$. For crops of citrus (with and without a fodder cover under the canopy), cotton, berseem, fodder, maize, rice, sugarcane, and wheat, a subroutine entitled "crop" is developed. It may be used only as a subroutine and supplied data through a call statement as follows:

cll'crop' (A, B, C, D, E, F)

in which,

A = crop code

| | |
|---|---|
| 1 - citrus w/c | 5 - maize |
| 2 - citrus wo/c | 6 - rice |
| 3 - cotton | 7 - sugarcane |
| 4 - berseem | 8 - wheat |

B = number of days since planting

C = variable receiving computed value of $K_{co}$

D = Julian date of planting

E = Julian date of harvest

F = present Julian date

An example of the use of "crop" is given in lines 99-144. The subroutine "crop" is called from line 49 of the main program.

## Description of Root Depth Subroutine

In order to define the reservoir of soil moisture available to the growing crops, it is necessary to estimate the rooting depth. The information is also important in evaluating the stress adjustment to potential evapotranspiration.

For the purpose of this model, the root depth calculations are divided into two main parts. Crops such as berseem, cotton, maize, rice, sugarcane and wheat are assumed to extend their roots in a linear proportion with the lapse time between planting and the time of 90 to 100% of maximum $K_{co}$. Citrus and crops which are perennial maintain a fixed rooting depth. The initial and final rooting depths along with the days to extend the root zone were presented earlier in Tables 2 and 3.

The root depth subroutine is called from line 50 in the main program and executed in line 145 - 204.

## Description of Penman Subroutine

An important method for calculating $E_{tp}$ for an alfalfa reference crop is given in the subroutine "Penman". Use is by appending to main program or another subroutine and executed through a call statement. Data necessary for the calculations can be entered through the call statement or in response to "enter" requests within the program.

The call statement for the Penman subroutine is an extension on and follows the same format as described for previous subroutines.

cll'Penman'(A, B, C, D, E, F, G, H, I, J, K, L, M, N, O)
Parameters A-N are input and control variables defined either numerically or by variable:

A = Operational mode, 0 for external data entry, 1 for internal data definition.

B = Units of calculation, 0 for English, 1 for metric.

C = Output control, 0 for no printout, 1 for intermediate and final results of calculations being output on the HP 9825A tape printer.

D = Soil heat flux computation control, 0 for real time irrigation scheduling computations, 1 for all other cases. This parameter will affect the input or definition of parameters K, L, and M.

E = Maximum temperature of day or average day for calculations involving average $E_{tp}$ for periods longer than one day.

F = Minimum temperature of day or average day.

G = Control format of radiation data, 0 for solar radiation, 1 for fractional sunshine, 2 for sunshine hours.

H = Radiation, angles/day. fraction of possible sunshine per day, or hours of sunshine per day.

I = Wind run, miles/day or km/day.

J = Modified Julian date in which October 1st is Day 1.

K = Average daily temperature for period proceeding period of calculation if D = 1, and average daily temperature for the day three days previous if D = 0.

L = Average daily temperature for period succeeding period of calculation if D = 1, and average daily temperature of the day two days previous if D = 0.

M = Two times the days in the period of calculation for D = 1, and the average of daily temperature of the day previous to the day of calculation if D = 0.

N = Maximum relative humidity in %.

O = Computed value of $E_{tp}$ in inches/day or mm/day supplied back to the calling program.

The Penman subroutine is called from line 46 of the main program and is found in lines 205 - 254.

<u>Description of Jensen-Haise Subroutine</u>

The modified version of the Jensen-Haise equation is programmed in a subroutine format to facilitate its use in various calculations which require an estimate of potential evapotranspiration from the reference crop alfalfa. The subroutine can be appended to another subroutine or main program and executed through a call statement, the value of $E_{tp}$ is computed directly. The second option is to enter necessary information manually by responding to a series of "enter" statements contained in the code.

The call statement must have the following format:

cll'Jensen-Haise'(A, B, C, D, E, F, G, H, I, J)

where the call parameters A-D, and F-H are any numeric or variable defined input data. E is the value of $E_{tp}$ returned from the program. Definitions of the other parameters follow:

A = System of units, 0 for English, 1 for metric.

B = Value of $C_T$ if program is to operate with external input data.

C = Value of $T_x$ if program operates with external input. (Note that both $C_T$ and $T_x$ will be returned by the program if data are entered internally).

D = Value of solar radiation in langleys/day or sunshine as in the hours or fraction of total possible. (External input only)

F = Control for data entry, 0 for data supplied in call statement, 1 for internal data definition.

G = Output control, 0 for no output, 1 for output on HP 9825A tape printer.

H = Value of average daily temperature.

I = Form of radiation, 0 = $R_x$, 1 = S (fraction), 2 = S (hrs.).

J = Modified Julian date, October 1st = Day 1.

If the program is to operate in the manual mode, $C_T$ and $T_x$ will be calculated, thereby requiring that maximum and minimum temperatures for the hottest month of the season and the site elevation be known. An example of the utilization of the Jensen-Haise routine can be found at program at line 48. The subroutine itself is in lines 255-287.

# APPENDIX B

## COMPUTER LISTING OF EVAPOTRANSPIRATION MODEL

```
0: "Program For Calculating Et For Field Crops In Pakistan":
1: dim A$[365,19],D$[10]
2: ent "Tape Track of Data File?",A;trk A
3: ent "Climatic Data File?",A;ldf A,A$
4: ent "Year of Data?",r19
5: ent "radiation form? 0=Rs,1=S(frac),2=S(hrs)",r31
6: ent "Etp by Penman(0) or Jensen-Haise(1)?",A
7: if A=1;ent "Jensen-Haise CT(karif)?",r24,"Jensen-Haise Tx(karif)?",r25
8: if A=1;ent "Jensen Haise CT(rabi)?",Z,"Jensen-Haise Tx(rabi)?",Y
9: ent "Number of Crops To Be Output?",r20
10: for M=1 to r20
11: ent "Crop Code?",r1;ent "Planting Date,Month?",D$,"Day?",r2
12: cll 'DATE CONVERSION'(0,1,r2)
13: ent "Harvest Date, Month?",D$,"Day?",r3
14: cll 'DATE CONVERSION'(0,1,r3)
15: r3)r4;if r3<r2;r3+365)r4
16: ent "Table Number?",B
17: ent "Output Frequency in Days?",L
18: fmt 9,15x,"Table ",f2.0,".  Estimated Et during ",f4.0," for ",c10
19: if r1=1;"Citrus w/c")D$
20: if r1=2;"Citrus woc")D$
21: if r1=3;"Cotton     ")D$
22: if r1=4;"Berseem    ")D$
23: if r1=5;"Maize      ")D$
24: if r1=6;"Rice       ")D$
25: if r1=7;"Sugar Cane")D$
26: if r1=8;"Wheat      ")D$
27: wrt 6.9,B,r19,D$;wrt 6;wrt 6
28: fmt 2,17x,"Days",7x,"Root",4x,"Kco",6x,"Etp",8x,"Actual",5x,"Cumulative"
29: fmt 3,16x,"Since",6x,"Depth",11x,"(mm/day)",7x,"Et",7x,"Et To Date"
30: fmt 4,15x,"Planting",5x,"(cm)",23x,"(mm/day)",7x,"(mm)"
31: fmt 5,15x,"-------------------------------------------------------------"
32: wrt 6.2;wrt 6.3;wrt 6.4;wrt 6.5;wrt 6
33: fmt 6,16x,f4.0,7x,f4.0,5x,f4.2,5x,f4.1,8x,f4.1,7x,f6.1
34: 0)U)V)W
35: for I=r2 to r4
36: I-273)N;if N<=0;365+N)N
37: val(A$[N,4,6])/10)B;val(A$[N,7,9])/10)C;val(A$[N,10,12])/10)D
38: val(A$[N,13,15])/10)E;val(A$[N,16,17])*.1609)F;if r31=0;10*B)B
39: if A=1;jmp 8
40: if N-3<=0;(C+D)/2)G;jmp 2
41: (val(A$[N-3,7,9])+val(A$[N-3,10,12]))/20)G
42: if N-2<=0;(C+D)/2)H;jmp 2
43: (val(A$[N-2,7,9])+val(A$[N-2,10,12]))/20)H
44: if N-1<=0;(C+D)/2)J;jmp 2
45: (val(A$[N-1,7,9])+val(A$[N-1,10,12]))/20)J
```

```
46: r31)r32;cll 'Penman'(0,1,0,0,C,D,r32,B,F,N,G,H,J,E,T);jmp 3
47: 7)r26;Y)r27;if N)=274;r24)r26;r25)r27
48: r31)r32;cll 'Jensen-Haise'(1,r26,r27,B,T,0,0,(C+D)/2,r32,N)
49: cll 'crop'(r1,I-r2,K,r2,r3,I);T*K)R
50: cll 'ROOT DEPTH'(r1,I-r2,r2,1,S)
51: U+R)U
52: if W=0;wrt 6.6,I-r2,S,K,T,R,U;1)W
53: if V=L;wrt 6.6,I-r2,S,K,T,R,U;0)V
54: if I=r4;wrt 6.6,I-r2,S,K,T,R,U
55: 1+V)V;next I
56: wrt 6.5;wrt 6
57: if A=0;wrt 6,"              Calcul. Use Penman Etp and Assume:"
58: if A=1;wrt 6,"              Calcul. Use Jensen-Haise Etp and Assume:"
59: cll 'DATE CONVERSION'(0,0,r2)
60: fmt 8,17x,"Planting Date of ",c10,f3.0
61: wrt 6.8,D$,r2
62: cll 'DATE CONVERSION'(0,0,r3)
63: fmt 8,19x,"Harvest Date of ",c10,f3.0
64: wrt 6.8,D$,r3
65: next M
66: end
67: "DATE CONVERSION":
68: if p2=0;gto "TO REGULAR"
69: if cap(D$)="JANUARY";p3)p3
70: if cap(D$)="FEBRUARY";p3+31)p3
71: if cap(D$)="MARCH";p3+59)p3
72: if cap(D$)="APRIL";p3+90)p3
73: if cap(D$)="MAY";p3+120)p3
74: if cap(D$)="JUNE";p3+151)p3
75: if cap(D$)="JULY";p3+181)p3
76: if cap(D$)="AUGUST";p3+212)p3
77: if cap(D$)="SEPTEMBER";p3+243)p3
78: if cap(D$)="OCTOBER";p3+273)p3
79: if cap(D$)="NOVEMBER";p3+304)p3
80: if cap(D$)="DECEMBER";p3+334)p3
81: if p1=1;prt "Julian Date =",p3
82: ret
83: "TO REGULAR":
84: if p3<=31;"January")D$;p3)p3;gto "RET"
85: if p3<=59;"February")D$;p3-31)p3;gto "RET"
86: if p3<=90;"March")D$;p3-59)p3;gto "RET"
87: if p3<=120;"April")D$;p3-90)p3;gto "RET"
88: if p3<=151;"May")D$;p3-120)p3;gto "RET"
89: if p3<=181;"June")D$;p3-151)p3;gto "RET"
90: if p3<=212;"July")D$;p3-181)p3;gto "RET"
91: if p3<=243;"August")D$;p3-212)p3;gto "RET"
92: if p3<=273;"September")D$;p3-243)p3;gto "RET"
93: if p3<=304;"October")D$;p3-273)p3;gto "RET"
94: if p3<=334;"November")D$;p3-304)p3;gto "RET"
95: if p3<=365;"December")D$;p3-334)p3
96: "RET":
97: if p1=1;prt D$,p3
98: ret
```

```
99: "crop":
100: "This Subroutine Must Be Supplied The Following In The Call Statement":
101: " 1   crop code":
102: " 2.  days since planting":
103: " 3.  Variable for Recieving Kco":
104: " 4.  Julian Date of Planting":
105: " 5.  Julian Date of Harvest":
106: " 6.  Present Julian Date":
107: p5)p13;if p13(p4;365+p13)p13
108: if p2(0;0)p3;ret
109: if p2)p13-p4;0)p3;ret
110: if p1=1;gto "berseem"
111: if p1=2;gto "citrus wo/c"
112: if p1=3;gto "cotton"
113: if p1=4;gto "berseem"
114: if p1=5;gto "maize"
115: if p1=6;gto "rice"
116: if p1=7;gto "sugar cane"
117: if p1=8;gto "wheat"
118: "citrus wo/c":
119: .75*exp(-((p6-180)/400)^2)p3;ret
120: "cotton":
121: if p2(=42;.2+.00238*p2)p3;ret
122: if p2(98;6.9462e-2+p2(1.94799e-2+p2(-3.20859e-4+2.2544e-6*p2)))p3;ret
123: if p2)140;6.304e-5+p2(2.17174e-2+p2(-1.1893e-4+1.37862e-7*p2)))p3;ret
124: 2.37505e-5+p2(-3.903237e-3+p2(2.400357e-4-1.128125e-6*p2)))p3;ret
125: "berseem":
126: .9)p3;ret
127: "maize":
128: if p2(=42;.34+5.2551e-3*p2+2.551e-4*p2p2)p3;ret
129: if p2(=56;.7+.00714286*p2)p3;ret
130: if p13-p6)=42;1.1)p3;ret
131: 42-p13+p4+p2)p7
132: 1.1093+p7(-9.02393e-3-7.393548e-5*p7))p3;ret
133: "rice":
134: 2exp(-((77-p2)/80)^2))p3;ret
135: "sugar cane":
136: 133+(p4-69)/2.33)p7;120-(p4-69)/2.45)p8;p6-69)p9
137: if p9(154;1.05*exp(-((p9-p7)/p8)^2))p3;ret
138: 1.05*exp(-((p9-p7)/175)^2))p3;ret
139: "wheat":
140: 1-(p4-288)/980)p7;105+(p4-288)/3.5+.01)p8;80-(p4-288)/1.81)p9
141: 100-(p4-288)/2.45)p10;p6)p11;if p11(p4;p11+365)p11
142: p11-288)p12
143: if p12(p8;p7*exp(-((p8-p12)/p9)^3))p3;ret
144: p7*exp(-((p12-p8)/p10)^2))p3;ret
145: "ROOT DEPTH":
146: "This Subroutine Must Be Supplied The Followng":
147: "Information In The Call Statement":
148: "  1. Crop Code,p1":
149: "  2. Days Since Planting,p2":
150: "  3. Planting Date,p3":
151: "  4. System of Units,0=English;1=Metric":
152: "":
153: "Root Depth in centimeters or inches":
154: "Will Be Transfered Back As p5":
```

```
155: "":
156: if p1=1;gto "BERSEEM"
157: if p1=2;gto "CITRUS W/C"
158: if p1=3;gto "COTTON"
159: if p1=4;gto "BERSEEM"
160: if p1=5;gto "MAIZE"
161: if p1=6;gto "RICE"
162: if p1=7;gto "SUGAR CANE"
163: if p1=8;gto "WHEAT"
164: "CITRUS W/C":
165: 150}p5
166: if p4=0;p5/2.54}p5
167: ret
168: "COTTON":
169: if p2<=120;jmp 3
170: 180}p5;if p4=0;p5/2.54}p5
171: ret
172: p2/120*165+15}p5;if p4=0;p5/2.54}p5
173: ret
174: "BERSEEM":
175: if p2<30;jmp 3
176: p2/30*105+15}p5;if p4=0;p5/2.54}p5
177: ret
178: 120}p5;if p4=0;p5/2.54}p5
179: ret
180: "MAIZE":
181: if p2<=60;jmp 3
182: 120}p5;if p4=0;p5/2.54}p5
183: ret
184: p2/60*105+15}p5;if p4=0;p5/2.54}p5
185: ret
186: "RICE":
187: if p2<=70;jmp 3
188: 90}p5;if p4=0;p5/2.54}p5
189: ret
190: p2/70*75+15}p5;if p4=0;p5/2.54}p5
191: ret
192: "SUGAR CANE":
193: if p2<=130;jmp 3
194: 90}p5;if p4=0;p5/2.54}p5
195: ret
196: p2/130*75+15}p5;if p4=0;p5/2.54}p5
197: ret
198: "WHEAT":
199: 35 [illegible] 280)/1.76}p6
200: if p2<=p6;jmp 3
201: 120}p5;if p4=0;p5/2.54}p5
202: ret
203: p2/p6*105+15}p5;if p4=0;p5/2.54}p5
204: ret
205: "Penman":
206: if p1=0;gto "strt"
207: ent "units? 0=english,1=metric",p2
208: ent "print? 0=no,1=yes",p3
209: ent "time interval? 0=dailey,1=longer",p4
```

```
ent "Tmax?",p5,"Tmin?",p6
ent "radiation form? 0=Rs,1=S(frac),2=S(hrs)",p7
ent "radiation in approp. units",p8
ent "wind movement (miles or km)?",p9
ent "modified julian date?",p10
if p4=0;ent "T-3",p11,"T-2",p12,"T-1",p13;jmp 2
ent "T+1?",p11,"T-1?",p12,"delta T?",p13
ent "relative humidity?",p14
"strt":
if p7=2;cll 'Fractional Sunshine'(p8,p10);1)p7
if p2=1;p5*9/5+32)p5;p6*9/5+32)p6;p11*9/5+32)p11
if p2=1;p12*9/5+32)p12;p13*9/5+32)p13;p9/1.609)p9
if p4#0;if p2=0;(p11-32)5/9)p11;(p12-32)5/9)p12
if p4=0;5((p11+p12+p13)/3-(p5+p6)/2))p10;jmp 2
100(p12-p11)/p13)p18
if p3=1;prt "soil heat flux,langleys,=",p18
(p5+p6)/2)p19;.959-.0125p19+.00004534p19^2)p19;1-p19)p20
if p3=1;prt "C1=",p20,"C2=",p19
-.6959+.2946p5-.005195p5p5+89/tn^6*p5p5p5)p21
-.6959+.2946p6-.005195p6p6+89/tn^6*p6p6p6)p22
(p21+p22)/2-p14p22/100)p21;if p3=1;prt "vapor pressure deficiet=",p21
(p5-32)5/9+273)p22;(p6-32)5/9+273)p23
-7.77/tn^4*(273-(p22+p23)/2)^2)p24
(-.02+.261exp(p24))*11.71/tn^8*((p22+p23)/2)^4)p24
if p3=1;prt "Clear Day Rb=",p24
p10+273)p30;if p30)365;p30-365)p30
785exp(-((p30-166)/180)^2))p25
if p3=1;prt "Clear Day Rs=",p25
if p7=0;p24(1.2p8/p25-.2))p26
if p7=1;(.35+.61*p8)p25)p8;p24(1.2p8/p25-.2))p26
if p3=1;prt "Rb=",p26
.77p8-p26)p8
"pone":
if p3=1;prt "net radiation,Rn,=",p8
p20(p8+p18)+p19*15.36(.9+.011p9)p21)p27
if p2=0;.000673p27)p15;if p3=1;prt "Etp,inches,=",p15
if p2=1;.0171p27)p15;if p3=1;prt "Etp,millimeters,=",p15
ret
"Fractional Sunshine":
rad;2*π/365)p8
.40927971*sin(p8p2-2.960846357))p4
31p8)p5
acs(-tan(p5)tan(p4)))p6
.133333p6/p8)p7
p1/p7)p1;ret
"Jensen-Haise":
if p9#2;jmp 4
p10+273)p30;if p30)365;p30-365)p30
cll 'Fractional Sunshine'(p4,p10);785exp(-((p30-166)/180)^2))p25
(.35+.61p4)p25)p4;jmp 5
```

```
260: if p7≠1;jmp 4
261: p10+273→p30;if p30>365;p30-365→p30
262: 785exp(-((p30-166)/100)^2)→p25
263: (.35+.61p4)p25→p4
264: fxd 5
265: if p6≠1;gto "four"
266: ent "mean max temp for hotest month?",p9
267: ent "mean min temp for hotest month?",p10
268: ent "elevation of site?",p11
269: if p1≠0;9p9/5+32→p9;9p10/5+32→p10
270: if p1=0;.3048p11→p11
271: -.6959+.2946*p9-.005195*p9p9+89/tn^6*p9p9p9→p12
272: -.6959+.2946p10-.005195p10p10+89/tn^6*p10p10p10→p13
273: 50/(p12-p13)→p14
274: 7.6→p15
275: 38-p11/305*2→p16
276: 1/(p15+p16p14)→p2;if p7=1;prt "CT=",p2
277: -2.5-.14*(p12-p13)-p11/550→p3
278: if p7=1;prt "TX=",p3
279: ent "solar radiation?",p4
280: ent "temperature?",p8;if p1=0;(p8-32)5/9→p8
281: "four":
282: if p6≠1;if p1=0;(p8-32)5/9→p8
283: p2*(p8-p3)*p4→p5
284: if p1=0;.000673p5→p5;if p7=1;prt "Etp=",p5,"inches"
285: if p1≠0;.0171*p5→p5;if p7=1;prt "Etp=",p5,"millimeters"
286: fxd 2
287: ret
*25809
```

# APPENDIX C

## $E_{tp}$ DATA PREPARATION PROGRAM LISTING

```
0: "Program for Calculating Etp In Pakistan":
1: dim A$[365,19],D$[10],T$[365,9]
2: ent "Tape Track of Data File?",A;trk A
3: ent "Climatic Data File?",A;ldf A,A$
4: ent "radiation form? 0=Rs,1=S(frac),2=S(hrs)",r31
5: ent "Etp by Penman(0) or Jensen-Haise(1)?",A
6: if A=1;ent "Jensen-Haise CT(karif)?",r24,"Jensen-Haise Tx(karif)?",r25
7: if A=1;ent "Jensen-Haise CT(rabi)?",Z,"Jensen-Haise Tx(rabi)?",Y
8: for I=274 to 638
9: I-273)N;if N(=0;365+N)N
10: val(A$[N,4,6])/10)B;val(A$[N,7,9])/10)C;val(A$[N,10,12])/10)D
11: val(A$[N,13,15])/10)E;val(A$[N,16,17])*.1609)F;if r31=0;10*B)B
12: if A=1;jmp 8
13: if N-3(=0;(C+D)/2)G;jmp 2
14: (val(A$[N-3,7,9])+val(A$[N-3,10,12]))/20)G
15: if N-2(=0;(C+D)/2)H;jmp 2
16: (val(A$[N-2,7,9])+val(A$[N-2,10,12]))/20)H
17: if N-1(=0;(C+D)/2)J;jmp 2
18: (val(A$[N-1,7,9])+val(A$[N-1,10,12]))/20)J
19: r31)r32;cll 'Penman'(0,1,0,0,C,D,r32,B,F,N,G,H,J,E,T);jmp 3
20: Z)r26;Y)r27;if N)=274;r24)r26;r25)r27
21: r31)r32;cll 'Jensen-Haise'(1,r26,r27,B,T,0,0,(C+D)/2,r32,N)
22: A$[N,1,3])T$[N,1,3];str(T))T$[N,4,9]
23: next I
24: ent "Track of New Etp File?",A;trk A;ent "Number of New Etp File?",B
25: dsp "Is File Marked,If Yes Press cont";stp
26: rcf B,T$
27: end
28: "Penman":
29: if p7=2;cll 'Fractional Sunshine'(p8,p10);1)p7
30: if p2=1;p5*9/5+32)p5;p6*9/5+32)p6;p11*9/5+32)p11
31: if p2=1;p12*9/5+32)p12;p13*9/5+32)p13;p9/1.609)p9
32: if p4#0;if p2=0;(p11-32)5/9)p11;(p12-32)5/9)p12
33: if p4=0;5((p11+p12+p13)/3-(p5+p6)/2))p18;jmp 2
34: 100(p12-p11)/p13)p18
35: (p5+p6)/2)p19;.959-.0125p19+.00004534p19^2)p19;1-p19)p20
36: -.6959+.2946p5-.005195p5p5+89/tn^6*p5p5p5)p21
37: -.6959+.2946p6-.005195p6p6+89/tn^6*p6p6p6)p22
38: (p21+p22)/2-p14p22/100)p21
39: (p5-32)5/9+273)p22;(p6-32)5/9+273)p23
40: -7.77/tn^4*(273-(p22+p23)/2)^2)p24
41: (-.02+.261exp(p24))*11.71/tn^8*((p22+p23)/2)^4)p24
42: p10+273)p30;if p30)365;p30-365)p30
43: 785exp(-((p30-166)/180)^2))p25
44: if p7=0;p24(1.2p8/p25-.2))p26
45: if p7=1;(.35+.61*p8)p25)p8;p24(1.2p8/p25-.2))p26
46: .77p8-p26)p8
```

```
47: p20(p3+p15)[illegible] 011(p9)p21)p2[illegible]
48: if p2<[illegible].0008[illegible]p27)p15
49: if p2 1: 017(p27)p15
50: ret
51: "Fractional Sunshine"
52: rad;2[illegible] 365)p8
53: .409[illegible]sin(p8p2[illegible]0084[illegible])p4
54: 3(p8)p5
55: acs( tan(p5)tan(p4)))p6
56: 133.33p5/p6)p7
57: p1/p7)p1;ret
58: "Jensen Haise"
59: if p9[illegible], jmp 4
60: p10+[illegible]p30,if p30[illegible]p30 365)p30
61: cll 'Fractional Sunshine'(p4,p10):78exp( ((p30 166)/180)[illegible])p25
62: ( 35+.61p4)p25)p4; jmp 5
63: if p9#1; jmp 4
64: p10+2[illegible]p30,if p30>365;p30 365)p30
65: 78exp( ((p30 166)/180)[illegible])p25
66: ( 35+.61p4)p25)p4
67: fxd 5
68: if p11[illegible]p9[illegible]p9;9p10[illegible]p10
69: if p1<0 .3048p11)p11
70: [illegible]
71: [illegible]p10p10p10)p13
72: 50/(p12 p13))p14
73: [illegible]p15
74: [illegible] p1[illegible]p16
75: [illegible]p16[illegible]p2
76: [illegible] 144(p1[illegible])p1
77: if p6#1,if p1<0,(p8 [illegible])p8
78: p2#(p8 p[illegible])p2
79: if p1<0, 00[illegible]p2
80: if p1#1, 01/1#p[illegible]p2
81: fxd 2
82: ret
[illegible]
```

# APPENDIX D

# DESCRIPTION OF IRRIGATION SCHEDULING CODE

## Description of Main Program

Much of the main program's role in the irrigation scheduling model has been discussed in the body of this report. Of interest in this appendix is the operational aspects of the code.

Nearly all of the input to the irrigation scheduling model must come from pre-recorded tape files. Consequently, the first program lines deal with the problem structure. The user is initially asked if these files already exist (line 19, Appendix E), and where they are or are to be located (lines 21 and 23). If these files need to be set up, a subroutine entitled, "Initial Conditions" (lines 191-235, Appendix F) is called (from line 34, Appendix E). This subroutine will be discussed separately. Then an output option for the initial conditions and control parameters is presented and executed. The subroutine for outputing this information is entitled, "Output of Initial Conditions" (lines 259-276, Appendix F).

Input describing the potential evapotranspiration values on a daily basis are generated by the program listed in Appendix C and stored in a string array along with daily values of precipitation and wind. This array is labeled T${365,9} and only utilized in lines 69 and 70. The water supply data is also pre-recorded as an array W{ }. These two files must be user identified in lines 41 and 43.

The remaining piece of information before the execution of the irrigation scheduling model is the definition of output frequency. This is simply a parameter designed to control the number of days between the printouts of intermediate results and can be any value from 1 to 365.

The main program is supported by two separate files containing subroutines. The first file contains the following subroutines: (1) "Initial Conditions"; and (2) "Output of Initial Conditions". The second file contains subroutines: (1) "Irrigation Priority"; (2) "Crop"; and (3) "Root Depth". In addition, the main program file also contains subroutines: (1) "Date Conversion", (2) "Intermediate Results"; and (3) "Harvest Dates". Since some of these subroutines have been discussed previously, the following section will be abbreviated.

## Description of Subroutine "Intermediate Results"

As the program progresses from day to day in its simulation, the status of the irrigation system will be periodically printed according to the interval selected by the user. This subroutine (found between lines 149 and 167, Appendix E), is called from line 67 of the main program but does not pass any data through the call statement. Thus, no special considerations for using this subroutine need be made because it was data files from the main program. A series of p-variables are used as counters but do not affect parameter values in the main program.

Description of Subroutine "Harvest Date"

Once a crop is planted, the model requires a date of harvest. The subroutine, "Harvest Dates" is called at the beginning of the simulation from line 68 of the main program. Thereafter, the subroutine is called only from line 94 when initiated by a crop planting. "Harvest Dates" is found in lines 168 to 190 of Appendix E.

Description of Subroutine "Initial Conditions"

The fact that any modeling exercise must begin at some point in time requires that both the initial conditions of the system and the parameters controlling its simulation must be specified prior to the first execution. A subroutine entitled, "Initial Conditions" is provided to define this phase of the input when the user is either just setting up a study or when real conditions are not known and the model is to be cycled through a reason to generate "initial conditions". An option to output the values entered as data through this subroutine or to print them at some other time is provided by a subroutine "Output of Initial Conditions" which will be included in this discussion as well.

The data entered through this subroutine is divided into two parts. The first is a series of 37 r-variables which are the irrigation scheduling control parameters. A summary of the r-variable functions is given in Table 9. Once entered, the r-variables should be recorded on tape by marking a file of 320 bytes and recording the data by executing rcfi, r37. Once on a tape file, parameter changes are easily accomplished by loading the file (ldfi, r37), making the desired modification and then re-recording the array.

The second part of the data consists of three pieces of information recorded for each of the 50 fields. These data are stored in a string array I$(50,11) to minimize core requirements. In columns one and two is the crop code for that field. In columns 3-6 are the Julian dates of planting for each field. At the beginning of this model use, these data are arbitrarily set at the date of the opening of the planting season. The remaining columns, 7-11, are reserved for the average soil moisture depletion in each field. At the beginning, each field is arbitrarily defined as having 90% of the field capacity moisture level within the profile.

Should a user start with known conditions, a small program could be written to enter actual values of initial soil moisture depletion. A data file marked for 700 bytes must be marked for the I$ array. Note that both the r-variable array and the I$ array must be loaded onto tape files manually at the completion of the execution of "Initial Conditions".

It will be noted that r0 is not defined in Table 9. This variable is set aside as an output control parameter for the optional printing of the initial conditions. Since the I$ array and the r-variable arrays will also function and be updated during execution of the irrigation scheduling submodel, the r0 parameter can be periodically defined so that the output will occur at other desired times. This feature will allow the user to periodically check the progress of the program and evaluate what the model is predicting. Any time r0 is set equal to 1, the subroutine "Output of Initial Conditions" will be loaded from files and executed.

Description of Subroutine "Irrigation Priority"

The "Irrigation Priority" subroutine found in lines 191 and 253 of Appendix G is called from line 97 of the main program to identify the relative importance of each field for receiving a portion of the available irrigation supply. Priorities are calculated for 50 planted and fallow fields according to formulas described in the body of the text.

The "Irrigation Priority" subroutine has a special function which deserves mention here. The string array I$ contains, as mentioned earlier, the crop code of each field, the soil moisture depletion, and the planting date. When a field is pre-irrigated in preparation for a planting, it is necessary to distinguish this field from other fallow fields between the pre-irrigation date and the actual planting date. This is accomplished with an array F(50) representing the transitional status of each of the pre-irrigated fallow fields. A field which has been pre-irrigated is assigned an F-value equal to the crop code of the expected crop while the crop code listed in the I$ array continues to indicate a fallow field. By comparing the corresponding F and I$ values on a field by field basis, the pre-irrigated fields are distinguished. When this soil is dry enough for planting, the I$ designation is equated to the field's F value.

This subroutine also maintains the integrity of constraints placed on the maximum acreage that can be planted to any individual crop by giving irrigation priorities zero values for fallow fields in excess of this limit.

# APPENDIX E

## LISTING OF MAIN IRRIGATION SCHEDULING PROGRAM

```
0: "Punjab Irrigation Scheduling Program":
1: dim D$[10],T$[365,9],I$[50,11],P[50],F[50],S[50],H[50],W[365],A[9],B[9]
2: dim H$[9,11],N$[37,31]
3: for J=1 to 9
4: if J=1;"Citrus w/c ")H$[J]
5: if J=2;"Citrus wo/c")H$[J]
6: if J=3;"Cotton     ")H$[J]
7: if J=4;"Berseem    ")H$[J]
8: if J=5;"Maize      ")H$[J]
9: if J=6;"Rice       ")H$[J]
10: if J=7;"Sugar Cane ")H$[J]
11: if J=8;"Wheat      ")H$[J]
12: if J=9;"Fallow     ")H$[J]
13: next J
14: prt "This program is started on Oct 1and runs 365    days."
15: spc ;spc
16: prt "You will need tospecify control parameters, init-ial conditions"
17: prt ",and output opt-ions."
18: spc ;spc
19: prt "Do you need to  set up files forthese variables,yes or no?"
20: spc ;spc ;ent D$
21: prt "Which trk 1 filefor the control parameters?";spc ;spc
22: ent r38
23: prt "Which file  for initial condi-  tions?";spc ;spc ;ent r39
24: fxd 0
25: prt "Mark file ",r38
26: prt "for 300 bytes"
27: prt "Mark file ",r39
28: prt "for 660 bytes"
29: prt "if you already  haven't.";fxd 2
30: spc ;spc ;1)M
31: prt "Press CONTINUE  when completed.";stp
32: spc ;spc ;if cap(D$)#"YES";trk 1;ldf r38,r1,r37;ldf r39,I$
33: trk 0;if cap(D$)="YES";0)M;ldf 2,191,34
34: if cap(D$)="YES";cll 'Initial Conditions'
35: prt "Do you wish to  output initial  conditions and  "
36: prt "control param.  yes or no?";ent D$
37: if cap(D$)="YES";if M=1;ldf 2,191,38
38: if cap(D$)="YES";cll 'Output of Initial Conditions';spc ;spc
39: prt "At what interval,in days, shouldintermediate    results be out-"
40: prt "put?";ent r40;spc ;spc
41: prt "Which File Has  Etp&Prec Data?";ent r41
42: spc ;spc
43: prt "Which File Has  Water Supply    Data?";ent r42
44: fmt 1,40x,"Punjab Irrigation Scheduling Subprogram"
45: wrt 701.1
```

```
46: fmt 1,45x,"Output of Intermediate Results"
47: wrt 701.1;wrt 701;wrt 701
48: fmt 1,"     Date        Ltp to     Prec to     Crop        Number",z
49: fmt 2,"      Et to     Deep Perc    Status of Field Soil Moisture",z
50: fmt 3," Depletion"
51: wrt 701.1;wrt 701.2;wrt 701.3
52: fmt 1,16x,"Date",6x,"Date",19x,"of",7x,"Date",6x,"to Date",13x,"No.",z
53: fmt 2," of Fields in Range of"
54: wrt 701.1;wrt 701.2
55: fmt 1,16x,"(cm)",6x,"(cm)",17x,"Fields",5x,"ha-cm",6x,"ha-cm",8x,z
56: fmt 2,"0-25%     25-50%    50-75%    75-100%"
57: wrt 701.1;wrt 701.2
58: fmt 1,"----------------------------------------------------------------",z
59: fmt 2,"----------------------------------------------------------------"
60: wrt 701.1;wrt 701.2
61: trk 1;ldf r41,T$;ldf r42,W[*]
62: trk 0;ldf 4,191,63
63: (r19-r20)*.0145)r64;r40)r51
64: for I=1 to 50;val(I$[I,1,2]))F[I];next I
65: for L=274 to 633
66: L)r55;if L)365;L-365)r55
67: if r51=r40;cll 'Intermediate Results';0)r51
68: if L=274;cll 'Harvest Dates'
69: L-273)N;val(T$[N,4,9])/10)Z;r66+Z)r66
70: val(T$[N,1,3])/100)Y;r67+Y)r67;0)U
71: for M=1 to 50;0)O
72: val(I$[M,1,2]))J;val(I$[M,7,11]))r63;val(I$[M,3,6]))V
73: if J=0 or J=9;45)r52;r52(1-r63)r64)S[M];jmp 11
74: H[M])X;if V)H[M];365+X)X
75: if V(H[M] and L)365;365+X)X
76: if L)=X;str(9))I$[M,1,2];1+r37)r37;r(J+28)-1)r(J+28);jmp -4
77: L)X;if L)365;r55)X
78: cll 'ROOT DEPTH'(J,L-V,V,1,r52);(1-r63)r64r52)S[M]
79: cll 'crop'(J,L-V,r57,V,H[M],r55);if r63)=1;1)r63
80: log(1+100(1-r63))/log(101))r58
81: .8-16r63)r59;if r59(=0;0)r59
82: if r57r58)=.9;0)r59
83: r59(.9-r57r58)*Z)r60;Z*r57r58+r60)r62;jmp 2
84: .7Z)r62;if J=0;F[M])J;1)O
85: S[M]-r62+Y)S[M];if S[M](=0;r62+S[M])r62;0)S[M]
86: fxd 2;1-S[M]/r64r52)r63;r62*.202343+A[J])A[J]
87: if r63(=0;-r63r64r52*.202343+B[J])B[J];0)r63
88: str(r63))I$[M,7,11];if O=1;0)J
89: if J#0;jmp 4
90: fxd 0;if r63).16;str(r55))I$[M,3,6];1)U;str(F[M]))I$[M,1,2]
91: if U=1;r37-1)r37
92: if U=1;1+r(F[M]+28))r(F[M]+28)
93: next M
94: if U=1;cll 'Harvest Dates'
95: 1+r51)r51
96: if W[N](=0;gto "Point 1"
```

```
97: cll 'Irrigation Priority'
98: if W[N]<=0;gto "Point 1"
99: 0)J)K
100: for M=1 to 50
101: if P[M]>K;M)J
102: next M
103: if J=0;gto "Point 1"
104: val(I$[J,7,11])r65;0)P[J];r1)Q;if r65>=1;.9999)r65
105: S[J]/(1-r65)-S[J])K;if W[N]<.202343K;W[N]/.202343)Q
106: if K<=r2;K/r2)E;str(0))I$[J,7,11];r2-K)D;jmp 3
107: if K>r2;if K<=Q;K/Q)E;str(0))I$[J,7,11];Q-K)D;jmp 2
108: fxd 2;if K>Q;1)L;1-(S[J]+Q)/(S[J]+K))r63;str(r63))I$[J,7,11];0)D
109: val(I$[J,1,2]))X;D*.202343+B[X])B[X]
110: if D=0;W[N]-Q*.202343)W[N]
111: if D#0;W[N]-D/(1-E)*.202343)W[N]
112: if val(I$[J,1,2])=F[J];jmp -14
113: fxd 0;str(0))I$[J,1,2];jmp -15
114: "Point 1":
115: next L
116: end
117: "DATE CONVERSION":
118: if p2=0;gto "TO REGULAR"
119: if cap(D$)="JANUARY";p3)p3
120: if cap(D$)="FEBRUARY";p3+31)p3
121: if cap(D$)="MARCH";p3+59)p3
122: if cap(D$)="APRIL";p3+90)p3
123: if cap(D$)="MAY";p3+120)p3
124: if cap(D$)="JUNE";p3+151)p3
125: if cap(D$)="JULY";p3+181)p3
126: if cap(D$)="AUGUST";p3+212)p3
127: if cap(D$)="SEPTEMBER";p3+243)p3
128: if cap(D$)="OCTOBER";p3+273)p3
129: if cap(D$)="NOVEMBER";p3+304)p3
130: if cap(D$)="DECEMBER";p3+334)p3
131: if p1=1;prt "Julian Date =",p3
132: ret
133: "TO REGULAR":
134: if p3<=31;"January")D$;p3)p3;gto "RET"
135: if p3<=59;"February")D$;p3-31)p3;gto "RET"
136: if p3<=90;"March")D$;p3-59)p3;gto "RET"
137: if p3<=120;"April")D$;p3-90)p3;gto "RET"
138: if p3<=151;"May")D$;p3-120)p3;gto "RET"
139: if p3<=181;"June")D$;p3-151)p3;gto "RET"
140: if p3<=212;"July")D$;p3-181)p3;gto "RET"
141: if p3<=243;"August")D$;p3-212)p3;gto "RET"
142: if p3<=273;"September")D$;p3-243)p3;gto "RET"
143: if p3<=304;"October")D$;p3-273)p3;gto "RET"
144: if p3<=334;"November")D$;p3-304)p3;gto "RET"
145: if p3<=365;"December")D$;p3-334)p3
146: "RET":
147: if p1=1;prt D$,p3
148: ret
```

```
149: "Intermediate Results":
150: r55)M
151: cll 'DATE CONVERSION'(0,0,M)
152: fmt 1,c10,f2.0,2x,f6.2,2x,f6.2
153: wrt 701.1,D$,M,r66,r67
154: fmt 1,32x,c11,5x,f2.0,5x,f7.2,4x,f7.2,9x,f2.0,9x,f2.0,8x,f2.0,8x,f2.0
155: for J=1 to 7
156: 0)p1)p2)p3)p4)p5
157: for M=1 to 50
158: val(I$[M,7,11])H
159: if val(I$[M,1,2])=J;1+p1)p1
160: if val(I$[M,1,2])=J;if H(=.25;1+p2)p2
161: if val(I$[M,1,2])=J;if H).25;if H(=.5;1+p3)p3
162: if val(I$[M,1,2])=J;if H).5;if H(=.75;1+p4)p4
163: if val(I$[M,1,2])=J;if H).75;1+p5)p5
164: next M
165: wrt 701.1,M$[J],p1,A[J],B[J],p2,p3,p4,p5
166: next J
167: ret
168: "Harvest Dates":
169: for M=1 to 50
170: val(I$[M,1,2])p2;val(I$[M,3,6])K
171: "":
172: if p2)2;jmp 2
173: 1000)H[M];gto "Point 2"
174: if p2#3;jmp 2
175: K+233-.54(K-106))H[M];gto "Point 2"
176: if p2#4;jmp 3
177: if K)=335;K-214-1.02(K-335))H[M];gto "Point 2"
178: K+151-1.02(K+31))H[M];gto "Point 2"
179: if p2#5;jmp 2
180: K+114-.6(K-190))H[M];gto "Point 2"
181: if p2#6;jmp 2
182: K+149-.6(K-176))H[M];gto "Point 2"
183: if p2#7;jmp 2
184: K+292-.6(K-64))H[M];gto "Point 2"
185: if p2#8;jmp 2
186: K+181-.68(K-288)-365)H[M];jmp 2
187: 0)H[M]
188: "Point 2":
189: next M
190: ret
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```

# APPENDIX F

## LISTING OF IRRIGATION SCHEDULING DATA PREPARATION PROGRAM

```
191: "Initial Conditions":
192: for I=1 to 50;"          "]I$[I];next I
193: ent "Maximum Depth of Irrigation?",r1
194: ent "Minimum Depth of Irrigation?",r2
195: ent "Economic Priority of Citrus w/c?",r3
196: ent "Economic Priority of Citrus wo/c?",r4
197: ent "Economic Priority of Cotton?",r5
198: ent "Economic Priority of Berseem?",r6
199: ent "Economic Priority of Maize?",r7
200: ent "Economic Priority of Rice?",r8
201: ent "Economic Priority of Sugar Cane?",r9
202: ent "Economic Priority of Wheat?",r10
203: ent "CSMD For Citrus w/c?",r11
204: ent "CSMD For Citrus wo/c?",r12
205: ent "CSMD For Cotton?",r13
206: ent "CSMD For Berseem?",r14
207: ent "CSMD For Maize?",r15
208: ent "CSMD For Rice?",r16
209: ent "CSMD For Sugar Cane?",r17
210: ent "CSMD For Wheat?",r18
211: ent "Field Capacity of Soil in %?",r19
212: ent "Wilting Point Percentage?",r20
213: ent "Maximum Acreage of Citrus w/c?",r21
214: ent "Maximum Acreage of Citrus wo/c?",r22
215: ent "Maximum Acreage of Cotton?",r23
216: ent "Maximum Acreage of Berseem?",r24
217: ent "Maximum Acreage of Maize?",r25
218: ent "Maximum Acreage of Rice?",r26
219: ent "Maximum Acreage of Sugar Cane?",r27
220: ent "Maximum Acreage of Wheat?",r28
221: ent "Number of Fields in Citrus w/c?",r29
222: ent "Number of Fields in Citrus wo/c?",r30
223: ent "Number of Fields in Cotton?",r31
224: ent "Number of Fields in Berseem?",r32
225: ent "Number of Fields in Maize?",r33
226: ent "Number of Fields in Rice?",r34
227: ent "Number of Fields in Sugar Cane?",r35
228: ent "Number of Fields in Wheat?",r36
229: 50-r29-r30-r31-r32-r33-r34-r35-r36)r37
230: if r37<0;beep;dsp "Too Many Fields Given";wait 5000;jmp -9
231: 1)I
232: for K=1 to 8
233: r(K+28)→r? [illegible]
234: if [illegible]
235: [illegible]
236: [illegible]
237: [illegible]
238: for K=1 to 50
239: [illegible]
240: next K
```

```
241: fxd 1
242: for I=1 to 50
243: if val(I$[I,1,2])=1;str(1)]I$[I,3,6]
244: if val(I$[I,1,2])=2;str(1)]I$[I,3,6]
245: if val(I$[I,1,2])=3;str(106)]I$[I,3,6]
246: if val(I$[I,1,2])=4;str(335)]I$[I,3,6]
247: if val(I$[I,1,2])=5;str(190)]I$[I,3,6]
248: if val(I$[I,1,2])=6;str(176)]I$[I,3,6]
249: if val(I$[I,1,2])=7;str(64)]I$[I,3,6]
250: if val(I$[I,1,2])=8;str(288)]I$[I,3,6]
251: if val(I$[I,1,2])=9;str(999)]I$[I,3,6]
252: next I
253: for I=1 to 50
254: fxd 2
255: str(.1)]I$[I,7,11]
256: next I
257: trk 1;rcf r38,r1,r37;rcf r39,I$;trk 0
258: ret
259: "Output of Initial Conditions":
260: trk 0;ldf 3,N$
261: fmt 9,40x,"Listing of Control Parameters and"
262: fmt 1,44x,"Field by Field Conditions"
263: wrt 701.9;wrt 701.1;wrt 701;wrt 701
264: fmt 8,80x,"Field by Field Status";wrt 701.8
265: fmt 2,"r-Variable          Description           Value",z
266: fmt 3,20x,"Field No.    Crop      Planting Date          SMD"
267: wrt 701.2;wrt 701.3;wrt 701;wrt 701
268: fmt 7,2x,f3.0,2x,c31,4x,f6.2,21x,f3.0,6x,c11,3x,c10,f3.0,5x,f9.2
269: fmt 8,69x,f3.0,6x,c11,3x,c10,f3.0,5x,f9.2
270: for I=1 to 50;val(I$[I,1,3])]U
271: val(I$[I,3,6])]p10;if p10=999;"         "]D$;0]p10;jmp 2
272: cll 'DATE CONVERSION'(0,0,p10)
273: if I<=37;wrt 701.7,I,N$[I],rI,I,M$[U],D$,p10,val(I$[I,7,11])
274: if I>37;wrt 701.8,I,M$[U],D$,p10,val(I$[I,7,11])
275: next I
276: for I=1 to 9;wrt 701;next I;ret
*161
```

# APPENDIX G

## LISTING OF IRRIGATION SCHEDULING SERVICE PROGRAM

```
"Irrigation Priority":
196)r77;62)r78;282)r79;260)r80;156)r81;15)r82;240)r83;124)r84;310)r85
296)r86;205)r87;64)r88
r31)r71;r32)r72;r33)r73;r34)r74;r35)r75;r36)r76
for I=1 to 50
if val(I$[I,1,2])#0;val(I$[I,1,2]))F[I]
if val(I$[I,1,2])=0;r(68+F[I])+1)r(68+F[I])
next I
for J=3 to 8
if .5r(J+68))=r(J+20);0)Q[J];jmp 5
if N)r(J+80) or N(r(J+74);0)Q[J];jmp 4
if N((r(J+80)+r(J+74))*.5;(N-r(J+74))/(.5r(J+80)-.5r(J+74))2r(J+20))Q[J]
if N((r(J+80)+r(J+74))*.5;jmp 2
2r(J+20))Q[J]
next J
for I=1 to 50;val(I$[I,7,11]))K;val(I$[I,1,2]))J
if J=0;gto "Next Loop"
if J=9;gto "9.Fallow"
if 100K(r(J+10);0)P[I];gto "Next Loop"
r(J+2)+(100-r(J+2))*(100K-r(J+10))/(100-r(J+10)))P[I];gto "next Loop"
"9.Fallow":0)P[I]
for J=3 to 8
if Q[J]<.5;jmp 5
if r(J+68))=2r(J+20);0)Q[J];jmp 4
if N(r(J+74) or N)r(J+80);0)P[I])Q[J];jmp 3
1+r(J+68))r(J+68);r(J+2)+(N-r(J+74))(100-r(J+2))/(r(J+80)-r(J+74)))P[I]
J)F[I];Q[J]-1)Q[J];gto "Next Loop"
next J
"Next Loop":
next I
ret
"crop":
p5)p13;if p13<p4;365+p13)p13
if p2<0;0)p3;ret
if p2)p13-p4;0)p3;ret
if p1=1;gto "citrus w/c"
if p1=2;gto "citrus wo/c"
if p1=3;gto "cotton"
if p1=4;gto "fodder"
if p1=5;gto "maize"
if p1=6;gto "rice"
if p1=7;gto "sugar cane"
if p1=8;gto "wheat"
"citrus w/c":
.75*exp(-((p6-180)/400)^2))p3;ret
"citrus wo/c":
.6*exp(-((p6-180)/400)^2))p3;ret
"cotton":
if p2<4.5;.23+.00238(p2)p3;ret
if p2<98;.6.9462e-2+p2(1.94799e-2+p2(-3.20859e-4+2.2544e-6*p2)))p3;ret
if p2)148;6.304e-5+p2(2.17174e-2+p2(-1.1393e-4+1.37862e-7*p2)))p3;ret
2.37505e-5+p2(3.903232e-3+p2(2.400397e-4-1.128125e-6*p2)))p3;ret
```

```
52: "fodder"
53: 83)p3;ret
54: "maize"
55: if p2<=4.;.4 5..55e 3*p2+2.95e 4*p2p2)p3;ret
56: if p2<56;.77,00 1.36*p2)p3;ret
57: if p13-p6)=42;1.1)p3;ret
58: 42-p13+p4+p2)p7
59: 1.1093+p7(-9.02293e 3+7.37340e 5*p7))p3;ret
60: "rice":
61: 2exp( ((77 p2)/50) 2))p3;ret
62: "sugar cane":
63: 133+(p4-69)/2.33)p7;120-(p4 69)/2.45)p8;p6 69)p9
64: if p9<154;1.05*exp( ((p9-p7)/p8)^2))p3;ret
65: 1.05*exp(-((p9-p7)/175)^2))p3;ret
66: "wheat":
67: 1-(p4-288)/900)p7;105+(p4-288)/3.5+.01)p8;80 (p4-288)/1.81)p9
68: 100-(p4-288)/2.45)p10;p6)p11;if p11<p4;p11+365)p11
69: p11-288)p12
70: if p12<p8;p7*exp(-((p8-p12)/p9)^3))p3;ret
71: p7*exp(-((p12-p8)/p10)^2))p3;ret
72: "ROOT DEPTH":
73: if p1=1;gto "CITRUS W/C"
74: if p1=2;gto "CITRUS W/C"
75: if p1=3;gto "COTTON"
76: if p1=4;gto "FODDER"
77: if p1=5;gto "MAIZE"
78: if p1=6;gto "RICE"
79: if p1=7;gto "SUGAR CANE"
80: if p1=8;gto "WHEAT"
81: "CITRUS W/C":
82: 150)p5
83: if p4=0;p5/2.54)p5
84: ret
85: "COTTON":
86: if p2<=120;jmp 3
87: 180)p5;if p4=0;p5/2.54)p5
88: ret
89: p2/120*165+15)p5;if p4=0;p5/2.54)p5
90: ret
91: "FODDER":
92: 120)p5;if p4=0;p5/2.54)p5
93: ret
94: "MAIZE":
95: if p2<=60;jmp 3
96: 120)p5;if p4=0;p5/2.54)p5
97: ret
98: p2/60*105+15)p5;if p4=0;p5/2.54)p5
99: ret
100: "RICE":
101: if p2<=70;jmp 3
102: 90)p5;if p4=0;p5/2.54)p5
103: ret
104: p2/70*75+15)p5;if p4=0;p5/2.54)p5
105: ret
```

```
106: "SUGAR CANE":
107: if p2<=130;jmp 3
108: 90}p5;if p4=0;p5/2.54}p5
109: ret
110: p2/130*75+15}p5;if p4=0;p5/2.54}p5
111: ret
112: "WHEAT":
113: 85-(p3-288)/1.96}p6
114: if p2<=p6;jmp 3
115: 120}p5;if p4=0;p5/2.54}p5
116: ret
117: p2/p6*105+15}p5;if p4=0;p5/2.54}p5
118: ret
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```

# APPENDIX 27

# A SURVEY OF THE GRADUATES OF THE FIRST ON-FARM WATER MANAGEMENT AGRICULTURAL OFFICER TRAINING COURSE

Dwayne G. Westfall and Douglas J. Merrey[1]

## INTRODUCTION

The University of Agriculture (Faisalabad) is responsible for training the Agricultural Officers (AO) for the field teams of the On-Farm Water Management Pilot Project of all the four provinces of Pakistan. Colorado State University provides advisory assistance to this training program. The first course was completed on October 20, 1977 and is described in a previous report (Awan, et al., 1978). From October to November, 1978 a survey was conducted of all but two of the 16 graduates of this course. We assumed that during the year since graduation these AO's would have had sufficient experience to help us in improving the effectiveness of the training course. Our survey had three basic objectives:

1. to find out whether the graduates are doing the work they were trained for, and more generally, to learn about their working conditions and problems;
2. to elicit their opinions and perceptions regarding the effectiveness and strengths and weaknesses of the course and their suggestions for improving it; and
3. to test their technical knowledge and their understanding of the purposes of the On-Farm Water Management (OFWM) program as a measure of the effectiveness of the course.

## PROCEDURES

The authors of this report personally conducted all but two of the interviews. Two people in Sind were on leave and the questionnaires were left for them to fill out and return by mail. The two graduates from Baluchistan were not interviewed because an active OFWM program had not been initiated at the time of the survey.

In each province the graduates were gathered in a room and explained the purposes of the survey. It was stressed that the information collected was to be used for evaluating the training course and not their own job performance. The

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questionnaires were then distributed and the respondents were asked to fill them out themselves. The questionnaire used is included here as Appendix "A". Most required about two hours to complete the questionnaire. One of the authors explained in Urdu the objectives of the survey, and answered respondents' questions to clarify the meaning of some of the questions. Despite this effort, however, the respondents had difficulty in understanding some questions and some misinterpretation occurred. This experience raises questions about the effectiveness of training in English medium, even to students having M.Sc degrees from English medium institutions (Table 1).

QUALIFICATIONS OF THE GRADUATES

All of them hold degrees in agriculture or an agricultural discipline. Nearly 70 percent hold a B.Sc. degree while the other 30 percent have M.Sc. degrees.

We asked the graduates what their current job assignment was. The results are presented in Table 2. Of the 14 men trained, 10 are working as Agricultural Officers. Two are assigned to the Office of the Director while one has left the OFWM Project. One of the two working as a Land Development Officer was in the NWFP where very few watercourses had been completed at the time of the interview.

We also asked the graduates what specific types of work they had been doing since graduation. The responses were very diverse covering all aspects of the OFWM Project including watercourse cleaning and maintenance, precision land leveling, organizing watercourse committees, profile and topographical surveys, watercourse improvement and agronomic demonstrations. The wide range of activities reported fully justifies the attempt to provide training in all aspects of water management in the training course.

PERCEPTIONS OF THE TRAINING PROGRAM

The interviewees were asked to evaluate how well the training course prepared them for their job. The responses are reported in Table 3. Five respondents (38.5%) said the course had prepared them very well for their jobs while an equal number rated the training as adequate. Three graduates (23%) rated their training as "somewhat inadequate" while none regarded it as very inadequate. In general the Sind graduates rated the training more positively than did those from Punjab or NWFP. Those that rated training as somewhat inadequate gave two reasons: 1) lack of adequate extension training; and 2) lack of proper training in watercourse cleaning and maintenance.

We asked the graduates to specify the strength and weaknesses of the course content in each subject area. The

Table 1. The academic qualifications of graduates.

| Qualification | Province: Punjab | Sind | NWFP | Total No. | Percent |
|---|---|---|---|---|---|
| B.Sc. (honors) | 5 | 2 | 2 | 9 | 69 |
| M.Sc. (honors) | 2 | 2 | 0 | 4 | 31 |
| Total | 7* | 4 | 2 | 13 | 100 |

*One other graduate who moved to another agency is excluded.

Table 2. Present job assignments of graduates.

| Job Assignment | Province: Punjab | Sind | NWFP | Total |
|---|---|---|---|---|
| Agricultural Officer | 6 | 3 | 1 | 10 |
| Land Development Officer (LDO) | 0 | 0 | 1 | 1 |
| Office of Director | 1 | 1 | 0 | 2 |
| Other Agency | 1 | 0 | 0 | 1 |
| Total | 8 | 4 | 2 | 13 |

Table 3. Adequacy of training received.

| Response | Punjab | Sind | NWFP | Total No. | Percentage |
|---|---|---|---|---|---|
| Very well | 2 | 3 | 0 | 5 | 38.5 |
| Adequate | 1 | 1 | 1 | 5 | 38.5 |
| Somewhat inadequate | 2 | 0 | 1 | 3 | 23 |
| Very inadequate | 0 | 0 | 0 | 0 | 0 |
| Total | 7 | 4 | 2 | 13 | 99 |

responses were classified as rating the training in each subject as adequate or inadequate. Table 4 presents the results. The general opinion was that training was adequate. Agronomy and Agricultural Extension, though rated as adequate by a large majority, received the most criticism. The major criticisms of the extension training were that not enough time was spent on this subject and the course content was the same as that taught in University courses, hence it contained nothing new.

The criticisms of the agronomy training included: 1) lack of attention to variation in agronomic conditions of different provinces; 2) pest control recommendations were inadequate; 3) the latest agronomic recommendations were not given; and 4) more time needs to be spent on the techniques involved in establishing field demonstrations. Other suggestions that were made were that more Province - specific sociology training should be given and more emphasis should be placed on watercourse cleaning and maintenance and the economics of watercourse improvement. Several also suggested a further increase in the amount of field work in the course.

In response to questions asking what specific changes they would suggest for improving each component of the training program, we received a wide variety of responses, many of which did not seem very helpful. Some of the questions were obviously not understood by the respondents. In general, the graduates agreed that the trainers worked hard and did a good job, though some criticized the trainers for arriving late for lectures, and not adhering to the training schedule more closely.

The recommendations regarding course content included training in entomology and plant pathology and reducing the Punjab orientation of the course content. Some graduates criticized the length of the course (4½ months) but most felt the length was about right. Almost half the respondents suggested more trips to research institutes while a few suggested the need for more field work on watercourse improvement and maintenance and spending more time visiting OFWM Project watercourses and other programs.

Finally, we asked the graduates if they felt a need for a refresher course, and if so, in what subject. Seven responded that they did feel such a need and listed a very wide variety of topics. The results of our examination of their technical knowledge, reported below, also suggests that refresher courses would be useful.

PROBLEMS ON THE JOB

We asked a series of questions concerning the graduates' problems and work conditions. Only about half responded to

Table 4. Evaluation of adequacy of training by subject.

| Subject matter | Province: Punjab Adequate | Punjab Inadequate | Sind Adequate | Sind Inadequate | NWFP Adequate | NWFP Inadequate | Total Adequate | Total Inadequate |
|---|---|---|---|---|---|---|---|---|
| Agricultural Extension | 6 | 1 | 2 | 2 | 2 | 0 | 10 | 3 |
| Agronomy | 4 | 3 | 3 | 1 | 2 | 0 | 9 | 4 |
| Soil Science | 6 | 2 | 4 | 0 | 2 | 0 | 11 | 2 |
| Farm Management | 6 | 1 | 4 | 0 | 2 | 0 | 12 | 1 |
| Sociology | 7 | 0 | 3 | 1 | 2 | 0 | 12 | 1 |
| Engineering | 7 | 0 | 4 | 0 | 1 | 1 | 12 | 1 |

Table 5. Farmer cooperation in water management activities.

| Farmer Cooperation in following areas | Punjab Yes | Punjab No | Sind Yes | Sind No | NWFP Yes | NWFP No | Total Yes | Total No |
|---|---|---|---|---|---|---|---|---|
| Watercourse Improvement | 5 | 1 | 0 | 2 | 1 | 0 | 6 | 3 |
| Cleaning and Maintenance | 0 | 6 | 0 | 1 | 1 | 0 | 1 | 7 |
| Changes in agronomic practices | 4 | 2 | 1 | 1 | 0 | 0 | 5 | 3 |
| Precision land leveling | 4 | 2 | 1 | 1 | 1 | 0 | 6 | 3 |
| Total | 13 | 11 | 2 | 5 | 3 | 0 | 18 | 16 |

the question asking them to specify the problems they faced. Those problems identified included such things as having too much work to do and lack of cooperation from farmers. The pattern of responses suggest the AO's do not perceive any major obstacles to carrying out their jobs.

About half the respondents reported they get good co-operation from other team members to carry out their AO responsibilities while the other half felt that such cooperation is not adequate. Most did feel their supervisor encourages them and several Punjab graduates mentioned they had gotten more encouragement recently. In terms of perceived administrative problems, Punjab and Sind respondents pointed out three areas of dissatisfaction. They claimed that: 1) travel allowance (TA) is not sufficient, given the expense of operating motorcycles, etc; 2) TA is not paid in a reasonable amount of time and is arbitrarily cut; and 3) they should be made eligible for the 30% residence allowance.

Obtaining the cooperation of farmers for watercourse cleaning and maintenance - their major duty - was perceived by most of the respondents as their major problem. Table 5 presents the responses to a question on farmer willingness to cooperate in various activities. Some interviewees did not appear to understand the question; their responses are excluded. All the Punjab and Sind respondents claimed farmers do not cooperate with them for cleaning and maintenance and the one positive response for NWFP is questioned since at the time of the interview there had been no cleaning and maintenance program in that province. For other water management activities a majority of the respondents do report farmer cooperation.

In response to a question asking for suggestions to improve the level of cooperation, several suggested some legal authority needs to be given to the OFWM teams for enforcing watercourse improvement and maintenance. Several also suggested making PLL more attractive by increasing the land holding ceiling (presently 25 acres in Punjab and NWFP, and 32 acres in Sind) and increasing the subsidy for very small land holders.

In general, despite the various problems enumerated above, the AO's we interviewed had very positive attitudes toward the OFWM Project and toward their jobs.

## TECHNICAL KNOWLEDGE OF AGRICULTURAL OFFICERS

The final section of the questionnaire was designed to determine the level of technical knowledge of these AO's. Unfortunately, the results were not as gratifying as we had hoped.

Johnson, Early and Lowdermilk (1977) report that Pakistani farmers have very poor knowledge of the rooting depths of major crops. This lack of knowledge leads to inappropriate irrigation. We asked the AO's some of the same questions asked by these three researchers that related to irrigation practices. The correct rooting depth of various major crops was not well understood by the interviewers. Their answers were classified as acceptable or unacceptable. At least half of the answers given were unacceptable (Table 6). For rice and sugarcane 75% of the answers were unacceptable while for berseem 67% were unacceptable.

We asked the interviewees to give crop production recommendations for growing wheat, cotton and rice. Under each parameter, soil preparation, irrigation, pesticides, fertilizer, and seed variety we classified their responses as acceptable or not acceptable. For most parameters a large majority of responses were acceptable. Most of the unacceptable answers for pesticides recommendation were for rice where no insecticide was recommended for stem borer control. The fertilizer recommendations that were unacceptable were for cotton and rice; these were either too high or did not include phosphorus.

The largest number of unacceptable answers were given for number of irrigations; 25 percent of the respondents recommended too many irrigations for wheat, 40% recommended too many for cotton, and 50% gave unacceptable answers for rice irrigation. The respondents' weak knowledge of irrigation was confirmed by their answers to the question, "How deep will a 3 inch irrigation penetrate the soil?" Only one of the 12 responding to this question gave an acceptable answer; the other 11 responses were unacceptable. (Table 8)

Table 9 summarizes the responses to the other technical questions. Twenty-three percent of the interviewees could not give an acceptable definition of a cusec; similarly 33% did not know what the typical watercourse conveyance efficiencies are; 46% could not give an acceptable definition of consumptive use; and 25% did not know the advantages of precision land leveling. All but one respondent did know the advantages of furrow irrigation.

This poor performance on questions relating to irrigation practices is nearly matched by the performance on extension related questions. Fewer than 50% of the interviewees seemed to understand the question on how to set up a fertilizer demonstration, though all these people did give acceptable answers. Thirty-three and 42%, respectively, did not understand the usefulness of using demonstrations in farmers' fields under their growing conditions to convince them to adopt new practices. Many suggested pamphlets as the best way to educate farmers which is not as effective a demonstration because a large percentage of farmers are illiterate.

Table 6. Knowledge of rooting depths of major crops.

| Crop | Correct Depth | Acceptable No. | Acceptable Percent | Unacceptable No. | Unacceptable Percent | Total Responses | Range Given By Interviewees |
|---|---|---|---|---|---|---|---|
| Rice | 9-12 in. | 3 | 25 | 9 | 75 | 12 | 6 in. to 6 ft. |
| Sugarcane | 2-3 ft. | 3 | 25 | 9 | 75 | 12 | 4 in. to 10 ft. |
| Berseem | 2 ft. | 4 | 33 | 8 | 67 | 12 | 2 in. to 7 ft. |
| Wheat | 5-6 ft. | 5 | 45 | 6 | 55 | 11 | 4 in. to 6 ft. |
| Cotton | 5-6 ft. | 6 | 50 | 6 | 50 | 12 | 12 in to 10 ft. |
| Corn | 4-5 ft. | 5 | 42 | 7 | 58 | 12 | 2 in. to 8 ft. |

Table 7. Knowledge of crop production recommendations.

| Crop | Soil Preparation | | Irrigation | | Pesticides | | Fertilizer | | Variety | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A* | Una** | A* | Una** | A* | Una** | A* | Una** | A* | Una** |
| Wheat | 12 | 0 | 9 | 3 | 12 | 0 | 11 | 0 | 12 | 0 |
| Cotton | 10 | 0 | 6 | 4 | 9 | 1 | 7 | 3 | 9 | 1 |
| Rice | 10 | 0 | 5 | 5 | 6 | 4 | 8 | 2 | 9 | 1 |

*Acceptable
**Unacceptable

Table 8. Responses to the question "How deep will a 3-inch irrigation penetrate the soil?"

| Correct depth | Acceptable | Unacceptable | Range given by interviewees |
|---|---|---|---|
| 18-24 in. | 1 | 11 | 3 in. to 4 ft. |

Table 9. Interviewees' response to questions of a technical nature

| Questions | Answers | | | |
|---|---|---|---|---|
| | Acceptable | | Unacceptable | |
| | No. | % | No. | % |
| Organize watercourse committee | 8 | 62 | 5 | 38 |
| Set up fertilizer demonstration | 6 | 100 | 0 | 0 |
| What is a cusec | 10 | 77 | 3 | 23 |
| Advantages of furrow irrigation | 12 | 92 | 1 | 8 |
| Conveyance efficiencies | 8 | 67 | 4 | 33 |
| Advantages of PLL | 9 | 75 | 3 | 25 |
| Advantages of cleaning & maintenance | 12 | 92 | 1 | 8 |
| What is consumptive use | 7 | 54 | 6 | 46 |
| Convince farmer to use fertilizer | 6 | 67 | 3 | 33 |
| Convince farmers to adopt new practices | 7 | 58 | 5 | 42 |

## SUMMARY AND RECOMMENDATIONS

The survey of the graduates of the first OFWM training course for Agricultural Officers achieved its objectives and has provided us with many useful insights into the strengths and weaknesses of the course.

In terms of the first objective, to learn whether the graduates are doing what they were trained for and what sorts of problems they face on the job, we discovered that the respondents feel the training was adequate and did prepare them for their jobs. They do not seem to have any major on-the-job problems or grievances.

Our second objective was to elicit their opinions on the effectiveness of the training and ways to improve it. Most were basically satisfied with the training. Some of the problems and suggestions they mentioned have been dealt with in the second and currently in the session of the third training courses. Their suggestions that the agronomy and extension components need strengthening are well-taken in view of their performance on the technical knowledge questions.

Our third objective was to test the graduates' basic knowledge of the subjects taught in the course as a test of the effectiveness of the training. The performance on questions regarding irrigation methods and extension methods was not satisfactory and suggests these components need strengthening.

Based on this survey, we suggest the following recommendations:

1. More emphasis needs to be given to the Agricultural Extension and Agronomy components of the training program. Special emphasis should be placed upon establishment of result demonstration using irrigation and agronomic inputs. Every trainee should be required to help establish a demonstrarion in the field.

2. A watercourse cleaning and maintenance operation should be physically accomplished during the training course. This should include the physical process from initial farmer contact through the cleaning and maintenance operation.

3. In order to encourage the trainees to study more diligently and to raise the standards of the course, examinations need to be given on a regularly scheduled basis. Passing marks and acceptable class room attendance should be required for graduation.

4. Since getting the farmers to cooperate with them is perceived as a major problem by the AO's, more attention needs to be given to teaching human interaction skills and building up their confidence in their ability to work with farmers.

5. Greater attention to the importance of increasing agricultural production as the real goal is needed, both in the training course and in the policies of the OFWM Project.

6. Refresher courses need to be given regularly on the provincial level in order to raise the level of expertise in areas where the AO's are weak and to keep the AO's informed of the latest recommendations.

7. The difficulties the respondents faced both in understanding our questions and in giving acceptable answers raises questions about the efficiency of English medium training: Consideration should be given to using Urdu at least to supplement English - language presentations.

In conclusion, many of the above recommendations have been at least partly included in the third training course which began in March, 1979.

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Appendix A

SURVEY OF OFWM AGRICULTURAL OFFICERS

Name of interviewee _______________ Date _______________

Office/Team to which assigned _______________

Province _________ Position presently held (A.O. LDD, etc.)

_______________ Grade Level (NPS) _______________

Date completed Training Course at Agricultural University

_______________

Academic Qualifications (Degree & Subjects _______________

_______________

1. Since completing the training program what have you been doing? (Note: List all changes in position, transfers, and major activities, such as watercourse improvement, topographical surveys, land leveling, etc. Where applicable get numbers e.g. of watercourses maintained, acres leveled, etc., by interviewees. Press on organizational, watercourse and land leveling maintenance, and extension work done.)

_______________

_______________

_______________

2. (a) How well has the training you received at the training course prepared you for doing your job?

   (1) Very well; (2) adequately; (3) somewhat inadequate; (4) very inadequate

   (b) Please state your reasons for your answer in detail

   _______________

   (c) Specific strengths and weaknesses in training course content:

   Agricultural extension---

   Agronomy---

   Soil Science---

Farm Management/Economy---

Sociology---

Engineering---

Integration of above subjects---

Others---

3. What specific changes would you suggest for improving the training program to better prepare you for your job?

   a) Personnel---

   b) Course Content---(specify subjects)

   c) Length of course---

   d) Mix of field and classroom work---

   e) Field Trips---

   f) Others---

4. Do you feel the need for a refresher course? If yes, specify the subjects/areas you would like covered.

5. On the job problems: Please specify what problems you are facing in doing your job as an Agricultural Officer.

   a) What are the duties of A.O.?

   b) Are you doing work for which you were trained (explain)?

   c) Do you get cooperation from other team members including the team leader to do A.O. work?

   d) Does your Supervisor encourage you to work as an A.O. or in a watercourse improvement or land development capacity? Has this attitude changed recently?

   e) What are your quotas? Are they reasonable?

   f) Are farmers willing and/or anxious to cooperate with you in the following areas.

      (1) Watercourse improvement. Why?

(2) Watercourse cleaning and maintenance. Why?

(3) Changes in their agronomic or cultural practices. Why?

(4) Precision land leveling. Why?

(5) What do you suggest to correct problems encountered in 1, 2, 3 and 4 above?

(6) How many farmers associations have you organized on watercourses? Problems encountered.

(7) What other problems have you faced/encountered? Give reasons and possible solutions.

(g) Are TA, Pay, Cycle and expenses sufficient and promptly paid in such a manner that they do not detract from your work? Explain specific instances.

(h) Administrative problems you encounter.

(i) Others.

7. The OFWM Program

a) What are the goals of the OFWM Project as you understand them?

b) Are these goals being fulfilled? Give reasons.

c) How can an effective cleaning and maintenance program be achieved?

d) What suggestions do you have to improve the OFWM program?

8. Technical Knowledge

a) Give the rooting depth in the soil of the following crops (assuming a well-cultivated, irrigated silt loam soil)

| | | |
|---|---|---|
| Rice | Wheat | Sugarcane |
| Cotton | Berseem | Corn |

b) What recommendations do you give farmers for the following?

| Crops | Variety | Soil Preparation | Number of Irrigations | Pesticides | Fertilizer |
|---|---|---|---|---|---|
| Wheat | | | | | |
| Cotton | | | | | |
| Rice | | | | | |

c) How deep will a 3-inch deep irrigation penetrate into a silt loam soil that has a moisture content slightly above the wilting point at time of irrigation?

d) How do you organize a watercourse committee?

d) How do you set up a fertilizer demonstration on cotton?

f) What is a cusec?

g) What are the advantages of furrow irrigation compared to basin irrigation?

h) What is the typical conveyance efficiencies of watercourse before and after improvement?

i) What are the advantages of cleaning and maintenance of a watercourse?

j) What are the advantages to precision land leveling? Is it economical to the farmer?

k) Outline steps you would follow in order to get a farmer to use fertilizer on his wheat.

l) What is meant by the term "Consumptive Use"?

m) What is the best method you can use to convince a farmer that a certain farming practice is beneficial to him under his conditions?

# APPENDIX 28

## TRAINING AGRICULTURE OFFICERS FOR THE ON-FARM WATER MANAGEMENT DEVELOPMENT PROJECT

Dwayne G. Westfall, Qurban Ali Awan
Douglas Merrey and Norman S. Illsley[1]

### INTRODUCTION

The second training course for the Agricultural Officers of the On-Farm Water Management Development Project (OFWMDP) was conducted at the University of Agriculture at Faisalabad (UAF) from April 19 to August 30, 1978. The Agricultural Officer is one member of the eight man field team under the OFWMDP. The field team consists of two Watercourse Development Officers, five Land Development Officers and one Agricultural Officer. The general responsibility of this team is to bring about a significant increase in water use efficiency and increase agricultural production through the following programs:

1. Improvement and renovation of watercourses
2. Precision land leveling of farmers' fields
3. Training and education of farmers regarding efficient use of irrigation water and other cultural practices
4. Insure improved watercourses are properly cleaned and maintained.

In theory, all watercourse reconstruction is to be accomplished under the supervision of the Watercourse Development Office, precision land leveling under the supervision of the Land Development Officer, while the Agriculture Officer is in charge of training and education of farmers and supervision of watercourse cleaning and maintenance. In practice, all these people have to be cross trained so they can efficiently perform all jobs. This is particularly true for the Agricultural Officer. In the field he may be expected to design and supervise improvement of watercourses, survey for and supervise precision land leveling as well as perform his extension responsibilities. Therefore, the Agricultural Officer training program has to include watercourse design and improvement, techniques of land surveying and precision land leveling as well as training for his extension responsibility. This cross training requirement has led to the

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development of an interdisciplinary training program involving seven departments at UAF and nine faculty members. Colorado State University (CSU) has the responsibility of advising the training program and during the 1978-79 fiscal year allocated 11.5 man-months of field party personnel time to the program. In addition to this time, training aids and other educational materials are being developed by CSU staff members at the Fort Collins campus.

TRAINING PROGRAM

The second training course began on April 19, 1978. The initial enrollment was 11 trainees, 6 from Punjab, 4 from Sind and 1 from NWFP. Midway through the course one trainee from the Sind dropped out when he accepted a position as Lecturer at the Agricultural University at Tando Jam. The rest of the trainees completed the course and graduated on August 30, 1978. The names, Provinces and initial posting locations of the graduates are as follows:

| Name | Province | Posting Location |
|---|---|---|
| Ghulam Asghar | Punjab | Jahania |
| Intisar Ahmad | Punjab | Jahania |
| S. Sajjad Hussain Naqvi | Punjab | Lallian |
| Muhammad Saleem Javeed | Punjab | Jahania |
| Muhammad Asghar Bajwa | Punjab | Lallian |
| Muhammad Razzaq | Punjab | Lallian |
| Abdul Razaque Qureshi | Sind | Hyderabad |
| Muhammad Usman Sial | Sind | Nawabshah |
| Ghulam Dastigir Kalier | Sind | Nawabshah |
| Olas Khan | NWFP | D. I. Khan |

The UAF faculty that participated as trainers for the course and subject matter responsibility are as follows:

| Trainer | Department | Faculty |
|---|---|---|
| Qurban Ali Awan | Irrigation & Drainage | Agricultural Engineering & Technology |
| Arshad Ali | " " | " " |
| M. Rafique | " " | " " |
| Kh. Altaf Hussain | Farm Power & Machinery | " " |
| Fateh Muhammad | Agronomy | Agriculture |
| Atta Muhammad Ranjah | Soil Science | Agriculture |
| M. Akhtar Bajwa | Farm Management | Agric. Econ. & Rural Sociology |
| Abdul Rehman Qazi | Rural Sociology | " " |
| M. Akram Zia | Agric. Extension | Agric. Education & Extension |

The CSU Field Party members that acted as Advisors to the training program are as follows:

| Advisors | Area of Responsibility |
|---|---|
| Dwayne Westfall | Training Advisor/Agronomy, Soils and Agric. Extension |
| Douglas Merrey | Rural Sociology |
| Helmer Holje | Farm Management |
| Norman Illsley | Farm Power and Machinery |
| Tom Trout | Irrigation and Drainage |

In addition to the CSU Field Party advisors two CSU Personal Service Contract Agricultural Engineers, Liaquat Masood and Zahid Saeed Khan, assisted the trainees in the areas of farm machinery operation and maintenance and watercourse survey, respectively.

The detailed outline of the training course schedule and the principles and skills taught are included as Appendix A and B, respectively. Although the sequence of subjects taught was somewhat different from that in the first course in 1977 (Awan et al., 1978), the basic principles and skills taught were very similar.

The overall effectiveness of the training program was acceptable. Having completed the course the trainees were able to design a watercourse for improvement, perform precision land leveling, organize a watercourse committee, clean and maintaining a watercourse and teach the farmers how to increase production through adoption of improved irrigation and cultural techniques. They were probably more confident of their ability to design a watercourse for improvement and to perform precision land leveling than they were in the organization of watercourse committees and in working with farmers on improved practices.

The course places an important emphasis on the teaching of practical field related skills. This is accomplished by allocating a major percentage of the training time to working in the field where the trainees learn by doing. This is very important and cannot be overemphasized.

Although as discussed in the next section many of the same problems and weaknesses occurred during the second training course that characterized the first course, the general consensus was that the second course was more effective and efficient than the first. This is not surprising since the first course was a new experience for everyone and a training program that had never been taught previously was being initiated. We feel the third course will be even better than the second.

## PROBLEMS ENCOUNTERED

Developing the skills and confidence needed to organize effective watercourse committees and to work with farmers to help them improve their cultivation practices has proven more difficult to teach than the more technical skills. This is understandable because watercourse design and precision land leveling skills are measured by the accuracy with which an individual makes physical measurements. The results are immediately tangible as numbers, drawings, etc., and the person has physical control over them. Working with farmers to organize a watercourse committee or to encourage adoption of a new irrigation or cultural practices is far more difficult and rather frightening for the inexperienced. The Agricultural Officer is often trying to bridge conflicts that exist in a village and get opposing groups to cooperate. Here physical control is not possible. The young age and inexperience of the Agricultural Officers are a handicap, but perhaps a more significant problem is that many of the trainees would rather use authoritarian means to get farmer cooperation; some of them do not sympathize with the voluntaristic approach and see this as a waste of time. It is very difficult to overcome this attitude and to build self-confidence, especially since none are willing even to admit to a lack of confidence. The desire to use more authoritarian means is probably largely a result of the lack of self-confidence of the trainees.

In the case of adoption of new irrigation and cultural practices the Agricultural Officer is attempting to change practices that have been used for many years and have become customary. It is sometimes difficult to convince the trainees themselves of the advantages of the new agronomic practices. For those who are not originally farmers, or from farming background, the new agronomic practices have little meaning. Those who are farmers, or from farming background, often have the same beliefs and attitudes as their potential clients have and having learned them from childhood as part of the socialization process cannot easily change. Finally, another inhibiting factor is the relatively low prestige of extension workers as opposed to engineers, therefore, there is a tendency of the trainee to take more interest in the engineering skills and less on acquiring extension skills.

These are very difficult problems to overcome and the lack of self-confidence of the trainees in these areas is understandable. More field work related to sociology and extension needs to be included in the training program. More imaginative techniques for teaching (even socializing) the trainees to accept their role and to perform it well will be necessary. This problem is being given increased attention by the CSU advisor and UAF trainers.

Another major problem was trainee absenteeism and tardiness. This was a constant problem and detracted significantly from the overall effectiveness of the whole program. Accurate records were not maintained regarding trainee absenteeism but it is estimated that it averaged about 15%. Tardiness resulted in delayed lectures, delayed departures for field trips and disrupted training exercises. We are not aware of a fool proof, yet practical, solution to the problem of absenteeism and tardiness. The trainees are Agricultural Officers in the OFWMDP and consequently the University trainers and CSU advisors have no direct jurisdiction over them.

The tardiness and absenteeism of the trainers was also a disrupting factor. Trainers often were requested by the University to attend a meeting or some other university commitment would arise. This often fell during the time they were scheduled to give a lecture. The University assignment was generally given first priority and many lectures were missed, wasting the trainees' time. Only occasionally was another trainer asked to take over the lecture.

At the beginning of the course all the trainers had good intentions of giving two major exams plus several short quizzes during the training period. For various reasons many of these quizzes and exams never materialized. Consequently, the trainees were not motivated to study. Their major motivation was interest in the subject and peer pressure; neither of these proved very constructive.

Although the trainees are M.Sc. graduates their comprehension of English, particularly spoken English, is not very good. In the first course there was considerable criticism of instructors that used Punjabi in the class room as some of the trainees from NWFP and Baluchistan were not fluent in this language. Language was not a major problem in the second course. The trainees in the second course all understood Urdu, therefore, the instructors that desired could use Urdu as a means of communication. This was useful as the level of comprehension of spoken English was low. In each training program the medium of instruction will remain, officially, English but the use of Urdu in the class room to supplement and clarify English presentations will also continue.

Transportation, housing and food problems were generally minor and easily rectified. Considerable difficulty did occur in pay and daily allowance matters that were out of the control of the University. Eventually these problems were resolved but they had an adverse effect upon the morale of trainees. On one occasion the Punjab trainees threatened to boycott class unless they received their daily allowance. Since the University had no control over the matter a tense situation arose and several hours of training time were lost.

## RECOMMENDATIONS

1. Accurate attendance records should be kept on all trainees and disciplinary action taken for unexcused absence or habitual tardiness. The most immediate method of disciplinary action is to withhold the trainees' daily allowance for unexcused absence. The Deputy Director, Punjab OFWMDP has asked that the University handle all payment of daily allowance for their trainees. The projected amount of daily allowance will be transferred to the University which will disburse the funds monthly. This will facilitate the withholding of any daily allowance for unexcused absences. At least 75% attendance at lectures and on field trips should be required for graduation. If a trainee is absent for over 6 days he should be dismissed from the training program and sent back to the Province headquarters for appropriate disciplinary action.

2. In order to place more emphasis on obtaining skills that will enable the trainees to become more confident in working with farmers, more training time should be given to the development of sociological and extension skills. More field time should be devoted to farmer contacts, establishment of agronomic demonstrations and organization of water users associations. As part of the training, and as a requirement to be certified as having completed the course, the trainees should be divided into small groups (three or four), under the guidance of the trainers, each group would organize and conduct a cleaning and maintenance program on a watercourse. This would provide a valuable practical experience of working with the farmers to the trainees.

3. Regular tests should be given in every subject. These should be a combination of quizzes and examinations that emphasize practical matters. Exams should be included in the training schedule so they are not forgotton during the course of the program. The trainees should be required to obtain passing grades on the tests in order to graduate; high achievements should be rewarded with special recognition.

4. Appropriate transportation needs to be assigned to the University on a permanent basis. In the past all the transportation has been on loan from Punjab OFWM. This has caused some administrative problems that could be avoided if the University had full control of the vehicles.

5. The question has arisen as to how much value field trips to the various Agricultural Research

Institutes are to the trainees. These trips are enjoyable and beneficial for psychological reasons and build morale but their technical value is questioned. The trips that involve long travel distances probably should be deleted and that time used for field work in establishing agronomic demonstrations in farmers' fields and at the University.

SUMMARY

The second Agricultural Officer training program was conducted at the University of Agriculture at Faisalabad from April 19 to August 30, 1978. This interdisciplinary program included subject matter training in irrigation engineering, agronomy, agricultural extension, rural sociology, soil science, farm management and farm machinery. The main objectives of the training program were to teach these very important members of the On-Farm Water Management Field Team how to work with farmers to improve agronomic practices and to keep their watercourses cleaned and maintained. A considerable amount of time was spent on engineering skills such as watercourse design surveying, etc. This is necessary because every field team member has to be cross trained in all skills.

The major benefit of the OFWMDP will be obtained when farmers use their additional supply of water to increase agricultural production. Every facet of the training curriculum should be oriented toward teaching skills that will result in the achievement of this benefit. When the Agriculture Officer is able to show farmers how to use their increased water supply to increase agricultural production, Pakistan will reap the ultimate benefit of the On-Farm Water Management Development Project.

# APPENDIX A

## AGRICULTURAL OFFICER DETAILED TRAINING COURSE OUTLINE
## UNIVERSITY OF AGRICULTURE, FAISALABAD

| Subject | Lectures (Periods)* | Field (Days) | Trainer |
|---|---|---|---|
| April 19 | | | |
| Inauguration of Course | 3,4 | | |
| Watercourse Improvement Introduction | 5 | | Qurban |
| OFWM Project (slide show) | 6 | | Reuss |
| April 20 | | | |
| Evaluation of knowledge level of trainees and introduction over Rural Sociology | 1 | | Qazi |
| Structural attributes of village organization | 2 | | Qazi |
| Evaluation of knowledge level of trainees over Irrigation and Drainage | 3 | | Qurban |
| Units of water measurement | 4,5 | | Qurban |
| Evaluation of knowledge level of trainees over Soil Science | 6 | | Ranjah |
| Soil Science terminology and soils of Pakistan | 8 | | Ranjah |
| April 21 | | | |
| Free | | | |
| April 22 | | | |
| Holiday | | | |
| April 23 | | | |
| Use of levels | 1,2 | | Qurban |
| Use of levels | | 1/3 | Qurban |
| Process of collective decision making | 6 | | Qazi |
| Assessment of need for more water | 7. | | Qazi |
| April 24 | | | |
| Cutthroat flumes | 1 | | Rafique |
| April 25 | | | |
| Evaluation of previous knowledge of trainees over Agricultural Extension | 1 | | Zia |
| Identifying specific needs of farmers related to water management and design of program | 2,3 | | Zia |
| Introduction to cleaning and maintenance | 4,5 | | Mumtaz Awan (Guest) |
| Assessment of satisfaction, interview vs. participant and observation | 6,7 | | Qazi |

| Subject | Lectures (Periods)* | Field (Days) | Trainer |
|---|---|---|---|
| April 26 | | | |
| Evaluation of previous knowledge of trainees | 1 | | Fateh |
| Cotton Production Guidelines | 2,3 | | Fateh |
| Essential nutrients, functions and symptoms | 4,5 | | Ranjah |
| Profile survey of watercourse | 6 | | Arshad |
| Introduction & closing of B. M. survey | 7 | 1/3 | Arshad |
| April 27 | | | |
| Cotton Production Guidelines | 1,2 | | Fateh |
| How to conduct method & result demonstrations related to project | 3,4 | | Zia |
| Nutrient mobility in soils | 5,6 | | Ranjah |
| April 28 | | | |
| Free | | | |
| April 29 | | | |
| Characteristics of Costs | 1 | | Qazi |
| Legal authority and personal influence | 2 | | Qazi |
| Soils of Pakistan | 3,4 | | Ranjah |
| Flow measuring devices | 5-9 | | Qurban |
| April 30 | | | |
| Cutthroat flumes watercourse at Thokriwala | | 1 | Rafique |
| May 1 | | | |
| Free | | | |
| May 2 | | | |
| Date reduction regarding conveyance losses, etc. | 1,2 | | Rafique |
| Preparation of intensive interviewing schedule and followup discussions | 3,4 | | Qazi |
| Packaging extension teaching methods to meet a single program objective evaluation of objectives | 5,6 | | Zia |
| May 3 | | | |
| Field trip to Mona | | 1 | Mumtaz Awan (Guest) |
| May 4 | | | |
| Evaluation of previous knowledge of trainees over farm machinery | | | Altaf, Illsley |
| Machinery for agriculture and their purposes, skills in tractor drawn equipment | | 8/9 | Altaf, Illsley |
| May 5 | | | |
| Free | | | |
| May 6-14 | | | |
| Trainees to become skilled in the use of hand, bullock and tractor drawn equipment | | 1 | Altaf, Illsley |

| Subject | Lectures (Periods)* | Field (Days) | Trainer |
|---|---|---|---|
| May 15 | | | |
| Examination over Agricultural Implements | 1 | | Altaf, Illsley |
| Discussion over the subject | 2,3 | 1/2 | Altaf, Illsley |
| May 16 | | | |
| Maintenance of extension records and report writing | 1,2 | | Zia |
| Determining irrigation requirement | 3,4 | | Qurban |
| Irrigation scheduling | 5,6 | | Rafique |
| May 17-18 | | | |
| Studying relevant leadership characteristics (initial farmer contact) | | 2 | Qazi |
| May 19 | | | |
| Free | | | |
| May 20-22 | | | |
| Studying relevant leadership characteristics (initial farmer contact) | | 3 | Qazi |
| May 23-24 | | | |
| Watercourse losses | | 2 | Arshad |
| May 25-29 | | | |
| Precision land levelling use of levels data collection and computation | | 4 | Arshad |
| May 26 | | | |
| Free | | | |
| May 30-June 12 | | | |
| Organizing a watercourse committee and profile survey of watercourse | | 12 | Arshad, Qazi |
| June 2-9 | | | |
| Free | | | |
| June 13-15 | | | |
| Data reduction and profile survey computation and plotting | | 3 | Arshad |
| June 16 | | | |
| Free | | | |
| June 17 | | | |
| Methods of irrigation | 1,2,3 | | Trout |
| Fertilizer materials availability, soil reaction and production response | 4,5,6 | | Ranjah |

| Subject | Lectures (Periods)* | Field (Days) | Trainer |
|---|---|---|---|
| June 18 | | | |
| Evaluation of basin irrigation | 1,2 | | Rafique |
| Evaluation of irrigation at farmer's fields | | 4/5 | Rafique |
| June 19-20 | | | |
| Evaluation of farmer irrigation basin | | 2 | Rafique |
| June 21 | | | |
| Rice production guidelines | 1,3 | | Fateh |
| Evaluation over previous knowledge of trainees and introduction over farm management | 4 | | Bajwa |
| Farm business analysis | 5,6 | | Bajwa |
| Making fertilizer recommendations | 8,9 | | Ranjah |
| June 22 | | | |
| Computing farm costs and net returns for various enterprises | 1,2 | | Bajwa |
| Water management aspects of precision land levelling | 3,4 | | Shaw,Twitty |
| Pan evaporation measurements | 5,6 | | Qurban |
| June 23 | | | |
| Free | | | |
| June 24 | | | |
| Evaluation of farmer's irrigation | | | Rafique |
| June 25 | | | |
| Field visit to PARI | | 1 | Ranjah, Staff |
| June 26 | | | |
| Field visit to NIAB | | 2 | Ranjah, Staff |
| June 27-28 | | | |
| Topographic Survey | | 2 | Rafique, Arshad |
| June 29 | | | |
| Wheat production guidelines | 1,2 | | Fateh |
| Economic Principles | 3,4 | | Bajwa |
| June 30 | | | |
| Free | | | |
| July 1-2 | | | |
| Field trip to cotton research station at Multan | | 2 | Fateh, Staff |
| July 3,4,5 | | | |
| Field trip for economic analysis of farm plans | | 3 | Bajwa |

| Subject | Lectures (Periods)* | Field (Days) | Trainer |
|---|---|---|---|
| July 6 | | | |
| Sugarcane production guidelines | 1,2 | | Fateh |
| Efficient organization of individual enterprises | 3,4 | | Bajwa |
| Soil salinity SAR and ESP | 5,6 | | Ranjah |
| July 7 | | | |
| Free | | | |
| July 8 | | | |
| Orchard crop production guidelines | 1,2 | | Fateh |
| Complete and partial budgeting | 3,4 | | Bajwa |
| Direct seed rice application | 5,6 | | Fateh |
| July 9 | | | |
| Field trip to rice research centre at Kala Shah Kaku | | 1 | Fateh,Staff |
| July 10 | | | |
| Maize production guidelines | 1,2 | | Fateh |
| Narrative and supportive information,i.e. marketing, credit sources, etc. | 3,4 | | Bajwa |
| Irrigation network of Pakistan | 5,6 | | Guest |
| July 11-12 | | | |
| Field trip to Maize Research Centre at Yousafwala and Cotton Research Institute at Multan | | 2 | Fateh, Staff |
| July 13 | | | |
| Quality of irrigation water | 1,2 | | Ranjah |
| Summary of procedure for recommendations | 3,4 | | Bajwa |
| Canal water distribution system | 5,6 | | Qurban |
| July 14 | | | |
| Free | | | |
| July 15 | | | |
| Fodder crop (winter) production guidelines | 1,2 | | Fateh |
| Vegetable production guidelines | 3,4 | | Fateh |
| Mogha outlets and warabundi | 5,6 | | Qurban |
| July 16-17 | | | |
| Field trip for soil science investigation and analysis | | 2 | Ranjah |
| July 18 | | | |
| Watercourse design aids basic information, equations and their uses | 1-4 | | Qurban |

| Subject | Lectures (Periods)* | Field (Days) | Trainer |
|---|---|---|---|
| July 19 | | | |
| Watercourse design aids | 1-3 | | Qurban, Arshad |
| Examination over Soil Science (take home) | 5,6 | | Ranjah |
| July 20 | | | |
| Examination over farm management (take home) | 1,2 | | Bajwa |
| Watercourse structure | | 4/5 | Arshad |
| July 21 | | | |
| Free | | | |
| July 22 - Aug. 5 | | | |
| Topographic survey of unimproved watercourse and its command areas. Getting warabundi from canal irrigation department | | 13 | For first six days Qazi, Arshad & Qurban for remaining days. |
| July 28 - Aug. 4 | | | |
| Free | | | |
| Aug. 6-7 | | | |
| Computation of surveyed data and preparation of designed sheets for watercourse | 1-9 | | Arshad, Qurban |
| Aug. 8 | | | |
| Examination over Rural Sociology | 1-3 | | Qazi |
| Discussion on design of watercourse | 4-9 | | Qurban, Arshad |
| Aug. 9 | | | |
| Oil seed production guidelines | 1-2 | | Fateh |
| Aug. 10-13 | | | |
| Bench Mark Survey of Watercourse | 1-9 | | Arshad |
| Aug. 11, 14 | | | |
| Free | | | |
| Aug. 15 | | | |
| Examination over Agricultural Extension | 1-3 | | Zia |
| Discussion on the subject | Remaining day | | Zia |
| Aug. 16 | | | |
| Examination over production guildelines cotton, wheat, maize, fodder (take home) | 1-3 | | Fateh |
| Discussion on subject | 3-6 | | Fateh |
| Aug. 17 | | | |
| Difficulties in maintaining unimproved watercourse | 1-3 | | Monget (Guest) |

| Subject | Lectures (Periods)* | Field (Days) | Trainer |
|---|---|---|---|
| Aug. 18 | | | |
| Free | | | |
| Aug. 19-20 | | | |
| Field visit to Mona and Chiniot | | 2 | Qurban, Staff |
| Aug. 21 | | | |
| Visit to Agricultural Engineering Workshop and Agricultural Implements Manufacturing Enterprises at Faisalabad | | 1 | Qurban, Staff |
| Aug. 22 | | | |
| Field visit to OFWM research and training Lahore and land reclamation | | 1 | Qurban, Staff |
| Aug. 23 | | | |
| Examination over irrigation, precision land leveling, watercourse maintenance | 1,2,3 | | Arshad, Rafique |
| Discussion on subject | Remaining day | | Arshad, Rafique |
| Aug. 24-25 | | | |
| Free | | | |
| Aug. 26 | | | |
| Examination over watercourse design and water measurement devices, etc. | 1,2 | | Qurban |
| Discussion on subject | Remaining day | | Qurban |
| Aug. 27-28 | | | |
| Review, critique and prepare to depart for new job assignment as Agricultural Officers | 2-6 | | Westfall, Merrey |
| Aug. 29 | | | |
| Preparation to leave campus | | | Staff |
| Aug. 30 | | | |
| Closing ceremony and distribution of Certificates to successful trainees | | | Program announced separately |

*Detailed Timing of Periods

| Period | Time | Period | Time | Period | Time |
|---|---|---|---|---|---|
| 1 | 0700-0750 | 2 | 0750-0840 | 3 | 0840-0930 |
| 4 | 0930-1020 | 5 | 1020-1110 | 6 | 1110-1200 |
| 7 | 1200-1250 (lunch break) | 8 | 1250-1340 | 9 | 1340-1430 |

# APPENDIX B

## PRINCIPLES AND SKILLS TAUGHT IN THE AGRICULTURAL OFFICER TRAINING COURSE AT UNIVERSITY OF AGRICULTURE, FAISALABAD

### IRRIGATION AND DRAINAGE SKILLS

Survey techniques: taping and pacing, use of engineer's level, differential leveling, drawing profile of watercourse and surveying for watercourse design.

Elements of watercourse design: Assumptions, field data required, general procedures, starting point, backward interaction, treatment of culverts and model problems with solutions.

Cleaning and maintenance of watercourse: determining needs, advantages, techniques to accomplish and advantages to farmers.

Water measurement by Cutthroat flume: introduction, installation, reading, observation and maintenance.

Water measurement by other means: principles for head measurement, float method, weirs and flumes.

Soil moisture measurement: sun drying method and touch and feel method, equations, computations, examples and explanations for farmers.

Delivery losses and efficiencies: concepts, equations, computations, examples and explanations for farmers.

Application losses and efficiencies: concepts, equations, computations, examples and explanations for farmers.

Identification of land leveling needs and potential costs: field measurements/observations, justifications, estimating costs and predicted benefits.

Watercourse cleaning and maintenance: needs of cleaning ·d maintenance, increased water supply resulting from, benefits to farmers and organizing and conducting a cleaning and maintenance operation.

Improved methods of irrigation: border irrigation, factors effecting and recommended size of borders, furrow irrigation, length, spacing and depth of furrow and construction equipment.

Determining irrigation requirements: elements, equations used, use of charts, calculations and amount of water to be applied.

Determining irrigation capability: available supplies, how much to supply, adjustments with available time and model problems.

Irrigation and crop scheduling on seasonal basis: basic information, computations and time table of irrigation.

Determining leaching requirements: basic information, leaching requirements, expected benefits, alternate measures, removal of excess water, affects of remedial measures and predicted benefits.

Maintenance of level land: methods of maintaining level fields and use of proper implements to maintain level.

Practicals

Water measurement by: a. float method; b. weirs; c. Cutthroat flume.
Determination of conveyance losses
Use of engineer's level
Watercourse profile survey
Topographic survey and preparation of topographic maps
Field training in layout and construction of improved watercourse
Evaluation of irrigation practices to determine land leveling needs and time farm requires to irrigate fields

SOCIOLOGICAL SKILLS

Structural attributes of village organization, social, economic and numerical significance of difference caste, biradari and other solidary groups in the village.

The characteristics of caste endogamy and patrilineal and patrilocal family organization, extent and bases of factionalism, family dispute, social and economic dominance of one social group over the other, factional tendencies as impediments in the way of developmental activities, ways to resolve these conflicts.

Characteristics of village leadership, caste dominance, age, education, honesty, land ownership, etc.

Legal authority vs. personal influence in mobilizing collective efforts.

The process of collective decision making with special reference to cleaning and maintenance of common watercourses.

An assessment of the felt need for more water. The significance of getting more water through improving the watercourse.

Any alternative solutions available and their evaluation. The procedure for getting people to agree to the improvement of the watercourse. Preparation of the plan of work and its implementation.

Assessment of the satisfaction with the total operation.

Interviewing vs. participant observation as techniques of gathering sociological data.

Interviewing helps in reporting on values, beliefs, motivations and future plans. Participant observation highlights the problems of actual implementation of a plan.

Practicals

Preparation of an intensive interviewing schedule and involvement as participant observer for studying village attributes and the patterns of collective decision making.

Studying the relevant leadership characteristics so as to influence decision to clean watercourses.

AGRONOMIC SKILLS

Latest recommendations for land preparation, seeding rate, seeding method, fertilizer recommendations, pest control recommendations and irrigation requirements for all major crops. Principles of proper crop rotations as well as those commonly followed at present in canal and well irrigated areas.

Water requirements of crops, consumptive use, irrigation methods and choice of best methods.

Efficient use of water in relation to fertilization, influences of different levels of fertility on water requirements.

Practicals

Field trips to learn the position of the farmers in the area in regard to the agronomic recommendation, i.e. variety, cultural methods, inputs, plant protection measures, etc. What improvements can be suggested to help increase production (suggestions and improvements to the farmer). Field trips to cotton, rice and maize research centers and production areas.

SOIL SCIENCE SKILLS

Terminology frequently applied in soil science, soil analysis and agencies analyzing soil samples, criteria for soil evaluation. Soil sampling for fertility evaluation, salinity/sodicity, and moisture determination. Management of saline/alkali soils.

Plant food elements, importance, source and their deficiency symptoms, recommended doses of fertilizers. Fertilizer application and efficient use of irrigation water. Determination of texture of soil in the field by feel method.

Quality of irrigation water, criteria for quality of irrigation water, water sampling and agencies analyzing water samples.

Practicals

Determination of soil texture by feel method, diagnosis of deficiency symptoms of plant nutrients. Field trips to observe the experiments and achievement of various agencies working on various aspects of soils.

EXTENSION SKILLS

Identification of actual water management problems, creation of awareness and interest in water management through mass media, mobilization of local resources for the solution of water management problems, principles of arranging demonstrations and tours, evaluation and reporting.

ECONOMIC SKILLS

Definition, scope and goals of farm planning.

Farm Business Survey: Type of data required for planning, sources of data, selection of area and period, interview schedules, interviewing farmers.

Farm Business Analysis: Computation of farm cost, working out unit cost of production of various farm enterprises, causes of cost variation on similar farms.

Guiding Principles: Law of comparative advantage, enterprise and resource combination.

Developing Farm Plans: Analysis of existing agricultural conditions at farm level. locating merits and demerits, application of partial budgeting technique, planning land labor and water use, developing optimum cropping patterns, economic comparison of old and new farm plans, need and procedure to revise plans over time.

Practicals

Developing a contact with the farmer. Explaining farm planning objectives and motivating farmers to participate.

Preliminary survey regarding agricultural conditions at the farm level.

Collection of basic data for application of a partial budgeting technique. Pretesting of the farm survey schedule.

FARM POWER AND MACHINERY SKILLS

The use of agriculture machinery on small farms under limited capital conditions. Use of correct piece of machinery to accomplish a specific land manipulation or farming operation.

Practicals

Trainees to become skilled and confident in maintenance and operation of power driven machinery for agriculture with particular emphasis on land leveling and planting equipment.

APPENDIX 29

# THE ON-FARM WATER MANAGEMENT TRAINING PROGRAM AT THE UNIVERSITY OF AGRICULTURE AT FAISALABAD

Dwayne G. Westfall, Douglas J. Merrey, Qurban Ali Awan, and Arshad Ali[1]

## INTRODUCTION

The loss of water from the watercourses in Pakistan has been well documented to average 47%. This loss is contributing to the soil salinity and waterlogging problems as well as resulting in a shortage of irrigation water required to increase agricultural production. The Punjab, Sind and NWFP have initiated an On-Farm Water Management Development Project (OFWMDP) in which Field Teams help farmers to improve their watercourses and carry out precision land leveling on farmers' fields to improve delivery and irrigation efficiency. After the watercourse has been improved the farmers must be shown how to use the increased water supply more efficiently. This is the responsibility of the Field Team, specifically the Agriculture Office. The University of Agriculture at Faisalabad (UAF) has the contract with the provincial governments to train the AO's for the field teams.

## DEVELOPMENT OF TRAINING PROGRAM

As the first training program was organized and conducted in the summer of 1977 it became apparent that this course could be an important motivative factor to bring the faculty at the University closer to the problems of the farmers, particularly as related to OFWM. Since most of the OFWM related problems do not presently have satisfactory solutions a research program was developed to provide the University faculty with an opportunity to identify problems and test alternative solutions.

It was felt that the course should be strongly field oriented and the trainees should be trained specifically in identifying farmer's problems in the fields, conducting and observing well planned demonstrations on the latest OFWM techniques, organizing watercourse committees to facilitate watercourse improvement and long term maintenance, as well as in the engineering skills required for watercourse improvement and precision land leveling. With this in mind a research proposal titled "Water Management Research Program for Rural

1/Agronomist and Social Anthropologist, Colorado State University Field Party, Training Course Coordinator and Chairman, Department of Irrigation and Drainage, University of Agriculture, Faisalabad, respectively.

Development" was proposed for funding by USAID in 1977. Due to various problems the approval of this research program has been delayed.

When one analyzes the watercourse improvement program it becomes obvious that if the water losses on all the 80,000 watercourses in Pakistan, or even a majority of them, are to be decreased substantially, additional effort and/or additional approaches must be initiated. Research has shown that a heavy cleaning and maintenance operation on unimproved watercourses can cut water losses by 25%. This involves removal of bushes excessive grasses and weeds and rebuilding of banks to provide at least a six inch freeboard. No engineering supervision is required. The major input is labor which would be provided by the farmers. The estimated cost of this program is Rs. 0.30 per foot. The average watercourse is approximately 12,400 ft. long and serves about 400 acres. A crew of 25 men would need about 13 days to accomplish a heavy cleaning and maintenance program on an average watercourse. The cost would be about Rs. 9.3 per acre. This program is completely labor intensive. As with improved watercourses the farmers must be shown how to use their increased water supply more efficiently so agricultural production can be increased. To accomplish this the person would have to receive training in the OFWM aspects of improved agronomic practices as well as watercourse cleaning and maintenance.

The Provincial Agricultural Extension Service (AES) is the logical organization to become involved in such a program. In the initial stages of the original On-Farm Water Management Project proposal one field assistant per five watercourses was to be left behind to work with farmers on continued cleaning and maintenance of improved watercourses and to improve agricultural production through increased water use efficiency. Since this was not made a part of the current project it is therefore critical that all Extension Staff in the provinces be given this capability in order to continue to reap the benefits of the watercourse improvement program.

The OFWM research and training capability of the University is being strengthened to include both training of OFWMDP and AES people and given the necessary research support by the recent approval by the Punjab Government of the PC-1 titled "Water Management Research and Training Program for Rural Development" for funding by USAID. Colorado State University (CSU) will have advisory responsibility. This new program provides for training of three groups of people in OFWM skills (1) Agricultural Officers of OFWM for a 4½ months course which is currently being taught, (2) Agricultural Officers/Assistants of the AES for six weeks and (3) Instructors of In-Service Agricultural Training Institute of AES for 4½ months. Group 3 will be integrated into the Agricultural Officer training course while a special short course will be established for group 2. The Agricultural Officer training program has been taught two times previously at UAF but the new PC-1 will give the University staff greater field capability and experiences so the effectiveness of the OFWM training program will be increased. After the instructors of the In-Service Agricultural Training Institutes have completed this 4½ months of training we expect they will integrate OFWM techniques into the training curriculum at the Extension Service Training Institutes where field assistants for AES are trained. This, along with the training of the Agricultural Officers/Assistants of the AES will give each province a greatly increased capability in OFWM techniques.

The research activity to support the training program covers eight areas: (1) Crop production as affected by irrigation methods, (2) Use of saline water for irrigation, (3) Improved method of watercourse rehabilitation, (4) Optimizing On-Farm Water Application, (5) Impact of improved water management techniques on surface and subsurface hydrology, (6) Extension methods to motivate farmers to adopt OFWM practices, (7) Testing water users associations and (8) Development of farm management plans related to OFWM.

## CONTENT OF TRAINING PROGRAMS

Interdisciplinary training programs comprising seven departments and nine faculty members have been developed. All the training faculty are also involved in the research portion of the PC-1. Adivsory support personnel from the CSU Field Party also participate in the training program (Table 1). The Agricultural Officer training course for the OFWMDP personnel contains much more technical information than does the six week course for Agricultural Officers/Assistants for AES. Since these personnel will be involved in teaching farmers cleaning and maintenance and agronomic techniques related to OFWM they do not have a need for the engineering skills. Also in their every day field activity they will not have access to the field equipment and logistical support to perform these functions.

### Agricultural Officer of OFWM Course

The training course curriculum for the Agricultural Officers and Instructors of In-Service Training Institutes of the AES is presented in Appendix I. The course can effectively handle 20 trainees. It is anticipated that the OFWMDP demand for each course (taught two times a year) will be from 10-15 people. Consequently, about nine In-Service Staff can be trained during each course. The projected breakdown of personnel to be trained in shown in Table 2.

The training course curriculum is heavily field oriented (70%) where the trainees learn by doing. Past experience has shown this to be the only effective method in teaching the

Table 1. Faculty involved in OFWM training at UAF and CSU support personnel.

| Faculty | Department | Trainer |
|---|---|---|
| Agricultural Engineering and Technology | Irrigation & Drainage | Qurban Ali Awan<br>Arshad Ali<br>M. Rafique |
| | Farm Power & Machinery | K. Altaf Hussain |
| Agriculture | Agronomy | Dr. Fateh Muhammad |
| | Soil Science | Dr. Shah Muhammad |
| Agricultural Economics and Rural Sociology | Farm Management | M. Akhtar Bajwa |
| | Rural Sociology | Abdul Rehman Qazi |
| Agricultural Education and Extension | Agricultural Extension | M. Akram Zia |

| USAID/CSU | Support Personnel |
|---|---|
| Dr. John Reuss | Chief of Party |
| Dr. Dwayne G. Westfall | Training Advisor and Agronomist |
| Mr. Norman Illsley | Agricultural Engineering - Farm Machinery |
| Mr. Douglas J. Merrey | Social Anthropology - Rural Sociology |
| Dr. Helmer Holje | Agricultural Economist |
| Mr. Dwayne Konrad | Agricultural Engineer - Irrigation |

Table 2. Projected breakdown by province of personnel to be trained per year.

| Province | Agricultural Officer/ Assistant | In-Service Staff | Agricultural Officers of OFWMDP | Total |
|---|---|---|---|---|
| Punjab | 28 | 10 | 12 | 50 |
| Sind | 16 | 6 | 7 | 29 |
| NWFP | 4 | 2 | 2 | 8 |
| Baluchistan | 2 | 0 | 1 | 3 |
| Total | 50 | 18 | 22 | 90 |

types of skills necessary. After the trainees themselves have performed an operation such as watercourse cleaning and maintenance, establishing an agronomic or irrigation demonstration, etc. they gain self-confidence in their ability and are not hesitant in performing these activities once they have been posted in the field. Only through practically oriented training do they achieve the desired level of expertise.

Agricultural Officers/Assistants of AES Course

The training course for the Agricultural Officers/Assistants of AES will be of 6 weeks duration and much less technical than the training program described above. Since the Extension Service personnel will not have access to surveying equipment, flumes, etc., a minimum amount of time will be spent on these subjects. The objective of this training program will be to teach this group only the fundamental techniques of watercourse cleaning and maintenance as well as agronomic and irrigation practices as related to OFWM. They are employees of the AES and upon returning to their various posts will integrate watercourse cleaning and maintenance and improved irrigation and agronomic practices into their programs. The training curriculum for this six-week course is shown in Appendix II. In this course, 60% of the training time is spent in the field. Since most of their work would be involved in areas where watercourses have not been improved by the OFWMDP these people will be trained to perform a heavy cleaning and maintenance program on unimproved watercourses. Research has shown that about 25% of the watercourse loss can be saved by this operation. No engineering skills are required, just rebuilding banks to have proper thickness and freeboard and removal of weeds and other obstructions in the watercourse. Pucca structures and linings are not included in this program because of the obvious limitations of funding and technical skill to supervise their installation.

SUMMARY

The interdisciplinary OFWM training at the UAF is designed to teach the practical skills that are needed in working with farmers. There are two courses taught, a 4½ month course contraining highly technical subjects and a less technical six-week course. The Agricultural Officers of OFWMDP and instructors of the In-Service Training Institute of the Agricultural Extension Service attend the 4½ month course while the Agricultural Officers/Assistants of the Agricultural Extension Service attend the six-week course.

A research project at the UAF has been developed to increase the effectiveness of the training programs by providing the faculty with funds to conduct field research projects related to OFWM. These research program cover the major areas of training and will serve as a nucleus of expertise in OFWM techniques at the University.

## Appendix I

Training course curriculum for Agricultural Officers of OFWM and Staff of In-Service Training Institutes of AES.

| Subject | Lecture (Hours) | Field (Days) |
|---|---|---|
| **Irrigation and Drainage Department** | | |
| Watercourse Improvement | 2 | - |
| Introduction to On-farm Water Management | 2 | - |
| Units of water measurement | 2 | - |
| Flow measurement devices | 2 | - |
| Cutthroat flumes and conveyance losses | 4 | 2 |
| Data reduction from flume measurements and conveyance losses | 4 | - |
| Watercourse structures | 4 | - |
| Field trip to improved watercourse at Tikhriwala | - | 1 |
| Field trip to improved watercourse at Mona | - | 1 |
| Field trip to improved watercourse at Chiniot | - | 1 |
| Watercourse Design | | |
| Watercourse design aids | 3 | - |
| Use of levels | 2 | 1 |
| Bench mark survey | 2 | 5 |
| Profile survey of watercourse, data reduction, computations and plotting | 2 | 6 |
| Topographic survey of watercourse and its command area. Irrigation Department Warabundi | 2 | 14 |
| Computation of survey data and preparation of design sheets for watercourse | - | 5 |
| Field trip to OFWM Research and Training Center in Lahore | - | 1 |
| Evaluation and Improvement of Irrigation Practices | | |
| Methods of irrigation | 3 | - |
| Water management aspects of land leveling | 2 | - |
| Precision land leveling, data collection and computations | 4 | 4 |
| Irrigation design aids, basic information, equations and their use | 4 | - |
| Pan evaporation and consumptive use | 4 | - |
| Determining irrigation requirements and irrigation scheduling | 4 | - |
| Evaluation of farmers irrigation system and time required to irrigate | 2 | 3 |

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| Watercourse Cleaning and Maintenance | | |
| Difficulties in maintaining watercourses | 3 | - |
| Needs and benefits of watercourse cleaning | 2 | - |
| Implementation of a watercourse cleaning and maintenance program (conducted in cooperation with Agriculture Extension and Rural Sociology Department) | 2 | 5 |
| Examinations | 8 | - |
| | 67 | 49 |

Rural Sociology Department

| | | |
|---|---|---|
| Organizing of Watercourse Committee | | |
| Reasons for conservatism | 1 | - |
| Characteristics of village socio-cultural organization | 2 | - |
| Institutional development | 2 | - |
| Personal approaches | 1 | - |
| Evaluation of village problems and social relationships | - | 2 |
| Planning and organizing a watercourse committee to accomplish a cleaning and maintenance program (In cooperation with Irrigation and Drainage, Agricultural Extension Departments) | - | 1 |
| Watercourse Cleaning and Maintenance | | |
| Implementation of a watercourse cleaning and maintenance program (conducted in cooperation with Irrigation and Drainage and Agricultural Extension Departments) | - | (5) |
| Examinations | 3 | - |
| | 9 | 3 (5)* |

Agricultural Extension Department

| | | |
|---|---|---|
| Organizing a Watercourse Cleaning & Maintenance Program | | |
| Extension methods | 3 | - |
| Extension implications in cleaning and maintenance | 2 | - |

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| Convincing farmers to undertake a cleaning and maintenance program | 2 | - |
| Planning and organizing a watercourse committee to accomplish a cleaning and maintenance program (conducted in cooperation with Irrigation and Drainage Department and Rural Sociology) | - | (1) |
| Watercourse Cleaning and Maintenance | | |
| Implementation of a watercourse cleaning and maintenance program (conducted in cooperation with Irrigation and Drainage and Rural Sociology Departments) | - | (5) |
| Agronomic and Irrigation Improvement | | |
| Methods and results demonstration | 1 | - |
| How to conduct a method and results demonstration related to agronomic and irrigation improvement | 3 | - |
| Packaging extension teaching methods to meet a single program objective and evaluation of these objectives | 2 | - |
| Examinations | 3 | - |
| | 16 | (6)* |

Farm Management Department

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| Introduction | 1 | - |
| Farm business analysis | 2 | - |
| Computing farm costs and net returns from various enterprises | 2 | - |
| Economic principals | 2 | - |
| Effective organization of individual enterprises | 2 | - |
| Partial and complete budgeting | 3 | - |
| Narrative and supportative information for marketing, credit source, etc. | 2 | - |
| Summary of procedures and recommendations | 2 | - |
| Field trip on economic analysis of farm plans | - | 1 |
| Examinations | 3 | - |
| | 19 | 1 |

Agronomy Department

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| Crop Production Guidelines | | |
| Cotton | 2 | - |
| Rice | 2 | - |
| Wheat | 2 | - |

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| Sugarcane | 2 | - |
| Fodder crops | 2 | - |
| Maize | 2 | - |
| Oil seed | 2 | - |
| Orchard | 2 | - |
| Field Demonstrations | | |
| Implementation of a rice, cotton or wheat planting and/or fertilizer demonstration in the field (depending on season, to be conducted in cooperation with Farm and Power Machinery Department) | 2 | 3 |
| Field Trips | | |
| Cotton Research Center at Multan | - | 1 |
| Maize Research Center at Yousufwala | - | 1 |
| PARI at Faisalabad | - | 1 |
| NIAB at Faisalabad | - | 1 |
| Rice Research Center at Kala Shah Kaku | - | 1 |
| Examinations | 4 | - |
| | 22 | 8 |

Soil Science Department

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| Soil science terminology and soils of Pakistan | 1 | - |
| Soils of Pakistan | 2 | - |
| Essential nutrients, functions and symptoms | 2 | - |
| Nutrient mobility in soils | 2 | - |
| Making fertilizer recommendations | 2 | - |
| Soil salinity - SAR & ESP | 2 | - |
| Quality of irrigation water | 2 | - |
| Soil science field trip | - | 1 |
| Examinations | 3 | - |
| | 16 | 1 |

Farm Power and Machinery Department

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| Machinery for agriculture | 2 | - |
| Operation of bullock and tractor drawn agricultural machinery | | 8 |
| Implementation of a rice, cotton or wheat planting and/or fertilizer demonstration in the field (depending on season, to be conducted in cooperation with Agronomy Department) | - | (3) |
| Examinations | 2 | - |
| | 4 | 8 (3)* |
| Grand Total of Course | 153 | 69 |

*Conducted in cooperation with other departments and time counted in cooperating departments total.

## APPENDIX II

Training course curriculum for Agricultural Officers/Assistants of the Agricultural Extension Service.

| Subject | Lecture (Hours) | Field (Days) |
|---|---|---|
| **Irrigation and Drainage Department** | | |
| Watercourse Improvement | | |
| Introduction to On-Farm Water Management Project | 2 | - |
| Units of water measurement | 2 | - |
| Flow measurement devices | 2 | - |
| Cutthroat flumes | 2 | - |
| Installation of flumes and flow measurements | - | 1 |
| Seepage loss on watercourses | - | 1 |
| Observation of improved and unimproved watercourses | - | 1 |
| Field visit to OFWM teams in Faisalabad area | - | 1 |
| Evaluation and Improvement of Farmers Irrigation Practices | | |
| The irrigation system of Pakistan | 1 | - |
| Methods of irrigation (bed and furrow, basin, etc.) | 3 | - |
| Field techniques of soil moisture determination | 2 | - |
| Water management aspects of precision land leveling and maintenance of level fields | 2 | - |
| Evaluation of farmers time required to irrigate (before and after cleaning and maintenance) | 1 | 2 |
| Cleaning and Maintenance of Unimproved Watercourses | | |
| Needs and benefits of watercourse cleaning | 2 | - |
| Implementation of a cleaning and maintenance program on an unimproved watercourse (conducted in cooperation with Agricultural Extension and Rural Sociology Departments) | 2 | 5 |
| | 21 | 11 |
| **rm Power and Machinery Department** | | |
| Agricultural machinery for land leveling and maintaining level fields | - | 1 |
| | 0 | 1 |

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| **Agronomy Department** | | |
| Crop Production Guidelines | | |
| Wheat | 2 | - |
| Cotton | 2 | - |
| Rice | 2 | - |
| Sugarcane | 2 | - |
| Maize (Grain) | 2 | - |
| Fodder crops | 2 | - |
| Agronomic implications of increased water availability through watercourse cleaning and maintenance | 2 | 1 |
| Efficient use of irrigation water on agronomic crops | 2 | 1 |
| Rooting characteristics of field crops | 2 | - |
| Demonstrations on bed and furrow making, planting and irrigation techniques | - | 2 |
| | 18 | 2 |
| **Soil Science Department** | | |
| Soils of Pakistan | 1 | - |
| Physical properties of soil as related to water management | 1 | - |
| Soil salinity and alkalinity | 1 | - |
| Water quality standards and use of saline water for irrigation | 2 | - |
| Consumptive use calculations and water holding capacity determinations | 2 | - |
| Soil reclamation and soil amendments | 2 | - |
| Nutrient deficiency symptoms of crops | 1 | - |
| Fertilizer requirements and irrigation relationships | 2 | - |
| | 12 | 0 |
| **Agricultural Extension Department** | | |
| Extension methods | 3 | - |
| Extension implications in cleaning and maintenance | 2 | - |
| Convincing farmers to undertake a cleaning and maintenance program | 2 | - |
| Planning and organizing a cleaning and maintenance program (conducted in co-operation with Irrigation and Drainage Department and Rural Sociology) | - | (1) |
| Implementation of cleaning and maintenance program of an unimproved watercourse (conducted in cooperation with Irrigation and Drainage and Rural Sociology Departments | 1 | (5) |
| | 7 | (6)* |

| | Lecture (Hours) | Field (Days) |
|---|---|---|
| **Rural Sociology Department** | | |
| Reasons for conservatism | 1 | - |
| Characteristics of village socio-cultural organization | 2 | - |
| Institutional development | 2 | - |
| Personal approaches | 1 | - |
| Evaluation of village problems and social relationships | - | 2 |
| Planning and organizing a cleaning and maintenance program (in cooperation with Irrigation and Drainage, Agricultural Extension Departments) | - | (1) |
| Implementing a cleaning and maintenance program of an unimproved watercourse (5 days, conducted in cooperation with Irrigation and Drainage and Agricultural Extension Departments) | 1 | (5) |
| | 6 | 2 (6)* |
| **Farm Management Department** | | |
| Introduction of farm planning | 1 | - |
| Concepts of partial budgeting | 1 | - |
| Economic organization of individual crops | 2 | - |
| Selection of most economical crops for production | 2 | - |
| Economic benefits of increased water availability through cleaning and maintenance of a watercourse | 2 | - |
| Economics of land leveling | 2 | - |
| | 10 | 0 |
| Grand Total of Course | 74 | 18 |

*Conducted in cooperation with other Departments and time counted in cooperating departments total.

APPENDIX 30

# THE WATER USER ASSOCIATION RESEARCH PROJECT AN INTERIM REPORT[1]

Ashfaq Hussain Mirza and Douglas J. Merrey[2]

## INTRODUCTION

### A. Background: The On-Farm Water Management Project

During this decade there has been a major change in development strategy in many developing countries, including Pakistan. In the past there has been an emphasis on large-scale capital-intensive projects such as dams and steel mills. While such projects have undoubtedly contributed much to increasing the GNP, and have increased the potential for further development, it has become obvious that they have not substantially improved the employment opportunities or incomes of the poor who form the majority of the population. The same observation applies to the so-called "Green Revolution": while overall agricultural production dramatically increased, the benefits have accrued mainly to the large farmers and not to the vast majority of small farmers. Furthermore, agricultural production has stagnated again in recent years.

In Pakistan, even before the completion of the Tarbella Dam Project, research on local watercourses and water management practices demonstrated that huge amounts of water are being wasted, and that at a relatively low cost this water could be conserved and utilized for increasing both agricultural production and the well-being of millions of small farmers. The Pakistan Government therefore launched the On-Farm Water Management Pilot Project. This Project aims to improve water management practices, and thus agricultural production, by:

1. organizing farmers to improve the efficiency of their watercourses;
2. aiding farmers in precision leveling of their fields;
3. encouraging farmers to adopt better irrigation and cultivation practices.

To help farmers reduce their watercourse losses, the Government provides technical advice, and pakka nakkas, check structures, and pakka lining where necessary; the farmers sharing the watercourse must form an executive committee to coordinate their efforts, and they must provide all labor.

1/Research carried out under USAID Agreement No. 204-77-3. Technical support provided by CSU under Contract AID/ta-C-1411.

2/Principal Investigator, Agriculture University, Faisalabad, and Assistant Professor, Dept. of Sociology, CSU.

This project has made considerable progress in Punjab; the OFWM Directorate claims over 100 watercourses completed or under construction.

## B. Objectives of this Study

The OFWM Project is specifically directed toward helping small farmers. Because of the small land holdings a relatively large number of farmers share each watercourse. A critical problem has been that of effectively organizing farmers, especially for maintenance of watercourses after improvement. Frequent and regular maintenance is essential if the farmers are to reap the benefits of watercourse improvement. University of Agriculture, Faisalabad, was therefore asked to do a study on the possibilities of organizing water users associations on each watercourse. The study is divided into two stages. Stage one is further subdivided into two phases. The specific objectives of phase one are to:

1. ascertain the degree of success of farmers in organizing to maintain improved watercourses;
2. identify the major characteristics of rural society that both inhibit and promote effective farmer organization;
3. identify the types of village and watercourse social organization where water users associations are most likely to succeed; and
4. based on the results of phase one research, suggest alternative modes of organization to be tested in phase two of the study.

In phase two water users associations are to be established on several watercourses in order to test various modes of organization on different types of watercourses. Their progress will be carefully monitored. Based on this experience, the project will make definite policy recommendations to the Government on the most effective means of organizing water users associations.

During stage two similar research will be initiated in the North West Frontier Province (NWFP) and Sind, to be carried out by local institutions in these Provinces under separate contracts.

## C. Theory and Assumptions

This report makes several assumptions. These are:

1. the reader is already familiar with the OFWM Project;
2. the OFWM Project is basically a sound and practical program that can make a significant contribution to rural, social and economic development;
3. the future of Pakistan's agriculture lies in development of small and medium size farms;

4. the organization of farmers into larger self-managed democratic organizations through which they can help themselves socially and economically is essential to the future of Pakistan; and
5. organizing water users associations to enable farmers to more effectively maintain and manage their irrigation water is the key to the success of the OFWM Project, and beyond that, the experience of farmers in this project may encourage them to organize and cooperate in obtaining credit and other inputs, storage and marketing of their product and other self-help activities.

In the past, social scientists often "explained" peasant agriculturists' behavior in terms of their "irrationality", "tradition", "ignorance", and the like. However, this study is based on recent social science theory that emphasizes the essential rationality of individual actors, including peasant farmers, within the limits of perceived social economic, and ecological constraints and information available to them. To "explain" behavior by saying it is "traditional" is no explanation at all. Furthermore, peoples' own conscious explanations of a particular behavior, while important as data, are usually insufficient in themselves as explanations.

This is not to say that farmers are necessarily "rational" in the narrow sense assumed by economists; one cannot assume farmers are necessarily motivated by the desire to maximize their monetary profit. In fact, people in all societies have various combinations of goals, which are often contradictory, and rarely conform to the western-trained economists' assumptions (or hopes). The social scientist must attempt to identify the multiplicity of factors, conscious and unconscious, material and nonmaterial (culturally-defined goals and perceptions), which generate particular kinds of decisions and lead to particular patterns of behavior. Only then can he successfully design innovations, such as new forms of organization, that will be perceived as beneficial by the clients and adopted.

D. Methods

Both the Mona Reclamation Experimental Project and the OFWM Project have reconstructed a number of watercourses in various areas of the Punjab. Since the total number of watercourses completed is small, a random sample would not be meaningful; instead we are choosing an "opportunity sample." In order to observe the level of maintenance we have tried to select watercourses that have been completed some time ago. We have also tried to select watercourses that have different characteristics; for example the Mona Project watercourses are in a SCARP area, while the Faisalabad area ones are not.

We are using four questionnaires as the basic core of our research strategy. Three are completed utilizing key informants to collect data on village social structure, watercourse social and land holding patterns, and the process of watercourse improvement. The fourth is administered to either a random sample of, or all, watercourse shareholders, depending on the number: generally 15-25 persons are interviewed. This questionnaire is designed to collect data on the interviewee's economic condition, participation in improvement, opinions and perceptions of problems, and possible solutions.

Since we are interested in gathering data on human interrelationships--group and individual patterns of conflict and cooperation, dependence on simple survey methods is inadequate. People are reluctant to discuss these matters with outsiders and in fact usually try to suppress them. Therefore it is essential for our study to supplement the use of questionnaires with more informal "participant observation" techniques. Our Research Officers therefore have spent 10 to 15 days on each watercourse studied. In addition to using the questionnaires, they have spent hours in informal discussions with people, trying to gain their confidence, and probing for a deeper understanding of the interplay of human relationships of village social life. In the end this method is a compromize. Ten to 15 days is not enough time to completely understand these matters; yet more time cannot be spent because of the necessity of covering a sufficient number and variety of watercourses to discover the range of variation, and the extent to which similar problems are found on all watercourses.

E. Hypotheses

The following are the working hypotheses guiding this research. Each hypothesis listed is based on the assumption of "all other things being equal."

1. Effect of Physical Characteristics

a. Where farmers perceive a shortage of water they are more likely to cooperate to maintain the watercourse. On watercourses in shortage areas farmers are more likely to have tried to maintain their watercourse well before improvement, and the level of maintenance after improvement should be relatively good. Since cooperation among shareholders is essential for effective maintenance, good maintenance is an indicator of ability to cooperate with little or no outside aid.

b. In SCARP areas where water is relatively abundant, even though more water is wasted, there will be less cooperation to maintain the watercourse.

c. Long single-branch watercourses will be relatively well maintained as water must travel further, increasing potential losses, and more farmers will have a greater interest in maintenance; watercourses consisting of several relatively short branches will be relatively less well maintained.

2. Sociological Factors

a. Effect of Inequality

i. On watercourses characterized by greater inequality in land holding (either among owners or among big owners and tenants), carrying out of reconstruction may be relatively easier but the likelihood of long term organization for maintenance will be less.

ii. The greater the equality of the distribution of power and influence, the more effective will be long term maintenance. However, if there are no people on the watercourse who have influence and respect--i.e. there are no constructive leaders--there will be relatively less cooperation.

b. Effect of Size of Holdings

The greater the percentage of small but economically viable (5-25 acres) holdings, the greater will be the interest in and incentive for maintenance. Farmers with very small holdings may see little incentive in the effort of improvement and maintenance, and in fact often have supplementary sources of income, reducing incentive further. Larger farmers tend to get the work done by servants and tenants who have little incentive to work effectively.

c. Effect of Biraderi/Zat Structure

Patterns of cooperation and conflict will be biraderi-based. Successful organization for improvement and maintenance is more likely on single-biraderi watercourses or on watercourses where biraderis have evolved mutually acceptable conflict resolution mechanisms. Watercourses dominated by two zats or biraderis with equal power/influence will be highly polarized, and cooperation will be problematical. These expectations also apply to sectarian divisions, especially where these overlap with kinship divisions.

d. Effect of Location on the Watercourse

Since middle and tail farmers tend to benefit proportionally more from improvement and maintenance they will have more incentive to cooperate to carry out maintenance. Where influential and powerful farmers are concentrated at the head, there will be significantly less cooperation for maintenance; where they are concentrated at the tail there will be more.

e. Effect of Previous Relationships

Where the farmers have cooperated on other projects (schools, cooperatives, roads, joint tubewells) they are more likely to cooperate for maintenance of their watercourse. Where there is a previous history of conflict and hostility, there will be less cooperation on the watercourse.

f. "Settlers" (families who settled the canal colonies when the canals were built) and "refugees" (families who came from India after Independence) are more likely to be able to cooperate than the original inhabitants ("locals" predating the canal system). For reasons that are not entirely clear, "locals" have a reputation for being more quarrelsome and litigous than others.

g. Farmers with greater exposure to mass media, more education, greater interaction with Government officials, and greater adoption of new cultivation practices are more likely to perceive the value of watercourse improvement and maintenance and are more likely to cooperate for maintenance.

In real life, "all things being equal" does not hold, of course, behavior is the result of a complex interaction of many factors. Hypotheses such as those listed above oversimplify. The value of the intensive methods we have adopted is that they make it possible to identify relationships and mechanisms that can at best be inferred or assumed in a purely statistical survey.

F. Progress to Date

A number of administrative problems delayed the project for many months. The research was begun in June 1978, in the Mona Project area. By mid-August the four watercourses, two in the Mona area, and two near Faisalabad, reported on here had been completed. As this report is written the sixth watercourse is nearly complete. Various factors have combined to delay the project; monsoon rains; the theft of our office typewriter and subsequent harrassment of our employees by the police; the involvement of the project Jeep in an accident, causing injuries to our Research Officers that kept them from work for some time; difficulty of travel for a month while the Jeep was being repaired; Eid holidays; rapid turnover in Research Officers and the slow procedures that must be followed to replace them; and further administrative problems in getting the second installment ot the financial grant, which has taken up much of the Principal Investigator's time.

Barring unforeseen further delays, we hope to complete ten watercourses by the end of December 1978. Thus the final report on phase one will be based on a sample of ten watercourses.

G. Purpose of this Report

This is an interim report, written to inform concerned persons of what has been accomplished so far. The conclusions and recommendations presented here are tentative. However, we hope it will stimulate thought and discussion. The authors will welcome comments and criticisms of their assumptions, methods, conclusions, and recommendations. We shall judge the success of this report by the quality and quantity of constructive suggestions and criticisms generated, and not by the mellifluousness of songs of praise.

## PRESENTATION AND COMPARISON OF THE DATA

A. General Introduction and Village Social Structure

Table 1 presents basic technical data on the four watercourses discussed in this report. Two are in the Mona Project, SCARP II area, while the other two are in District Faisalabad and were improved by the On-Farm Water Management (OFWM) Directorate, Punjab. One of these has a supplementary tubewell owned by the village Cooperative Society; the other has no tubewell and has less water available than the other watercourses.

Table 2 summarizes the basic outline of village social structure data in comparative form. In both the Mona Project villages the agricultural households are one third or less of the total households, whereas they form a majority of village households in the Faisalabad area villages. In all four villages a very large percentage of the agriculturalists are owners of their own land. Both the Faisalabad villages are larger than the Mona Project villages--Chak D is especially large with 658 households. Both of these Faisalabad villages are overwhelmingly single-caste villages, while both the Mona Project villages are multi-caste. Chak B is especially divided in this respect. Finally, religious sectarianism was not a factor in any of these villages.

Table 1. Basic watercourse data.

| | Chak A Distt: Sargodha | Chak B Distt: Sargodha | Chak C Distt: Faisalabad | Chak D Distt: Faisalabad |
|---|---|---|---|---|
| 1. Improving organization | Mona Project | Mona Project | OFWM, Punjab | OFWM, Punjab |
| 2. Tubewells | SCARP II | SCARP II | Cooperative | None |
| 3. Name of canal | Lower Jhelum--Northern Branch | Lower Jhelum--Northern Branch | Jhang Branch | Rakh Branch |
| 4. Name of distributary | Ratokala | Fatehpur | Khai | Lakhuana |
| 5. Branches (sarkari) | Single | Single | Single | Multiple |
| 6. Major crops | Kinno, wheat, rice | Kinno, wheat, sugarcane | Sugarcane, wheat, cotton | Sugarcane, cotton, maize |
| 7. Total culti. area--village | 1363 acres | 674 acres | 965 acres | 2525 acres |
| 8. Commanded area, village | 1363 acres | 674 acres | 890 acres | 1825 acres |
| 9. No. of moghas | 2 | 2 | 3 | 4 |
| 10. No. of improved w/c | 2 | 2 | 3 | 1 |
| 11. Sample w/c commanded area | 463 acres | 337 acres | 290 acres | 375 acres |
| 12. Discharge: Mogha | 1.76 cusecs | 1.11 cusecs | 1.58 cusecs | 1.48 cusecs |
| Tubewell | 1.33 cusecs (approx.) | 1.50 cusecs | 1.41[1] cusecs | 0 cusecs |
| Total | 3.09 cusecs | 2.61 cusecs | 2.99 cusecs | 1.48 cusecs |
| 13. Total length w/c (sarkari) | 9,000 feet | 10,000 feet | 9,840 feet | 17,850 feet |
| 14. Date completion improvement | October 76 | May 77 | December 77 | April 78 |
| 15. Date studied | June 78 | July 78 | July-August 78 | Aug.-Sept. 78 |

1/The 2JB cooperative tubewell is run far less frequently than SCARP tubewells.

Table 2. Summary of social structure of sample villages.

| Village | Chak A | | Chak B | | Chak C | | Chak D | |
|---|---|---|---|---|---|---|---|---|
| No. and percent | No. | % | No. | % | No. | % | No. | % |
| Agric. household | 70 | 33 | 48 | 27 | 154 | 55 | 477 | 73 |
| Non-Agric. " | 142 | 67 | 132 | 73 | 127 | 45 | 181 | 27 |
| Total | 212 | 100 | 180 | 100 | 281 | 100 | 658 | 100 |
| No. and percent Agriculturists who are | | | | | | | | |
| Owners | 60[1] | 86 | 37 | 77 | 131 | 85 | 347 | 73 |
| Tenants | 2 | 3 | 0 | 0 | 3 | 2 | 0 | 0 |
| Owners-Tenant | 8 | 11 | 11[2] | 23 | 20 | 13 | 130 | 27 |
| Total | 70 | 100 | 47 | 100 | 154 | 100 | 477 | 100 |
| Locals | 0 | 0 | 0 | 0 | 0 | 0 | 477 | 100 |
| Settlers | 54 | 77 | 48 | 100 | 153 | 99 | 0 | 0 |
| Refugees | 16 | 23 | 0 | 0 | 1 | 1 | 0 | 0 |
| Total | 70 | 100 | 11 | 100 | 154 | 100 | 477 | 100 |
| No. of Agric. subcastes | 7 | | 11 | | 3 | | 6 | |
| No. & % Agric. households in largest subcaste | (Gujjar) 35 | 50 | Jat Kahoot 16 | 33 | Jat Randhawa 150 | 97 | Jat Athwal 450 | 94 |
| 2nd largest subcaste | (Sayid) 13 | 19 | Jat Attar 6 | 13 | 1 | 1 | Jat Hanjra 12 | 3 |

1/ Includes village chowkidar who gets 2 acres land as remuneration.
2/ Includes 3 households of 1 zat not engaging in agriculture at the moment.

B. Watercourse Social Organization

1. Social Structure

a. Chak A

Table 3 shows that despite the multi-caste nature of the village, the Gujjars are numerically absolutely dominant on the watercourse. All except two of the households have their total landholdings on this watercourse; these two exceptions have their major holdings located on the other (also improved) watercourse in the village. On this watercourse, there are large, medium and small holdings. Table 7, on the distribution of size of landholdings in sample villages, shows that six farmers out of the total 21 own more than 25 acres total. The four farmers with the smallest holdings (2-6 acres) are all located at the head. The remaining eleven are medium sized, ranging from 11 to 23 acres. The largest holdings are generally located in the middle of the watercourse. With their large kinno orchards, the income of the larger land owners is probably substantial. Most of the non-Gujjars' land is located on the tail of the watercourse. All but one of the households in this village are settlers. Two of the three watercourse committee members from Chak A have more than 25 acres of land in the middle section of the watercourse; the third has 18 acres in the tail section. The Numberdar, with the largest land holding on the watercourse, is not a committee member, but the third member in fact is allied with him.

b. Chak B

Table 4 shows that this watercourse is multicaste in structure. All the major agricultural castes and subcastes of the village are represented on the watercourse, except the five Kariale and one Khokar households. However, three out of the five Kariale households in the village in fact do not possess any land. None of the village Shia households have land on this watercourse; all 32 households are Sunni. This village is predominantly a settler village.

Nineteen of the 32 households, nearly 60%, have total land holdings of more than 25 acres.[3] Of

3/The Mona Project is not governed by the rule that at least 75% of the farmers must own 25 acres or less, as is the OFWM Project. Also, in the legal records, many of these holdings are undoubtedly in the names of more than one person.

Table 3. Chak A watercourse structural attributes.

| S. No. | Major Caste | Sub-Caste | No. of house-holds | Religious sect | Settle-ment status[1] | Tenancy status |
|---|---|---|---|---|---|---|
| 1. | Gujjar | Same | 15 | Sunni | Settler | Owners |
| 2. | Malik | Khokar | 1 | Sunni | Settler | Owners |
| 3. | Sayyed | Same | 2 | Shia | Settler | Owners |
| 4. | Rajput | Raja | 1 | Sunni | Refugee | Owners |
| 5. | Jat | Jaisak | 1 | Sunni | Settler | Tenant |
| 6. | Muslim Sheikh | Same | 1 | Sunni | Settler | Tenant |
| | Total | | 21 | Sunni 19<br>Shia 2 | Settler 20<br>Refugee 1 | Owners 19<br>Tenant 2 |

1/Settlers are those who settled the village during British times as part of the colonization schemes.
Refugees are persons who came from India as a result of Partition.
Locals are original inhabitants, predating the canal system.

Table 4. Chak B watercourse structural attributes

| S. No. | Major Caste | Sub-Caste | Total No. of house-holds | Religious sect | Settle-ment status | Tenancy status |
|---|---|---|---|---|---|---|
| 1. | Jat | Kohoot | 10 | Sunni | Settlers | All owners |
| 2. | Jat | Attar | 3 | Sunni | Settlers | All owners |
| 3. | Jat | Bore | 2 | Sunni | Settlers | All owners |
| 4. | Jat | Mekan | 1 | Sunni | Settlers | All owners |
| 5. | Jat | Badhor | 3 | Sunni | Settlers | All owners |
| 6. | Jat | Jatriane | 2 | Sunni | Settlers | All owners |
| 7. | Jat | Marth | 1 | Sunni | Settlers | All owners |
| 8. | Malik | Tiwana | 5 | Sunni | Settlers | Mixed |
| 9. | Arain | - | 1 | Sunni | Refugees | Owner |
| 10. | Kasai | - | 1 | Sunni | Settler | Tenant |
| 11. | Musalli | - | 1 | Sunni | Settler | Tenant |
| 12. | Tarkhan | - | 1 | Sunni | Settler | Owner |
| 13. | Jat | Mianey | 1 | Sunni | Settler | Owner |
| Total | | | 32 | Sunni<br>Shias | Settler 31<br>Migrant 1 | Owner 25<br>Tenant 2<br>Mixed 5 |

these the largest holding is 80.5 acres, but ten are owners of 50 acres or more. However, only three of these own more than 25 acres on this watercourse. Two of these, one Bore (38.5 acres) and one Tiwana (31 acres) have all their land on this watercourse whereas the third, a Mekan, has 40.5 out of his total 50 acres on this watercourse. These three were watercourse improvement committee members. The fourth committee member, a Jatriane, owns 14.5 acres on this watercourse out of a total 50 acres. Thus it appears that size of land holding was a major criterion in choosing watercourse committee members.

c. Chak C

This is basically a single-caste village and watercourse. Table 5 shows that all the land on the watercourse is owned by Jat Randhawas; there are one Arain and one Mochi tenant. All but the Arain are settlers. Two of the Randhawa are Ahl-e-Hadith and three are Shia, but informants say there has never been any religious conflict in the village.

Only three farmers have total holdings larger than 25 acres; but one of these, the Arain, is a tenant. The largest holding is 37.5 acres; all of this land is on the watercourse under study. All of the other holdings are small, but not so small as to be economically nonviable. Nine farmers have some land on other watercourses, but even these farmers' major holdings are on this watercourse. Presumably this dependence on one watercourse encourages a greater commitment to the efficient operation of this watercourse.

d. Chak D

Table 6 shows that all the shareholders on this watercourse are Sunnis, locals, and own the land they cultivate. One Jat subcaste, the Athwal, dominates the watercourse. Forty-eight of the 56 shareholders have all their land on this watercourse. The holdings are generally small: there are 11 medium sized holdings (12 to 24 acres). Of these five have a greater part of their holdings on another watercourse. There are just three holdings of 25 or more acres; and 28 (50%) holdings of five acres or less.

Table 5. Chak C watercourse structural attributes.

| S. No. | Major Caste | Sub-Caste | No. of house-holds | Religious sect | | Settle-ment status | | Tenancy status | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Jat | Randhawa | 20 | Sunni | 15 | | | Owner | 16 |
| | | | | Ahle-Hadith | 2 | Settler | | Mixed | 2 |
| | | | | Shia | 3 | | | Tenant | 2 |
| 2. | Arain | Arain | 1 | Sunni | | Refugee | | Tenant | |
| 3. | Mochi | Mochi | 1 | Sunni | | Settler | | Tenant | |
| | Total | | 22 | Sunni | 17 | Settler | 21 | Owner | 16 |
| | | | | Ahl-e-Hadith | 2 | Refugee | 1 | Tenant | 4 |
| | | | | Shia | 3 | | | Mixed | 2 |

Table 6. Chak D watercourse structural attributes.

| S. No. | Major Caste | Sub-Caste | No. of house-holds | Religious sect | Settle-ment status | Tenancy status |
|---|---|---|---|---|---|---|
| 1. | Jat | Athwal | 46 | Sunni | Local | Owners |
| 2. | Jat | Hanjra | 6 | Sunni | Local | Owners |
| 3. | Jat | Isra | 2 | Sunni | Local | Owners |
| 4. | Jat | Saboke | 1 | Sunni | Local | Owners |
| 5. | Rajpur | Kharal | 1 | Sunni | Local | Owners |
| | Total | | 56 | | | |

e. Comparison: Size of Land Holdings

Table 7 shows the distribution of size of land holdings, both on the watercourse and total size for the four sample watercourses. Both of the Mona Project villages have relatively high percentages of large holdings. Both of the OFWM villages are well within the eligibility guidelines, having small percentages of farmers with 25 or more acres. However there is a major contrast between the two Faisalabad area villages: while the Chak C watercourse has no farmers with uneconomically small (less than five acres) holdings, in Chak D half of the total holdings are below five acres.

f. Comparison: Distribution of Power and Influence

We used a formal technique to elicit data on sample farmers' perceptions of the "power and influence" of other farmers on the watercourse. Briefly, we asked each person to rate all the others on the watercourse on their influence within their village and biraderi, and with Government officials, then scored the responses on a zero to four basis. The higher the percentage of a person's possible score achieved, the greater is his influence (see Appendix for a discussion of the method in more detail).

The "Centrality Ratio" refers to the percentage of farmers achieving 60% or more of their possible score; the higher the percentage, the larger the percentage of farmers who are perceived as influential by their fellow shareholders. The "Concentration Ratio" refers to the percentage of farmers' scores, beginning with the highest, whose sum equals one half of the total power and influence score of all shareholders. The closer this percentage is to 50, the greater is the equality of farmers' influence.

In Chak B as Table 8 shows, no one is perceived as having any significant influence, either within the village, or with Government officials. This is consistent with the extremely fragmented, multi-biraderi structure of the village and watercourse. Chak C exhibits the highest percentage of persons with significant influence in their village and biraderi (31.8%). Furthermore, unlike the other three watercourses, no one in Chak C is perceived as having zero or negligible influence: all command at least some respect among their fellows.

Table 7. Distribution of size of land holdings on sample watercourses.

| Size of land holdings | Chak A | | Chak B | | Chak C | | Chak D | |
|---|---|---|---|---|---|---|---|---|
| On sample watercourse | No. | % | No. | % | No. | % | No. | % |
| 25 acres or more | 6 | 28.6 | 4 | 12.5 | 3 | 13.6 | 1 | 1.8 |
| 12-24 acres | 10 | 47.6 | 14 | 43.7 | 10 | 45.5 | 6 | 10.7 |
| 5-11 acres | 2 | 9.5 | 4 | 12.5 | 7 | 31.8 | 12 | 21.4 |
| Under 5 acres | 3 | 14.3 | 10 | 31.3 | 2 | 9.1 | 37 | 66.1 |
| Total | 21 | 100 | 32 | 100 | 22 | 100 | 56 | 100 |
| Total land holding | | | | | | | | |
| 25 acres or more | 8 | 38.1 | 19 | 59.4 | 4 | 18.2 | 3 | 5.4 |
| 12-24 acres | 8 | 38.1 | 8 | 25.0 | 10 | 45.4 | 11 | 19.6 |
| 5-11 acres | 2 | 9.5 | 5 | 15.6 | 8 | 36.4 | 14 | 25.0 |
| Under 5 acres | 3 | 14.3 | 0 | 0 | 0 | 0 | 28 | 50.0 |
| Total | 21 | 100 | 32 | 100 | 22 | 100 | 56 | 100 |

Table 8. Summary and comparison of power and influence on sample watercourse.

| | Chak A | | Chak B | | Chak C | | Chak D | |
|---|---|---|---|---|---|---|---|---|
| | Village/ Biraderi | Govt. Off. | Village/ Biraderi | Govt. Off. | Village/ Biraderi | Govt. Off. | Village/ Birader | Govt. Off. |
| Centrality Ratio[1] | 19% (4/21) | 19% (4/21) | 0 | 0 | 31.8% (7/22) | 13.6% (3/22) | 11% (6/56) | 5.35% (3/56) |
| Concentration Ratio[2] | 19% (4/21) | 14.3% (3/21) | 21.9% (7/32) | 15.6% (5/32) | 36.3% (8/22) | 22.7% (5/22) | 27% (15/56) | 14% (8/56) |

1/Percentage of farmers achieving 60% or more of possible score.
2/Percentage of farmers score equal to half the total power/influence score.

Table 9. Institutional services available in village.

| Service | Chak A | Chak B | Chak C | Chak D |
|---|---|---|---|---|
| 1. On pakka road | yes | - | yes | yes |
| 2. Bus stop | yes | - | yes | - |
| 3. Train station | - | - | - | - |
| 4. Boys' primary school | yes | yes | yes | yes |
| 5. Girls' primary school | yes | yes | yes | - |
| 6. Boys' middle school | - | - | yes | - |
| 7. Girls' middle school | - | - | yes | - |
| 8. Boys' high school | yes | - | yes | - |
| 9. Girls' high school | - | - | - | - |
| 10. Medical dispensary | - | - | yes | - |
| 11. Veterinary dispensary | - | - | yes | - |
| 12. Bank branch | yes | - | yes | - |
| 13. Cooperative Society | - | - | yes | - |
| 14. Post Office | yes | yes | yes | yes |
| 15. Fertilizer Agency | - | - | yes | yes |
| 16. Resident Field Assistant | yes | yes | yes | yes |
| 17. Electricity | yes | - | yes | - |
| Total | 10 | 5 | 15 | 5 |
| Miles from nearest city | 8 | 6 | 10 | 10 |

Chak A has the second highest centrality ratio on the village and biraderi parameter (19%), but the highest on the influence with Government officials parameter (19%). Chak D has a relatively low centrality ratio on both parameters.

The differences among the four villages in concentration ratio is less significant: in village influence the highest is Chak C (36.3%), the lowest Chak A (19%). Influence with Government officers is generally concentrated in even fewer hands than influence within the biraderi.

2. <u>"Progressiveness" of Sample Farmers</u>

"Progressiveness" is very difficult to measure. In general the concept refers to openness to new ideas, willingness to experiment, and a desire to improve one's way of life. One indirect measure of the overall progressiveness of a village is to look at the institutional services available. Table 9 shows that Chak C has the most services, followed by Chak A. The other two villages have significantly fewer services. There seems to be no correlation between availability of services, and differences in the number of large land holdings or distance from the city.

We have also tried to measure "progressiveness" of sample farmers by examining their educational level, and use of radio, since these are frequently associated with willingness to modernize. Education above the primary level is likely to be indicative of progressiveness; primary education is probably insufficient to change attitudes since persons with a primary education are often functionally illiterate.

Table 10 shows that the educational achievements of sample farmers are consistent with the number of institutional services available in the village: Chak C and Chak A respondents have significantly higher educational levels than the other two villages; fewer than ten percent of the Chak D farmers have any education at all. Table 11, showing frequency of radio listening by sample farmers, is also consistent with the above trends, but not decisively so.

The final measure of "progressiveness" we have experimented with involves asking sample farmers about the helpfulness of ten kinds of government employees they are likely to come into contact with. Their answers were converted to numerical scores and added together. Table 12 gives the results, which again are consistent with other measures. While over 70%

Table 10. Distribution of sample farmers by educational achievement.

| Education completed | A No. | A % | B No. | B % | C No. | C % | D No. | D % |
|---|---|---|---|---|---|---|---|---|
| None | 4 | 26.67 | 4 | 25.00 | 2 | 11.77 | 20 | 90.91 |
| Primary (1-5) | 2 | 13.33 | 7 | 43.75 | 1 | 5.88 | 0 | 0 |
| Middle (6-9) | 3 | 20.00 | 3 | 18.75 | 8 | 47.00 | 2 | 9.09 |
| Matriculate (10-11) | 4 | 26.67 | 1 | 6.25 | 4 | 23.53 | 0 | 0 |
| F.Sc/F.A (12) | 0 | 0 | 1 | 6.25 | 1 | 5.88 | 0 | 0 |
| Graduate (BA/B.Sc) | 2 | 13.33 | 0 | 0 | 1 | 5.88 | 0 | 0 |
| Total | 15 | 100 | 16 | 100 | 17 | 100 | 22 | 100 |
| Total middle or above education | 8 | 60.00 | 5 | 31.25 | 14 | 82.35 | 2 | 9.09 |

Table 11. Use of radio by sample farmers.

| Times listened in a week | A No. | A % | B No. | B % | C No. | C % | D No. | D % |
|---|---|---|---|---|---|---|---|---|
| Frequently | 4 | 26.67 | 6 | 37.50 | 8 | 47.06 | 2 | 9.09 |
| Sometimes | 3 | 20.00 | 1 | 6.25 | 2 | 11.77 | 0 | 0 |
| Never | 8 | 53.33 | 9 | 56.25 | 7 | 41.17 | 20 | 90.91 |
| Total | 15 | 100 | 16 | 100 | 17 | 100 | 22 | 100 |

Table 12. Sample farmers' perceptions of helpfulness of government services.[1]

| Score | A No. | A % | B No. | B % | C No. | C % | D No. | D % |
|---|---|---|---|---|---|---|---|---|
| Very helpful (10-22) | 4 | 26.7 | 0 | 0 | 6 | 35.29 | 3 | 13.64 |
| Some help (5-9) | 7 | 46.7 | 7 | 43.8 | 6 | 35.29 | 8 | 36.36 |
| Little help (1-4) | 4 | 26.7 | 9 | 56.2 | 3 | 17.65 | 7 | 31.82 |
| None/harmful (0 or below) | 0 | 0 | 0 | 0 | 2 | 11.77 | 4 | 18.18 |
| Total | 15 | 100 | 16 | 100 | 17 | 100 | 22 | 100 |

1/We asked farmers to rate the helpfulness of the following: Agricultural Officer, Field Assistant, Bank/Credit people, Cooperatives Department, Revenue Patwari, Canal Patwari, Zilidar, Canal SDO, Overseer, Watercourse Area Team, Watercourse Committee. The answers were scored as very helpful = +2, harmful = 2, no contact or no help or harm = 0, +1 and -1 were also used for less extreme statements. The scores awarded to each service by each respondent was totalled.

Table 13. Summary of "progressiveness" ranking.

| Parameter | Ranking 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Avail Institute Services | C | A | D[1] | B[1] |
| Educational level | C | A | B | D |
| Frequency Radio listening | C | B | A | D |
| Helpful Government Services | A | C | D | D |
| Overall rank (score) | C (15) | A (12) | B (8) | D (6) |

Scoring: Each instance of rank No. 1 = 4, No. 2 = 3, No. 3 = 2, No. 4 = 1. Maximum score is 16, minimum is 4.

1/Chaks D and B rank equally on institutional services so both are awarded 2 points.

of the respondents in both Chak C and Chak A rated Government services as of some help or very helpful, 50% or fewer of the respondents in the other two villages rated government services so highly. It is notable that in both the Faisalabad villages some farmers rated government services negatively-harmful--overall, while no farmers felt so negatively in the Mona Project area.

Table 13 shows the ranking of each village by the four "progressiveness" measures used, and the ranking "score" achieved: it shows Chak C ranking as the most "progressive" followed by Chak A, Chak B and D.

3. Intergroup Relations Before Improvement

In order to predict the likelihood of success of a watercourse improvement program (or any other social action program) it is necessary to understand the basic relationships among key individuals and groups. Therefore, in this section, short descriptions of these relationships are presented.

a. Chak A

Even though the Gujars are numerically very dominant, Chak A is still a multicaste village. However, the existing factions are not based completely on caste structure. There are two leaders in the village who, in order to achieve dominance, have organized factions around their personalities. "X" is a religious-minded person who is interested in welfare-oriented projects. All of his land is on the other watercourse. One day we observed that he was personally supervising repair of the link road and also construction of a kacha link between the metalled road and the village. By and large, his support seems to come from small farmers and kamis.

The other major leader "Y" is a graduate (B.A.) and believed his education qualifies him as a leader. He projects an image of "progressiveness", and has successfully cultivated relations with various Government officials, though both leaders claim to have influence in the Government. Both are relatively large owners and commercially-oriented progressive farmers. In general, the larger farmers tend to support Y.

Both of them use every opportunity to enhance their own reputation at the other's expense--or at least to blacken the other's reputation. For example a man recently put a drum into the distributary to obstruct the water flow and thus steal extra water. Leader Y is said to have reported this to the police, with the claim that he was X's man. Although X has been helping this man, he claims that he had no hand in his obstructing the water.

Similarly, during improvement of the first watercourse, Y served meals which turned out to be insufficient in quantity. The next time X served and pointedly prepared a surplus. The intention was to demonstrate his superiority to the other.

In the factional line-up, about 35 percent of the Gujars are in Y's group, which besides the Malik Khokhars, includes the Sayids and the Jaisak Jat. One reason for the split among the Gujars is that there is another rival Gujar leader who wants to establish his own leadership, and has allied himself with Y. He too is a big owner and has influence in the Government bureaucracy. Significantly, unlike the other two, all of his land is on the sample watercourse. He is therefore not forced to cooperate or compete with the other two over watercourse-related issues.

The tension between the two groups is very active, but has not resulted in any fights or even public incidents. Both the leaders are reported to plot behind the scenes to reduce the prestige and honor (izzat) and thus the number of followers of the other; but the differences do not prevent them from cooperating on road and watercourse construction and maintenance, or from presenting an appearance of unity to outsiders.

An undercurrent of tension and hostility was also noticed on the part of the small farmers against the big and the influential. This is not inseparable from the factional division as noted above. The small farmers complained of manipulation by the influentials to have Government officers act in their favor. As examples, the small owners pointed out that buffalo bathing tanks were built near the deras of the influentials. Of the total five on the two watercourses in the village, they say three were built very close to the deras of each of the three most influential farmers, for their exclusive use. Small farmers also complain that the big landlords manage to get tubewell water during "rest" periods whereas the tubewell water supply for them is interrupted even during their normal running times. Again, this tension between the small and large owners is not public, and does not prevent cooperation on projects or presenting a unified front to outsiders.

b. Chak B

The level of tension and hostility among some of the Jat subcastes seems very high at both the village and the watercourse level; one of our research officers noted that even the children rarely play in groups, apparently because of the tension. However, the villagers were reluctant to discuss these matters, and in the short time available, we were unable to penetrate their defenses and learn the details of their disputes. The Attar group is divided four households versus two over a land dispute, whose details are not clear. The Kariale and the Bore have each taken separate sides in this dispute as a result of a long-standing competition for influence in the village. There have also been several murders in Chak B resulting from these inter-biraderi disputes, but our data on these are also contradictory. Some smaller farmers (and tail farmers) expressed unhappiness with, and fear of, some of the larger owners. The absence of any influential leaders, as discussed in the power and influence section above, is both a result and an indication of the relationship among the residents of this village.

c. Chak C

This village is dominated by Randhawas. The Randhawa are not divided into named or bounded groups and emphasize their unity to outsiders. However, in fact, two "groups" have formed around two men competing for leadership in the village. Only one of these has land on this watercourse; the other has land on other watercourses. Both men are cousins (mother's brother's son/father's sister's son). Their competition led to one incident eight years ago in which shots were fired and several men wounded, leading to a court case.

Chak C has a Cooperative Society established about 60 years ago with contributions of Rs.10 to 20. During the 1960's the Society invested Rs.40,000 on three tubewells at the heads of three watercourses in the village; shareholders buy water at a rate of Rs.4 per hour. Five thousand rupees was also spent on building a girls' primary school, and 5,000 on the Union Council office. In addition, loans have been made to farmers.

The Society is under the control of one of the competing leaders (the one not on the sample watercourse) and is another issue dividing them. There is difficulty in recovering farmer loans, and the opposition to the controlling leader say they wish the Society to be dissolved. Some accuse the Secretary of the Society of misuse of funds, claiming he refuses to show the financial records to them. This tension has, however, had no effect on watercourse improvement or the ability to cooperate to maintain the three improved watercourses in the village.

d. Chak D

The dominant subcaste, the Athwal, are divided into two factions. The larger group is led by one of the four numberdars in the village. Though he has the nominal support of perhaps 90% of the Athwal, much of it is apparently not very committed. The other faction, though smaller, is led by an "obstructionist" who is willing to use violence to intimidate others and achieve his ends; and he is said to have a great deal of influence with the police. Most people are therefore afraid of him. He abducted the daughter of the leader of the other group which led to a shooting incident about seven years ago, resulting in injuries on both sides. Ten people were charged by the police and have spent time in jail; their cases are still being appealed.

The leader of the larger group has attempted to compromise, by attending prayers at the death of a member of the opposition party, for example, and also by offering to settle the court cases between them. These attempts have failed and the two groups do not attend each others' marriages or funerals.

Another numberdar, a watercourse committee member, is the former chairman of the Union Council and presently a member of the "Rabita Committee." He projects an image of "progressiveness" and is credited by some with having tried to bring improvements to the village. He tried to get a girls' primary school and electricity for the village while Chairman of the Union Council, and contributed land for the building of the boys' Primary School and for the Union Council building. This apparent "progressiveness" led to a vote of no confidence in him in the Union Council because of resistance to establishing a girls' school. He has also tried to bring about compromise in the above conflict but one of them refused, so he remains aloof from this conflict.

Neither of these numberdars is a strong leader, able to control his followers; hence the larger faction is not a bounded or unified group in any sense. There are jealousies and competition even within the group. Much of the tension and conflict is individual-based; and cooperation on joint projects is difficult because they do not have any effective mechanism for resolving disputes and controlling obstructionists.

4. The Process of Watercourse Improvement

a. Chak A

The other watercourse in Chak A was among the first improved by the Mona Project. Its success led three farmers on the sample watercourse to apply to the Mona Project for renovation in August 1976; these three subsequently became the committee members.

Table 14 reveals that the majority caste has two representatives on the committee. Two members are among the most influential men on the watercourse; the third, though not very influential himself, is a close relative of the numberdar. The Sayid is a close friend and ally of leader Y, and therefore is also associated with the Chairman of the committee.

The lined section was not in the original WAPDA plans (even though it passes through the village). The watercourse members themselves decided that they would pay for pakka nakkas provided the section of the watercourse through the village was lined instead. WAPDA agreed to this.

The general formula for dividing the improvement work was assignments in proportion to land holding. The committee oversaw all of the work. Two general meetings were held: one for fixation of the location of pakka nakkas and one to make a decision on having a lined section and paying for pakka nakkas.

There was no significant conflict among the Chak A farmers during the improvement project. With regard to just one decision, a change in the watercourse route, one farmer opposed it, but later agreed, though unhappily. This was a man owning

Table 14. Characteristics of Chak A committee members.

| Caste | Landholding Vill. | Landholding W/C | Locat. | % B/V[1] Score | % G/O[2] Score | Any other position |
|---|---|---|---|---|---|---|
| Gujjar | 37½ | 37½ | Middle | 48 | 32 | - |
| Gujjar | 29 | 29 | Middle | 91 | 89 | Chairman |
| Sayid | 18 | 18 | Tail | 96 | 93 | - |

1/B/V = "Biraderi Village" - percent of possible score in power/influence.
2/G/O = "Government Officer" - percent of possible score in power/influence.

Table 15. Characteristics of committee members.

| Caste/ subcaste | Landholding Vill. | Landholding W/C | Location on W/C | % B/V[1] Score | % G/O[1] Score | Any other position held |
|---|---|---|---|---|---|---|
| Bore | 38½ | 38½ | Middle | 57 | 40 | - |
| Jatriana | 50 | 14.6 | Head | 16 | 11 | - |
| Tiwana | 31 | 31 | Head | 42 | 35 | - |
| Mekan | 50 | 40.5 | Middle | 50 | 28 | - |

1/See notes to Table 14.

Table 16. Distribution of support and opposition on decisions during the process of watercourse improvement.

| Issue | Supporters/ gainers | Opposition birader | acres | position | Final decision |
|---|---|---|---|---|---|
| a. Uprooting trees | All others | 1 Kahoot | 50 | H | All but one cut his trees |
| | | 1 Badhore | 25 | M | |
| | | 1 Marth | 50 | M | |
| | | 1 Kahoot | 50 | T | |
| b. Point from which digging to start | All others | 1 Kahoot | 50 | H | Acceptance of WAPDA decision to start at tail |
| | | 1 Tiwana | 80½ | H | |
| | | 1 Qasai | 2 | H | |
| | | 1 Badhore | 12½ | H | |
| c. Rerouting watercourse | 1 Bore (Committee member) | 1 Badhore | 12½ | H | Acceptance of Irrigation Department decision in favor of the Bore |
| | | 1 Mekan | | | |
| | | 1 Bahore | 25 | H | |
| | | 1 Kahoot | 29 | M | |
| d. Nakka location and No. | All others | 1 Kahoot | 50 | H | Compromise with WAPDA |
| | | 1 Badhore | 25 | H | |
| | | 1 Kahoot | 29 | M | |
| e. Division of work | All | None | | | 2 did not work; others did their share |
| f. Section to be lined | - | - | | | No section lined |

20 acres of land split into two parcels, 16 acres at the head and 4 acres in the middle. He lost some land as a result of rerouting while his brother gained. He considers the change illegal and complained to the researchers, but had not pursued the case further.

Although the leaders of Chak A claimed that decisions were taken by simple majority vote rule, small owner informants claimed that decisions were made not by a voting rule but by committee members who, along with other influentials, so dominated the situation that free expression was not possible. All decisions were taken by the committee which was dominated by the most powerful farmers in the village.

This watercourse also irrigates portions of nine squares of land at the tail located in another village, "E". There are 27 E farmers on the watercourse, divided into four different castes. All of them seem to be small land holders, with little or no education.

Although the E channels appear to be part of the "sarkari khal" (the Mona Project maps are contradictory on this point), this part was left unimproved. When contacted, the farmers of E claimed that before the improvement began they were told their portion would also be improved, and therefore one committee member was selected from among them. The E farmers did their share of the work but when the work was completed up to the end of Chak A land and the beginning of theirs', the Mona Project personnel refused to extend the construction further. The Mona Project people we contacted claimed that the E farmers were not willing to improve the tail portions irrigating their land. However, informants in Chak A supported the viewpoint of the E farmers.

Another reason given by Mona Project people was that only the main channel was to be improved under their plans and E's portion was considered to be a branch line like the other two branches in Chak A and hence not improved. The E farmers expressed great dissatisfaction and claimed that they are suffering from a severe water shortage. They claim that they get less water than before improvement; some of them tried to improve their watercourse themselves, but without success. Futher, they accuse two Chak A farmers (both committee members) of stealing water during their time and claim the tubewell is shut off during their time.

The Chak A leaders, who refer to the E farmers as "jangalis", may have played a role in misleading them. The E farmers certainly believe this to be true. Be that as it may, our research assistants arranged a meeting between Mona Project personnel and these E farmers, but it appeared they were too divided among themselves to cooperate on a heavy cleaning and maintenance project on their portion of the watercourse. The E farmers are not included in our random sample as we learned of them only near the end of our stay in Chak A and their committee representative was not available. If they had been included, the generally positive image of this watercourse would have been somewhat reduced.

b. Chak B

On this watercourse the farmers were apparently pursuaded by the Mona Project extension staff to improve their watercourse. The first meeting of the watercourse members was held in December, 1976; then an application for renovation was filed on January 18, 1977. The criteria for selection of the watercourse executive committee members are unclear, but as discussed above, and as the data summarized in Table 15 suggest, size of landholding seems to have been the main criterion. No chairman was ever selected. The Mona Project staff apparently nominated the members in a general meeting. The largest subcaste, the Kahoot, is not represented; nor were the farmers at the tail of the watercourse represented directly. Three of the four members have the three highest scores in biraderi/village influence.

Table 16 lists the decisions during watercourse improvement that led to controversy:

i. The four farmers who opposed cutting of the trees are from three different biraderis and located at the head, middle and tail. All four have relatively large landholdings. The main argument they put forward is that the trees are Government property. Ultimately all agreed to remove their trees except one, a Kahoot owning land at the head of the watercourse.

ii. WAPDA decided digging for kacha improvement should begin at the tail; four head farmers were opposed but finally cooperated in the digging.

iii. A dispute arose between two farmers, a Bore, and a Badhore, over the route of the watercourse in the middle sections; the Bore claimed the old route was wrong, and the watercourse should be rerouted through land belonging to the Badhore. Two other farmers, a Badhore and a Kahoot, apparently supporting the Badhore, proposed the work continue on the old route, but the Bore refused until the case was settled. Ultimately the Irrigation Department was called on to make a decision, which was made in favor of the Bore; that is, they sanctioned the new route. Mona Project personnel supported this decision and the watercourse was built on the new route. At the time of our research, there was still bitterness between the Bore and the Kahoots (who had strongly supported the Badhore, in pursuit of their own aims) over this incident.

iv. Three farmers, two Kahoots and a Badhore, all with relatively large land holdings, opposed the WAPDA plans in regard to the number and location of pakka nakkas, hoping to get more for themselves. Informants say Mona Project personnel compromised to settle the dispute.

Two farmers also did not do their share of the work on kacha improvement, but others did it for them, so this did not lead to trouble. It is notable that, as Table 16 reveals, most of the obstruction and conflict was initiated by head farmers. Some informants also complained that committee members were partial toward their own supporters, and the influential farmers were favored by the WAPDA personnel, who exempted one farmer from cutting his trees, and allotted additional nakkas to certain farmers. It is difficult to judge the extent to which these accusations are true, because the high level of animosity and jealousy among the Chak B farmers leads to a tendency to try to tarnish the reputation of their competitors.

To conclude, we may say that the process of improvement was accompanied by a great deal of conflict. This is not surprising in view of the pre-existing tensions among the various biraderis in this village.

c. Chak C

Improvement of this watercourse was initiated because of the effort of one farmer, the largest landowner on the watercourse: after seeing an improved watercourse in Thikriwala, he convinced others of its benefits. The improvement location, and uprooting of trees, were initiated in August, 1977.

Table 17 presents the data on the characteristics of the committee members. Three of the four members have the highest scores in power/influence within their village/biraderi, and these are the only three with scores above 60% in influence with Government officials.

The fourth member has little influence, and is the only member with land at the tail. In fact, five of the seven persons scoring high on power and influence have their lands at the head of the watercourse; another has his land at both the head and middle; and the seventh has land in the middle. Two of the committee members made most of the decisions pertaining to watercourse construction themselves; and no one expressed any dissatisfaction with their decisions.

During construction, the only controversy that arose was one farmer's refusal to cut a valuable jamun tree on the watercourse route; when OFWM stood firm that it must be cut in order to continue, all the other farmers convinced him to remove the tree. We may conclude, then, that the process of watercourse improvement was remarkably smooth and conflict-free. This lack of conflict during improvement is consistent with the relatively low level of tension and competition among the people of this village.

d. Chak D

The numberdar projecting a relatively "progressive" image described above, is credited with initiating the improvement project. Uprooting of trees began on November 15, 1977, and kacha improvement on December 2; the kacha improvement was completed on February 20, 1978. The lined section (branch AB; see map) was completed March 12, and installation of pakka nakkas on April 25, 1978.

As can be seen from Table 18 Branch A had no representative on the committee. The Chairman of the committee, and most influential person, is at the very head of the watercourse. Informants say selection of committee members was on the basis of <u>patti</u> (persons paying land revenue, historically, through one numberdar).

Table 17. Characteristics of committee members.

| Caste | Landholding Vill. | Landholding W/C | Location on W/C | | % B/V[1] Score | % G/O[1] Score | Any other position |
|---|---|---|---|---|---|---|---|
| Randhawa | 15½ | 12 | H | | 91 | 92 | - |
| Randhawa | 6¼ | 6¼ | H<br>T | 3¼<br>3 | 41 | 25 | - |
| Randhawa | 37½ | 37½ | M<br>H | 25<br>12½ | 88 | 75 | W/C Committee Chairman |
| Randhawa | 30 | 25 | M | | 84 | 66 | - |

1/See notes to Table 14.

Table 18. Characteristics of committee members.

| Caste | Landholding Vill. | Landholding W/C | Location[1] Branch | Location[1] Posi | % B/V[2] Score | % G/O[2] Score | Other score position |
|---|---|---|---|---|---|---|---|
| Athwal | 25 | 25 | AB | Head | 100 | 100 | Chairman W/C Comm. |
| Athwal | 4 | 4 | B-1 | Tail | 53 | 47 | - |
| Athwal | 23 | 8 | B-2 | Tail | 74 | 69 | Numberdar |
| Athwal | 6 | 6 | B-2 | Tail | 37 | 20 | - |
| Athwal | 4 | 4 | B-2 | Tail | 46 | 29 | - |
| Athwal | 17 | 8 | B-2 | Tail | 89 | 88 | Numberdar |
| Athwal | 12½ | 12½ | B-2 | Tail | 42 | 23 | - |

1/See map of Chak D watercourse.
2/See notes to Table 14.

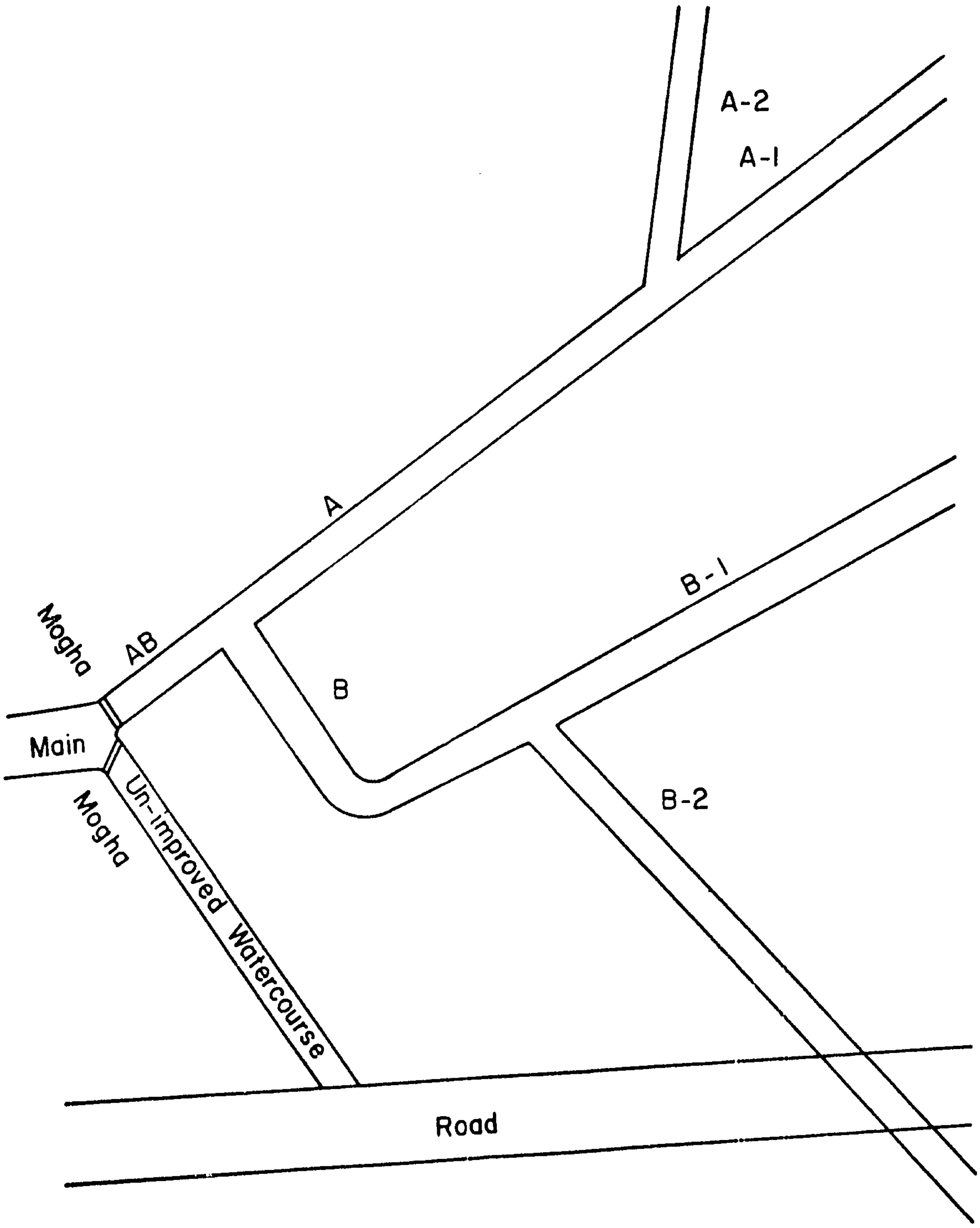


Figure 1. Map of improved watercourse at Chak B

During construction there does not seem to have been much conflict over uprooting of trees, division of work, or location of nakkas. A few trees were left standing with the agreement of OFWM. There was at least one conflict over the route which was solved by referring it to the patwari; and there was some delay in installing nakkas and culverts when some farmers hesitated to pay the masons. There was also conflict between the brother of the "obstructionist" farmer and OFWM personnel.

According to OFWM informants, the initiating farmer, despite his "progressive" image, often did not come on site to manage the work. In fact, OFWM personnel seem to have been somewhat misled by his image of "progressiveness." The "obstructionist" is reported not to have done his share of the work; but it was done for him so this did not lead to severe conflict. His holding on this watercourse is not large, so that his share of the work was not a large percent of the total.

Most of the farmers expressed considerable dissatisfaction about the process and results of improvement. First, they say, the point from which improvement began is not in fact the mogha: there is a long "main" watercourse which has two branches; neither this main branch nor the other branch have been improved. Some trees had however been removed from part of the main branch. It was difficult to discover why the main branch was not improved. One possible reason is that farmers now cut its banks to irrigate adjacent lands; this would be difficult after improvement as no nakkas are sanctioned on it. Indeed, the influential head farmer has managed to get a "private" pakka nakka installed on this main branch near his dera, though it is not legal. Another reason suggested by some farmers is that conflict of some farmers with OFWM lead to its nonimprovement; another, related factor may have been an alleged link between an OFWM officer and the "obstructionist" (see below).

The farmers complained about the behavior and alleged incompetence of one of the Government officers while praising others. They felt he was rude and insulting toward them; and they claimed the watercourse level was incorrect in some places so that some land gets less water than before.[4]

Finally, farmers accused one officer of getting involved in their factional politics on the side of the "obstructionist." The farmers on the other branch applied to have their watercourse improved too. This man, who has the bulk of his land on the middle portion of this watercourse, objected; informants attribute his opposition to a desire to continue his practice of cutting the watercourse banks to steal water. Also his "enemy" favored it and he therefore "automatically" opposed it. It is alleged by our informants that the "obstructionist" and the officer in question have a mutual friend in Faisalabad. The farmer is said to have approached the officer through this man and even though other farmers had uprooted all their trees, and an overwhelming majority (49/56 - 88%) favored improvement in a formal vote, he managed to prevent improvement of that branch.[5]

The farmers on the improved watercourse are also unhappy with the number of nakkas, saying with their fragmented holdings (and lack of unity) there ought to be more nakkas. The OFWM response is that no more are sanctioned by the Irrigation Department. The result is that farmers are cutting the banks in some places, causing degradation of the watercourse.

e. Comparison

These short descriptions simplify what is really often a complex and long process. Table 19 shows just how long the process can be. The fastest improvement was done by the Chak A farmers in two months; the OFWM watercourses both took longer than the Mona Project watercourses. At Chak C informants reported problems of cement supply delayed the project; Chak D's watercourse is much

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4/Informants suggest this is due to the design, which is based on average slope of the watercourse, and does not consider undulations--alternating high and low fields; it may be speculated that the design here might have included check and drop structures. We emphasize here that the truth of the above allegations is not confirmed, and is not relevant to our purpose, which is to report farmers' <u>perceptions</u>.

5/Again, we are reporting informants' <u>perceptions</u> which have a significant impact on their attitude towards Government programs.

Table 19. Time required to complete the improvement process.

| | A | B | C | D |
|---|---|---|---|---|
| a. Date begun uprooting trees | 12. 9.76 | 10.2.77 | 8.77 | 15.11.77 |
| b. Kacha improvement completed | 12.10.76 | 15.3.77 | 10.77 | 20. 2.78 |
| c. Pakka nakka installation completed | 10.11.76 | 14.5.77 | 12.77 | 25. 4.78 |
| d. Total time (a-c) | 2 months | 3 months | 4 months | 5 months |

Table 20. Perceived sources of losses before and after improvement.

| Source of loss | No. of responses | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Before improvement | | | | After Improvement | | | |
| | A | B | C | D | A | B | C | D |
| a. Spills over sides | 14 | 9 | 11 | 14 | 0 | 1 | 0 | 0 |
| b. Seepage | 14 | 15 | 10 | 11 | 0 | 6 | 0 | 0 |
| c. Water standing in ditches | 14 | 12 | 9 | 12 | 0 | 6 | 0 | 0 |
| d. Vegetation in channels | 13 | 14 | 9 | 20 | 1 | 7 | 0 | 1 |
| e. Silting | 15 | 14 | 12 | 20 | 1 | 6 | 0 | 1 |
| f. Illegal cuts | 0 | 1 | 2 | 15 | 0 | 2 | 0 | 3 |
| g. Improper level | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 4 |
| h. Rat holes | 1 | 0 | 0 | 0 | 3 | 0 | 9 | 6 |
| i. Livestock crossing | 2 | 1 | 6 | 0 | 0 | 1 | 0 | 0 |
| j. Kacha nakkas | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| k. No loss | 0 | 0 | 0 | 0 | 11 | 7 | 8 | 14 |
| No. of respondents | 15 | 16 | 17 | 22 | 15 | 16 | 17 | 22 |

longer than the others, and its improvement was not a smooth process; it took over five months to complete.

It is not possible for twenty or fifty people, whose pre-existing relationships are so complex and so long-standing, to cooperate on a watercourse project without conflict. The cultural mechanisms for cooperation on such projects are not well developed, and often nonexisting, in Pakistan. Nevertheless, these short vignettes illustrate both the existing social relationships among the shareholders and their importance, and how the type of relationship that develops between the farmers and the Government officers can significantly effect the success of the project. Awareness of these two factors, and deliberately planned strategies to deal with them, can significantly improve the success of such community self-help projects.

The experience of Chaks B and D illustrate the pitfalls of working in villages with relatively high levels of tension--especially when the worker is ignorant of these, or takes sides. Chak A and Chak B illustrate a frequent problem: the tendency to appear to favor the influential minority over the less articulate, and non-influential majority.

5. <u>Quality of Maintenance of Improved Watercourses After Improvement</u>

We were unable to measure the present level of water losses, and no data are available on losses before improvement. We asked farmers what their sources of losses were before improvement, and what, if any, sources of loss they noted after improvement. Table 20 summarizes the results. It demonstrates, indirectly, that farmers perceive far fewer sources of loss, and thus presumably less loss, after improvement.

In Chaks C and D we asked about changes in the time required to irrigate their land. Table 21 presents this data. All but one of the sample farmers in Chak C noticed improvement--often significant; while in Chak D eleven noted improvement, but six claimed they get less water, and four more claimed there has been no change. Also the magnitude of perceived improvements is greater in Chak C than in Chak D. The accuracy of the farmers' perceptions may not be exact, but the general results are consistent with the relative levels of satisfaction with, and maintenance of, the two improved watercourses.

Table 21. Reported time required to irrigate land in minutes per kanal.[1]

| | Chak D | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Farmer No. | 1 | 3 | 5 | 6 | 10 | 14 | 15 | 20 | 22 | 23 | 31 | 32 | 34 | 36 | 40 | 42 | 43 | 44 | 46 | 48 | 50 | 56 |
| Prior to improvement | 14 | 9 | 10 | 17 | 12 | 28 | 18 | 22 | 7 | 15 | 10 | 19 | 10 | 60 | 20 | 17 | 8 | 30 | 12½ | 36 | 17¼ | 12 |
| Immediately after improvement | 21 | 15 | 10 | 11 | 14 | 24 | 14 | 21 | NA | 11 | 14 | 17 | 15 | 60 | 16½ | 34[2] | 10¼ | 22½ | 8-1/3 | 36 | 13 | 8 |
| Presently | 21 | 15 | 10 | 11 | 14 | 24 | 14 | 22 | NA | 11 | 14 | 17 | 15 | 60 | 16½ | 8½ | 10¼ | 22½ | 8-1/3 | 36 | 13 | 8 |
| Direction of change (No. of responses) | Improvement - 11<br>Deterioration - 6 | | | | | | Same - 4<br>NA - 1 | | | | Total - 22 | | | | | | | | | | | |

| | Chak C | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Farmer No. | 1 | 2 | 5 | 6 | 7 | 8 | 10 | 12 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| Prior to improvement | 28 | 16½ | 8 | 16½ | 5½ | 3½ | 14 | 41½ | 16½ | 8-3/4 | 21½ | 21 | 36 | 15 | 23½ | 22½ | 70½ |
| Immediately after improvement | 24 | 12 | 4½ | 16½ | 2¼ | 18½ | 7 | 22½ | 14¼ | 6 | 21½ | 15 | 21½ | 7½ | 14 | 17 | 56½ |
| Presently | 22 | 8 | 4½ | 16½ | 2¼ | 18½ | 7½ | 22¼ | 14¼ | 6 | 16½ | 15 | 21½ | 7½ | 14 | 17 | 56½ |
| Direction of change (No. of responses) | Improvement - 16<br>Deterioration - 0 | | | | | | Same - 1<br>Total - 17 | | | | | | | | | | |

1/A kanal is 1/8th of an acre. These figures are based on farmers' statement about warabandi time and amount of land they can irrigate in their time.

2/This trend is related to a route hange.

Table 22 shows the frequency of cleaning before and after watercourse improvement. While Chak C's watercourse has been cleaned monthly before and after improvement, the frequency of cleaning has declined in Chak A and B. In Chak B it is irregular because of the refusal of head farmers to cooperate. Chak D farmers seem to be cleaning their watercourse more frequently since improvement, but our observations of cleaning suggest this is true only on the portions near the pakka road.

Table 23 shows that the formulas for dividing the cleaning labor vary among the four villages; two have a fine system, in theory, to enforce participation, but informants say these are not effective. It is noteworthy that the watercourse executive committee no longer exists or plays a role, per se, in maintenance after improvement of the watercourse.

Table 24 shows the relationships among our rating of maintenance of different sections of the watercourse, and the relative distribution of power and influence. We hypothesized that the concentration of influence at the tail would enhance the likelihood of good maintenance. Chak D is not included because a head, middle, tail division seems not to fit; but except for portions near the pakka road, most of its maintenance was fair at best because of cutting of banks, broken nakka covers, and excessive vegetation. Chak B, the most poorly maintained watercourse, has most of the power and influence (93.6% of the total score) and the committee members, concentrated at the head and middle. Chak A, relatively better maintained, has its influence (90.18%) and committee members concentrated at the middle and tail. In Chak C the result is more ambiguous; it is also well maintained, the differences in power and influence among the head, middle and tail sections are not very great but are more concentrated at the head. The committee members are also more evenly distributed.

6. Sample Farmers' Opinions of Forming Water User Associations

After explaining to sample farmers the basic idea of a water user association, we asked if they favored the idea. Table 25 gives the results. Over 60% of the respondents favor the idea. The majority of farmers in all but one village favor it; in Chak C eight farmers favored and nine opposed. The opposition was a result of their satisfaction with the present arrangements, they said.

Table 22. Interval between cleanings.

| | A | B | C | D |
|---|---|---|---|---|
| Before improvement | 1 month | 1 month | 1 month | 6 months |
| After improvement | 2 months | 2-6 months (irregular) | 1 month | 3 months |

Table 23. Division of labor and enforcement of participation for cleaning watercourse.

| | A | B | C | D |
|---|---|---|---|---|
| Formula for division of labor | By size of land holding | Work together from head: each works up to his own land | 1 man per household | 1 man per square (households take turns) |
| Enforcement | Nonparticipants pay Rs.10/day for gur for participants | "requests" | Social pressure, requests | Rs.20 for tea, cold drinks, for participants (rarely - if ever - used) |

Table 24. Section of watercourse, maintenance quality, and power.

| Section of watercourse | Maintenance quality[1] | % Farmers 25 acres | % Total power/influence score (village/biraderi) | Average power/influence score per farmer | No. of committee members |
|---|---|---|---|---|---|
| | | Chak A | | | |
| Head | Fairly good[2] | 0<br>(0/5) | 9.82<br>(33) | 6.6 | 0 |
| Middle | Medium[3] | 40.0<br>(4/10) | 50.84<br>(171) | 17.1 | 2 |
| Tail(of Chak A section) | Fairly good | 50.0<br>(3/6) | 39.29<br>(132) | 22.0 | 1 |
| | | Chak B | | | |
| Head[4] | Very poor[2] | 58.8<br>(10/17) | 51.[illegible]<br>(174) | 10.23 | 2 |
| Middle | Medium to poor | 80<br>(8/10) | 42.4<br>(144) | 14.4 | 1 |
| Tail | Good | 20<br>(1/5) | 6.4<br>(22) | 4.4 | 0 |
| | | Chak C | | | |
| Head | Good[2] | 0[5]<br>(0/11) | 55.82<br>(403) | 36.64 | 1 |
| Middle | Medium[6] | 50<br>(2/5)[7] | 25.48<br>([illegible]) | 37.0 | 2[8] |
| Tail | Medium[6] | 0<br>(0/6) | 18.70<br>(135) | 22.5 | 1[9] |

1. "Good" - no cuts in banks, no vegetation obstructing water flow, no trees, no broken nakkas, few or no rat holes. "Poor" is the reverse of this.
2. Silt tank not cleaned recently on any of these watercourses.
3. Trees recently planted along watercourse.
4. Head includes 5 nonzamindar caste, very small, holders who themselves have no power, and who reduce the percentage over 25 acres (10/12 without these), and average power influence.
5. The Arain tenant is not counted.
6. Not "good" only because of rat holes.
7. One of these has some land on the head too.
8. One of these has land at the head too.
9. He has land at the head too.

Table 25. Sample farmers' opinions on formation of water user associations.

| | Chak A | | Chak B | | Chak C | | Chak D | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| Opinion | No. | (%) | No. | (%) | No. | (%) | No. | (%) | No. | (%) |
| Favor | 11 | (73.3) | 12 | (75) | 8 | (47.1) | 12 | (54.55) | 43 | (61.4) |
| Do not favor | 4 | (26.7) | 4 | (25) | 9 | (52.9) | 10 | (45.45) | 27 | (38.6) |
| Total | 15 | | 16 | | 17 | | 22 | | 70 | |

Table 26. Opinion of legalization of water user associations.

| | Chak A | | Chak B | | Chak C | | Chak D | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| Opinion | No.* | (%) | No.* | (%) | No.* | (%) | No.* | (%) | No.* | (%) |
| Favor | 11 | (100) | 12 | (100) | 8 | (100) | 12 | (100) | 43 | (100) |
| Do not favor | 0 | | 0 | | 0 | | 0 | | 0 | |
| Total | 11 | | 12 | | 8 | | 12 | | 43 | |

*No. = those favoring WUA's in Table 25.

Table 27. Opinion of forming an executive committee within the water user associations.

| | Chak A | | Chak B | | Chak C | | Chak D | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| Opinion | No. | (%) | No. | (%) | No. | (%) | No. | (%) | No. | (%) |
| Favor | 10 | (90.0) | 6 | (75) | 5 | (62.5) | 7 | (58.3) | 28 | (71.8) |
| Do not favor | 1 | (9.[illegible]) | 2 | (25) | 3 | (37.5) | 5 | (41.7) | 11 | (28.2) |
| Total | 11 | | 8 | | 8 | | 12 | | 39 | |

Table 26 shows that 100% of all those favoring establishing water user associations favor their being given a legal basis.

Table 27 shows that nearly 72% of these farmers also favor having an executive committee manage the association affairs. All farmers except one in one village, when asked, opposed establishing a separate panchayat for settling disputes.

## CONCLUSIONS AND RECOMMENDATIONS

Since this is an interim report, our conclusions and recommendations must be tentative. In the final report, not only will our sample be larger, but our analysis will be more sophisticated, and will include statistical analyses to test hypotheses. Nevertheless, we do have some tentative conclusions to present.

### A. Conclusions Based on Comparison of the Data

Inspection of Table 28 suggests the following conclusions:

1. The hypothesis that water shortage *per se* leads to better maintenance is not confirmed. Chak D, with the least water (no tubewell, high pieces of land, and farmers claim the mogha was reduced in size some years ago) is not well maintained; Chak A, with much water, is well maintained. Chak C, with both a supplementary tubewell and a supplementary mogha in the summer, is also well maintained.

2. SCARP area watercourses are not necessarily less well maintained. At Chak A, a well maintained SCARP watercourse, many farmers are commercially oriented and know that water is a key to improving their profits on their kinno orchards. This profit-orientation, also characteristic of Chak C, but not of the other two watercourses, is not necessarily connected with large land holdings (Chak C farmers have medium-sized holdings), but it *is* probably a key predictor of likelihood of success in cooperating to manage a watercourse.

3. The hypothesis that long single branched watercourses will be better maintained than watercourses with several short branches receives some support from our data: two of the three single branch watercourses are well maintained; the one multi-branch watercourse is less well-maintained.

Table 28. Compariso[illegible] [illegible] four watercourses.

| | | A | B | C | D |
|---|---|---|---|---|---|
| 1. | Tubewell | SCARP | SCARP | Cooperative Tw. | None |
| 2. | W/C branches (Sarkari Khal) | Single | Single | Single | Multiple |
| 3. | % total holdings over 25 acres Rank: lowest = 1 | 38.1 (3) | 59.4 (4) | 18.2 (2) | 5.4 (1) |
| 4. | % total holdings, 5-24 acres Rank: highest = 1 | 47.6 (2) | 40.[illegible] (4) | 81.8 (1) | 44.6 (3) |
| 5. | % total holdings under 5 acres | 14.3 | 0 | 0 | 50 |
| 6. | Centrality ratio (biraderi/village) highest rank = 1 | 19 (2) | 0 (4) | 31.8 (1) | 11 (3) |
| 7. | Concentration (equality) ratio (biraderi/village) highest rank = 1 | 19 (4) | 21.9 (3) | 36.3 (1) | 27 (2) |
| 8. | Biraderi structure on watercourse | Single dominant | Multiple | Single | Mainly single(divided) |
| 9. | Locations of influence on W/C: average per farmer biradari/village influence. Score (No. of committee members in brackets) H | 6.6 (0) | 10.23 (2) | 36.64 (1) | Not calculated |
| | M | 17.1 (2) | 14.4 (1) | 37.0 (2) | |
| | T | 22.0 (1) | 4.4 (0) | 22.5 (1) | |
| 10. | Rank: evaluation of level of previous cooperation; highest cooperation = 1 | 1 | 3 | 1 | 3 |
| 11. | Settlement status | Settlers and refugees | Settlers | Settlers | Locals |
| 12. | Ranking of progressiveness | 2 | 3 | 1 | 3 |
| 13. | Rank degree of conflict during improvement (least = 1) | 1 | 3 | 1 | 2 |
| 14. | Rank quality maintenance (best = 1) | 2 | 4 | 1 | 3 |
| 15. | Rank support of water users associations | 2 (73.3%) | 1 (75%) | 4 (47.1%) | 3 (54.55%) |

4. Inequality of land holding *per se* does not seem to be correlated with ease of carrying out watercourse improvement or its maintenance.

5. *However*, a high percentage of small but economically *viable* farm units does seem to be strongly correlated with ability to cooperate to build, and to maintain a watercourse; and the existence of a large percentage of very small farmers (less than 5 acres), as in Chak B, seem to inhibit cooperation on the watercourse.

6. The watercourse with the greatest *equality of power and influence* (Chak C) is also the *best maintained*; but the relationship is not clear cut for the other three watercourses.

7. There *is* a positive correlation between a high percentage of farmers being recognized as influential within their village by their peers (centrality ratio) and the ability to cooperate: the two best maintained (Chak C and Chak A) have the greatest percentage of farmers with significant influence; the worst maintained does not have even a single person recognized as influential.

8. Patterns of cooperation and conflict are biraderi-based. The watercourse most fragmented into separate biraderis, Chak B, is the worst maintained; the best maintained (Chak C) is totally dominated by a single subcaste. Chak D, though dominated by one subcaste, is divided into separate *pattis*, and into hostile groups, mainly the result of one man's behavior.

9. Both equality of influence on the head, middle and tail sections (Chak C), and its concentration at the middle and tail (Chak A) are positively correlated with cooperation for maintanance, as predicted; similarly, concentration of power at the head (Chak B and to a lesser extent Chak D) reduces the incentive and ability to cooperate for maintenance.

10. Although the only village inhabited by "locals" in our sample exhibits little cooperation (Chak D), the watercourse with the most conflict is inhabited by "settlers" settled in British times. Therefore the relationship between settlement status and cooperation is unclear and probably nonexistent.

11. Previous successful cooperation on community projects is a strong predictor of cooperation on the watercourse (however concentration on such locations will accentuate differences in development of different communities).

12. A high level of "progressiveness," as measured by availability of institutional services, educational level, exposure to mass media, and positive interaction with government officials, is correlated positively with ability to cooperate. (However the same warning about accentuating differences applies as that given in No. 11 above.)

13. The informal watercourse executive committees do not continue to function after the improvement project is completed.

14. Finally, we found a high degree of overall support for the idea of establishing water user associations with a firm legal foundation.

At this preliminary stage, it is not clear which of the above are in fact "causal" and which are "intervening" variables; similarly, the direction of causation--the distinction between dependent and independent variables--is not clear in some cases. Does "cooperativeness" of a community lead to their obtaining institutional services such as schools which then raises the educational levels; or do institutional services encourage greater cooperation? It is hoped that as the study progresses, and we refine our instruments, we shall be able to specify the causal relationships more rigorously.

B. Preliminary Recommendations

1. This study demonstrates that village and watercourse social organization do significantly, effect the short and long term success of watercourse improvement programs in a predictable manner. Therefore we recommend that:

   a. Social surveys precede all watercourse improvement projects as an aid in choosing watercourses where the likelihood of success is high, and in order to anticipate, and attempt to prevent, the development of problems that will impair the success of the program. Chak D is a perfect illustration of this: it was chosen, the work planned, based on the perception of "progressiveness" of one man at the watercourse; knowledge of the social relations on that watercourse could have significantly improved the effectiveness of the project there. OFWM has a mandate to do such surveys, but has not been able to do them so far. If the OFWM Directorate wishes we shall attempt to develop guidelines for carrying out such surveys as part of our final report.

b. OFWM workers should receive more training in social skills in order to develop abilities to anticipate, and thus prevent or at least deal with disputes and problems on other watercourses. They also need more training in order to prevent prejudices against locals ("jangalis" as they are often insultingly called) from diminishing their effectiveness. Fairly or unfairly, some OFWM personnel are perceived by farmers as arrogant, further reducing their effectiveness. These factors were a major source of the problems at Chak D.

c. The informal executive committees no longer function after improvement is finished. Further, on most watercourses there are no mechanisms for insuring participation of farmers in the maintenance of the watercourse beyond the (always ephemeral) voluntary willingness to cooperate with trusted leaders. Therefore, it is important that OFWM Agricultural Officers keep working with farmers on a regular basis to encourage better maintenance and more efficient use of the water.

2. Beyond this, it is imperative that farmers be encouraged and aided to organize themselves into legally constituted associations with specific powers and responsibilities for management of their water supply. The failure of informal organizations used so far demonstrates the importance of this step to the long term success of the OFWM project. It is notable that a solid majority of our sample farmers favor forming water user associations, and <u>all</u> of those favoring such an organization also favor its legalization.

3. In order to improve the likelihood of success of phase two of this study, when we shall be having organizations organized and monitoring their success, we suggest the following:

   a. A special law to facilitate organizing water user associations, even if temporary, would facilitate testing whether it would be wise to organize such associations under the existing Cooperative or Company Acts, or whether a separate law is required. The authors are not optimistic about the likelihood of successful organization under existing laws.

b. It is imperative that OFWM cooperate with us on phase two. They have been very cooperative on phase one, but the level of cooperation required in phase two may be inhibited by their compulsion to achieve quotas of watercourses improved. Specifically, we need to cooperate with OFWM on choosing of sites; coordination of their work and our research; and most important, we need their personnel to organize the experimental associations under our guidance.


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Finally, despite all of the aid of others, we alone are responsible for this report. The views expressed are not necessarily those of the supporting agencies.



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## SUMMARY OF TENTATIVE CONCLUSIONS AND RECOMMENDATIONS

This interim report is based on research completed on four watercourses exhibiting a variety of sociological characteristics. Our research methods have combined the use of formal questionnaires with more informal techniques in order to achieve a deeper understanding of key social processes. Among the tentative conclusions suggested by our data are:

1. Maintenance of watercourses after improvement is a major problem that must be solved.

2. The social organization of watercourses is a major determinant of the likelihood of a successful improvement and maintenance program. It appears that the best maintained watercourses are those with at least some of the following characteristics:
   a. single sarkari khal branch;
   b. a high percentage of small but economically viable land holdings (5 to 25 acres);
   c. relative equality among farmers of power and influence and especially, a high percentage of farmers being recognized as influential and a low percentage of farmers with no or little influence;
   d. equality of influence of all sections of the watercourse, or concentration of influence at the middle and tail sections;
   e. a low level of pre-existing conflict and hostility;
   f. a previous history of cooperation on community projects;
   g. nonfragmentation into separate competing biraderis none of which are dominant; and
   h. a high level of "progressiveness" as measured by educational level, exposure to mass media, and the like.

3. Most farmers interviewed favor establishing legally constituted water user associations. Given the lack of effective social mechanisms to ensure cooperation among watercourse shareholders, such legally constituted organizations are essential to maximize the impact of the On-Farm Water Management Project on water management in Pakistan.

4. A previous knowledge of the social relations on a watercourse, training in the use of this knowledge, and the attitude of the Government personnel towards their clients, are important for choosing watercourses on which to work, and in order to plan the work so as to anticipate, and reduce the effect of, conflict.

Our preliminary recommendations are:

1. Social surveys ought to precede all watercourse improvement projects in order to plan ways to minimize the effect of conflict and inability to cooperate on the success of the program.

2. OFWM workers should all receive more training in social skills, and the organizational problems of watercourse improvement and maintenance should be given greater attention.

3. Special legislation to facilitate organizing water user associations, even if on a temporary, experimental basis, would greatly facilitate the usefulness and significance of phase two of our study for Government policy.

4. The close cooperation of the OFWM Directorate, Punjab, will be essential for phase two of our study--organizing experimental water user associations.

## APPENDIX

### Methodological Note on Measuring Power and Influence

The "power/influence" scale we used is a modification of a method suggested by David Freeman. On each watercourse we asked sample farmers to rate the "power and influence" of all the watercourse shareholders both within their biraderi and village, and with government officials. We made no attempt to make fine distinctions between power and influence--we explained it to our respondents simply as the ability to influence or lead people. Respondents were asked to rate each person, one at a time, and their answer was converted to a score on a 0 to 4 basis, with 4 signifying very influential. In the "biraderi village" column if a person was influential in the biraderi but not in the rest of the village he was given a score of 2.

The sum of the responses (and the percentage of his highest possible score) was calculated for each watercourse member. Any person who received 60% or more of his possible score is deemed to have a significant amount of power and influence. The percentage of farmers scoring 60% or above is called the "centrality" score; and indicates the percentage of farmers regarded as having a significant degree of power/influence.

The scores of each farmer were also ranked from highest to lowest, and the number of farmers' scores accounting for half of the sum of the total of all scores was calculated. This is used as an indication of the equality or "concentration" of the power/influence on the watercourse: the closer to 50% of the farmers required to equal 50% of the total score, the more equal are the farmers among themselves in relative power/influence; the fewer the number of scores totalling 50% of the total score, the greater is the concentration of, or inequality of, power/influence on that watercourse.

# APPENDIX 31

## IRRIGATION AND HONOR: CULTURAL IMPEDIMENTS TO THE IMPROVEMENT OF LOCAL LEVEL WATER MANAGEMENT IN PUNJAB, PAKISTAN

Douglas J. Merrey[1]

"Social organizations are the central vehicles through which water management technologies are delivered, utilized, improved, and maintained." (Freeman and Lowdermilk, 1978: 704)

In recent years the organization of irrigation systems has become an important research topic among social scientists. No adequate theoretical perspective either for understanding the structure and operation of single systems, or for making useful comparisons among systems, has yet been developed (Hunt and Hunt, 1976: Freeman and Lowdermilk, 1978). However, organization and management have come to be recognized as of central importance, not only in terms of their political implications (Wittfogel, 1957), but as major constraints on the productivity, stability and efficiency of irrigation systems.

Pakistan has one of the largest and most complex irrigation systems in the world, and the country is heavily dependent on its irrigated agriculture. This system is operating at a very low level of efficiency, whether measured in terms of world-wide agricultural production standards, or in terms of its potential productivity (Corey and Clyma, 1975; Government of Pakistan, Planning Commission, 1978). In addition to the large number of reports identifying the technological deficiencies in the system, there have been several recent sociological studies on organizational problems (cited below). Inadequate and inappropriate organization appears to be the major constraint retarding the efforts to improve Pakistan's irrigation system.

As useful as these recent studies are, they remain in-lete as explanations of the management of irrigation in stan for two reasons:

1. All of these studies are focused on the village/watercourse level, that is, the primarily informal relationships among irrigators at the village and watercourse level. There are as yet no studies of the workings of the Provincial Irrigation Departments themselves, or how these departments relate in practice to the users of the water and to

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state related Departments such as Agriculture and the Water and Power Development Authority (WAPDA).[2]

2. All of the studies to date focus on social structural attributes of the local system. However, none have discussed the culture of irrigation, that is, the rules, goals, assumptions, and beliefs of the actors in the system; nor have they discussed the strategies pursued by these actors.

If planners and policy makers wish to develop effective programs, they must have a thorough understanding of the culture of their clients. If it is assumed that farmers in rural Pakistan, for example, share with the planners the same set of values, goals, and assumptions, any program developed based on this assumption is likely to fail. Therefore, in this paper I first present a brief summary of the recent sociological research on local level water management in Pakistan. Then, after presenting a working definition of culture, and briefly describing what happened during the course of reconstruction of one watercourse, I discuss key features of Punjabi culture and their implications for improving the organization of water management in Pakistan. This discussion is based on detailed field work in one village, supplemented by experience with a broader study of watercourse organizational problems (Mirza and Merrey, 1978). The goal is to identify and discuss the implications of a major feature of Punjabi rural culture that must be considered if effective forms of social organization for water management as well as other productive purposes are to be developed. Throughout the paper I discuss Punjabi culture specifically, as most of the research has been done in Punjab; but the major conclusions and their implications are relevant for the other provinces of Pakistan as well.

## SUMMARY OF SOCIOLOGICAL FINDINGS

### Terminology

Before proceeding further, a few comments on terminology seem necessary. In general, Punjabi villagers recognize several ranked categories of people. The three major categories are Sayid, zamindar, and kami. Sayids are believed to be descendents of the Prophet Muhammad, and are therefore supposed to be respected; when they own land, they may, for the purposes of this paper, be included with zamindars. In Punjabi, "zamindar" is best translated as "agriculturalist," and includes "castes" such as "Jat" and "Rajput" who traditionally are farmers or at

2/Mirza (1975) and Lowdermilk, Freeman and Early (1977) do have some comments on the relationships between water users and the Irrigation Department bureaucracy, but neither are systematic studies of this issue. A partial exception, focusing on India, is Gustafson and Reidinger (1971).

least land owners. Kamis are traditionally non-agriculturalist "castes" who may have a skill (carpenters, blacksmiths, potters) or be unskilled laborers (e.g., Masali). Their caste and their profession overlap and are hereditary both in theory and to a large extent in practice. Kamis traditionally work for particular farmers and are paid at harvest time, and have certain ceremonial roles; these ties are, however, weakening and being replaced by purely cash relationships. Though kamis do sometimes play important roles, village politics and water management are mainly the concern of zamindars. Therefore, this paper, like the other studies to be discussed, will not discuss the role of kamis.

Sociological studies of rural Pakistan tend to use "caste" (the usual translation for zat and qaum), "subcaste," and "brotherhood" (i.e., biradari) rather loosely and interchangeably. In fact, certain "castes," such as Arians and Gujars, tend not to be further subdivided within villages, though there are exceptions; but the local group is still best referred to as a "biradari". Jat and Rajput "castes" on the other hand, often, but not always, are further subdivided into local groups, also referred to as biradaris by the people themselves. I place "caste" in quotation marks because it is an open question as to whether this is even the appropriate term to use here.

Alavi (1972), who has presented the best discussion of "biradari," says that kinship, not caste, is the major basis for rural Punjabi social organization, and "biradari" is the basic kinship institution. The term biradari has several referents depending on context, but its most significant referent for the purpose of this paper is what Alavi (1972) terms the "biradari of participation," whose members generally reside in one village. Although common patrilineal descent is the premise of this group, horizontal (fraternal, including cousin) ties receive special emphasis; these are reinforced by marriage relations and ritual exchanges (vartan bhaji) on certain ceremonial occasions. Brothers and cousins of all types exchange sisters and daughters in marriage, both ideally and in practice, leading to a high degree of biradari endogamy. Where the literature being summarized uses the terms "caste," "subcaste," and biradari," in what follows I use the term "biradari" and mean the biradari of participation. It is important to keep in mind that since "biradari" has different referents in different contexts, they are not necessarily bounded groups (see Alavi, 1972).

Sociological Conclusions

All of the studies reviewed here have been carried out under the auspices of the Colorado State University Water Management Project in Pakistan. All have focused specifically on the local level organizational factors enhancing or inhibiting the introduction of programs for watercourse reconstruction and maintenance. This issue is important as Pakistan has launched a Pilot On-Farm Water Management Project, whose key element is watercourse reconstruction. In this project, the government provides technical advice and materials (bricks, cement, cement water-control structures); the shareholders on a watercourse are expected to provide all labor and keep the watercourse maintained after it has been rebuilt. If this project is successful, millions of acre feet of water, now wasted, can be saved and utilized to improve production at a relatively low cost (see Eckert, Dimick and Clyma, 1975). However, its success depends on effectively organizing farmers to reconstruct, maintain, and manage their own watercourses.

The major conclusions of the sociological studies under review are:

1. The "central mobilizing social unit" at the village and watercourse level is the biradari (Lowdermilk, Freeman and Early, 1977 (Vol. 1):48; also see Lowdermilk, Clyma and Early, 1975:32-42; Freeman and Lowdermilk, 1976:653-58; Mirza, 1975; Mirza and Merrey, 1978). Freeman and Lowdermilk (1976:687-692) emphasize the important role of biradaris in mosque and school construction as well as traditional watercourse maintenance.

2. A high level of polarization and conflict in a village makes organizing such communities for watercourse improvement a risky business (Freeman and Lowdermilk, 1976:693-705; Lowdermilk, Freeman, Early, 1977 (Vol. 1):49; Mirza and Merrey, 1978).[3] Such conflict is generally between biradaris or if within a biradari tends to split it into two biradaris.

3. Communities characterized by two (or more) biradaris of agriculturalists of about equal size and power will exhibit more tendency toward polarization and be more difficult to organize for collective projects (Mirza, 1975:96).[4]

   Conversely, communities dominated by a single biradari, or having a number of small biradaris none of which are dominant, may be better candidates for collective projects (Mirza and Merrey, 1978). It is important to note here that the number of biradaris, and degree of polarization of a community, are not permanent

3/See Freeman and Lowdermilk (1976 and 1978) for a method of determining degree of polarization in terms of extent of overlapping versus cross-cutting of conflict structures.

4/But Mirza (1975:73) also says "There is nothing conclusive about single and multiple castes..." in villages.

characteristics of a community; rather they are points on a longer development cycle. This has not been explicitly recognized by any of the studies under review except Mirza and Merrey (1978).

4. Communities with a relatively equal distribution of power and influence (and/or landholding) and a high percentage of people recognized as influential are better candidates for cooperative projects than those dominated by a few powerful people, or those having no influential people. These observations are still hypotheses and are not conclusively confirmed (Lowdermilk, Freeman and Early, 1977 (Vol. 1):49; Mirza, 1975; Mirza and Merrey, 1978).[5]

5. Not only are large landlords generally less cooperative in cleaning and maintaining the watercourse and more prone to factionalism (Mirza, 1975), but they tend more often to violate sanctions (such as by stealing water) than smaller farmers (Lowdermilk, Freeman, and Early, 1977 (Vol. 1):50). These observations are contrary to the assumptions often made by policymakers.

6. Power and influence are significantly associated with size of landholding, mass media exposure, high adoption of improved technology, and more knowledge of available irrigation and agricultural services (Freeman and Lowdermilk, 1976: 706-709.) Other factors such as personality and official contacts are also very important.

7. Previously existing forms of cooperation or a previous history of successful cooperation on community projects are important predictors of likely success in watercourse improvement projects (Mirza, 1975; Lowdermilk, Clyma and Early, 1975, 41-42; Mirza and Merrey, 1978).[6]

8. Cooperation for watercourse improvement is more likely to be successful where there is a single government-sanctioned watercourse branch (sarkari khal) (Mirza and Merrey, 1978).

9. Cooperation for watercourse improvement is also more likely to be successful on watercourses with fewer shareholders (Mirza, 1975).

/See Freeman and Lowdermilk (1978) for a method of determining "centrality" and "concentration" of power and influence.

/I would qualify this: since there is variation over time in a community's ability to cooperate it may be the case that communities which had cooperated previously later become conflict-ridden.

10. Farmers at the tail of a watercourse are more likely to support cooperative efforts at watercourse improvement since their potential gains are greater than those at the head (Mirza, 1975; Lowdermilk, Freeman and Early, 1977).

11. Equality of influence on all sections of the watercourse, or concentration of influence at the middle and tail, seem to be conducive to successful cooperation for watercourse improvement (Mirza and Merrey, 1978). That is, if the influential people stand to gain substantially they are more likely to support and get others to support the project.

12. A high level of "progressiveness" as measured by educational level, exposure to mass media, etc., seems to be an important predictor of cooperation on community projects (Mirza and Merrey, 1978).

## STRATEGIES, RULES, AND GOALS: THE CONCEPT OF CULTURE

The sociological factors affecting the ability of Pakistani farmers to cooperate on a watercourse improvement program that have been summarized above seem likely to be confirmed in a study presently being conducted on water users associations. One could criticize the list of findings or at least add to it; nevertheless they provide very useful guides, especially in choosing communities where the likelihood of a successful watercourse improvement program will be greater (Lowdermilk, Freeman and Early, 1977; Freeman and Lowdermilk, 1976; 1978). However, they do not tell us why people behave as they do; that is, why are biradaris so competitive? Why do Pakistani farmers find it so difficult to cooperate on projects they themselves recognize as beneficial? Why is there such a dearth of "constructive" and effective civic-minded community leaders? The answers to these questions may be sought at several levels of abstraction; but since our purpose is to identify factors relevant to planning effective forms of farmer irrigation associations (given present social conditions) in rural Pakistan, I shall focus on specific cultural factors that underly the sociological ones described above.

By "culture" I mean all of the percepts, concepts, recipes, skills, values, standards, goals, etc. that people learn and in terms of which they behave and interpret others' behavior. What has been learned must be clearly distinguished from its material manifestations: overt behavior, and statistical patterns of behavior that may be observed and counted. In these terms, the locus of culture, since it is learned, is within individuals; social and economic systems which we observe in operation "are created and maintained as products or by-products of culturally guided human action and, as such, are artifacts of culture" (Goodenough, 1963:271).

There are, then, two orders of phenomena here toward which prediction is directed (Goodenough, 1963:269; 1971:20-21). One is actual behavior--a statement of probabilities based on a sample of past events, such as "a watercourse whose members are divided into two opposing biradaris are prone to conflict." The other type of prediction is based on standards of behavior, that is culture: the rules and standards in terms of which people operate, judge others, and predict, the goals people pursue, and the strategies used to achieve their goals. A description of a culture is a predictive statement in the same sense as a grammar is for language; it does not tell us what people will do, necessarily, but what things are likely or regarded as appropriate under particular circumstances.

There is a complex feedback relationship between these two levels of phenomena (Goodenough, 1963; 1971) whose ramifications are beyond the scope of this paper.[7] This relationship is an important consideration in understanding social and cultural change, and in planning innovations. Even if a new form of organization is introduced, people are likely to continue behaving within it in terms of their previous culture, and will assume others in their society will too. If these rules and standards are inappropriate for the successful operation of the new form, it will fail, or at least be transformed into something quite different from the original intentions of the initiator. On the other hand, if behavior in terms of the old rules proves disadvantageous (psychologically as well as materially) to the people involved, and behavior in terms of the new set perceived as advantageous, people can and often do change their culture. I shall return to this point in the conclusion.

In the next section I present a case study of a watercourse improvement program, then in the following section I discuss certain key features of Punjabi culture that affect Punjabi farmers' capacity to cooperate on such collective projects.

## WATERCOURSE RECONSTRUCTION: A CASE STUDY

### Canal Irrigation: Its Initial Impact on One Village

As part of a larger study of the relationship between introduction of canal irrigation and social organization,[8] I had an opportunity to observe an experimental attempt at carrying out a watercourse improvement program. The village

7/Goodenough (1971) has also distinguished several levels or senses of the term "culture" depending on the perspective of the observer which also cannot be pursued here. Culture as defined here is not the traditional "superorganic" conceptualization of sociologists and anthropologists.

8/See acknowledgements at the end of the paper.

studied, "Gondalpur" (a pseudonym), is located in Central Punjab, on the Chaj "doab" (the area between the Jhelum and Chenab Rivers). This part of the doab has traditionally been called "Gondal Bar" because historically the Gondal "tribe" dominated the area.

Before 1901 there was no canal irrigation in this area. The ancestors of many of the present inhabitants of Gondalpur had large herds of camels, sheep, goats, cows, and water buffalo; they also had one Persian well (chai) irrigating 18 acres of land as of 1857, and practiced some rainfed agriculture. As the accompanying table shows, during the 49 years between the British land settlement (1857) and the arrival of the canal water in Gondalpur (1904/05), there was a substantial rise in population (much of it because of in-migration), and a gradual extension and intensification of agriculture. There was also a fairly large-scale transfer of control over land to outsiders--and a concomitant increase in tenancy; and a large increase in the number of "castes" represented.

The Lower Jhelum Canal was officially opened in 1901, but its water did not reach Gondalpur until the 1904-05 rabi (winter) season. Its impact was immediate: hundreds of acres of land came under cultivation during both the summer (kharif) and rabi growing seasons. Former herders became farmers, either on their own land or as tenants on others' lands. The area available for grazing animals declined so that even a few years after the canal was introduced most farmers were devoting a substantial percentage of their land to growing fodder for their animals. Other changes since the introduction of canal irrigation include a further rise in population, increasing fragmentation of land holdings, and increasingly intensive agriculture. As is true elsewhere in Punjab, the water table has also risen 40 to 60 feet so that today nearly everywhere it is less than 20 feet below the surface. In some areas it is less than 5 feet, and a large low-lying tract in Gondalpur has become waterlogged and an adjacent previously productive area saline and unproductive.

Gondalpur land is irrigated by three watercourses, all of whose heads are located in other villages, and controlled by farmers larger and more powerful than any Gondalpur farmer. On two of them, most of even the Gondalpur land is owned by outsiders and cultivated by Gondalpur tenants. The third watercourse has several separate branches, as the accompanying map shows. One branch passes through the center of "Chak Aziz" (a pseudonym), before passing through Gondalpur to a third village, "Pindi" (a pseudonym). The main branch follows the line between Chak Aziz and yet another village into Gondalpur, then divides into three sub-branches which primarily irrigate the holdings of Gondalpur farmers.

Table 1. Changes in population and cultivated area in Gondalpur since 1857.[a]

| Year | Population | Area sown once in a year in acres | | | |
|---|---|---|---|---|---|
| | | Rainfed | Irrigated | | Total |
| | | | Well | Canal | |
| 1857 | 67[b] | 46.5 | 18 | 0 | 64.5 |
| 1881[c] | 215 | - | - | - | - |
| 1888/89 | - | 125 | 44 | 0 | 169 |
| 1891[c] | 310 | - | - | - | - |
| 1901/02 | 568 | 186 | 47 | 0 | 233 |
| 1904/05 | - | 152 | 36 | 86 | 274 |
| 1909/10 | - | 1 | 0 | 605 | 606 |
| 1911[c] | 565 | - | - | - | - |
| 1921[c] | 767 | - | - | - | - |
| 1931[c] | 758 | - | - | - | - |
| 1936/37 | - | 374 | 0 | 492 | 866 |
| 1951[c] | 914 | - | - | - | - |
| 1955 | 1027 | 104 | 0 | 654 | 758 |
| 1961[c] | 1117 | - | - | - | - |
| 1968/69 | - | 87 | 0 | 668 | 755 |
| 1972[c] | 1246 | - | - | - | - |
| 1977[d] | 1449 | - | - | - | - |

a. Source: unpublished village records

b. The 1857 settlement records gives the following population

| Households | People | Zat |
|---|---|---|
| 10 | 56 | Gondals |
| 1 | 2 | Mochi (leather workers) |
| 3 | 9 | Cuhra(non-Muslim, very low status, untouchables) |
| 14 | 67 | Total |

c. Census figures taken from unpublished village records to 1951; 1961 and 1972 figures are from District Census Report (Gujrat) for these years.

d. Based on complete household census. The number of zats had increased to 24 in 1977.

## Watercourse Social Organization

The Gondals are the dominant land owners in Gondalpur. As Table 2 shows they are divided into four major named biradaris, the Khudaya (branch D), Khizarane (branch B), Muradke (branch C), and "Miane". The first three named so dominate particular branches of the watercourse that these are known by their names. Members of other biradaris also have land on various branches. A few Awan have very small holdings on B and C; two Bhattis have some land on branch B, as do three Sayid refugee families; and some Muradke and Khudaya have land on branch B.[9] On branch D, aside from the Khudaya, a few Pindi farmers also have land, as do the religious leaders of Gondalpur, the "Miane". The Numberdar[10] and his family, having relatively large holdings, (50-80 acres) are Khudaya; the Miane holdings are also relatively large (25 acres for each of three households) while the other two Gondal biradaris are mostly small farmers (5 to 20 acres).

At the head of branch A are four related households of Kharal zat. One has become a very large land owner (about 300 acres), having bought much land elsewhere. He has about 50 acres on this watercourse. His brother also has about 50 acres on branch A and their half-brother's two sons have about 50 acres between them. Though these two half-brother's sons often quarrel with each other they did not during the watercourse project; I shall refer to them collectively as the "step nephews". Following the Kharal, on Gondalpur land, branch A irrigates the land of several small Langah farmers (one to ten acres). The members of this biradari, though poor, have marriage relations with the Khudaya, Muradke, Kharal, and a large Pindi landlord. Some land belonging to the Gondalpur Miane is irrigated after the Langahs', then at the tail branch A irrigates small portions of the relatively large holdings of several Pindi families.

## Watercourse Conditions Before Improvement

Pakistan's irrigation system is a continuous-flow system. Farmers have a right to water proportional to the size of their holdings. Usually they get water at a fixed time on a weekly basis. From the beginning, government policy has been to interfere as little as possible in local water management; the Irrigation Department directly manages the headworks, canals, and distributaries, but not the watercourses. When the system was built the government laid out the route of the watercourses, but their building and maintenance was the responsibility of

9/Most of this latter is either waterlogged or saline, or not commanded because the land is high and on the other side of the low-lying waterlogged area (see Figure 1).

10/"Numberdar" (numbardar, Lambardar) is hereditary position created by the British. He collects the land revenue and irrigation fees for the government, keeping a percentage for himself; and acts as the intermediary between the villagers and government officials.

Table 2. Zamindar biradaris involved in watercourse reconstruction.[a]

| Biradari | Number of Households | Number of People | Watercourse[b] branch | Position on branch |
|---|---|---|---|---|
| Gondal-Khudaya | 11 | 70 | mainly on D; a little on B. | Head; Middle; Tail |
| Gondal-Khizarane | 21 | 105 | B | Head; Middle; Tail |
| Gondal-Muradke | 7 | 43 | C; a little on B | Head; Middle; Tail |
| Gondal-Miane | 5 | 36 | D; a little on A | Middle; Tail |
| Langah | 5 | 36 | A | Middle |
| Awan | 11 | 47 | B and C - very small holdings | Middle |
| Bhatti-Rajeane[c] | 18 | 78 | B (2 households) | Middle |
| Sayid | 3 | 25 | B | Head; Middle |
| non-Gondalpur biradaris: | | | | |
| Kharal (Chak Aziz | 3 | ? | A (a little on B) | Head |
| 3 Pindi biradaris[d] | under 10 | ? | A & D | Tail on both |

a. This is not a complete list of all biradaris in Gondalpur; only those having land irrigated by the watercourse reconstructed are listed. Figures are based on 1977 complete household census.
b. See Figure 1.
c. Only two households of this biradari have land on this watercourse. There are 7 Bhatti biradaris in Gondalpur with a total of 91 households and 421 people as of 1977.
d. These biradaris did not play an important role in the improvement project--there major holdings are on other watercourses; they generally acted together on this project.

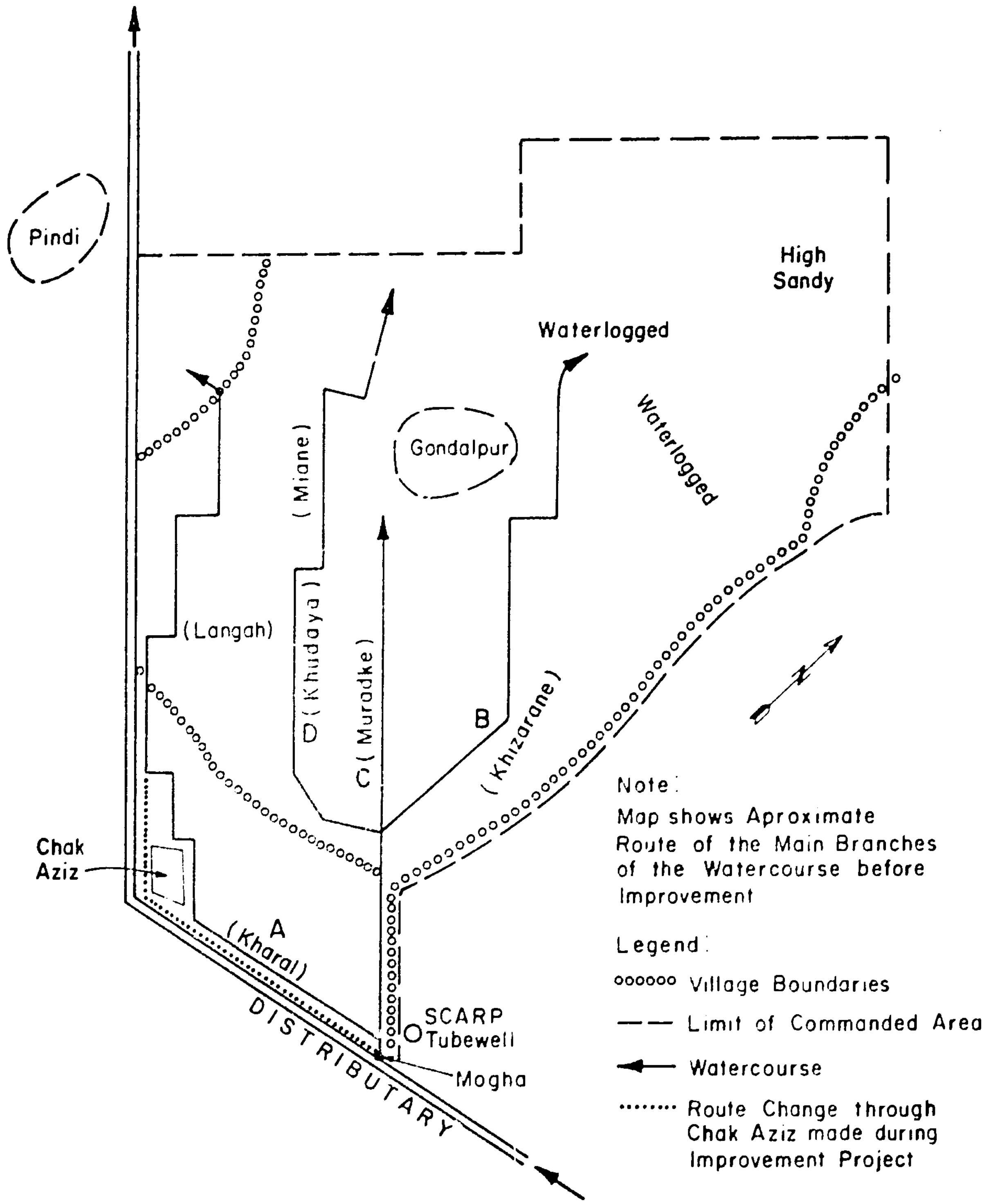


Figure 1. Sketch map of watercourse, Gondalpur.

the shareholders. The government retains residual powers activated by appeals from farmers to set water rotations, settle disputes, or change the route (see Johnson, Early, and Lowdermilk, 1977; 1237; Michael, 1967; Jahania, 1973).

At the time of the study (1976-77) the level of maintenance of all the branches on the watercourse studied was extremely poor. A Salinity Control and Reclamation Program (SCARP) tubewell had been installed at the head of the watercourse in the mid-60's, doubling the amount of water flowing through the watercourse. As is generally the case in the SCARP areas, the intensity of cultivation increased substantially as a result of increased water supplies.[11]

However, the capacity of the watercourse was not increased; further, for some years after the installation of the tubewell, there was no perceived water shortage. According to informants this led to a decrease in maintenance efforts, atrophying the already weak sanctions enforcing participation in watercourse cleaning. Further, fragmentation of plots had led to increased numbers of "illegal" (i.e., not sanctioned by the Irrigation Department) cuts in the main water channels. The watercourse, on all branches, was choked with grass, bushes and trees; leaked through rat holes, thin banks, and at junctions; and water remained standing in many low sections after irrigation. On branch A, since the Chak Aziz lands are relatively high, the owners actively sabotaged efforts to clean the head of the watercourse. Silting raised the water level, and thus their ability to irrigate their high land; but it blocked an increasingly large percentage of the water from reaching the middle and tail farmers.

This lack of maintenance, combined with increasing pressure to raise production (limited by water) had created a considerable dissatisfaction with the condition of the watercourse by 1976.

## The Improvement Process

In response to this dissatisfaction I was instrumental in arranging for the Mona Reclamation Experimental Project to choose this watercourse for an experimental improvement program;[12] in this program the Government supplies technical advice and supervision, and materials such as concrete outlets (nakkas); the farmers are responsible for supplying all labor for the earthen improvements, masons for installing nakkas, etc., and for subsequent maintenance. Some Gondalpur farmers had heard about the success of the improvement program in other villages; a

11/Previously informants say there had been little double-cropping. Now most of the land--especially that of small farmers--is double cropped.

12/The arrangement was that I would observe, but not participate, in the process; in fact, people often sought my intervention to influence the engineers and upon occasion I did offer suggestions to the Mona personnel--which were never followed.

survey by the author indicated that the farmers were actually aware that the losses from their watercourse were high and were eager to improve it.

The improvement program on this watercourse undoubtedly faced more problems than is usually the case on a single watercourse; but this makes it an important case to study as all of the problems encountered characterize other watercourse reconstruction efforts to various degrees. A description of all that happened during the six months of active improvement work would constitute a book in itself; a brief summary will show the kinds of problems faced by the project. At a farmer meeting in June, 1977, two committees were set up; one, for branch A, included a Kharal representative from Chak Aziz (the youngest of the two "step nephews"), a Gondalpur Langah, and the Pindi numberdar. For the "main branch" and branches B, C, and D, one Khudaya, one Khizarane, and an Awan were chosen. The branch C Muradke refused to take part in the improvement program on their branch and therefore had no committee member. There were several reasons for their refusal: they did not perceive much of a water shortage; they preferred to continue cutting their watercourse freely; and they were angry at the Awan over unrelated issues and opposed any program the Awan supported.

Work began on Branch A--but on the same day as an announcement of land allotment under the land consolidation program in Gondalpur; therefore, only Chak Aziz shareholders were present at the work site and they successfully pressured the government engineer to start work on a new route for the watercourse, parallel to the distributary around their village (see Figure 1). This route had been discussed previously and opposed by the middle shareholders, but now it became a fait accompli and they could not oppose it. Since the old route had passed through the step nephews' land and another Kharal's courtyard, while the new one is on government land and higher than the old one, the Kharal benefitted substantially from this change.

Over the next few months work continued, fitfully, on branch A, and the engineer had branch D and B work begun even though he had not yet done a survey to indicate the route, width, and depth. The farmers on B and D discovered their water supply was reduced as a result, leading to considerable tension between them and the engineer. At a meeting with the farmers the engineer accused the farmers of not cooperating with him and gave them an ultimatum--to follow his instructions without argument or he would abandon the project; the farmers were angry but agreed to his demands. These branches were then surveyed and the work redone.[13]

A number of disputes broke out among the farmers (aside from a series of continuing disputes between the farmers and Government officials):

1. On branch D, two Khudaya, the numberdar (supported by the Miane), whose land was at the head and middle, and his paternal cousin, a watercourse committee member most of whose land is at the tail, disputed over how far towards the tail the improvement work should go. The numberdar (and Miane) wanted the work to stop about 1,000 feet short of the cousin's land, so that no improvement work would be done on the section through their land. When the tail cousin refused to cooperate unless his demands were met the numberdar agreed, though the Miane continued to protest and refused to cooperate on the work.

2. The Miane, near the middle and tail of D, continued to dispute with the Khudaya over how far the improvement should go, and over the route of the watercourse. The engineer, based on his survey, wished to straighten it. Since it skirted the edge of the Mianes' land and over the years had been shifted, increasing their land, moving it would reduce their land slightly. It was straightened, finally, but over their continuing protest.

3. On branch B, the Khizarane leader frequently argued with Muradke, Khudaya, and Sayid shareholders over division of the work.

4. On branch A the Pindi shareholders and the Miane were lax about doing their share of the work, leading to conflict with the others.

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13/There were significant differences among the branches in the labor organization for improvement and the efficiency of the work. Except for a few portions of branch D done collectively, the work on each portion of all the branches was divided among the shareholders proportional to the amount of land irrigated. The large farmers at the head and tail of branch A had their tenants and servants do the work, while the small farmers in the middle did their own share--and did them more quickly. Most of branch D was done by tenants, kamis and hired laborers--and more time was spent smoking and gossiping than working, significantly slowing the work. All but a few of the branch B shareholders did their own work, and theirs was completed very quickly.

5. The Langah committee member and the Kharal member disputed over route changes demanded by the Kharal and division of work shares; because of his weak position, the Langah pursued these issues more with the engineer than the Kharal directly. In every case, the Kharal won, because both the government officials and other farmers feared the consequences of the Kharal not cooperating, given their strategic position on the watercourse.

6. The Kharal "step nephews", who had traditionally taken "unauthorized" water from the main branch, successfully sabotaged the work on that branch, including preventing the removal of trees and straightening of the route. There seemed to be three reasons for their obstructionism: they realized taking illegal water from the main branch would be more difficult; they would lose a little of the land they occupied if the watercourse were straightened; and they were jealous. They opposed any program that would benefit the weaker Gondalpur people, perhaps fearing it would lead to their becoming more independent of them.

7. The Kharal demanded, and by threatening to sabotage the project, obtained extra nakkas and double-sized culverts for their land; but even after getting these the two "step nephews" in particular continued to sabotage the work.

A project that was expected to be completed in less than two months was not finished in December 1977, the sixth month, when I left; and when I returned in May, 1978 I discovered that some sections still had not been reconstructed, especially in the middle and tail sections of A and B; some of the sanctioned nakkas had not been installed, and several of the installed ones had been damaged; and there had been no cleaning and maintenance done. All the branches were choked with weeds and silt and leaked from new "unauthorized" cuts in the rebuilt banks. Even in October, 1978, the normal watercourse cleaning in preparation for the rabi season had only been haphazardly done.

The sections completed up to December, 1977, immediately after reconstruction, did not leak, and farmers enthusiastically reported up to five times as much water reaching their fields as before. However, by November, 1978 the water delivery had drastically declined though farmers said not quite to pre-improvement rates. I observed that the sides, because of both poor construction and very poor maintenance had deteriorated considerably and were leaking badly; much water remained standing in the ditch after irrigation; and many farmers felt discouraged about the prospects of maintaining even the present levels of efficiency.

## PUNJABI CULTURE: THE CONCEPT OF IZZAT

There is no doubt that one source of the problems faced by this project is the relationship that developed between the farmers and the government officials supervising the program.[14] Another factor was that the potential benefits of the program were not perceived as equally distributed (Doherty and Jodha, 1977). Indeed equal distribution of benefits in a watercourse reconstruction program is impossible to achieve because of differences in size of landholdings, differences between owners and tenants, and most crucial, the relatively greater benefits accruing to farmers with land at the tail than to those with land at the head of the watercourse. However, the active attempts by the step nephews to sabotage the program in order to prevent others from benefitting, and the disputes that developed among persons whose benefits were about equal, suggests these factors are insufficient as explanations of the problems encountered. In fact, the major source is to be sought within the sociocultural organization of rural society. Punjabi rural society is characterized by a set of values and mechanisms which encourage conflict-make conflict endemic and unavoidable, and thus tend to discourage cooperation on a long term basis.[15]

The most fundamental concept, or theme, in rural Punjabi culture, in terms of which much of Punjabi behavior can be understood is the concept of izzat.[16] Izzat may be glossed as "honor," "esteem," "reputation" or "face". It is a

14/Although some of these engineers and extension workers have rural backgrounds, their education has seemingly made them unfit for rural work; possessing a degree, and a respectable position in the government bureaucracy, they are "officers". They create barriers between themselves and their clients by wearing western clothes, speaking an urban dialect, and doing all they can to create the impression they possess a superior knowledge and position which ought to be respected. When the clients assert themselves, and refuse the "officer" the "respect" (read "obeisance") he claims, conflict arises, and the officer's low opinion of his clients is confirmed in his mind. This kind of relationship between government and farmers is not confined to Pakistan.

15/I am not arguing that there is no cooperation; Lowdermilk, Clyma and Early, (1975: 41-47), for example, discuss several forms of cooperation. But the patterns they discuss are among a few individuals, usually relatives, and tend to be on a short term basis. These authors (p. 47) minimize the importance of the factors discussed here as major impediments to organization.

16/This is the most common and broadest term; there are others but they tend to have more restricted meanings. The term has obvious affinities, conceptual and historical, with the Middle Eastern and Mediterranean concept of "honor". This paper does not pretend to be a complete discussion of izzat, which has important ramifications in many areas of Punjabi life.

"limited good" (Foster, 1965): one acquires more izzat only at others' expense. As in a zero-sum game, the success of one person is a threat to all the other players, a characteristic that generates competition and jealousy. For example, when Government officials agreed to a very reasonable request for a double-width culvert for truck access to one of the Kharal's brick kiln, his step nephew demanded a double size culvert for himself. Informants said his izzat was at stake: if he got less than his step uncle he would lose izzat. Government personnel, not accepting the rules of the izzat game, rejected his demand, which led to further problems with the man.

All men wish to avoid losing izzat, but many men also attempt to increase their own izzat, or reduce others'. One acquires and increases one's izzat by several different strategies. First, one must have the ability and more important the willingness, to use force. There is a famous Punjabi saying: "Whoever holds the stick owns the buffalo." This does not mean force is necessarily frequently resorted to; it is enough to create the impression that one is willing and able to do so, and in times of tension, much calcuation and speculation revolves around this issue. The Kharal step nephews were feared because they had demonstrated their willingness to use force in previous fights. The Bhattis of Gondalpur, mostly tenants and poor, in the past had also had a lot of izzat for the same reason. On the other hand, the Khudaya numberdar, despite land holdings, his government contacts, and several adult brothers, had less izzat than he might have had because it was known that he feared violence (this was not an unreasonable fear since his father has been murdered).

A second means of acquiring izzat is possession of influence with government officials, and willingness to use it for one's supporters and against one's "enemies". The numberdar had some izzat from this source but was not willing to use it against "enemies'; the Kharal step nephews, some Pindi landlords, and a recently deceased poor and landless Bhatti leader before his death, all had a substantial amount of izzat from this source (as did the author). A third source is willingness to entertain guests lavishly, whether they are government officials or relatives at a wedding--even if one bankrupts himself in the process. The deceased Bhatti leader mentioned above, kept himself bankrupt but high in izzat by this means.

Success in competition, whether organized games such as kabadi or a stick fight, is another source of izzat. Winning, not a valiant loss, is the key. Another source is generosity, not to the general public, but toward individuals (who are obliged then to render support).[17] Finally, successful one-upmanship,

17/Religious generosity such as building a mosque earns one "respect" (adab) for piety, but is not itself a source of izzat; pious acts score points in a different game.

including getting revenge for a previous defeat or insult, is important. For example, disputes are often taken to the police; and the person or group that can avoid jail or beating by the police, while getting the opponent punished, and spend the least money on the case, "wins". Such cases often become very long, involved, and expensive; but they continue even when people are aware that after so much trouble and expense they will have nothing tangible to show.

In order to improve one's izzat one must have taqat (strength, power), but taqat alone is insufficient; one must use this power to help one's clients or defeat one's enemies. The richest of the Kharals has less izzat than one would predict from his wealth and government contacts because he was unwilling to use his position in this way. A person whose taqat and izzat are increasing attracts followers and allies who hope to benefit; but he also attracts the jealousy and fear of others who are likely to band together behind the scenes to plot strategies to limit or reduce him. If it is a group (such as biradari) or several brothers who are getting too powerful, efforts will be made to sow dissension and thus weaken their unity; because individuals' primary loyalties are to themselves and each one assumes this to be true of others, efforts to divide groups, even two brothers, often succeed.

People recognized as "leaders" are supposed to work for the benefit of their followers as a group; but more often than not, such persons keep their own interests in mind first and attract clients by aiding individuals (against the police or an enemy for example) who are then obliged to them. Only infrequently do leaders work for the benefit of a group or community as a whole--and even when they do, others may accuse them of seeking only their own benefit.

Opposition is often expressed verbally in terms of issues, but in fact the issue is nearly always a pretext: men oppose or support decisions and programs based on their perceptions of their competitors' position. For example, even though all farmers were suffering the exactions of a corrupt tubewell operator, they did nothing because, informants explained, if one man or group proposes petitioning for his removal, others will oppose, not out of love for the tubewell operator, but to prevent the others from utilizing the issue to gain some advantage, or to pursue some long-standing grudge. This can be carried further: the non-cooperative behavior of several Kharal on branch A during the watercourse reconstruction was interpreted by informants as based on a desire to prevent others from benefitting--even if it meant foregoing their own benefits.[18] Opposition is also not "legitimate" in the

18/There is a Punjabi saying, "If my neighbor's wall falls it is good--even if it falls on me".

western parliamentary sense: opposition is always personal (or interpreted by others as personal), and aimed at weakening others or strengthening one's own position.

There is a strong ethic of loyalty to one's kinsmen; one ought to be prepared to make sacrifices for their benefit--and on occasion people do. Marriage within the biradari--siblings and cousins exchanging children--is intended to cement their affections and relationships. Divisions within the community, in Gondalpur and other villages, are usually between biradaris; this was the case for most disputes over the watercourse improvement program. There is a feeling of a biradari's izzat, which must be protected from others' attacks; and if a man's izzat suffers at the hands of a member of a different biradari, all of his close kinsmen will unite in opposition to the "enemies" (dushman).

Nevertheless, despite the emphasis on loyalty to one's kinsmen, tensions among biradari members are always present; patrilateral cousins and brothers often have tense and competitive relationships and do not completely trust each other. One's brother's or cousin's personal izzat is not necessarily one's own; hence a man is apt to be jealous of and feel threatened by a brother's success. Tension is also generated among biradari members by joint potential rights in land. One of the worst cases of conflict in Gondalpur history, resulting in two murders and three executions, occurred within the Khudaya biradari over land; one branch attempted to deprive another branch of rights to some land; tensions built up and the latter finally took action, by murdering the numberdar and his brother. The amount of land involved was in fact not great; the real issue was izzat. If the second group had allowed themselves to be deprived of the land, their izzat would have been severely damaged.[19]

During the improvement process there was much petty conflict among biradari members over work shares and the like; the Kharal are seriously divided, and the Khudaya only slightly less so; the Awan and Muradke, though separate biradaris in many senses, are closely intermarried--yet at the time of this study were involved in conflict over several issues. It is likely that the sociologists discussed above have overemphasized the unity of biradaris.

19/The numberdar and the cousin with whom he argued over the extent of work on the watercourse are the sons of the two murdered men; their relations are tense in part because of jealousy and dissatisfaction over the subsequent partitioning of their fathers' land; and in part because each fears the other will gain an advantage. An exchange of sisters would seem to be called for here, but each branch is marrying matrilaterally (outside the village), accentuating the division.

The sense of community within the village is real, but also inter-twined with izzat. In opposition to outsiders villagers will act together in a stick fight or a competitive game (such as kabadi), to preserve the izzat of their village. However, cooperation within a community to achieve a mutually beneficial goal is very difficult as people fear others may benefit more than they, or the leaders will gain undue influence. In some villages there are leaders who are sufficiently trusted (or feared) to insure that farmers cooperate to maintain their watercourse (Mirza and Merrey, 1978), but this is not true of most communities, and is not a permanent characteristic of any community.[20]

## THE IMPLICATIONS OF IZZAT FOR ESTABLISHING LOCAL LEVEL ORGANIZATIONS

Punjabi villages exhibit considerable variety in observable social organization: single, double, multicaste villages; villages with strong leaders and villages with no leaders; villages with no recent history of serious conflict, and villages where murders occur yearly; villages inhabited by descendents of the original (pre-canal system) inhabitants; colonists who came at the time of the building of the canals; and recent refugees from India. However, in contrast to the variation at this level, there is relatively less cultural variation: the concept of izzat described here is shared to a very large extent by rural Punjabis. However, it leads to somewhat different sociological patterns under different circumstances.

For one thing, people pursue different strategies depending (aside from personality differences) on the larger social context in which they find themselves. Pindi village for example is dominated by a number of very large landlords; they are all Gondal, but are subdivided into several biradaris. Tension among several of these has led to a number of murders over the years. Members of other Gondal biradaris attempt

20/One commentator on an early draft of this paper, as well as one of my Gondalpur informants with whom I discussed my conceptualization of izzat, suggested I have confused what my informant calls "false izzat" with "true izzat". True izzat refers to the more "positive" characteristics included in the concept, while "false izzat" includes more "negative" behaviors such as undercutting others, and creating fear in others. It is important to note that my informant here is a Langah, who are not active participants in the main game of izzat. Other Gondalpur informants, while understanding the distinction, insist nevertheless that obstructionists like the step nephew do have izzat in most people's eyes; men who are feared and referred to as "badmash" ("bad character", troublemaker, bully) are also respected (even admired) and regarded as having izzat; and the "badmash" themselves believe they are increasing their izzat by their tactics.

to remain neutral, or temporarily ally themselves with one or another side, or try to stir up incidents among others in order to weaken them. Many Gondalpur farmers are clients of the Pindi landlords; they work as tenants for the landlords, or help them when a show of force--or votes--are needed; in return they expect their patrons to help them against their enemies when needed. Normally the Gondalpur people do not compete directly with the Pindi landlords; they may be said to be operating in different political "arenas".

Everyone is concerned about his izzat; but not all men play the game of izzat actively. Many are content to avoid losing izzat by not initiating confrontations. If they retreat when someone forces an issue, they lose izzat, but avoidance of confrontations does not always mean weakness. The Langah, for example, being a small biradari with relatively few resources, are rarely involved in conflict, but when another group attempted to grab some of their land during the land consolidation program they faced the issue squarely. The grabbers backed down, losing considerable izzat, and the Langah gained. Nevertheless, since the Langah do not initiate confrontations, the extent of their izzat is limited.[21]

In contrast, the Awan, with a slightly larger number of men but less land than the Langah, have closely allied themselves with the Kharal step nephew, and exhibited a willingness to use force to achieve their ends. People are, therefore, reluctant to annoy them and their leaders have more influence and izzat in the community than one would predict from the size of their landholdings or numbers.

The process of collective decision-making is also conditioned by concern for izzat. I have observed several paryon-s (panchayats, i.e., informal "councils" of men) attempting to settle disputes, and several meetings at which decisions regarding the watercourse improvement program were made. At all of these meetings, discussion seems interminable to the outside observer; people usually "shout" (by American standards), often get excited, and often drag in seemingly extraneous issues. At paryon-s, after the disputing parties have had

21/The Langah illustrate another strategy for maintaining their izzat: as noted above they have marriage relations with the Khudaya, Muradke, Kharal, and a large Pindi landlord. None of these other groups have direct marriage relations with each other. The Langah are proud of these connections. These marriages strengthened their position and were a source of more izzat than their small size and lack of involvement in politics would lead one to expect. However, this strategy has a double edge: since they were mostly women-givers in these transactions, they were also affirming a certain inferiority.

their say, and there has been considerable public discussion, the three to five men who are to make the decision withdraw to discuss the case privately; their decisions are always presented as unanimous, and one suspects they are influenced by the trends in the public discussions.

Similarly, at the meetings on watercourse improvement, a "consensus" was arrived at on each issue (sometimes meaning those opposed kept quiet--though they did not always accept the decision); on some issues, such as selection of the members of the "executive committee" the more important men, representing the various biradaris withdrew to discuss the issue privately. Their decision was announced to the group and extension officer, and accepted with little further discussion.

An important function of this "consensus" form of decision-making is to preserve the izzat of all the participants. If a consensus, or at least the appearance of consensus, is not achieved, decisions are often postponed, even when a large majority are agreed. To press for a decision when some remain opposed is to attack the izzat of the opposition. This may lead to an escalation of the conflict. If a formal process such as voting or an election is used, someone must suffer a public defeat and thus lose izzat, creating bitterness and potential obstructionism. Since one's izzat is at stake, aside from the office or decision in dispute, people are likely to resort to "unfair" means to avoid losing. Given this orientation it would be folly to insist on formal voting and majority rule as the mechanism for decision-making in any institutions established on watercourses.

Of course people may make decisions by consensus, then "ratify" it by formally voting; but the voting rule is also apt to be utilized by persons bent on increasing their izzat by forcing votes and thus causing opponents to lose publicly: this would ultimately subvert the organization.[22] Secret ballotting does not completely solve the problem either: someone still loses izzat in a public way; and in a small community it is not difficult to figure out how particular people voted.

When villagers and government officials interact, both are concerned about their izzat. In villages with several competing leaders, they often compete for the "privilege" of entertaining visiting officials--especially potentially important ones. Part of the reason is an ethic of the importance of honoring a "guest" of the village; it is "beizzati," i.e., a loss of izzat, for the village not to treat a guest properly. Another aspect is the person who (publicly) treats a guest well gains points in the game of izzat over his opponents.

22/I suspect something like this may have happened in many cooperatives.

If he is able to translate this into influence (or even the impression of influence) with the official then his izzat is further improved.

Officials are also concerned with their own izzat both in the villagers' and their colleagues' eyes. This often leads them to avoid delegating authority (especially to villagers but including such people as extension workers) and to try to give an inflated impression of their own authority. Although they often flatter and cater to big landlords, they also try to maintain social distance between themselves and ordinary villagers by wearing western clothes, and by using speech that is authoritarian and sometimes rude. This includes use of familiar verbal and pronoun forms of address. Villagers on the other hand are expected to be polite, to accommodate themselves to an official's needs, and to accept his point of view without argument. Publicly villagers are often obsequious, but behind the official's back, they may ridicule him. Some officers seem to be aware of this; at any rate they are very insecure and vulnerable, and I have observed several very strong outbursts by officers when villagers have criticized them publicly. These factors obviously inhibit government workers' abilities to work effectively with rural people.[23]

Perhaps because of this social distance, and the concomitant lack of awareness of the divisions and competing concerns of the people they work with, government officials sometimes make decisions that seem "fair" to them, but are seen as izzat-threatening by some of the community people. The example of the conflict over the double-sized culverts discussed above illustrates this point. It is important for officials to make themselves aware of these factors and consider the likely consequences of decisions; this can only be done if they understand the relationships among the people involved, and the culture in terms of which they operate. It should be a cardinal rule that no one should lose izzat as a result of a seemingly reasonable decision. In the above case, either both should have been given a double culvert, or the person needing it should have been asked to pay for the extra width.

Finally, a major consequence of the concern for izzat is that a "civic" sense is very rare. The step nephews from Chak Aziz are not unique in Punjab: there are many individuals who will actively sabotage a program to keep others from benefitting, even if it means foregoing benefits for themselves. Other people have no mechanism to neutralize or control determined obstructionists, even when a large majority

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23/The On-Farm Water Management Project workers are a notable exception to this, which may be one factor in their generally good reputation among villagers.

favor a particular program. It may be possible to solve this problem by strong government intervention, but this creates other, perhaps more serious, problems.

## CONCLUSION

This paper is by no means a complete discussion of the role of izzat in Punjabi social life; nor is the concept of izzat the only characteristic of Punjabi culture relevant to understanding why conflict is so endemic and cooperation so rare. A complete discussion would have to dissect the social and economic structure of rural Punjab; the dynamics of family and kinship, and the profound changes that have occurred in Punjabi society during the last 100 years. All these would have to be related to the historical and general cultural context of South and Southwest Asia. The discussion would have to include an analysis of the assumption of hierarchy and inequality in social relations that is only superficially overlaid by the Muslim ideology of equality; and it would have to include a discussion of attitudes toward land. This brings the discussion full circle back to izzat: hierarchy is expressed in the idiom of izzat, and possession of land and cattle are perceived as primary sources of izzat.

To reiterate, not all men actively "play" the game of izzat; but all those involved in "politics" in its broadest sense do. This includes a large number of men who are not "leaders" by any definition of the term. All Punjabi communities exhibit these same characteristics, but some more than others, and some are able to overcome them temporarily in order to accomplish community-wide projects; but these latter are a small minority.[24] The game may not have been unadaptive under pre-canal social conditions. During the period immediately preceding the building of the canal, population pressure seems to have been building--perhaps explaining why canal irrigation was adopted so quickly (Boserup, 1965). After the canal there was no shortage of land, no severe population pressure, and no pressure from the larger system to "develop": hence the minimal level of cooperation required to operate the system at a low level of efficiency was sufficient.

Now the pressure is again increasing: the demands of the larger system require increased production; the local subsystem too is under increasing local pressure as productivity on a per capita basis is probably not even being maintained.

24/See Pettigrew (1978) for a discussion of the role of izzat in East Punjab. Many of the characteristics of Punjabi rural society are found to varying degrees throughout north India and Pakistan; many of the implications of this paper for organizing farmers apply to these areas too.

Water and its mismanagement is a key constraint. Large-scale capital-intensive projects such as dams, canals, and tubewell schemes will continue to be constructed and operated in order to maintain and improve the productivity of Pakistan's irrigation system; but it is now recognized that many of the major problems--low productivity, waterlogging, and salinity, among others,--are the result of local-level mismanagement. Increasing attention and investment are, therefore, being focused on improving local water management practices, by involving local water users in projects to improve the efficiency of their watercourses, as well as their cultivation practices.

There are two possible strategies either the government can intervene directly and rebuild or enforce the reconstruction of watercourses, and use of better cultivation practices; or it can encourage local initiatives. The former strategy, in which the government itself would line all watercourses with cement for example, has been considered. Many farmers find it attractive. In theory at least it would require less maintenance. However, aside from the prohibitively high cost (Eckert, Dimick and Clyma, 1975), such a strategy would constitute further centralization, reducing the responsiveness of the system to local-level problems, and ultimately risking its viability.[25] Its effective administration would also be problematical.

The administrative and social impediments to the strategy being pursued are also substantial. Nevertheless, from an ecological perspective, a decentralized approach is most viable. In fact, paradoxical as it may seem, I would argue that the current program has not gone far enough toward encouraging local organization and initiative: not only should the government encourage the organization of local water users to manage their own local sub-systems, but these local organizations ought to be integrated into the operation of the system at higher levels (as in Spain, for example; are Radosevich, 1975). This decentralization would increase the responsiveness of the larger system to local needs and perturbations.

Given the sociocultural characteristics summed up in the concept of izzat that seem to prevent rural Punjabis from organizing and cooperating, how can local organizations succeed? In the discussion of "culture" and its relationship to behavior I emphasized the complexity of this relationship. It is not a fixed one to one or one-directional relationship. Since patterns of behavior are "generated" by a mixture of material and cultural constraints and rewards, changes in these constraints and rewards should generate changes in behavioral patterns (Barth, 1966; 1967; Goodenough, 1963). It cannot be

25/See Rappaport (1971); Flannery (1972); Lees (1974); this perspective is being developed in another paper presently being written by this author.

assumed that people will alter their customary behavior patterns and cultural values in the absence of compelling constraints and/or rewards to do so. Mere exhortation will not suffice.[26]

The solution is to create such constraints and rewards, designed with the specific cultural characteristics and material resources of the population in mind. A three-pronged strategy is suggested here:

1. Legal and administrative mechanisms are required to facilitate organization (such as an enabling law for local watercourse organizations, and their federation into larger organization). These organizations ought to be given real responsibilities.[27]

2. Sufficient rewards need to be built in to attract farmers to organize, and continued rewards held out to maintain the organization over the long run (for example free materials for watercourse reconstruction, credit and agronomic inputs at special rates for members of successful organizations, special public recognition for communities with effective organizations).

3. Sanctions are needed to be applied initially to individuals and groups who sabotage organizational efforts and local improvement projects, and eventually to be applied to local communities who lag behind in organizational efforts, or do not fulfill their responsibilities (such as watercourse maintenance). Such sanctions will have to be applied by an external authority, to avoid their becoming another weapon in the game of izzat, and will have to be swift, certain, severe, and just. This "external authority" should not be another arm of the Government bureaucracy;

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26/Although the emphasis in this paper has been on cultural factors as the independent variables "explaining" particular forms of behavior, this is an oversimplification. In fact, at a more abstract level than patterns of individual behavior, culture - including the set of values and strategies summarized by the term izzat - should be seen as a product of a particular social structural, economic and ecological context. Attempts to change only cultural values (by "education," "preaching," etc.), without changing the basic social structure and the constraints and rewards built into it, are not likely to succeed (see Silverman, 1968).

27/Gustafson and Reidinger (1971) seem to be among the first advocates of establishing water users associations; see also Water Management Research Project Staff (1976).

rather, it should be a body deriving its authority from local communities, but above any particular community.[28]

The facilitating mechanisms, rewards, and sanctions must be designed to fit the local milieu; what works in the Philippines may not work in Pakistan. For example, formal voting and elections ought not to be overemphasized at least initially in the operation of an association as this requirement may lead to its being sabotaged in the game of izzat. Communities that organize themselves effectively ought to receive public recognition aside from the material benefits that will hopefully accrue. In time such a stategy may encourage, if not a redefinition of izzat, at least a recognition of more constructive behaviors as sources of increased izzat.

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28/Federation of local organizations into larger bodies is probably a necessary component of a successful decentralized water management organization, settling disputes and imposing sanctions would be only one of the higher-level functions.

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# APPENDIX 32

## OPTIMIZATION OF LENGTHS OF ALTERNATIVE WATERCOURSE IMPROVEMENT PROGRAMS IN PAKISTAN

John Reuss[1]

## I. INTRODUCTION

Over the past several years a substantial amount of information has been collected concerning watercourse losses in Pakistan. Due to the high water losses encountered, improvement programs have been designed and undertaken. To date, these are largely either experimental programs or pilot operational programs but serious consideration is being given to more substantial operational programs.

Several studies (2,3,4) contain information on costs and returns from earthen improvement either with or without permanent control structures and/or improvements involving brick or concrete linings of various types. These studies have assumed that the complete main channel or official watercourse would be improved by either one method or the other, but studies have not considered the alternative of lining the heavily used portions and using lower cost improvements on the less used tail reaches. This paper undertakes the development of a theoretical basis for determining the optimum amount of any contemplated improvement or the optimum point on the watercourse at which a high cost program would switch to a lower cost alternative.

There are many practical considerations to watercourse improvement that are relevant, in addition to the more theoretical approach given here. At present information is being assembled from various watercourses that have been studied in some detail so that the application of these theoretical approaches to field situations can be properly examined. However, various organizations and agencies are presently involved in analyzing water management alternatives for new or revised programs. It therefore seems appropriate to issue a progress report on the theoretical aspects at this time.

While some important conclusions are fairly obvious from the material presented here, comprehensive recommendations must await the more complete analysis.

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## II. THEORETICAL CONSIDERATIONS

Let us consider a watercourse with a flow Q at any point. The inflow is defined as $Q_o$, the delivery as $Q_D$ and the watercourse losses as $Q_L$ so that:

$$Q_o = Q_L + Q_D \tag{1}$$

First we will consider the case of watercourses with a single main branch, although several of the relationships are valid for branched watercourses as well.

### Linear Loss Assumption

The first assumption is that the loss rate along the channel is uniform and is a constant fraction of the inflow. Thus, if Q is the rate of flow at any point and $Q_o$ is the inflow rate, a plot of $Q/Q_o$ as a function of distance should give a straight line. This assumption has several weaknesses but plots of $Q/Q_o$ for several watercourses that have been intensively studied do tend to be linear even though there is substantial point scatter. Slopes of these lines indicate loss rates of from 4% to 13% of the inflow per thousand feet. (5,6)

We will now define a relative loss k with the dimensions $ft^{-1}$ defined as the fraction of the inflow that will be lost per unit length in any part of the channel where water is flowing. The change in flow per unit length $\frac{dQ}{dL}$ is now given by:

$$\frac{dQ}{dL} = -kQ_o \tag{2}$$

The above mentioned losses of 4% to 13% per thousand feet correspond to k values of $4 \times 10^{-5}$/ft to $1.3 \times 10^{-4}$/ft.

Watercourse improvement programs are of various types. Certain high cost improvements may nearly eliminate loss, while other improvements may only achieve moderate loss reduction. Therefore, it is convenient to utilize a loss reduction factor f, which is the fraction that the initial loss is reduced as a result of improvement. If k for an unimproved watercourse were $5 \times 10^{-5}$/ft and the improvement reduced losses by 90%, f would be 0.90. At any point on the watercourse the reduction in loss per unit length is given by:

$$\frac{dQ_L}{dL} = kfQ_o \tag{3}$$

The change in volume of water saved per unit distance is given by the change in flow multiplied by the time of operation so that:

$$\frac{dW_s}{dL} = kfQ_ot \quad (4)$$

Here t is the time the water is flowing at any particular point L and $W_s$ is the volume of water saved by treatment. The change in water lost per unit distance, i.e. the loss per foot $dW_L/dL$, is simply the special case where f is equal to 1. The loss per unit length and the expected water savings by two types of improvement programs are shown in Fig. 1. For illustration, I have assumed a loss of 7%/1000 ft in the unimproved system of a k value of 7 X $10^{-5}$. The lining treatment was assumed to reduce losses by 6.5%/1000 ft and the earthen improvement by 3.5%/100 ft, which corresponds to f values of .93 and .50 respectively. Inflow was assumed to be 3 cusecs for 336 days or 2016 acre-ft/year. In this illustration, at the head of the watercourse where t is equal to 1, the loss per foot would be .14 acre-ft/year of which .13 acre-ft/year would be saved by lining or .07 acre-ft/year would be saved by earthen improvement. Moving down the channel to where the watercourse only operates 84 hours per week, t is equal to 0.5 and the loss per foot is .07 acre ft/year of which .065 and .035 acre ft/year are saved by lining or earthen improvement respectively.

Defining $R_n$ as the net return per unit length per year $dR_n/dL$ is given by multiplying $dW_s/dL$ by the value of the water saved V and subtracting the annual cost of the improvement per unit length C.

$$\frac{dR_n}{dL} = VkfQ_ot - C \quad (5)$$

It is convenient, using units common in Pakistan, to define V in terms of Rs/ac-ft, k as $ft^{-1}$, $Q_o$ in acre-ft/year, t is dimensionless (years/year), and C in Rs/ft per year. Plots of $R_n$/ft for the lined and unlined cases, illustrated in Fig. 1, are shown in Fig. 2 assuming an annual cost of Rs. 4/ft for the lining and Rs. 1.25/ft for the earthen improvements, and the value of water V as Rs. 100/acre-ft. At this point, confusion can easily arise concerning the time of inflow, $t_o$, and the necessity of adjusting the optimum time t for the time that the watercourse is not in operation. Here the adjustment is already accounted for since $Q_o$ is calculated as acre-ft/day times the number of operating days/year so that $Q_o$, in effect, represents the product $Q_ot_o$. This method simplifies the calculations and eliminates the need for carrying $t_o$ in the calculations. It is used throughout this paper.

Conventional economic theory suggests that, if one were considering an expensive improvement program such as lining, one would only wish to apply it to those reaches on which the net return is positive, i.e. $dR_n/dL$ is greater than zero, or the marginal return is greater than the marginal cost.

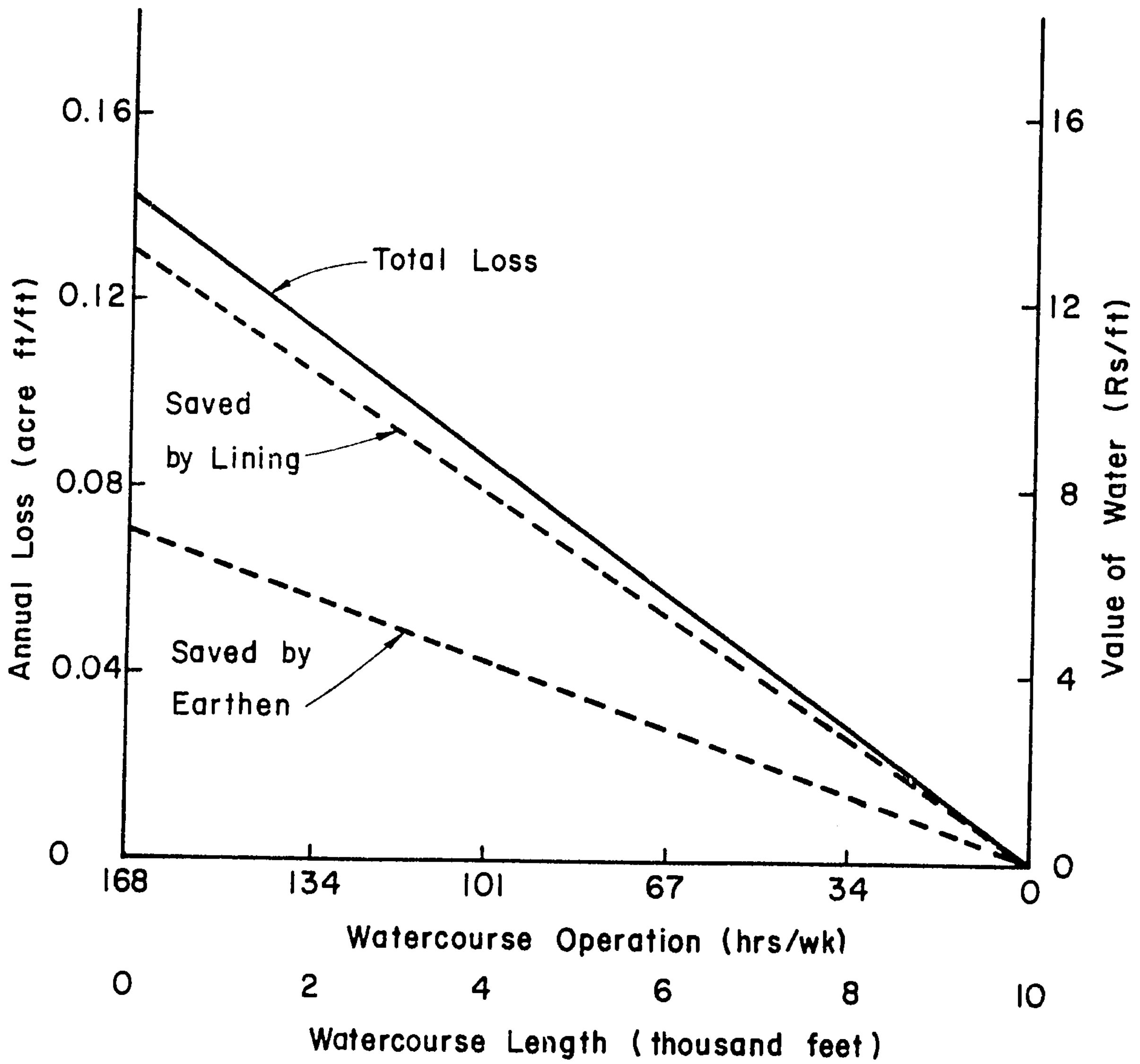


Figure 1. Annual water loss and amount saved per foot of watercourse assuming lining or earthen improvement as a function of distance. Value of water is given on the right hand scale.

Therefore, setting the left side of (5) equal to zero and solving for t:

$$t = \frac{C}{VfkQ_o} \tag{6}$$

Using the above units, t is dimensionless and C is the annual cost per foot. Multiplying by 168 converts t to hours per week of "warabundi" or irrigation turn time. In this manner, we can calculate directly the hours per week of use required to justify the treatment. The implication is that, for sections of the watercourse having less than the indicated use, we could not justify the cost of improvement. In Fig. 2 the optimum t values for the two systems are shown by the points where the diagonal lines cross the zero-return axis or at about 51 and 30 hours per week for the lined and unlined cases, respectively.

Let us now consider the case where the two methods of watercourse improvement are contemplated for the same watercourse using the lining on the upper reaches and the earthen improvement at the tail. Again economic theory suggests that the optimum point to switch from the higher cost to the lower cost treatment is that point at which the returns per unit length from the two methods are equal. From (5) we can write:

$$Vkf_\ell Q_o t - C_\ell = Vkf_h Q_o t - C_h \tag{7}$$

In (7) the subscripts h and $\ell$ refer to the higher and lower cost treatments, respectively. Rearranging, we obtain (8) which allows us to calculate the time of use required to justify the higher cost treatment over the lower cost treatment.

$$t = \frac{C_h - C_\ell}{VkQ_o(f_h - f_1)} \tag{8}$$

From our example, t is 0.455 (76.5 hours per week) and represents the intersection of the lines for the two cases in Fig. 2.

The above equation only allows us to calculate the use time at which treatments should be changed to maximize net returns. In order to determine the total amount of water saved or the total return it is necessary to integrate Eq. (4) or (5), respectively, over distance. This cannot be done directly as t is dependent on distance. A couple of approaches appear feasible.

First, we can use a simple numerical method. The t used to this point is the fraction of the inflow time at any point on the watercourse so that:

$$t = \frac{h}{168} \tag{9}$$

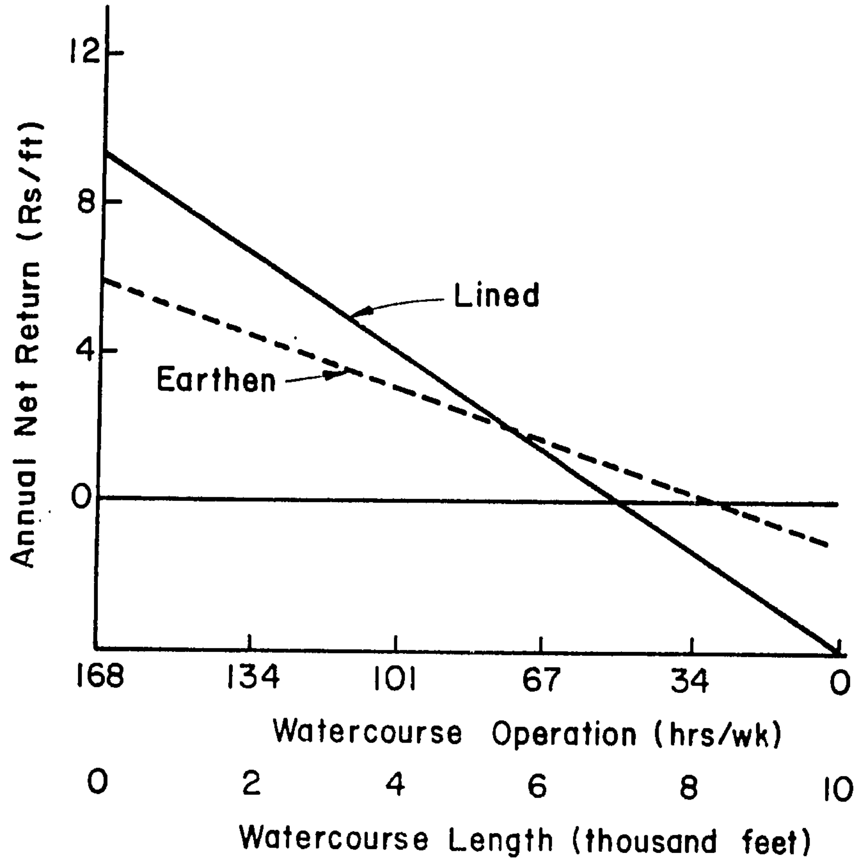


Figure 2. Annual net returns per foot of watercourse for lining and earthen improvements as a function of hours per week. Assumptions are given in text.

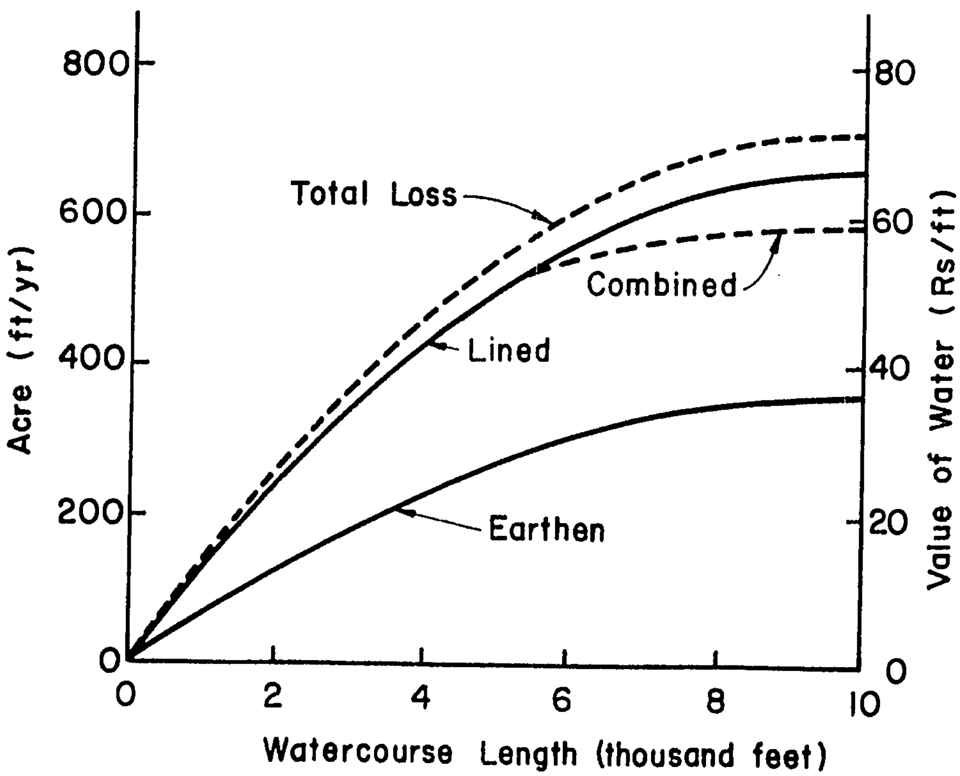


Figure 3. Total annual water loss and amount saved by lining or earthen improvements. Gross value of water is given on the right hand scale.

where h is the weekly hours of turn time. Replacing t in (4) and integrating the left side we have,

$$W_S = \frac{kfQ_o}{168} \int_0^L h(dL) \tag{10}$$

Here $kfQ_o/168$ represents the water saved per foot-hour and the term $\int_0^L h(dL)$ can be obtained by summing the weekly foot-hours above that point. The water lost from the unimproved watercourse, $W_L$, again is simply the special case where f is equal to unity. As water is delivered from the watercourse to the field branches at specified points, usually a few hundred feet or more apart, it is a relatively simple matter to sum the weekly foot-hours above any point on the watercourse. Malhotra (1) has used the principle of loss being proportional to foot-hours in a graphical optimization scheme. This method will be further discussed in the section on branched watercourses below.

The net return to treatment above any point is given by,

$$R_n = \frac{kfQ_o}{168} (\Sigma \text{ weekly foot-hours}) - CL \tag{11}$$

The second method of integrating with respect to length is to assume that the time of use is a linear function of length such that,

$$t = (1 - \frac{L}{L_T}) \tag{12}$$

The term $L/L_T$ is the fraction of time the watercourse is in use at any distance. This relationship assumes that the outlets are uniformly distributed along the watercourse. The validity of that assumption for individual watercourse is subject to question, but it could certainly be useful for developing general guidelines and policies. This assumption is implied by the use of the improved or distance scale in Figs. 1 and 2. Substituting for t in (4) gives,

$$\frac{dW_s}{dL} = kfQ_o(1 - \frac{L}{L_T}) \tag{13}$$

Relationships analogous to (6) and (8) can then be developed for determining optimum L or $L/L_T$ values. Probably more interesting is the fact that using this assumption the total water lost or saved is given by the area under the curves in Fig. 1. This can be calculated by integrating (13) with respect to L to obtain (14).

$$W_s = kfQ_oL(1 - \frac{L}{2L_T}) \tag{14}$$

The total water loss and the water saved by either of the improvement programs is shown in Fig. 3. In our example, water is valued at Rs. 100/acre-ft so that the gross value of the water ($VW_s$) saved is 100 times the number of acre-ft saved and is given on the right hand scale. Again assuming a single main branch and that use time decreases linearly with length it can be shown geometrically that 75% of the total loss will occur in the upper 50% of the watercourse, or conversely, that 75% of the benefit of improvement will be realized by improving the upper 50%.

The net return from a single type of treatment is calculated by multiplying the value of water times the volume of water saved and subtracting the cost:

$$R_n = VkfQ_oL(1 - \frac{L}{2L_T}) - LC \tag{15}$$

Net returns for the example lining and earthen cases are shown in Fig. 4. Note that returns reach a maximum and then decline as the treatments are continued towards the tail of the watercourse, particularly for the higher cost lining treatment.

Where two types of improvement are to be used on the same watercourse, some complexities arise. Normally, the high cost lining would be at the head and we can define the length of lining as $L_h$. If L is less than $L_h$, the water saved $W_s$ and the net return $R_n$ are given directly by (14) and (15), using the f and C values for the high cost lining. If L is greater than $L_h$, the "Water Saved" curve continues from $L_h$ as if it were the low-cost curve displaced upwards, as shown in Fig. 3. Mathematically, this is given by:

$$L > L_h$$
$$W_s = kf_hQ_oL_h(1 - \frac{L_h}{2L_T}) + \int_{L_h}^{L} kf_\ell Q_o(1 - \frac{L}{L_T})dL \tag{16}$$

Integrating (16) and rearranging we have:

$$L > L_h$$
$$W_s = kQ_oL_h(f_h - f_\ell)(1 - \frac{L_h}{2L_T}) + kf_\ell Q_oL(1 - \frac{L}{2L_T}) \tag{17}$$

We again obtain the net returns by multiplying the water saved $W_s$ by the value and subtracting the cost so that:

$$R_n = VW_s - L_hC_h - (L - L_h)C_\ell \tag{18}$$

Net returns for the combined system are also shown in Fig. 4. Net returns for the complete watercourse are substantially higher for the combined system than for either alternative applied singly.

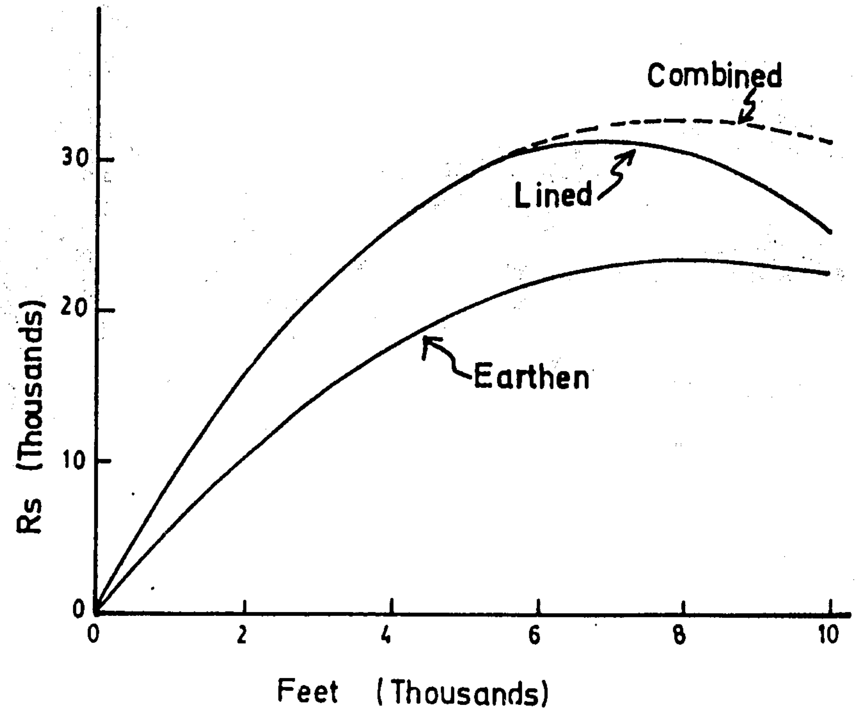


Figure 4. Annual net returns from earthen, lined or combined improvements, assuming optimum lining length for the combined case.

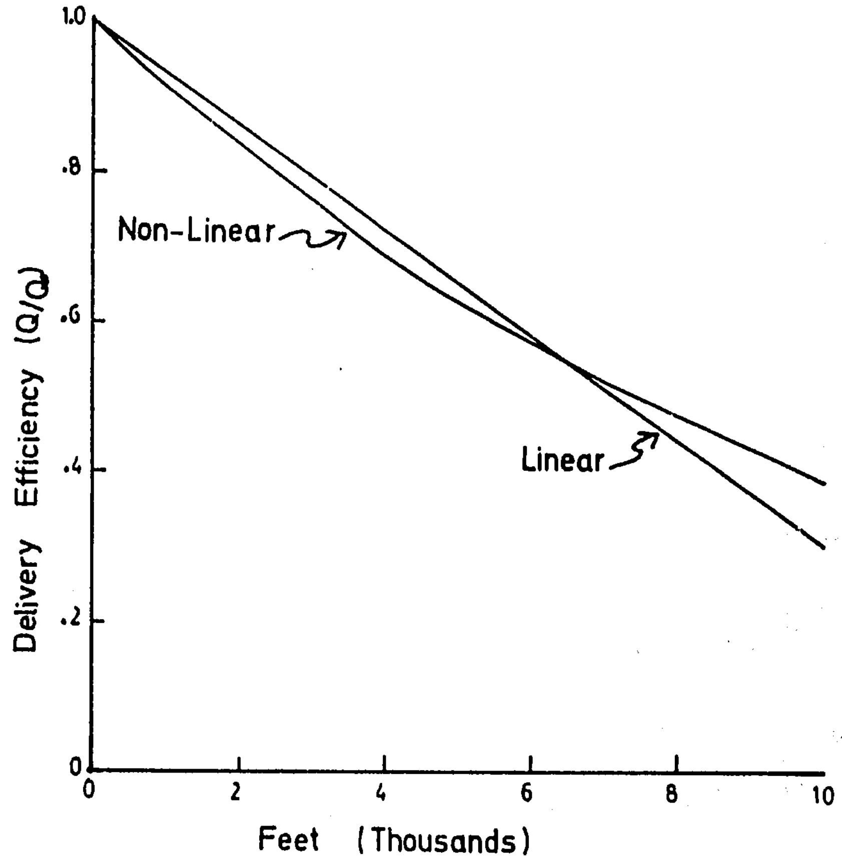


Figure 5. Fraction of inflow delivered as a function assuming linear and non-linear models. Linear model loss $.00007Q_o$/ft and non-linear loss $9.34 \times 10^{-5}Q$ per ft. Area under the two curves is the same.

## Nonlinear Loss Assumptions[2]

In the above section, the assumption was made that the loss per unit length in an operating watercourse is a constant fraction of the inflow. As a consequence of this assumption, the curve of $Q/Q_o$ as a function of distance must be linear as shown in Fig. 5.

From our example, where the loss rate is 7%/1000 ft, this model predicts that flow would be zero at about 14,300 ft. Losses in excess of 7%/1000 ft are not uncommon but experience shows that watercourses with an inflow of 3 cusecs can and do deliver water well in excess of 14,000 ft. This leads us to suspect that the true model may be nonlinear and that the loss per unit distance decreases with distance, giving a concave shape to the curve of $Q/Q_o$.

Two mathematical models that may be appropriate to test in this regard are the exponential or first-order decay model, and a second-order polynomial (quadratic) model. In the exponential decay model, the loss per unit distance at any point is proportional to the flow Q at that point.

$$\frac{dQ}{dL} = -k'Q \tag{19}$$

With this assumption the relationship of $Q/Q_o$ with distance is given by:

$$Q/Q_o = e^{-k'Q} \tag{20}$$

Where e is the base of natural logarithms

With the second-order polynomial model, the assumption is that the initial loss per foot is some fraction $k_o$ of the inflow and that this fraction declines linearly with distance by the factor k,

$$\frac{dQ}{dL} = -Q_o(k_o - k_1L) \tag{21}$$

Here the relationship of $Q/Q_o$ with distance is given by a second-order polynomial.

$$Q/Q_o = \frac{k_L L^2}{} - kL + 1 \tag{22}$$

Figure 5 is a plot of $Q/Q_o$ for the linear and the nonlinear models. The coefficient for the exponential model was selected so that the area under the curves is equal to that of the linear model. Coefficients for the quadratic model were determined by regression to approximate the quadratic model as closely as possible. Most sets of field measurements have sufficient variability so that it is not possible to demonstrate that either the linear or nonlinear models are most appropriate.

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2/At this point we include only a brief discussion of the assumptions and some of the consequences of the nonlinear loss assumptions. Readers interested in the mathematical development of these assumptions should refer to Appendix A.

Two methods could be used to fit either of the nonlinear models. The coefficients could be determined by taking one measurement in addition to the outlet discharge for the exponential model, and two measurements for the quadratic. (See Appendix A for details.) Either model could be fit by using regression techniques if a series of measurements were available. The water loss/ft predicted by the nonlinear and linear models is shown in Fig. 6. These graphs plainly show that the nonlinear models predict greater losses at the head of the watercourse and smaller losses at the tail than do the linear models. The equations for determining the optimum length for improvement are more complicated, particularly for the exponential model, than are those for the linear assumption, but solutions can be obtained.

As a result of the assumption that losses are greater at the head and less at the tail, the optimum length for improvement tends to be less than for the linear model. In our example the optimum length, if lining is to be the only improvement, is 6,947 feet for the linear assumption, 5993 for the exponential and 6,063 feet for the quadratic assumption. The optimum points at which to switch from lining to earthen improvement are 5,453, 4,721, and 4,812 feet for the linear, exponential, and quadratic assumptions, respectively.

Interestingly, the net benefits predicted from the watercourse improvement programs are higher for most of the watercourse, if the nonlinear assumptions are used (Fig. 7). Only if the improvements are carried out for the entire watercourse do benefits become the same for both linear and nonlinear. In our example, if lining were carried out up to 4,000 feet, annual benefits would be about Rs.26,000 and Rs.32,000 for the linear and nonlinear assumptions, respectively.

Branched Watercourses

To this point, we have only considered the case of a watercourse with a single, main branch. In Pakistan there are often one or more branch points in the official watercourse or "sarkari khal." It is, therefore, appropriate to examine the effect of branching on the optimizing conclusions that we have reached thus far. For the purpose of illustration, we will use our prior assumptions of 10,000 feet watercourse with an annual inflow of 2,016 ac-ft and a loss rate of 7% of inflow/1000 ft. We will also use our previous assumption that the use is equally distributed with length so that the fraction of the flow time at any point is given by $L/L_T$, where L is the length served below that point and $L_T - L$ is the length served above the point. With this assumption, we can set the flow time at the start and end of any reach.

Three example watercourse configurations, each having a total length of 10,000 ft, are shown in Fig. 8. The flow times and annual flows at the start and end of each reach

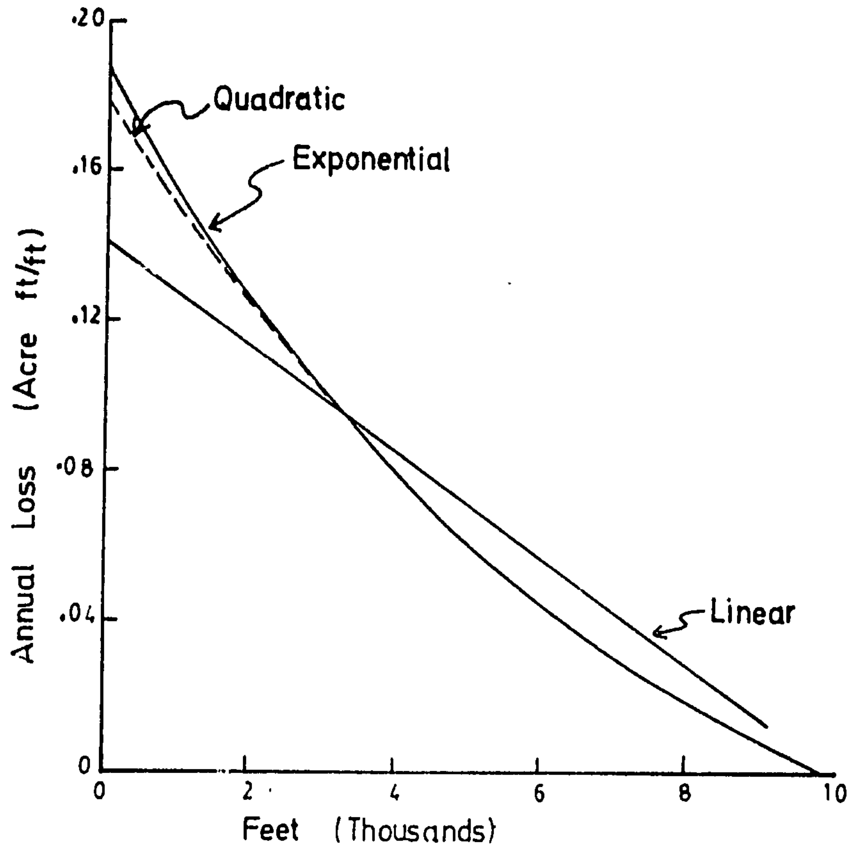


Figure 6. Annual loss per foot as a function of distance for the linear, exponential and quadratic examples.

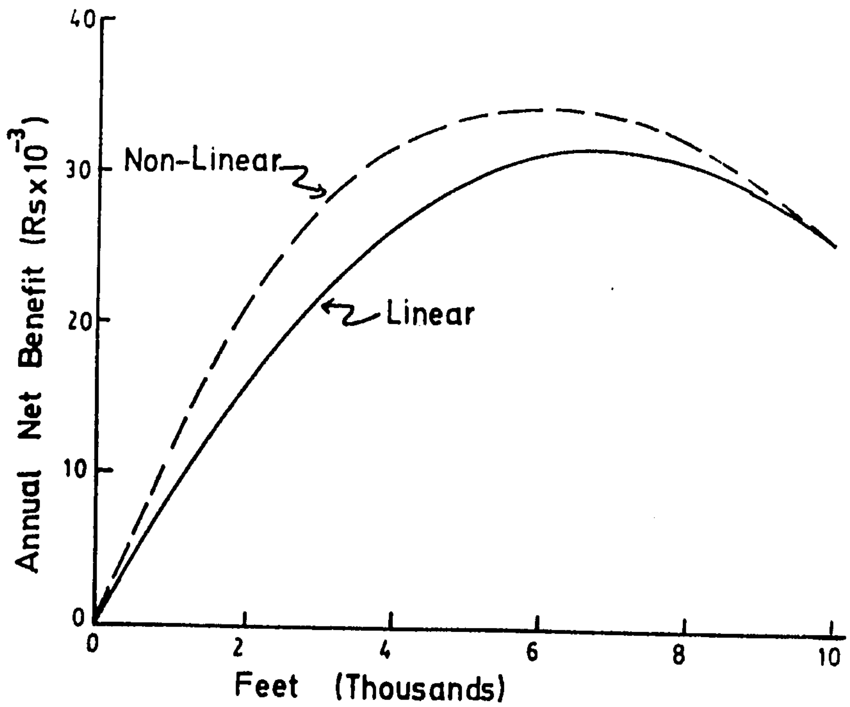


Figure 7. Comparison of annual net benefits from lining assuming linear and non-linear models.

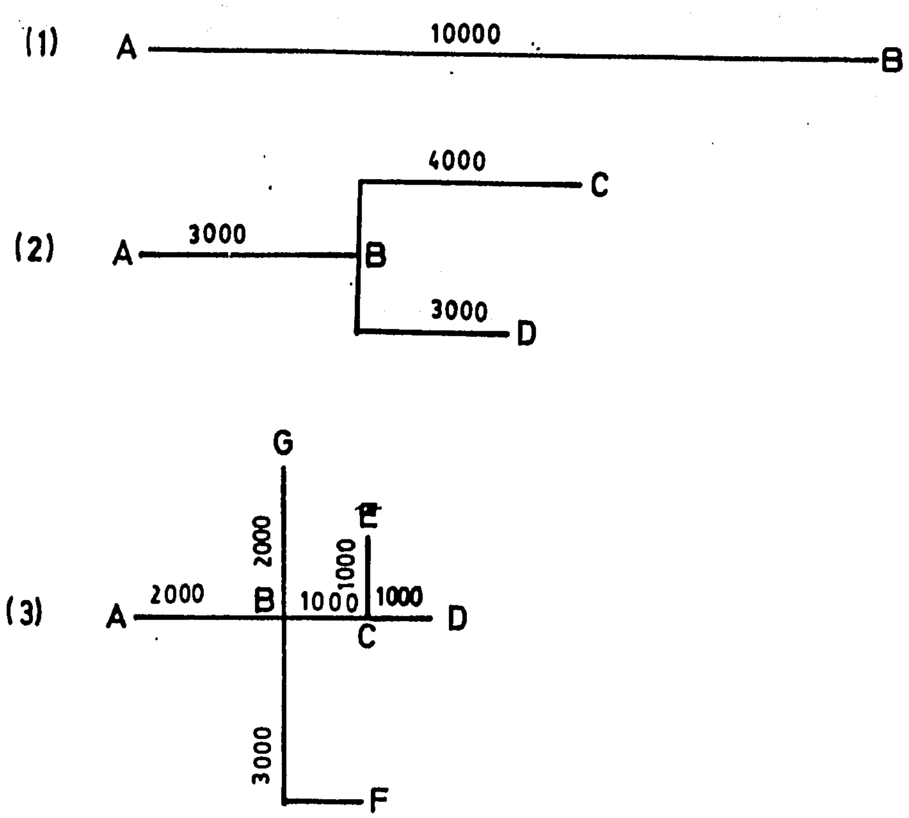


Figure 8. Schematic of example watercourse configurations. Total length is 10,000 ft. in all cases.

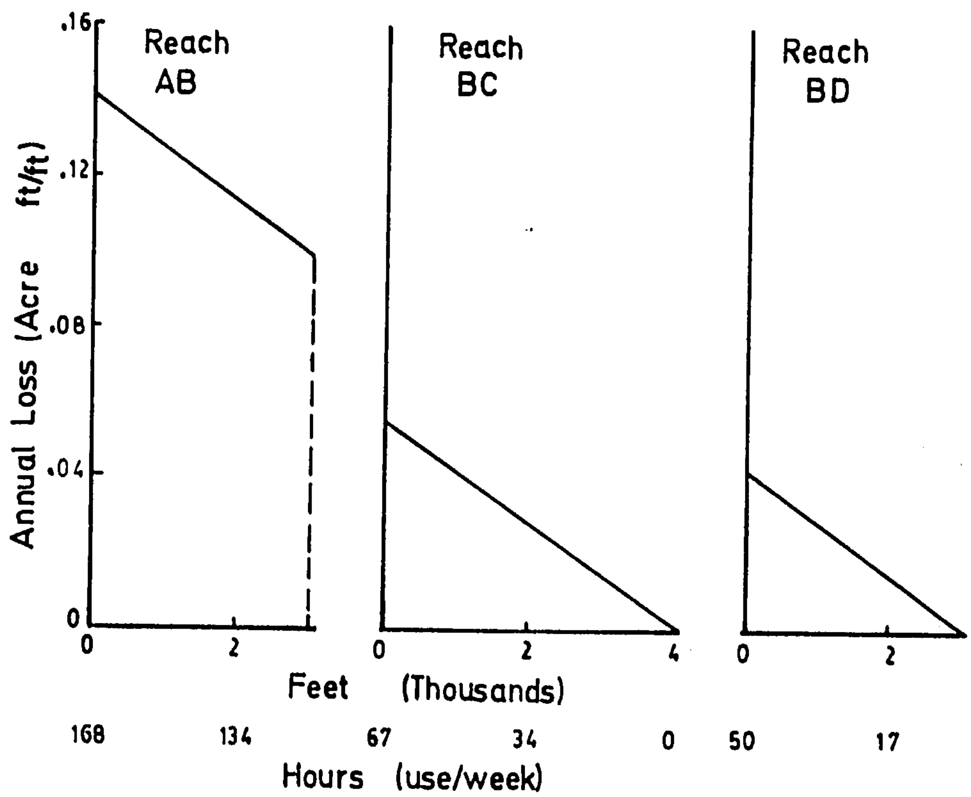


Figure 9. Annual loss per foot from the various reaches assume the single branched configuration (2) shown in Figure 8.

were calculated using the above assumption and are shown in Table 1.

Configuration (1) is the unbranched case, as discussed in previous sections. Configuration (2) has one branch point, B, and three reaches, AB, BC, and BD. For the branched case, it appears that each reach must be considered separately. Loss per foot as a function of distance for each reach is shown in Fig. 9 separately.

The annual water loss per foot at any point, or the amount that could be saved by improvement, can still be calculated by Eq. (3), and this loss declines linearly with distance. Annual loss as a function of distance for configuration (2) is shown in Fig. 9. The total loss in each reach is given by the area under the curve and can probably best be determined by a simple geometric calculation of that area. Total water saved by any treatment applied to a reach is given by:

$$W_s = \frac{Q_o h_e L_R k f}{168} + \frac{\left(\frac{Q_o h_s}{168} - \frac{Q_o h_e}{168}\right) L_R k f}{2} \tag{23}$$

Where $h_s$ and $h_e$ are the hours per week for the start and end of the reach and $L_R$ is the length of the reach. Eq (23) can be simplified to:

$$W_s = \frac{Q_o L_R k f}{336}(h_s + h_e) \tag{24}$$

Again, the water loss $W_L$ is the special case where f is equal to unity. Water losses for the reaches in the samples are shown in the right hand column of Table 1. For the same total length, water losses decrease as branching increases due to a shorter mean flow path. The optimum point to switch from the high cost lining program to the low cost earthen improvement is still a function of time only as given by Eq. (8), and for our example is 76 hours. For the two branched configuration, lining would be less practical than the earthen alternative below the first branch point, for in neither case does any reach below the first branch point flow for more than 76 hours per week.

Assuming a combination of lining and earthen reconstruction, with annual costs of Rs. 4 and Rs. 1.25 per foot as used previously, the costs and returns for reconstruction of each reach were calculated for all configurations (Table 2).

The highly branched configuration (3) has four short branches that do not even show a positive return for earthen improvement and certainly should not be lined. From a practical standpoint, earthen improvement of the lower reaches is probably necessary if the upper reaches are lined, due to the increased flow that would occur at the end of the lining.

Table 1. Comparison of optimum length of lining and returns for three watercourse configurations.

| Watercourse configuration | Reach | Loss | Length lined | Length earthen | Annual cost | Water saved | Return | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Gross | Net |
| | | ac-ft | ft | ft | Rs. | ac-ft | Rs. | Rs. |
| (1) No branches | -- | 706 | 5,453 | 4,547 | 27,496 | 593 | 59,268 | 31,772 |
| (2) 1 branch point | AB | 359.8 | 3,000 | 0 | 12,000 | 334 | 33,400 | 21,410 |
| | BC | 112.8 | 0 | 4,000 | 5,000 | 56 | 5,600 | 600 |
| | BD | 63.5 | 0 | 3,000 | 3,750 | 32 | 3,175 | (575) |
| | | 536.1 | | | 20,750 | 422 | 42,175 | 21,435 |
| (3) Multiple branches | AB | 254.0 | 2,000 | 0 | 8,000 | 235.9 | 23,590 | 15,590 |
| | BC | 35.3 | 0 | 1,000 | 1,250 | 17.7 | 1,765 | 765 |
| | CD | 7.1 | 0 | 1,000 | 1,250 | 3.6 | 355 | (645) |
| | CE | 7.1 | 0 | 1,000 | 1,250 | 3.6 | 355 | (645) |
| | BF | 63.5 | 0 | 3,000 | 3,750 | 31.8 | 3,175 | (575) |
| | BG | 28.2 | 0 | 2,000 | 2,500 | 14.2 | 1,420 | (1080) |
| | | 395.2 | | | 18,000 | 306.8 | 30,660 | 13,410 |

Table 2. Comparison of flow times, annual flows and water losses of each reach with sample configurations.

| Configuration | Reach | Length | Time Start | Time End | Annual flow $Q_S$ | Annual flow $Q_E$ | Loss |
|---|---|---|---|---|---|---|---|
| | | ft | hrs/wk | | ac-ft/yr | | ac-ft/yr |
| (1) | AB | 10,000 | 168.0 | 0 | 2,016 | 0 | 705.6 |
| (2) | AB | 3,000 | 168,0 | 117.6 | 2,012 | 1,411 | 359.8 |
| | BC | 4,000 | 67.2 | 0 | 806 | 0 | 112.8 |
| | BD | 3,000 | 50.4 | 0 | 605 | 0 | 63.5 |
| | | | | | | | 536.2 |
| (3) | AB | 2,000 | 168.0 | 134.4 | 2,016 | 1,613 | 254.0 |
| | BC | 1,000 | 50.4 | 33.6 | 605 | 403 | 35.3 |
| | CD | 1,000 | 16.8 | 0 | 202 | 0 | 7.1 |
| | CE | 1,000 | 16.8 | 0 | 202 | 0 | 7.1 |
| | BF | 3,000 | 50.4 | 0 | 605 | 0 | 63.5 |
| | BG | 2,000 | 33.6 | 0 | 403 | 0 | 28.2 |
| | | | | | | | 395.2 |

As mentioned above, Malhotra (1) has utilized the foot-hours concept in a graphical optimization scheme for branched watercourses. In these graphs, foot-hours are plotted as a function of length. Foxed length is presumed desirable; or stated another way, some fixed cost is feasible and beneficial. The object of the optimization is to improve the maximum foot-hours within this fixed cost constraint. This also minimizes the loss within the constraint. Malhotra's scheme apparently considers the slope of these curves as well as the percentage of foot-hours improved on each branch, but neither is identified as the sole or firm criterion. The analysis presented here indicates that, to obtain the maximum foot-hours of improvement within a fixed cost constraint, one simply starts at the head of the watercourse and successively selects the reaches with the maximum turn time until the resources available are fully utilized. The maximum utilization of resources occurs when no unimproved reach operates more hours per week than any improved reach. In Malhotra's scheme, this would occur if the slope of the foot-hours vs foot curves were equal at the cutoff point in all branches. The plots are unnecessary, however, as the slope is merely foot-hours/foot or hours, and it is much simpler to select the reaches with maximum hours than to determine foot-hours/foot. Finally, it appears that the percentage of foot-hours that can be included by a fixed percentage of improvement will generally be higher for branched systems than for a single main channel. Thus for the two branch systems (configuration 2), 84% of the total foot-hours could be included by improving 50% of the total channel length. With the more highly branched configuration (3), improvement of half the length would include more than 88% of the total foot-hours.

Distribution of Benefits

Most watercourse systems in Pakistan and many in India are operated on a turn or "warabundi" time basis. The irrigation turns are on a weekly basis and the time per week allotted to any operator is nearly proportional to the percentage of the total commanded acres that are held by that operator. Additional time may be granted to operators that are served by channels that are dry at the start of his turn to compensate for the wetting of the channel. Some time may be subtracted from the allotment of an operator at the end of the channel who would otherwise benefit from the water draining from the channel after water is diverted to another branch. No adjustment of warabundi is made for channel losses. The warabundi system does not result in equal water delivery for land located at the head and tail of the watercourses. Several studies have shown higher cropping intensities at heads of the watercourses as compared to the tail reaches.

Since it is common practice to equalize turn time rather than water delivery, the benefits of watercourse improvement tend to accrue most heavily to the previously deprived "tail enders."

For a general analysis, let us assume that the time allotted is equally distributed along the watercourse. Thus, the delivery to each increment of distance would be proportional to the flow at that point and the proportionality constant is $1/L_T$ so that,

$$\frac{dW_D}{dL} = \frac{Q}{L_T} \tag{24}$$

A plot of $Q/L_T$ as a function of distance, for an unimproved watercourse and for the combination lined and earthen case, is shown in Fig. 10 using our previous linear assumption.[3] The distance between the lines represents the improvement in total delivery. In the case of the combined improvement, 54.5% of the watercourse would be lined but about 67% of the improved deliveries would occur below the end of the lined section.

Assuming that the theoretical delivery distribution is an equal share of the inflow, Table 3 shows the percentage of theoretical delivery distribution with distance for the unimproved and the various improved systems, as well as the percentage increase in delivery that would be achieved by improvement. Unless a very high cost program is utilized that would conserve almost all of the water, the tail-end farmer would still receive significantly less water than those at the head. However, the tail farmer's supplies are increased proportionally much more than for the head farmers. In our example, the watercourse has head-to-tail losses of 70% resulting in the loss of 35% of the total inflow. This is not a particularly high loss for watercourses in the Punjab. An earthen improvement program that reduces losses by 50% would only result in the savings of 17.5% of the inflow. Yet our calculations show the tail-end farmer receives more than double (116.7%) his previous supply.

It is not unusual for tail-end farmers who have participated in watercourse improvement programs to claim their water supplies have doubled. We tend to discount such claims as being over enthusiastic. Perhaps we should not be too hasty in discounting such claims.

If we undertake a combined program of lining the head and doing earthen improvements at the tail, perhaps the tail-end farmer would be reluctant to share in the cost of lining that does not reach his property. In fact, he should not be reluctant as he stands to gain the most. Head farmers would stand to gain the least water, assuming the costs were equally shared by all farmers.

3/A more thorough mathematical treatment is given in Appendix B.

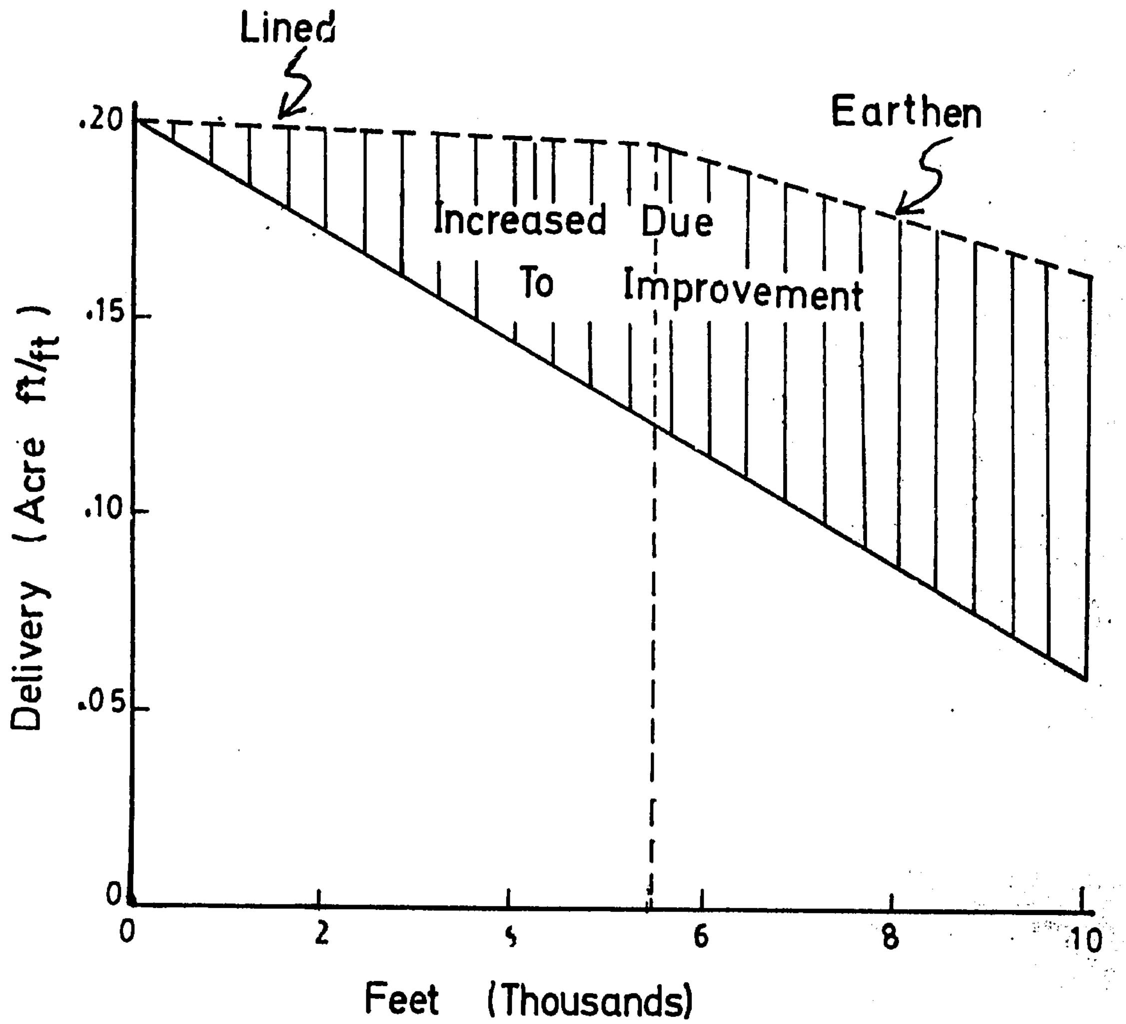


Figure 10. Distribution of increased delivery as a function of distance assuming linear model.

Table 3. Distribution of benefits - full length treatment.

| Distance | Unimproved | Earthen | | Lined | | Combined | |
|---|---|---|---|---|---|---|---|
| (ft X $10^3$) | Ed* % | Ed % | Increase % | Ed % | Increase % | Ed % | Increase % |
| 0 | 100.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 |
| 1 | 93.0 | 96.5 | 3.8 | 99.5 | 7.0 | 99.5 | 7.0 |
| 2 | 86.0 | 93.0 | 8.1 | 99.0 | 15.1 | 99.0 | 15.1 |
| 3 | 79.0 | 89.5 | 13.3 | 98.5 | 24.7 | 98.5 | 24.7 |
| 4 | 72.0 | 86.0 | 19.4 | 98.0 | 36.1 | 98.0 | 36.1 |
| 5 | 65.0 | 82.5 | 26.9 | 97.5 | 50.0 | 97.5 | 50.0 |
| 6 | 58.0 | 79.0 | 36.2 | 97.0 | 67.2 | 95.4 | 64.5 |
| 7 | 51.0 | 75.5 | 48.0 | 96.5 | 89.2 | 91.9 | 80.2 |
| 8 | 44.0 | 72.0 | 63.6 | 96.0 | 118.2 | 88.4 | 100.9 |
| 9 | 37.0 | 68.5 | 85.1 | 95.5 | 158.1 | 84.9 | 156.5 |
| 10 | 30.0 | 65.0 | 116.7 | 95.0 | 216.7 | 81.4 | 171.3 |

*Ed - efficiency of delivery

## III. DISCUSSION AND CONCLUSIONS ON THEORETICAL ASPECTS

The foregoing technical analyses help to establish a sound theoretical basis for evaluating watercourse improvement alternatives. On the basis of these principles, we must give serious consideration to mixing high and low-cost improvement programs on the same watercourse. Admittedly, some of the detailed analyses require many simplifying assumptions that may lack reality when applied to a particular field situation. However, the important lesson to be learned here is that analyses of improvement alternatives, based on the assumption that one method will be used throughout, may give a distorted picture of the economic viability of the method when applied to certain sections of the watercourse. Specifically, relatively high cost linings should seriously be considered for high water use sections of the watercourses, even though they would not be economically feasible if used throughout.

In terms of optimization, we have presented a relevant method for analyses using both linear and nonlinear assumptions. The nonlinear assumption results in optimum solutions as shorter lengths of improvement than does the linear, but it also predicts higher benefits.

At this time, we prefer the linear assumption for general use. While our previous discussion mentioned possible reasons for higher losses at the head, which would be consistent with the nonlinear assumption, there are some counterbalancing factors that tend to increase losses near the tail. In the first place, we have considered largely the steady state losses from a flowing watercourse. In fact, significant nonsteady state losses such as channel wetting occur. The channel wetting loss tends to assume greater importance near the tail where the watercourses are dry much of the time. These alternately used channels also tend to develop more porous banks below the normal water level due to rodent and insect activity than do the more heavily used channels.

Most measurements taken to date have not been designed specifically for testing the linear vs nonlinear assumption. Usually, a significant amount of scatter is found in plots of $Q/Q_o$ vs distance due to such factors as rate of inflow and elevation of the outlet. These data sets generally have not provided support for the nonlinear assumption.

The linear assumption is conservative in that it predicts lower net benefits than the nonlinear assumption. However, one should probably exercise care in recommending optimum improvement lengths based on the linear assumption since these length recommendations tend to be nonservative. Perhaps it would be better to recommend lining lengths somewhat shorter than those predicted from the linear optimization. Fortunately the net benefits are fairly insensitive to moderate errors in the optimum length. Table 4 shows annual costs and

Table 4. Cumulative annual costs and net returns for optimum lining (5453 ft) and lining 10% more or 10% less than optimum.

| Distance (ft) | Annual cost 10% less (Rs.) | Annual cost Optimum (Rs.) | Annual cost 10% more (Rs.) | Annual net return 10% less (Rs.) | Annual net return Optimum (Rs.) | Annual net return 10% more (Rs.) |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1000 | 4000 | 4000 | 4000 | 8449 | 8449 | 8449 |
| 2000 | 8000 | 8000 | 8000 | 15587 | 15587 | 15587 |
| 3000 | 12000 | 12000 | 12000 | 21415 | 21415 | 21415 |
| 4000 | 16000 | 16000 | 16000 | 25933 | 25933 | 25933 |
| 5000 | 19747 | 20000 | 20000 | 29112 | 30253 | 29140 |
| 6000 | 20997 | 22496 | 23995 | 31037 | 31127 | 31037 |
| 7000 | 22247 | 23746 | 25245 | 32257 | 32347 | 32257 |
| 8000 | 23497 | 24996 | 26495 | 32771 | 32861 | 32771 |
| 9000 | 24747 | 26246 | 27745 | 32579 | 32699 | 32579 |
| 10000 | 25997 | 27496 | 28995 | 31682 | 31772 | 31682 |

net returns for the example assuming optimum lining and 10% more and 10% less than optimum. Annual net returns for the entire watercourse are identical for the 10% more and 10% less cases and differ from the optimum by about Rs. 100. However, costs increase or decrease by Rs. 1500. It appears that there is little to be gained by crowding the optimum so that in light of the nonlinear assumption favoring shorter linings, we may consider the optimum point from the linear assumption to represent the maximum.

# APPENDIX A

## NONLINEAR ASSUMPTION, THEORETICAL DEVELOPMENT

In Section II the assumption was made that the loss per unit length in an operating watercourse is a constant fraction of the inflow. As a consequence of this assumption, a plot of $Q/Q_o$ as a function of distance, must be linear as shown in Fig. 2. In our example where the loss rate is 7%/1000 ft, this model would predict that flow would be zero at about 14,300 ft. Losses of 7%/1000 ft are not uncommon but experience shows that watercourses with an inflow of three cusecs can and do deliver water well in excess of 15,000 feet. This leads us to suspect that the true model may be nonlinear and that the loss per unit distance decreases with distance, giving a concave shape to a curve of $Q/Q_o$ vs length. Two mathematical models that seem appropriate to test in this regard are an exponential decay model and a second-order polynomial model.

<u>Exponential Decay Model</u>

In this model the loss per unit distance, dQ/dL at any point is proportional to the flow Q at that point so,

$$\frac{dQ}{dL} = -k'Q \tag{A1}$$

Here k' is the relative loss per unit distance similar to k in Section II and again has the units $ft^{-1}$. Equation (A1) can be integrated with respect to distance to obtain (A2).

$$Q = Q_o e^{-k'L} \tag{A2}$$

Where e is the base of natural logarithms. In order to determine k we could determine the flow $Q_o$ at the outlet and the flow Q at distance L. Taking the natural logarithm of both sides of (A2) and rearranging, we have

$$k' = \frac{\ln(Q/Q_o)}{L} \tag{A3}$$

In the example shown in Fig. 5 (Section II), L was chosen as 6,305 ft and k' determined as $9.34 \times 10^{-5}$/ft. This distance was chosen as the point in which the area under the curve for the two models is the same. An alternative to taking measurements at only the outlet and one other point is to determine Q at a number of points and determine k' from the slope of a linear regression of the form:

$$\ln Q_o = \ln Q_o - k'L \tag{A4}$$

To find the water lost per unit length $(dW_L)/dL$ we substitute for Q from (A2) into (A1) and multiply by the time t.

$$\frac{dW_L}{dL} = tk'Q_o e^{-k'L} \tag{A5}$$

In this case both t and L are unknown so we replace t with $(1 - L/L_T)$.

$$\frac{dW_L}{dL} = k'Q_o e^{-k'L} - kQ_o \frac{L}{L_T} e^{-k'L} \tag{A6}$$

The plots of loss per unit length, as a function of distance, for the linear assumption and the two nonlinear assumptions, are given in Fig. 6, Section II. In order to determine the net return per unit length of a particular treatment we must know the fraction of water previously lost that will be saved by the treatment. We will again define this fraction a f. The net return per unit length is:

$$\frac{dR_n}{dL} = VfkQ_o e^{-k'L}(1\frac{L}{L_T}) - C \tag{A7}$$

The point at which it is no longer economical to apply an improvement is again the point at which the net return per unit length is equal to the cost per unit length. Setting $R_n$ equal to zero and rearranging we have:

$$e^{-k'L} - \frac{L}{L_T} e{-k'L} = - \frac{C}{VfkQ_o} \tag{A8}$$

Unfortunately there is no simple solution to (A8) but graphical or iterative solutions are relatively simple. In our linear example in Section II, lining was assumed to save 93% of the water. Using .93 for f, $9.34 \times 10^{-5}$ for k' and inflow, value, and costs the same as for the linear assumption, we find the optimum length for lining to be 5,993 ft or about 1000 ft less than with the linear assumption.

If we wish to obtain the optimum length at which to switch from the high cost to the low cost alternative, the relationship is,

$$e^{-k'L} - \frac{L}{L_T} e^{-k'L} = \frac{C_h - C_\ell}{VkQ_o(f_h - f_1)} \tag{A9}$$

Again we resort to an iterative solution which shows that the optimum point to switch from the lined to the earthen alternative is 4721 ft, compared to 5453 ft for the linear assumptions. In order to calculate the total water lost or the total amount saved by an alternative, we integrate (A6) with respect to L to obtain,

$$W_L = Q_o e^{-k'L}(\frac{L}{L_T} + \frac{1}{k'L_T} - 1) + C \tag{A10}$$

Evaluating the constant of integration, C, at L = 0, $W_L = 0$,

$$W_L = Q_o e^{-k'L}(\frac{L}{L_T} + \frac{1}{k'L_T} - 1) + Q_o(1 - \frac{1}{k'L_T}) \tag{A11}$$

The water saved by an improvement program would be obtained by multiplying (A11) by the factor f appropriate to the program in question, and net returns are obtained by multiplying by fV and subtracting the cost.

$$W_s = fW_L \tag{A12}$$

$$R_n + VfW_L - LC \tag{A13}$$

Figure A1 shows a comparison of water saved by lining for the linear and nonlinear assumptions, using our previous example. The total water saved is the same in this case but the water saving has been shifted to the head of the channel. This tends to give greater returns to improvements near the head of the channel but relatively less near the tail, as shown in Fig. 7, Section II.

Quadratic Model

In this model the assumption is that the initial loss is some fraction of the inflow and that this fraction declines linearly with length,

$$\frac{dQ}{dL} = -Q_o(k_o - k_1 L) \tag{A14}$$

where $k_o$ is the initial loss per unit distance and $k_1$ is the decline in loss per unit distance.

Integrating and then dividing through by $Q_o$, we find that $Q/Q_o$ is a second order polynomial with distance.

$$Q/Q_o = \frac{k_1 L^2}{2} - k_o L + 1 \tag{A15}$$

The 1 in (A15) arises from evaluation of the constant of integration, which turns out to be $Q_o$.

One method of utilizing this model would be to obtain flow measurements at the inlet and two other points, $L_1$ and

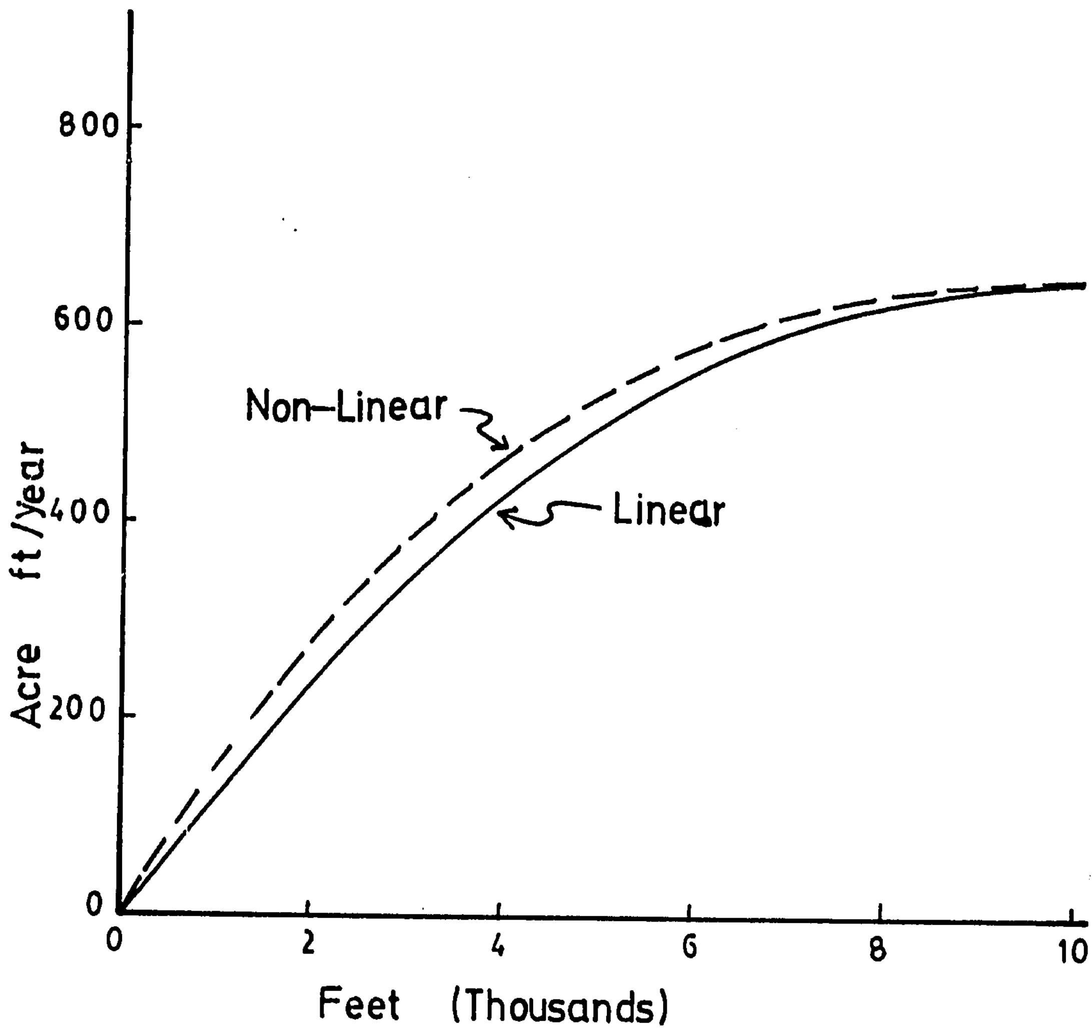


Figure A.1. Annual savings in water as a function of lining as predicted by linear and non-linear models.

$L_2$. Equation (A15) could then be solved with two unknowns for $k_o$ and $k_1$. In practice one would more likely take a series of measurements at different distances and determine the coefficients by means of a second-order polynomial regression of $Q/Q_o$ vs distance. The coefficient of the squared term would estimate $k_1$, the coefficient of the linear term would estimate $k_o$ and the intercept should be near 1.0. For purposes of illustration we have a fit a second-order polynomial to eleven equally spaced points on the exponential decay model. The $Q/Q_o$ plots for the two shown in Fig. 5, Section II models are almost identical. Estimated values of $k_o$ and $k_1$ obtained by this procedure were $8.79 \times 10^{-5}$/ft and $5.56 \times 10^{-9}$/ft$^2$ respectively.

Again the product $-t(\frac{dQ}{dL})$ gives us the water loss per unit distance $\frac{dW_L}{dL}$. Replacing t by $(1 - \frac{L}{L_T})$ from (A14) we can write

$$\frac{dW_L}{dL} = Q_o(k_o - k_1 L)(1 - \frac{L}{L_T}) \qquad \text{(A16)}$$

The water loss per unit length for any point on the watercourse can be calculated from (A16) and is shown in our example in Fig. 6. In order to calculate the optimum length for implementing an improvement program, we again multiply $dW_L/dL$ by the value of the water and the fraction saved and set the product equal to the annual cost per unit length of improvement. Rearranging we obtain,

$$\frac{k_1 L^2}{L_T} - \left(\frac{k_o}{L_T} + k_1\right)L + k_o = \frac{C}{VfQ_o} \qquad \text{(A17)}$$

If the optimum point to switch from a high cost method to a low cost alternative is desired, the relationship becomes,

$$\frac{k_1 L^2}{L_T} - \left(\frac{k_o}{L_T} + k_1\right)L + k_o = \frac{C_h - C_\ell}{VfQ_o(f_h - f_\ell)} \qquad \text{(A18)}$$

Solution of (A17) or (A18) for the optimum length, L, can be obtained by means of the standard quadratic formula.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad \text{(A19)}$$

where $x = L$

$$a = \frac{k_1}{L_T}$$

$$b = \left(\frac{k_o}{L_T} + k_1\right)$$

$$c = k_o \frac{C}{VfQ_o} \text{ or } k_o = \frac{C_h - C_\ell}{VQ_o(f_h - f_\ell)}$$

The optimum length to line in this case would be 6,063 feet, while the optimum length at which to switch from lining to earthen improvement would be 4,812 feet. Solutions are very similar to the exponential decay model, as indeed they should be when our input data comes from this source.

In order to calculate water loss to any point, L, we rearrange (A16) and integrate with respect to L to obtain (A20).

$$W_L = Q_o\left[\frac{k_1 L^3}{3L_T} - \left(\frac{k_o}{2L_T} + \frac{k_1}{2}\right)L^2 + k_o L\right] \tag{A20}$$

The constant of integration is zero in this case and, therefore, has been dropped. The water saved by any treatment or the net returns can then be calculated using (A12) and (A13).

# APPENDIX B

## MATHEMATICAL DEVELOPMENT

### THEORETICAL DISTRIBUTION OF BENEFITS

Using the linear assumption, the change in flow at any point is given by Eq. (2) Section II as $-kQ_o$. Equation (2) can be rearranged and integrated to give.

$$Q = Q_o - kQ_o L \tag{B1}$$

Irrigation times are theoretically equal and if all water entering the watercourse reached the field and the water use was evenly distributed along the watercourse the delivery per foot of watercourse $dW_D/dL$ would be given by $Q_O/L_T$, i.e. each section of the watercourse would deliver equal water to the land. In fact the flow diminishes along the watercourse so the delivery per foot is estimated by $Q/L_T$. Therefore,

$$\frac{dW_D}{dL} = \frac{Q}{L_T} \tag{B2}$$

Substituting for Q from (B1) we obtain,

$$\frac{dW_D}{dL} = \frac{Q_o - kQ_o L}{L_T} \tag{B3}$$

Plots of Eq. (B3) for the linear assumption for the unimproved condition and the combined improved condition are shown in Fig. 9, Section II. The total water delivered is represented by the area under the curves and the area between the curves represents the increase in deliveries as a result of the improvement. The area under the curve, i.e. the total delivery to any point L, is obtained by integrating (B3) to obtain:

$$W_D = \frac{Q_o L}{L_T}\left(1 - \frac{kL}{2}\right) \tag{B4}$$

The improved case is given by:

$$W_D = \frac{Q_o L}{L_T} - \frac{Q_o kL^2}{2L_T}(1-f) \tag{B5}$$

Equation (B5) is identical to (B4) in the unimproved case where f = 0. The area between the unimproved and improved curves represents the difference in total deliveries between the two systems and can be obtained by subtracting (B4) from (B5):

$$\Delta W_D = \frac{Q_o k f L^2}{2L_T} \qquad \text{(B6)}$$

Again the calculations for the combined case are more complicated. If $L<L_h$ the combined case is the same as the lined system. For $L>L_h$ the total delivery is given by,

$L>L_h$

$$W_D = \frac{Q_o L}{L_T} - \frac{Q_o k}{L_T}\left[L^2(1 - f_h) + (L - L_h)^2(f_h - f_\ell)\right]$$

The area between the improved and unimproved curves can be calculated from,

$L>L_h$

$$\Delta W_D = \frac{Q_o k f_h L^2}{2L_T} - \frac{Q_o k(L - L_h)^2(f_h - f_\ell)}{2L_T}$$

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## SYMBOLS AND UNITS USED

| Symbol | Description | Unit |
|---|---|---|
| $Q$ | flow | cusecs or acre-ft/year |
| $Q_o$ | flow at inlet | cusecs or acre-ft/year |
| $Q_L$ | flow lost in watercourse | cusecs or acre-ft/year |
| $L$ | length to any point | ft |
| $L_T$ | total length | ft |
| $L_h$ | length of high cost improvement (lining) | ft |
| $L_R$ | length of reach | ft |
| $\frac{dQ}{dL}$ | change in loss per unit distance | acre-ft/year |
| $W_D$ | water delivered | acre-ft/year |
| $W_L$ | water lost | acre-ft/year |
| $W_S$ | water saved | acre-ft/year |
| $\frac{dW_D}{dL}$ | water delivered per ft | acre ft/year per ft of watercourse |
| $\frac{dW_L}{dL}$ | water lost per ft | acre ft/year per ft of watercourse |
| $\frac{dW_S}{dL}$ | water saved per ft | acre ft/year per ft of watercourse |
| $k$ | relative loss per unit distance (linear model) | $ft^{-1}$ |
| $k_e$ | relative loss per unit distance (exponential model) | $ft^{-1}$ |
| $k_o$ | initial relative loss per unit distance (quadratic model) | $ft^{-1}$ |
| $k_1$ | decline in loss per unit distance (quadratic model) | $ft^{-1}$ |
| $t$ | time | varies - usually years/year (dimensionless) |
| $t_o$ | time of inflow | varies - usually years/year (dimensionless) |

## SYMBOLS AND UNITS USED

| Symbol | Description | Unit |
|---|---|---|
| $h$ | weekly flow time | hours/week |
| $h_s$ | weekly flow time at the start of a reach | hours/week |
| $h_e$ | weekly flow time at the end of a reach | hours/week |
| $f$ | fraction of total loss saved by improvement | dimensionless |
| $f_h$ | fraction saved by high cost improvement (lining) | dimensionless |
| $f_\ell$ | fraction saved by low cost improvement | dimensionless |
| $C$ | annual cost of improvement | Rs/ft per year |
| $C_h$ | annual cost of high cost improvement (lining) | Rs/ft per year |
| $C_\ell$ | annual cost of low cost improvement (earthen) | Rs/ft per year |
| $V$ | value of water | Rs/acre-ft |
| $R$ | return | Rs |
| $R_n$ | net return | Rs |
| $\frac{dR_n}{dL}$ | net return per unit length | Rs/ft |