IMPROVING IRRIGATION WATER MANAGEMENT ON FARMS

ANNUAL TECHNICAL REPORT

Colorado State University
June 1980

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Annual Technical Report
IMPROVING IRRIGATION WATER MANAGEMENT ON FARMS
April 1, 1979 to May 31, 1980

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

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

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Project Title: Improving Irrigation Water Management on Farms

Contract Number: AID/ta-C-1411

Principal Investigators: Gaylord V. Skogerboe, John O. Reuss and W. Doral Kemper

Contractor: Colorado State University

Contractor's Address: Water Management Research Project
Engineering Research Center
Colorado State University
Fort Collins, Colorado 80523

Contract Period: April 1, 1977 to May 31, 1980

Reporting Period: April 1, 1979 to May 31, 1980

Total Expenditures and Obligations Through Contract Period:	$2,500,000 April 1, 1977 to May 31, 1980
Total Expenditures and Obligations for Current Contract Year:	$750,000 April 1, 1979 to May 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 on watercourse improvement, including low cost methods of lining, cleaning and maintenance studies, essential improvements using paraprofessionals; also studies on chemical weed control, water-fertilizer interaction studies, measurement of tuvewell pumping efficiency and the initiation of a new series of studies on skimming wells; (2) continued participation with the USAID Mission and USDA Soil Conservation Service in the On-Farm Water Management Pilot Project, including an intensive survey to determine the constraints encountered by small farmers participating in the Precision Land Leveling (PLL) program; (3) preparation of plans for improved water distribution systems for crop water management research activities at six research institutions. Construction had started at two of these locations prior to field party departure; (4) an analysis of strategies for water management development alternatives was completed. This was used extensively by GOP and International Bank for Development (IBD) for planning future projects; (5) the third class of Water Management Extension officers completed the special training course at the University of Agriculture, Faisalabad. An intensive six-week course in water management extension for agricultural extension officers was instituted. The research project at UAF planned in conjunction with this training program was funded and initial field work is underway; (6) the first phase of research on the organization and structure of viable water users associations was completed; (7) observations of group actions and social dynamics at the village level provided us with an understanding of the problems associated with community action programs in Punjab; (8) plans were developed for the long term monitoring and evaluation of watercourses improved under the OFWM Pilot Project to be carried out by WAPDA; (9) experimental planter units were fabricated for service at UAF, MREP and with the OFWM Pilot Project. Bullock drawn land leveling equipment was designed; (10) a simulation model has been completed to evaluate the suitability of cropping patterns for any given water supply situation; and (11) a set of manuals describing the transfer of water management technology to developing countries has been completed.

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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 socioeconomic 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, 1979 to May 31, 1980)

1. Summary

Very early in the reporting year the CSU staff were informed that all field activities in Pakistan would terminate prior to October 1, 1979, and that all CSU Field Party would depart post by October 31, 1979. Project plans were therefore drastically revised in order to wind up the field party activity in as orderly a manner as possible. Among the most significant accomplishments of the reporting year were the following: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project. Research on watercourse improvement included low cost methods of lining, cleaning and maintenance studies, essential improvements using paraprofessionals, and continued monitoring of previously improved watercourses. Other aspects of the program included economics of improved watercourses, chemical weed control, water-fertilizer interaction studies, measurement of tubewell pumping efficiency and the initiation of a new series of studies on skimming wells; (2) continued participation with the USAID Mission and USDA Soil Conservation Service in the On-Farm Water Management Pilot Project. In connection with this program an intensive survey was conducted to determine the constraints encountered by small farmers in participating in the Precision Land Leveling (PLL) component of this project; (3) the CSU staff prepared plans for improved water distribution systems for crop water management research activities at six research institutions located throughout the country. Construction had started at two of these locations prior to field party departure; (4) an analysis strategy for water management development alternatives was completed. This analysis was used extensively by GOP and International Bank for Development (IBD) in the initial stages of planning for future development projects; (5) the third class of Water Management Extension officers completed the special training course at the University of Agriculture, Faisalabad. In addition, an intensive six-week course in water management extension for regular Agricultural Extension officers was instituted. The Water Management for Development Research Project at UAF planned in conjunction with this training program was funded and initial field work started; (6) the first phase of research on the organization and structure of viable water users associations was completed. This phase deals with the identification of organizational problems and consequences; (7) observations of group actions and social dynamics at the village level have provided us with a more basic understanding of the problems associated with community action programs in Punjab; (8) plans were developed for the long term monitoring and evaluation of watercourses improved under the OFWM Pilot Project. This program will be carried out by the Master Planning and Survey Division of WAPDA; (9) experimental planter units were fabricated for service at UAF, MREP and with the OFWM Pilot Project. Bullock drawn land leveling equipment was designed and an initial unit was constructed; (10) a simulation model has been completed that can be used to evaluate the suitability of cropping patterns consisting of the major crops of Pakistan for any given water supply situation; and (11) the completion of a series of manuals detailing the process of transferring the water management technologies which have evolved from the research experience in Pakistan to other developing countries. Of major importance is a set of manuals detailing the transfer process: executive summary, problem identification manual, development of solutions manual, and project implementation manual. This set is reinforced by a series of other manuals on technical aspects of water management improvement.

2. Water, Soil and Crop Management

a. Moisture Stress and Fertilizer Response

The analysis and interpretation of experiments on the interaction of moisture stress and fertilizer response has continued. Results from experiments on wheat in the Faisalabad area and at Mona were analyzed during the past year. In general, these are consistent with results obtained previously, and show that crop responses to fertilizer, particularly nitrogen, are not highly dependent on levels of water applied. Moderate to severe water stress did decrease yields, but acceptable yield could be obtained under stress conditions if adequate fertility levels were maintained. Satisfactory responses to fertilizer were again obtained under conditions of water stress.

In summary our data have consistently shown that fertilizer should be used at normal or near normal rates, even if water supplies are likely to be limited. The common belief that fertilizer is likely to be uneconomical or even counterproductive if water is short is simply incorrect.

b. Crop Stands

The difficulty in obtaining adequate stands of many crops has long been recognized by CSU staff as a major factor limiting crop yields. Simple experimental seeders, along with bed shapers to facilitate furrow and bed planting have been developed by CSU staff. Tractor drawn units of this type have been fabricated and placed at the Mona Project, University of Faisalabad, and the Water Management Research and Training Center at Lahore for testing. Development of the related bullock-drawn models was discontinued due to withdrawal of the CSU staff.

c. Crop Survey Methods

At the request of USAID/Islamabad staff, statistical analysis of a data set was collected by the Punjab Crop Reporting Service. These data were collected as part of a cooperative program with USAID with the objective of determining the effect of different harvest areas within the fields sampled on the precision of the yield estimates. The analysis clearly shows that in order to obtain accurate estimates of mean wheat yields in Punjab, harvest areas should be kept small so that resources can be concentrated on sampling a large number of fields. Harvest area of about 10 m^2 in each field or not more than 20 m^2 is recommended. A 95 percent confidence interval within plus or minus 2 maunds/acre (about 8 percent), will require about 100 fields and an estimate within plus or minus 1 maund/acre will require about 500 fields. Further analysis shows that yield estimates of a given field made by cutting sample areas from that field are generally very imprecise.

d. Weed Control

Numerous experiments have established the importance of weed control in obtaining the high yields necessary to efficient water utilization. Chemical weed control is in its infancy in Pakistan. In recent trials, CSU and MREP staff have established that for wheat and maize some of the chemicals now available give good control and a high rate of return on investment. Other chemicals were not effective, indicating that careful evaluation of these materials under local conditions is required.

e. Cropping Systems

A simulation model has been developed that can be used to match cropping systems to water supply. The model will accommodate any combination of eight major crops of Pakistan, any can be used to evaluate any cropping pattern in terms of land and water availability over time. It has been thoroughly tested and works well.

3. Watercourse Improvement

Research on several aspects of watercourse improvement programs has continued over the past year. This work includes both field programs and analysis of data previously collected. The following are among the most important.

a. Cleaning and Maintenance

Heavy cleaning and maintenance programs have been underway in the Mona project area for several years, and have proven to be an effective, low cost, and labor intensive method of saving water. In this program the watercourse is essentially rebuilt without benefit of engineering design or "pakka" structures. All brush and noneconomic trees are cleared away, but valuable trees are left. The banks are then rebuilt to a 6-inch freeboard. GOP and outside donors are presently considering initiation of a program of this type, or perhaps a more intensified form similar to the essential improvements program below, on a nationwide basis. During the past year this program ran almost entirely by Mona project staff with very little input by CSU staff. At least six new watercourses had been undertaken at the time of departure of CSU technicians.

b. Essential Improvement Programs

The lack of trained manpower for surveying, engineering design, and supervisory roles has proven to be a serious constraint on watercourse reconstruction programs. Therefore, a program involving reconstruction of watercourses under the supervision of nontechnical staff that had been given a short training course was undertaken. In this program paraprofessionals (field assistants) were given some 80 hours of special training, including approximate methods of establishing bed levels, slopes, and other design criteria. Each of these field assistants then proceeded to organize and supervise the reconstruction of one watercourse, including placement and installation of structures. After completion, the work was evaluated by CSU staff.

Three watercourses were improved by these methods. Several problems were noted, most of which could be avoided or alleviated by improvements in the training and by experience. The method, however, may well be cost effective even though the final product does not have the finished appearance found in watercourses improved under professional supervision.

c. Experimental Lining Methods

Test sections utilizing several lining techniques have been established. These sections are several thousand feet long to provide effective evaluation of durability as well as accurate water loss evaluations. Prefabricated concrete panels and several types of low-cost brick construction are being tested.

d. Facilities for Improved Water Management Research

Plans were completed for improved water management distribution systems at six locations in Pakistan. These include the Provincial Agricultural Research Institutes at Tandojam, Faisalabad, and Pir Sabak, plus the Rice Research Institute at Kala Shah Kaku, Cotton Research Institute at Multan, and the Agricultural Research Center near Islamabad. These facilities will allow for accurate water control and measurements for research purposes. Initial construction activity was started in late 1979 at Kala Shah Kaku and Faisalabad.

4. Economics of Watercourse Improvement

a. Optimization of Lengths of Alternative Programs

The program of developing methods for optimizing lengtns of various types of improvements within a single watercourse system was completed. Due to the varying usage of different sections of a watercourse, it has become apparent that on most watercourses, a single method of improvement throughout the system is not the best alternative. A more cost-effective method is to use more expensive, but also more effective, methods in heavy use sections, usually near the head of the watercourse. Less expensive methods would then be applied to those sections that are used less. The theoretical basis for optimizing the usage of various alternatives has been established and appropriate computational methods have been developed.

b. Economics and Watercourse Policy

In the final stages of the project it appeared appropriate to focus attention on the policy implications of the economics of watercourse improvement.

Prior to departure from Pakistan, a position paper was developed laying out alternative strategies for large-scale watercourse improvements in Pakistan. This paper included institutional and organizational strategies, as well as physical strategies with associated costs and expected benefits. It has apparently been widely used at the policy levels of the GOP and the international donor agencies interested in water resource development.

c. Constraints on Precision Land Leveling

An intensive survey was conducted to determine the constraints encountered by small farmers in participation in the precision land leveling (PLL) program. This program is conducted by the Provincial Agricultural Department with financial assistance from USAID and technical assistance from the USAID Soil Conservation Service under a PASA Agreement. In-depth interviews were conducted with a total of 120 farmers, 60 of which were aware of the program but had not participated. The survey was designed, conducted, and a preliminary report issued during May to September of 1979. Farmers who did not participate reported the most important reasons were 1) loss of cropping season, 2) not understanding the program, 3) tractor and equipment rental too costly, and 4) mistrust of government workers. Farmers who did participate perceived their major costs as 1) tractor fuel, 2) tractor time, 3) getting subsidy check cashed, and 4) equipment rental. These farmers were generally enthusiastic about the program and felt much more positive toward the program staff than they did toward other government workers with which they came into contact. Analysis of farm sizes indicates that even though substantial efforts are made to reach small farmers, it is the larger and better educated farmers who tend to participate, and that there may be some under reporting of farm size in order to qualify for subsidy payments.

5. Training Water Management Extension Officers

The viability of watercourse improvement programs ultimately depends on the increased crop production that results from utilization of water saved. At the request of the USAID Mission, CSU staff have helped to develop a training program for Water Management Extension Officers. This program is conducted at the University of Agriculture, Faisalabad, using university staff as trainers. After completing the four month training course, the officers are assigned to field teams of the On-Farm Water Management Pilot Project. His major responsibility is to promote more efficient use of irrigation water through improved water management practices and improved general production practices.

The third course was conducted from April to mid July of 1979 with 18 trainees. Direct CSU input to the training was reduced from that of former sessions due to increased experience and confidence of the UAF staff involved. Complete lesson plans were developed for all sessions. These have since been utilized by CSU staff for the development of a comprehensive training manual. Interviews were also conducted with former trainees in order to evaluate the effectiveness of the training in the various disciplines and to provide a rational basis for changes in the training program.

The above course is for employees of the On-Farm Water Management Pilot Project. In order to gain wider dissemination of improved water management practices, a six week course was developed for Agricultural Officers employed by the extension departments of the provincial agricultural departments. The first session of this course was conducted in September-October, 1979. This course stresses the agronomic and production aspects of water management.

6. Social and Institutional Problems in Water Management

a. Water Users Associations

Previous studies and observations by CSU staff and others have indicated 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 major factor limiting the effectiveness of watercourse cleaning, maintenance and improvement projects. At the request of USAID/Islamabad, CSU agreed to develop a research program to identify and test organizational structures that might be effective in promoting group action for watercourse improvement and maintenance. Professor Ashfaq Mirza, at the University of Agriculture, Faisalabad, was to conduct these studies in cooperation with Mr. Douglas Merrey, of the CSU Field Party. Due to the withdrawal of the CSU Field Team, only the initial phase dealing with identification of organizational problems and consequences was carried out.

Sociological characteristics, such as farm size, power and influence distribution among farmers, caste and kinship group structure, and measures of progressiveness, have been identified that appear to be conducive to good maintenance of village watercourse systems. These characteristics should provide a basis for selection of villages where programs dependent on cooperation at the village level have the best chance for success. Recommendations for selection procedures have been developed as a part of this project.

b. Village Level Social Dynamics

Observations at the village level have provided a much improved understanding of the motivation of individuals to engage in cooperative or obstructive activities. In a report on extensive observations Mr. Douglas Merrey has identified the maximization of the "izzat" or "honor" of the individual as a major motivational factor. While status considerations are important in most societies, they appear to be particularly intense in the Punjabi villages observed. An important feature of the concept is that the amount of "status", or "honor" is limited so that one important method for gaining it by an individual is to attempt to reduce or tear down that gained by another individual. This supplies a powerful motive for obstructive action in relation to cooperative programs such as watercourse improvement and maintenance. It also implies that for such programs, decision making processes need to be developed that will minimize the loss of "izzat" by those individuals who advocate a course of action different from that which is eventually adopted.

7. Water Management Research and Training Program for Rural Development

As discussed in (5) above, a successful training program for Water Management Extension Advisors has been developed at the University of Agriculture at Faisalabad. 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 it became apparent that a program of research and demonstration relative to these problems would help both faculty and trainees gain a better understanding of both the problems and possible solutions. The trainees would learn to identify problems in the field, observe well planned demonstrations of how to motivate farmers to adopt improved practices, followed by opportunities to work with the farmers and practice the demonstrated techniques. As a result, a research program was developed with the following major objectives.

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 groundwater in order to alleviate the 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 and 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.

Funding was arranged for through the Punjab provincial government to be supported by local currency agreements through USAID. Provincial approval was obtained too late to start most programs during the kharif (summer) cropping season of 1980, but a few field trials, largely of a demonstrational nature, were set out. Plans for more extensive trials to start during the rabi season were developed with several UAF investigators, but withdrawal of CSU Field Party did not allow for active participation in field activities.

8. <u>Tubewell Pumping Plant Performance Testing</u>

Pumping plant performance testing was completed on 106 SCARP (Salinity Control and Reclamation Project) tubewells in the Mona Project area. Average pumping efficiency was

48 percent and only 13 percent had efficiencies above the chosen standard of 60 percent. Eight of the poorest performing pumps were removed and repaired. Average efficiency of this group improved from 31 percent before repair to 51 percent after repair. The failure to attain the chosen 60 percent standard after repairs indicates either inadequate diagnosis and repair of the pumping plant, or well deterioration causing poor performance. Most likely both factors contributed.

These pump performance tests, combined with pilot preventive maintenance programs, are designed to provide a data base that can be used in designing an overall preventive maintenance program that will be cost effective. Benefits can be expected through reduced power costs and increased water supplies resulting from maintaining higher efficiencies, and from burn outs and repair costs through identification and correction of overloads.

9. Transfer Process and Related Manuals

Among the obligations of CSU under this project is the preparation of a series of manuals detailing the process of transferring the water management technologies which have evolved from the research experience in Pakistan to other developing countries. The key manuals in this series concern the basic process of transfer of technology. This transfer process set consists of four manuals: 1) an executive summary; 2) problem identification, 3) development of solutions and 4) project implementation.

In addition to the transfer process, manuals on several more technical aspects have been prepared. These include manuals on evaluation and improvement of basin, furrow and border irrigation; training of water management advisors; matching cropping systems to water supply; skimming well investigations; watercourse improvement; and the design of jet junctions for certain water lifting applications. These manuals represent a major effort on the part of both campus staff and returning field party members. They are complete and are listed under "Publications" (section G), below.

10. 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 Method for Acid Delinting Cottonseed

Cottonseed is often delinted before planting to improve overall seed quality and to facilitate passage through a plaster box. Cottonseed may be delinted mechanically with delinting saw gins or by treatment with concentrated sulfuric or hydrochloric acids. At this time, the Agricultural Development and Supply Corporation in Pakistan does not have the facilities for delinting cottonseed. Thus, agronomists and farmers who plan to sow cottonseed with mechanical planters must be capable of delinting their own seed.

The acid delinting method described in Appendix 1 was used to delint over 100 kg of cottonseed for field experiments conducted on Mr. Raja Aslam's farm near the Mona Reclamation Experimental Project (MREP). Cottonseed delinted by this method were virtually free of lint, while boll worms infesting the seed lot were killed by the acid. In addition, acid delinting of the cottonseed facilitated the removal of immature and broken seed and chaff. The percent germination of cottonseed used in the field studies at Mr. Raja Aslam's farm were improved from 45 percent lint seed to 70 percent for cleaned acid delinted seed.

b. A Field Study of Traditional and Improved Methods of Cotton Culture

Cotton, until recently, was the major source of foreign exchange for Pakistan. Average seed cotton yields and acreage planted to cotton have declined sharply since 1972. While the Government's price policies may have been partially responsible for the decline in cotton production, average acreage yields have declined to less than 1,000 lbs. seed cotton per acre. Investigations of cotton production in Pakistan suggest that the problems associated with declining yields have developed from, 1) varietal deterioration, 2) a lack of insect control, 3) poor seed quality, 4) low seeding rates, 5) flooding during the monsoon season, 6) level basin culture and 7) unleveled fields.

A cooperative cotton production field trial was conducted on the farm of Mr. Raja Aslam (Tubewell 62) in the Mona Reclamation Experimental Project area. A completely randomized design, replicated four times, was used to compare bedding treatments of Delta Pine 25 and AC-134 cotton varieties with "traditional" basin cultivated AC-134 cotton on a precision leveled eight-acre field.

The stands of certified AC-134 cotton variety in "traditional" basin treatments averaged 8,975 plants per acre and ranged from 5,900 to 11,300 plants per acre. The stands of AC-134 obtained in respective ridge furrows and broadbed treatments averaged 50,850 and 46,025 plants per acre, while stands of Delta Pine 25 averaged 33,900 plants per acre.

Although rank growth of the Delta Pine 25 indicated varietal deterioration, the overall performance of this variety was superior to that of the AC-134 cotton variety. The average seed cotton yield of Delta Pine 25 treatments was 1909 lbs. per acre and over 600 lbs. per acre higher than the highest average treatment yield of AC-134.

Within AC-134 treatments the economic analysis showed that Mr. Aslam was better off with the "traditional" methods of cotton culture. But, with increased inputs, principally insecticides, Delta Pine 25 grown on ridges between furrows nearly doubled net profits. These results suggest that cotton research in Pakistan should focus on varietal improvement, row spacing, plant populations and fertilizer rates. In addition, agencies responsible for maintenance of varietal integrity and extension services must be given more support or cotton production will continue to decline.

c. Improving Field Corn Stands in Seriously Crusted Soils

Research on soil crusting, conducted at the Colorado State University Agronomy farm in 1978, was continued in the Grand Valley of Western Colorado during the 1979 growing season. The problems associated with irrigated agriculture in this valley are somewhat analogous to those observed in Pakistan. Approximately 1/3 of the valley's irrigated area has been degraded by waterlogging and salt accumulations. Soil crusting problems are particularly troublesome on many of the poorly structured, high silt-content soils. In addition, the acid climate of the valley is particularly conducive to field studies involving soil crusting.

A 3 x 3 factorial design, replicated 4 times, was used to test the effects of prehydrated seed and seedbed treatments on the stand establishment and yield of field corn. Preplant initial seed moisture contents (ISMC) were 9, 23, and 31 percent, respectively. Two days after sowing, an average of 2.8 cm of water was applied to the study area with a semi-portable sprinkler irrigation system. After the sprinkler irrigation, the experimental area was subdivided into subplots consisting of crusted, soil mulched and pre-emergence irrigation treatments. Soil mulch subplots were mulched three days after sowing and pre-emergence irrigation subplots were irrigated seven days after sowing.

The data from this study reveal soil mulching to be the most effective method for improving stands and grain yields of field corn grown in severely crusted soils. A pre-emergence irrigation application, to soften surface crusts, was also shown to increase both stands and grain yields may result with two or more pre-emergence irrigation applications.

Prehydrating seed prior to sowing did not improve stands or fields of field corn grown in a severely crusted soil. Although prehydrated seed was observed to improve the stands and yields of pre-emergence irrigation treatments, a large decrease in the yields of soil mulch treatments occurred with increasing preplant seed moistures. Thus, prehydrating seed prior to sowing does not appear to be a feasible method for improving stand establishment and yields of field corn in severely crusted soils.

d. A Hand Operated Crust Breaker

A hand operated crust breaker has been found to perform well in both weakly and severely crusted soils. The use of this implement in soil crusting experiments indicates a farmer could break soil crusts on 3 to 4 acres per day. To operate the crust breaker, it is first centered over a seed row and then pushed at near normal walking speed. By simply exerting a slight downward force, the operator can break through more severely crusted portions of the field. Where crust strengths are too severe for normal operation of the implement, it may be necessary to tie weights on the lower handle to exert more downward force. The 4 to 4½ inch band of soil mulched by the crust breaker will permit normal emergence of seedlings. The crust breaker could be constructed in any village in Pakistan where a welder is available. The materials needed for construction are widely available throughout Pakistan.

e. Influence of Stubble and Tillage on Moisture and Nitrogen Conservation Under Monsoonal Conditions

Pakistan's dryland agriculture is characterized by cultural practices which lead to excessive loss of soil moisture and nitrogen. There is a general practice of excessive plowing and planking amongst the farmers in Pakistan. Research has shown that frequent tillage operations are rarely beneficial and frequently detrimental in addition to being costly. Studies have indicated that tillage operation wastes water by exposing moist soil to sun and wind. Soil surfaces loosened by tillage often lose all moisture to the depth of the tillage. Standing stubble has been reported to be more effective in reducing soil water loss than where all residue was flat, probably because stubble reduced wind velocity at the soil surface. Further, stubble has been found to reflect 9% more incident solar radiation than bare soil, thereby reducing evaporation.

Most studies showing conservation of moisture due to decreased tillage and stubble maintenance have been conducted in areas where snow catchment is a major problem. To study the influence of tillage and stubble on moisture and nitrogen conservation under monsoonal conditions, the present study was undertaken under rainfall conditions.

In this study, more moisture was conserved under long stubble than short stubble conditions. Weed growth was controlled to a great extent by use of herbicides in the no-till treatment compared to the tillage operation. The results of this study could be applied to the rainfed areas of Pakistan. The monsoonal precipitation could be conserved by manipulating stubble and tillage conditions to achieve effective weed control and minimizing evapotranspiration and reduce evaporative losses by creating a mulch.

f. Irrigation Scheduling in Punjab of Pakistan

A farm water management research project was conducted to determine practical irrigation scheduling techniques, demonstrate the potential for water scheduling for cool season and hot season crops and to evaluate the potential for improving on-farm irrigation application efficiency through closely controlled irrigation. The Class A evaporation pan with locally verified crop coefficients is recommended for practical irrigation scheduling in Pakistan.

Practical irrigation schedules on leveled land for wheat saved up to 10 cm of water, improved irrigation application efficiency by more than 20% and resulted in increased crop yields by 0.88 ton/hectare. For maize fodder up to 10 cm of water was saved, irrigation application efficiency improved by up to 38 percent and the increased crop yield was 24 tons of forage per hectare.

g. SCARP Tubewell Pumping Plant Performance in Mona Reclamation Experimental Project Area

Salinity Control and Reclamation Project (SCARP) tubewells are installed to lower or stabilize the high groundwater table that threatens and destroys valuable cropland and to provide more water to irrigators. The tubewells could be used to reclaim salinized soils.

Most of the 148 tubewells under this study were drilled and completed in 1964-65. The range in depth of the wells in the Mona Project area is from 250 to 400 feet. Static water levels are quite uniform at about 10 feet and specific capacities range from near 40 to over 100 gallons per minute per foot of drawdown (gpm/ft.). The tubewells were properly designed, pumps were laboratory tested and, apparently, construction was adequately supervised. The well construction and pump records for the SCARP tubewells are quite complete.

Tubewell casing and screen were manufactured to the type and slot size selected for the aquifer conditions. Generally, the screen was placed only next to the more permeable portion of the aquifer. Electric motors used to drive the pumps range in horsepower from 20 to 30 horsepower. Pump discharges range from 2 to 4 cusecs.

The SCARP tubewell program has been plagued by many problems and is being criticized daily for these problems. WAPDA reported in 1971 (1) that pumping costs for the Mona-SCARP tubewells were 40 to 50% higher than for private tubewells in the same area. It was also reported that the initial estimated tubewell life of up to 40 years was actually closer to 15 years. Utilization of public tubewells was said to be low due to repairs, down time and general mismanagement.

The average tubewell pumping plant efficiency for 106 SCARP wells was 48%. Only 13% of the plants had efficiencies above the chosen standard of 60%. An attainable plant efficiency is 75%. The effect of low plant efficiency is that cost of electrical energy is 12-15% higher than required. Generally, tubewell plant maintenance costs will be above normal on inefficient plants.

Specific capacity of the tubewells has dropped an average of 32% in 15 years. Maximum decrease in specific capacity was 65% (MN-62). Six tubewells showed a small increase in specific capacity since pumping began. Tubewell plant efficiency does not appear to be closely correlated to the degree of specific capacity change. However, the group of tubewells performing above 60% generally have specific capacities that are within 24% of original. Many of the original specific capacities were in the range of 95 to 115 gpm/ft. and are now 50 to 80 gpm/gt. Encrustation of the tubewell screen (or performations) is a likely cause for decreased specific capacities in these tubewells.

Tubewell production or discharge rate is about 80% of original discharge. This decrease does not include the complete closure of 23 tubewells because of highly saline water. It is not unreasonable to believe that the decrease in pumping rate, coupled with the decrease in percent utilization of the tubewells, could seriously affect or even reverse the favorable downward trend of the water table. The irrigators would welcome the additional water for their crops that they, apparently, have lost.

h. A Ponding Study of Factors Which Affect Watercourse Water Losses

Conflicting results between inflow-outflow measurements and ponding loss data have created questions about the measurement methodologies. This ponding loss study was undertaken to attempt to clear up the existing conflict between the two sets of findings, and to study, in depth, the earthen watercourse to determine the causes of water losses and to develop design techniques to reduce these losses.

Watercourse water losses were measured on 122 short channel sections from 18 watercourses by the ponding method. Five qualitative and six quantitative descriptive parameters were also measured on about half of the sections so that functional relationships between these factors and losses could be established.

The measured loss rates on the sections averaged 2.32 lps/100 m (0.25 cfs/1000 ft), which is in the same range as the previously reported flume loss measurements, and would convert to about 40 percent conveyance losses on a medium sized watercourse. That ponding loss measurements tend to be slightly less than inflow-outflow measurements can be explained by excess silt deposition in ponded sections and flume head loss induced water losses in inflow-outflow tests.

Statistical analysis of the results determined that SCARP watercourses lose significantly more water than non-SCARP channels, and that farmers' branches have higher loss rates than sarkari khal sections. A highly significant and consistent finding was that loss rates increase exponentially with flow depth increases in the channels. Loss rates doubled on the average with each 5 cm increase in flow depth. Manipulation of Manning's equation allowed similar exponential relationships to be derived between inflow rate changes and roughness coefficient variations (vegetative growth), and loss rates.

i. Operational Evaluation of Village Level Irrigation Conveyance Systems

In most canal systems the large majority of the total conveyance loss is steady state seepage. However, in small intermittently used irrigation channels (laterals, ditches, watercourses), there can be a significant transient loss component that is not measured in steady state measurements. Transient losses include: excess infiltrated water which wets up dry channel banks; water seepage and leakage during the time water is being transferred from one field to another; dead storage water left lying in the bottoms of channels after drainage of channel storage into the fields is complete; and losses resulting from short term watercourse breaches and outlet breaks.

In this study of five village level watercourse systems in Pakistan, total operational conveyance losses, including transient losses, were measured using an adaptation of the inflow-outflow method. The objectives were to determine the extent of the transient losses and to quantify the types of watercourse losses so that techniques to increase conveyance efficiencies could be evaluated.

On the five studied watercourses, the average primary channel section was full 36 percent of the time, while the average farmer's branch was utilized only during 2 percent of the rotation. Even though 45 percent of the total losses and 2/3 of the transient losses are in the branches, the cost to reduce them will be high because of the lengths involved.

j. Procedure for Evaluation and Improvement of Irrigation Systems

The evaluation of presently operating irrigation systems is conducted for the purpose of decision-making in relation to the level of required system improvement. A comprehensive procedure for the evaluation and improvement of irrigation systems is suggested. The procedure is based on the analysis of the performance of the system for an individual application, along with the irrigation management regime (intervals and depths of application), resulting in an analysis for the whole irrigation season.

The performance of an irrigation system can be fully described in terms of four parameters--the fraction of the absorbed water that is stored in the root zone, the fraction of the requirement that is met, the fraction of the delivered water that is absorbed, and the distribution of the water over the field. Most of the commonly used terms can be derived from these four parameters. If limits of acceptability for these parameters can be established, then the analysis of an irrigation system can be conducted to evaluate the irrigation performance and to determine how the irrigation can be improved (i.e., improve distribution, reduce or increase total application).

k. Consequences of and Farmers' Reactions to Indus Basin Water Management Constraints

The research undertaken by the Colorado State University Field Team in Pakistan (of which this work is an example) has attempted to look at the water use end of the system rather than the water source. This water use subsystem is the on-farm component of water management and assumes the primary and secondary subsystems at the given level of management. The hypothesis behind this approach is that the current water supply could be used more efficiently at the tertiary level of the system where the effect of a new water supply could have the greatest impact on food and fiber production. The complementary inputs of good quality seed, fertilizer, improved technologies, market outlets and production facilitating inputs as credit production incentives, and extension information are all closely tied to the effectiveness of land and water utilization. The village social setting, the interrelations between farmers and the institutional services that they receive from the government agencies provide the background for production that determines the acceptance of new technology and the speed with which it is delivered to the end user.

l. Farm Resource Productivities, Allocative Efficiencies and Development Policy in the Indus Basin, Pakistan

A production function analysis was performed on farm survey data obtained in the Indus Basin, Pakistan. The sampling procedure and specification of variables explicitly consider irrigation water and farm power inputs. The derived marginal productivities and estimates of social opportunity costs of resources are employed to examine the efficiency of resource allocation on several types of farms. Tentative implications for agricultural development policy are indicated.

The findings of this study indicate that programs to make more irrigation water available to farmers, particularly outside the normal summer cropping season so as to facilitate more harvests per year, would have extremely high rates of return. Desirable effects on food production, employment and the value productivity of labor would also be expected. Emphasis on water supply, together with already operating input supply and credit policies to encourage use of fertilizers, improved crop varieties and plant protection chemicals have much more desirable consequences than incentives toward tractor mechanization.

m. Problems of Farmer Organization in an "Appropriate Technology" Project: Lessons from the Watercourse Improvement Project in Pakistan

Pakistan's watercourses must be improved; if they are not the Indus Food Machine will never achieve its potential productivity. Both the Pakistan Government and various international donor agencies including the World Bank recognize this, and are planning large investments in watercourse reconstruction. There are two possible strategies for carrying out watercourse reconstruction: one is that the government take over the responsibility of improving and maintaining the watercourses, perhaps charging the farmers for the expense. This approach is being tried in India, and many Pakistan Government officials find it attractive. Under such an approach rapid progress in reconstructing watercourses would probably be achieved at the early stages. However, such an approach would entail either a major expansion of the existing Irrigation Department or creating yet another inefficient government bureaucracy; it would exacerbate the already serious shortage of trained engineers; and it would further reduce the farmers' sense of responsibility for their watercourses.

The other possible strategy, more viable in the long run though difficult to achieve in the short term, is to encourage the establishment of legalized Watercourse Associations with substantial responsibilities, federated into larger units, and integrated into the management of the larger system. CSU has recommended such a strategy to the Pakistan Government. The CSU suggestions involve establishing an association on each watercourse, with all shareholders as members. This association would be responsible for improving and maintaining its watercourse, and would have the legal power to obtain loans for financing improvements. Each watercourse association on a larger distributary would send a representative to a Distributary Association; and all these associations would be represented on a Canal Association for each major canal. The plan envisions giving these associations substantial responsibility for managing the canal system.

n. The Green Revolution in Pakistan: Whose Cornucopia?

The initial optimism about the high yielding varieties (HYVs) in the late 1960's and early 1970's as a solution to the world food problem is giving way to concerned pessimism. The technical literature is mixed in regard to the benefits received by different classes of farmers. Few studies have provided empirical data to show who benefited and how. The Pakistan experience with the HYVs, once hailed as a model for other countries, provides a good case study to attempt to answer several crucial questons which include: In what specific ways were small farmers and tenants at a disadvantage in adopting the HYVs of wheat? To what degree were scarce resources and services skewed toward the large landlords? How well do small farmers and tenants perform in yields per hectare as compared with larger farmers?

Like many other countries, Pakistan has experimented with many types of programs to get agriculture moving, such as introduction of HYV technology, private and public tubewell installation, many changes in price policy, and many changes between private and public distribution of fertilizer inputs. As described in this paper, the strategy used resulted in a situation where larger farmers were able to acquire requisite inputs while small farmers were at a disadvantage. Given the structure of rural society in Pakistan, as well as in a number of low income countries, the "trickle down" theory has not worked. The present agrarian structure in Pakistan will not change short of radical intervention by government or rural uprisings. However, if Pakistan desires to maintain political stability and to become self-sufficient in food grain, several short run steps can be taken, such as: improved credit facilities for small farmers, protection against frequent unjust eviction of tenants, improved extension services, and more availability of fertilizer.

o. Cancian's "Upper Middle Class Conservatism" Thesis: A Replication from Pakistan

During the past 40 years a substantial body of research has accumulated which reports the existence of a direct and linear relationship between socioeconomic status and the adoption of a variety of innovations. Despite the findings of this research, Cancian has formulated and provided empirical support for a different conception. In general, Cancian argues that the relationship is curvilinear. Specifically, he characterizes the relationship as one in which those of high middle economic rank have a lesser propensity to adopt innovations than their low middle rank counterparts in the early stages of the adoption process, while both innovate more than those of low rank and less than those of high rank.

This study has examined the relationship between economic rank and the adoption of agricultural innovations with data collected from 173 farmers residing in 10 villages in the Punjab Province of Pakistan. More specifically, this investigation centered on an assessment of Cancian's upper middle class conservatism thesis as represented in two specific hypotheses. Utilizing acres of land owned and acres of land cultivatible as measures of rank and an index based on the summation of eight weighted agricultural innovations as a measure of adoption, four tests for each hypothesis are presented. Regardless of the rank variable used in the assessment, the findings fail to confirm either of the hypotheses.

p. Agrarian Structure, New Technology and Distribution of Benefits: The Case of Pakistan

Empirical field data from 350 farms in 1970 and 384 farms in 1975 are utilized to test a model developed by Gotsch and modified by Freeman and Lowdermilk related to the distributive effect of technologies and services associated with the Green Revoluation in a semi-feudal agrarian structure. These technologies and services include: private tubewells, tractors, fertilizer, credit, and extension services. The components of the model include: 1) characteristics of the technology, 2) magnitude and relative distribution of land holding, 3) type and distribution of institutional services, and 4) distribution of income and power. The model shows how income and power are related to control of land assets which influence the distribution of institutional services which in turn strengthens efforts to maintain the status quo and local norms and traditions related to the landed elite. The data show how the particular technologies and services skewed benefits to the large farmers and explain why the high yielding wheat varieties program in Pakistan has become stalled in relationship to both adoption of associated practices and yields per acre. The paper suggests policy implications and strategies needed to increase aggregate wheat production which requires greater participation by small farmers and tenants.

q. The Loomis Social System Framework: Application to Irrigation System Research

Many researchers who are involved in the studying of irrigation systems with the purpose of utilizing their findings for the development of programs to change those systems, and/or the resulting farm practices, generally pursue a strategy of first identifying critical areas of the particular systems which should be subject to change before any activity is initiated. The purpose of this paper is to discuss one analytical format which may be used as a mechanism to systematically delineate such sociological problem areas. This format is created by using the concepts which make up the Loomis Social System Framework and organizing those concepts under criteria found to be of importance in the literature on irrigation systems.

If the format can serve the limited purpose of providing a set of parameters that will sensitize the researcher to what possibly may be happening in the irrigation system, then this may prove to be a very effective tool. This format still has to be tested and it undoubtedly will be modified to improve its capability. Yet, it is felt that the potential is there to help many people secure some direction in this complex arena of an irrigation system that will allow the researcher and the policy maker to better understand the mechanisms governing the operation of that system.

r. Analysis of Sampling Variation Within and Among Wheat Fields in Punjab

The variance encountered in harvesting four adjacent 3m x 4m quadrants from wheat fields in the Punjab has been analyzed. This analysis shows that the confidence intervals for mean yields are surprisingly insensitive to the size of the area harvested within each field.

Measurements of mean yields within plus or minus 1 to 2 mds/acre will require the sampling of some 100 to 200 fields. Confidence intervals of less than 1 md per acre will require 300-500 fields for the 95% confidence level and 500-800 fields to attain a 99% confidence level.

A breakdown of the variance estimates into within and among field components revealed that the within field components for subplots was very small compared to the among field component. This is, of course, the reason that yields estimated from crop cutting over many fields are insensitive to size of harvest area. The analysis also revealed that the within field standard deviation of $12m^2$ plots is linearly related to the mean and can be estimated by:

$$S_w = 0.16\bar{y}$$

Where S_w is the standard deviation and $\bar{y}$ is the mean yield of the subplots in mds/acre. The estimate can be extended to adjacent subplots of any size by:

$$S_w^2 = .307\bar{y}^2/H$$

Where S_w^2 is the within variance and H is the harvest area in m^2.

The survey data did not provide an estimate of the effect of taking more than one cutting location per field. However, by utilizing data available from CSU Water Management Research Project files it was possible to generate an estimate of this component, such that:

$$S_L^2 = .048\bar{y}^2$$

Where S_L^2 is the variance component due to different locations within the same field. Further analysis establishes that the variance observed among fields for any combination of harvest area and number of locations within fields will be estimated by:

$$S_{\bar{A}}^2 = .307\bar{y}^2/HN_L + .048\bar{y}^2/N_L + 71.5$$

Where $S_{\bar{A}}^2$ is the observed variance and N_L is the number of locations. The confidence interval C.I. can then be estimated by:

$$C.I. = \pm t_{PP} (S_{\bar{A}}^2/N_F)^{1/2}$$

Here, t is the tabular value of the t statistic at any probability level P and N_F is the number of fields sampled. Tables and graphs developed from these relationships demonstrate that for any given harvest area the confidence interval is reduced by dividing it into multiple harvest locations within the field. The increased precision thereby attained however, is quite small, particularly if more than two locations are taken and/or the number of fields sampled is large.

Finally, the confidence interval for the yield of any particular field can be estimated by:

$$C.I. = t_P\bar{y}(.307/HN_L + .048/N_L)^{1/2}$$

Tables based on this relationship reveal that very intense sampling is required to obtain accurate estimates of the yield of any particular field. For instance, if a $10m^2$ harvest area is cut at each location within the field some 30 locations are required for a 95% confidence of plus or minus 10% of the mean. These results indicate that in general it is impractical to attempt to accurately evaluate the yield of particular fields by cutting subsamples from that field.

s. Water Losses as a Function of Water Level in Watercourses and Resultant Effects of Cleaning on Delivery Efficiency

Loss of water in "mature" earthen watercourses increases exponentially as the level of water in the watercourse rises. Average losses were found to increase about 9% per cm of water level increase in Colorado and 12% in Pakistan. Vegetation growing in watercourses increased the ope··ting levels above the designed levels.

Cleaning vegetation from watercourses lowered the operating level of water by decreasing the roughness of the channel. Regular cleaning to keep the water levels at or below designed levels keeps losses at a small fraction of what they can be when vegetative growth is not controlled.

t. Special Equipment for Animal Powered Land Leveling

The lack of animal powered equipment for land leveling was indicated as one of the constraints on small farmers making use of precision land leveling in their water management practices in Pakistan.

Land leveling is typically done with large tractor powered scrapers and land planes. Most of the conventional machines do not lend themselves well to scaling down to the 1-1/2 hp power input that a team of draft animals can deliver. Therefore, alternate types of special equipment must be designed specifically for this application.

Two such implements are described: a scraper and a scraper-landplane. They were designed, but not fully tested, by the CSU Water Management Research Project before the project terminated in Pakistan in the fall of 1979.

u. Aids and Suggestions for the Successful Manufacture of Concrete Naccas

Water losses in irrigation systems have been appreciably decreased by using improved structures at control points along watercourses. These control points serve any of three functions: to divert the water into the desired branch watercourse; to drop the elevation of the watercourse where the natural ground slope is greater than the designed watercourse slope; and to terminate, or check, 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 have weak banks and are 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; however, when some contractors have tried to duplicate these naccas, they have had difficulty in achieving the performance of the naccas manufactured by the original contractor, Hasnain RCC, Sargodha. 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.

v. The Development of a Front-Mounted "Bulldozer" for Wheel Tractors to be Used in Pakistan

This paper describes the development of a front-mounted "bulldozer" for wheel tractors to be used in Pakistan. A few of these implements had been imported, and were being copied locally. However, it was felt that a machine better suited to local conditions could be developed.

The implement described in this paper performs better and costs less than previous machines, principally because of the unique method of raising the blade. Instead of hydraulic cylinders, a cable system using the geometry of the 3-point hitch controls the blade.

A first run of 15 units were manufactured and put in service. After about two months service, no problems had developed, and the operators liked the performance of the blade.

w. Roller Bedshaper for Basin-Furrow Irrigation

Cultivation of row crops on beds has certain advantages where surface irrigation is practiced. Beds can also relieve some of the damage caused by heavy rainfall. This paper describes the design of a simple bedshaping implement for use with tractors having three-point hitches. A modified version of the implement can be used with animal power.

x. The Effect of Chemical and Traditional Weed Control Methods on Yield of Wheat

A field size demonstration was conducted at the On-Farm Water Management Demonstration Farm to determine the potential use of chemical herbicides to control weeds in wheat. The return, over treatment costs, was Rs.750/A compared to no weed control and Rs.650/A and Rs.401/A compared to hand hoeing and bar harrowing, respectively. Weed control was as high as 97% with one chemical while hand hoeing and bar harrowing gave 75% and 49% weed control, respectively.

y. The Effect of Chemical and Traditional Weed Control Methods on the Yield of Wheat at Tubewell-56 and Phularwan Farm

The potential use of several chemical herbicides for the control of weeds in wheat was determined in comparison with traditional weed control methods. Very good yield increases were obtained from several herbicides. The return over treatment costs, compared to no weed control, was as high as Rs.669/A under heavy weed infestations. Compared to "normal" weed control practices that are followed by only a small percentage of farmers, the return was as high as Rs.618/A. These results show that weed control with chemical herbicides is very profitable and effort should be expended to educate farmers on their use.

z. Economic Analysis of the Response of Wheat to Water, Nitrogen and Phosphorus

Results from a water-fertilizer interaction experiment on wheat at the Mona Reclamation Experimental Project have been subjected to statistical and economic analyses to determine the optimum combination of inputs. The experiment was an incomplete factorial with 35 treatment combinations covering 5 levels of each of 3 factors, i.e. water, nitrogen and phosphorus. Multiple regression procedures were used to fit mathematical models to the response surface. The most appropriate model for this data set proved to be of the form,

$$Y = b_o + b_1x_1 + b_2x_1^{\frac{1}{2}} + b_3x_2 + b_4x_2^{\frac{1}{2}} + b_5x^3 + b_6x_3^{\frac{1}{2}}$$
$$+ b_6x_1x_2 + b_7x_1x_3 + b_8x_2x_3$$

The response to phosphorus at this location proved to be very small and did not give an economic return at any level of nitrogen or water inputs. Total water inputs, including rainfall, varied over the range of 24 to 73 cm, or from 50% to 150% of normal evapotranspiration. At low nitrogen rates there was very little difference in yield across this range, but at high N rates some response was noted. The major response was to nitrogen and high economic returns from nitrogen application were found at all water levels. At high nitrogen levels yield ranged from about 3.6 to 4.4 metric tons per hectare, depending on the water supplied. The optimum rates of water are highly dependent on the cost of water and the marginal rate of return on investment required. Optimum N rates were not particularly sensitive to the cost of water. At a marginal rate of return of Rs 2 for every rupee invested, optimum water applications were about 60, 50, 35 and 25 cm for water costs of Rs 2.5, 5, 10 and 15 per ha.cm, respectively. The corresponding optimum nitrogen rates were about 150, 135, 125 and 120 hg/ha, respectively.

aa. Watercourse Improvement: Methods, Costs and Loss Rates at Tubewell 78 Watercourse

The test watercourse sections at Tubewll 78 have provided data essential to the Pilot Watercourse Studies in the Mona project area and the Watercourse Improvement Component of the Punjab Agriculture Department's Water Management Development program.

These included (1) a determination that pakka lined watercourses (costing over Rs 25/acre foot) cannot generally be justified on a benefit/cost basis for branch channels, but may be justified for some main channels (Eckert, Dimick and Clyma, 1975); (2) that Pakistani masonry and concrete is commonly porous and requires a good coat of plaster to achieve the desired reductions in water loss; (3) that losses from watercourses in a sandy loam soil can be reduced to 20 to 35 percent of their present value by a thorough job of bank reconstruction and compaction, or core compaction; (4) that farmers can reduce their water losses by 50 percent by reconstructing and doing a medium to poor job of packing the new banks by expending less than 0.5 man hours per foot of watercourse and that the water saved has a lower cost than other sources of water in Pakistan; (5) that farmer participation in planning and constructing the improvements is helpful to gaining their support of a continued maintenance and cleaning program; and (6) the warabundi system of orderly scheduling of water does avoid appreciable operational loss and should not be discarded as long as the irrigation systems are susceptible to these operational losses.

F. Dissemination and Utilization of Research Results

Throughout the past year extra efforts have been made to assure a wide dissemination and utilization of research results. Credibility with the Government of Pakistan has increased over the years as a result of a wide range of project activities, and interest has increased at all levels from farmers to government officials. Increased interest has also been noted from a number of organizations interested in water resource development in the developing countries.

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.

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 the 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 for nearly three years. Progress has varied substantially among the various provinces, but the watercourse improvement program in the Punjab has been particularly impressive, with several hundred watercourses completed. This program has attracted attention among farmers and at all levels of government, and appears to have generated sufficient momentum to assure that it will be allotted substantial resources in the future.

During the past year there has been an increased interest by the International Bank for Reconstruction and Development (World Bank) in the On-Farm Water Management Pilot Project, and in the general area of water management in Pakistan. With the present uncertain status of future direct US aid to Pakistan there has been concern that the program would cease. However, a World Bank team has recently visited Pakistan on a project identification mission and, as a result, plans are being developed for two related development projects. One would be an extensive program that could reach as many as half the watercourses in Pakistan with a moderate level of improvement, while an intensive program would approach water management on a canal command basis, improving the system at all levels on perhaps 10% of the irrigated lands. Present total cost estimates for these two projects are of the order of US $150 to 200 million.

These programs are being developed as a result of high level policy decisions in the GOP that place a high priority on the water management component of the development process. The role of the CSU research project in identifying the needs and opportunities in this area has been unmistakable. Various reports and presentations by CSU over the years have had a major influence. During the past year, perhaps the most important was a paper prepared on alternative strategies for water management development. This was originally prepared for a top level (Federal Ministers, Secretaries, etc.) policy seminar that was to be held prior to field party departure, but was actually held several months later.

Precision land leveling is an important component of the On-Farm Water Management Pilot Project. At the request of USAID Islamabad an intensive survey of farmers in the project area was carried out in 1979 to determine the constraints governing the participation in this program by small farmers. Results of this program did confirm the basic viability of the land leveling program but revealed several weaknesses in reaching the target group of small farmers. These results will be utilized by USAID and GOP agencies in strengthening the program.

A training program has evolved for farm level extension personnel as a result of both the Pilot Project and the concern of provincial agricultural 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 to 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 conducted March-July of 1979. A complete set of lesson plans has been developed for this course and these have been utilized extensively in the preparation of a manual for on-farm water management training. In addition, a new course has been instituted to provide in-service training in water management extension for regular agricultural officers of the provincial Agricultural Extension Departments. This is a six-week course concentrating on the production aspects of water management. The first session was held September to October, 1979.

A research and demonstration program has now been developed in association with this training program and approved for funding by the provincial government. This research and demonstration program is designed to help develop solutions to farm production problems associated with water management and to provide practical experience in developing solutions to both the university faculty who serve as trainers and to the trainees.

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. 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. Recent reports from Pakistan indicate that contracts are being let for furnishing nearly half a million of these structures. One can only hope that reasonable quality control can be maintained with such rapid expansion.

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 the Mona Reclamation Experimental Project. This assistance would include both financial and technical support. While in Pakistan they consulted with Field Party staff as well as GOP personnel. At that time, a recommendation was made in support of establishing a facility in a location which would facilitate participation by faculty at the Sind Agricultural University at Tandojam. Apparently arrangements are still progressing satisfactorily for this facility.

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.

For several years an important component of the CSU program has been related to Water Users Associations, particularly at the local level. This work has involved several aspects of the problem including research directed towards identifying viable organizational structures in the local social settings, organization of ad hoc groups on watercourses improved in experimental programs, and work with senior policy making officials concerning the legal and institutional aspects. 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. No concrete action was taken by the Federal Government at that time. Recent reports indicate that the planned large new watercourse improvement programs will include the formation of associations to provide local input into construction planning and operation at the watercourse level, and that steps will be taken to provide a legal basis for these organizations.

Six Pakistani students sponsored by this project have been awarded advanced degrees at CSU during the past year. A unique feature of the program was that students would complete course work on campus, but research would be done in Pakistan under the direction of CSU Field Party staff who are also members of the graduate faculty. If some research was done on campus it would be supplemented by work done in Pakistan. Final examinations were to be administered in Pakistan. During the past year Mr. Mohsin Wahla completed a M.S. degree in Agronomy under this program. His research was conducted in Pakistan on the use of paraprofessionals in watercourse improvement. Mr. Mohammed

Akram completed an M.S. in Agricultural Engineering. His research involved effects of compaction on infiltration and was partly done in Pakistan. Mr. Khalid Gill was awarded a Ph.D. in Agronomy. His research involved work with water-nitrogen interaction and was largely done in Pakistan. Due to the early withdrawal of the Field Party it was necessary to arrange for the other students to complete their theses research on campus. These included Mr. Barkat Ali (M.S. in Agricultural Economics), Mr. Muhammad Hanif (Ph.D., Agronomy) and Mr. Zahid Saeed Khan (M.S., Agricultural Engineering). These students have all completed their programs and returned to employment in Pakistan. One other student, Mr. M.A.R. Farooqi, has not yet completed his program (Ph.D., Agronomy), but has changed to other sponsorship for completion. Abstracts of theses for the six students who completed during the year are included in the Publications section below.

Realizing the worldwide demand for expertise in on-farm irrigation related fields, the project has provided an opportunity for three state-side graduates to conduct field research in Pakistan. Thomas Trout was a member of the Field Party from 1976 to 1978 while a doctoral candidate in Agricultural Engineering. His dissertation research was largely conducted in Pakistan and he has published several reports and papers on work done in Pakistan. He has since served as a member of a World Bank project identification mission in Pakistan, and is presently a Research Assistant Professor at CSU. Mr. Larry Nelson, who returned to campus in 1977, conducted research at MREP related to problems of the kharif (summer) season crops, including high soil temperatures, crusting of soil, and the germination and emergence of maize and cotton. Reports on his work have been completed. Mr. Nelson has delayed completion of his Ph.D. in order to take a short term assignment as an instructor in a training program for agronomists in Egypt. Mr. Ray Renfro, Ph.D. candidate in Economics, conducted the survey of farmers to determine constraints on farmers participating in the precision land leveling program during the summer of 1979. He is presently working towards the completion of his doctoral program. We are proud of the achievements of these people in relation to our own program, and we are confident that their participation has made a substantial contribution to their career development.

Expertise developed in the research and surveys conducted in Pakistan is providing a substantial springboard for the water management project in Egypt. 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.

G. List of Publications

1. Water Management Technical Reports

a. Evaluation and Improvement of Irrigation Systems, by Gideon Peri and Gaylord V. Skogerboe. Water Management Technical Report No. 49A.

Abstract

A comprehensive procedure for the evaluation and improvement of irrigation systems is suggested. The procedure is based on the analysis of the performances of the system for an individual application, along with the irrigation management regime (intervals and depths of application), resulting in an analysis for the whole irrigation season.

The irrigation system is quantified by four parameters: distribution uniformity and delivery, deep-percolation and storage efficiencies. The irrigation management and irrigation regime are quantified by ratios of recommended and determined intervals and depths for the individual application.

Evaluation of performance of an individual application is based on the water distribution profile after irrigation. Efficiencies and coefficients that describe the irrigation performance are derived directly from the water distribution profile. Based on these efficiencies, the irrigation performance is determined and classified into the appropriate performance categories and subsequently, the need for improvement and types of improvements are determined.

The overall irrigation season is quantified by four parameters: marginal water costs, yield-water economic relations, crop water use efficiency and yield per unit of area. Besides the yield categories, the overall and seasonal levels of performance are quantified by the four water parameters and environmental and economic inputs. Evaluation leads to recommendations toward improvements of the irrigation system in regards to management and regime.

b. Evaluation and Improvement of Basin Irrigation, by Gideon Peri, Gaylord V. Skogerboe and Donald I. Norum. Water Management Technical Report No. 49B.

Abstract

A comprehensive definition and description of basin irrigation is given. A procedure is outlined for the design and evaluation of basin irrigation systems, showing the interactions between the various basin characteristics, the operational parameters, the management parameters, and the performance parameters. A general model is discussed by considering the various functions upon which it must be based (infiltration, advance, recession).

A simple model for the determination of the infiltrated water distribution under basin irrigation is also presented. It is shown that the actual distribution can be determined from limited field data. The model can be applied to both level and sloped basins. Comparison with other more complicated models shows satisfactory agreement in the distributions.

A complete infiltrated water distribution under basin irrigation can be approximated from limited field observations. Field procedures are described that will provide the parameters required to determine the distributions. However, as only two of the possible four parameters are sufficient to define each distribution, the selection of these parameters should be made on the basis of circumstances under which the field observations were made. General guidelines are given for the selection of the most reliable parameters. The main advantage of the method is its simplicity in both the field measurements required and in the data analysis. The procedure suggested is suitable for most practical cases, especially as a preliminary evaluation procedure when detailed studies are not warranted.

c. Evaluation and Improvement of Border Irrigation, by Gideon Peri, Donald I. Norum and Gaylord V. Skogerboe. Water Management Technical Report No. 49C.

Abstract

The evalua· ·n of border irrigation requires the use of a model that rel· · the operating conditions to the irrigation results, such as: (a) total water quantity delivered to the border; (b) water losses outside the border by runoff; (c) average depth of application; and (d) water distribution within the border. Evaluation for improving border irrigation can be carried out in two major ways: (a) field tests; and (b) theoretical models.

The improvement of border irrigation based on field tests requires the estimation of the infiltration equation and the advance and recession for a specific inlet stream and border parameters (slope, length, surface). The performance parameters can then be calculated to determine the irrigation performance and the need for improvements. Then, the operating conditions that are to be changed can be determined. This analysis comprises two stages: (a) utilization of the field test data already available; and (b) implementation of the recommended changes for further field tests.

Theoretical models for the evaluation and improvement of border irrigation performance enable one to predict the water distribution and losses for a given set of conditions, without direct field measurements. Only limited amounts of preliminary field work are required to predict the irrigation performance for a wide range of parameters and variables. Availa·le models are described, as well as the process for apply· ·hese models.

d. Factors Affecting Losses from Indus Basin Irrigation Channels, by Thomas J. Trout. Water Management Technical Report No. 50.

Abstract

Tertiary irrigation conveyance systems (watercourses) in the Indus Basin lose 30 to 50 percent of their flow. Watercourse systems were studied in depth by ponding and inflow-outflow methods to determine functional relationships between several measurable parameters and the loss rates. The objective was to determine simple design changes that are low cost and can lead to increased conveyance efficiencies in the earthen channels.

Statistical analysis of the collected data indicated that:

1. watercourse loss rates (lps/100m) increase with, but slightly less than proportional to, the usual flow rate in the channel;
2. loss rates are lower in more often used channels;
3. loss rates are higher in elevated channels;
4. loss rates are very sensitive to changes in flow depths, and thus increase with upward fluctuations in flow rates or roughness coefficients; and
5. intake rates into upper bank soils are very high and are apparently caused by extensive rodent and insect burrows inside the banks.

A watercourse loss model was constructed based on the derived relationships, and was applied to several practical watercourse design alternatives.

e. Farm Water Management in Upland Areas of Baluchistan, by W. D. Kemper, Mazher-ul-Haq and Ahmad Saeed. Water Management Technical Report No. 51.

Abstract

Water losses during delivery from source to the field averaged 24%, which is about half as much loss as in the Punjab. Reduced delivery loss was caused by watercourses being shorter (averaging about 3000 ft. from source to field) and having operating water surface levels that are commonly lower than the surface of adjacent lands. Higher cost of water (ranging from Rs.75 to Rs.1200 per acre-foot depending on the area and crops grown) also causes most of the farmers to take better care of their water.

Value of water also varied with the season, ranging from zero during January and February when some farmers allow karez water to run to the rivers to over Rs.1000/acre-foot in the months of May through August when some of these same

farmers are buying water from well owners at a cost of over Rs.1000/acre-foot.

There is a need for storage to save this water from seasons when its value is low to seasons when its value is high. Surface storage such as was built for Zandra Karez behind Sharon bund is considered by the farmers as highly beneficial.

Underground storage and a solution to the high costs of karez maintenance by installing a valved concrete pipe, perforated and gravel-packed in the intake portions of the karez, appears to be a promising possibility that should be investigated with farmers who see the need.

Overirrigation occurs in the average fields by almost 100%. In karez areas this is caused by lack of farmer control of the rate of delivery water. He wastes the water by over-irrigation rather than letting it go to more obvious waste. Well owners waste water because (1) they do not know how much is enough, (2) electric powered wells are on fixed rates per month and the well owners see the extra water as having zero cost.

Water management problems of these farmers are many, varied and worth solving. A diagnostic approach is suggested with technicians trained to work with farmers and groups of farmers to identify and develop solutions to their problems. This would require a more flexible development program than the Punjab On-Farm Water Management Program. Decisions as to which improvements will be implemented should be based on economic analyses, with improvements initiated only when anticipated benefits exceed costs.

Substantial farmers' inputs should be obtained on all improvements to assure their feeling of responsibility and build their pride of ownership and accomplishment.

Assisting karez shareholders to buy pumpsets for wells to complement their karez water during prolonged drought periods, or as the water table is lowered by surrounding wells should be considered, along with immediate implementation of the May 1978 groundwater ordinance, to protect the rights of groundwater users and prevent economic losses and social disruption that will result from resource dislocation and groundwater depletion.

The volume of runoff water is estimated to be ten times the volume of water retrievable from the ground per year. Farmers attempt to use this runoff water with sailaba type cultivation which involves holding flood waters with bunds until they have entered the soil. Over 90% of the bunds observed were breached due to lack of engineering and provision for overflow. Water trapped in the remaining bunds is not used effectively because the land is not leveled. Bunds are much higher than needed, but are not properly packed. Guidelines for constructing such systems are needed to help these sailaba bunds return more benefits than their costs. Practical research with farmers is needed to gain information on frequency and intensity of runoff events, effective low cost designs for bunds and overflow structures and on the amounts of water that should be retained and types of crops and cultural practices which will use that water most effectively.

f. Operational Irrigation Evaluation of Pakistan Watercourse Conveyance Systems, by Thomas Trout and S. A. Bowers. Water Management Technical Report No. 52.

Abstract

Five Pakistan watercourse systems, selected from various geographical areas of the Indus Basin, were evaluated during complete irrigation turn rotations while operating normally. This allowed a quantification of the various types of water losses, including transient condition losses such as dead storage, bank wash-outs, outlet leakage, and high initial seepage into dry channel banks.

Flow measurement was made with Cutthroat flumes and water volumes were determined through integration of the flow hydrographs.

Total conveyance losses ranged from 38% to 56% and averaged 45%. Six to 8% of the inflow was consistently lost to transient conditions of which about half was dead storage. Transient losses depended primarily on the length of channel filled and drained.

Steady-state conveyance loss rates were significantly higher in the farmers' branches than in the main channels, and increased rapidly as the flow rates increased.

Seepage rates into watercourse banks were much higher than intake rates into the surrounding fields on three watercourses, indicating a potential for conveyance loss reduction utilizing only improved earthen channels.

Application efficiencies, monitored on three of the studied watercourse command areas varied widely, and averaged 63%. Farmer water application did not correlate with measured antecedent soil moisture deficiencies.

g. Irrigation and Honor: Cultural Impediments to the Improvement of Local Level Water Management in Punjab, Pakistan, by Douglas J. Merrey. Water Management Technical Report No. 53.

Abstract

Inadequate organization of irrigation water users is now recognized as the major constraint to improving on-farm water management in Pakistan. Previous studies carried out by Colorado State University and Pakistani sociologists have identified characteristics of local social organization that either inhibit or facilitate the introduction of programs for watercourse reconstruction and maintenance. This report, based on a detailed study of one village, including observations of a watercourse reconstruction project, supplements previous studies by describing a major theme in Punjabi culture, the concept of izzat ("honor", "reputation"). Much of Punjabi 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.

h. Constraints on Small Farmers in the Precision Land Leveling Program in the Pakistani Punjab, by Raymond Z. H. Renfro, assisted by Muhammad Iqbal Ikhtar Niazi and Abdul Ghaffar. Water Management Technical Report No. 54.

One of the major objectives of the on-going Precision Land Leveling Program, under the direction of the On-Farm Water Management Pilot Project, is to level small farmer holdings. Based upon an intense cross-sectional survey of 120 farmers in Punjab, this report demonstrates that the Precision Land Leveling Program has been largely unsuccessful in achieving this objective since its inception in 1976. The sampling was conducted in six major areas of on-farm water management activity in precision land leveling and watercourse improvement. Sixty (one-half) of the farmers sampled had had precision land leveling work done on their land and received a government subsidy in the process. The remaining 60 represented farmers who were aware of the program but chose not to participate. This report analyzes the degree to which "small" farmers participated in the program, and identifies and evaluates the main constraints on small farmer participation. The major benefits and costs of land leveling (both primary and secondary, direct and indirect, pecuniary and nonpecuniary) are identified and evaluated, although no attempt was made to put a monetary value on the benefits. It is demonstrated that there are major distinctions between the group of farmers who participated in the program and the group who was aware of the program but did not participate, with respect to farm size (ownership versus operational sizes), education level, degree of status and power in the village, degree of cash farming and market orientation, type of watercourse, land fragmentation, tractor and tubewell ownership, and way of hearing about the program. Finally, the report makes several recommendations for improving the Precision Land Leveling Program, including methods to incorporate small farmers more extensively.

i. Organizational Problems and Their Consequences on Improved Watercourses in Punjab, by Ashfaq Hussain Mirza and Douglas James Merrey. Water Management Technical Report No. 55.

Based on an intensive survey of ten improved watercourses in Punjab, this study shows the inadequacy of present forms of social organization of watercourses for insuring their adequate maintenance. Using as the major criterion the quality of maintenance of improved watercourses, the study suggests the following sociological characteristics as conducive to good maintenance under present conditions: a large percentage of landholdings in the 6.5 to 25 acre range; relatively equal distribution of power and influence among farmers on the watercourse; a large percentage of farmers being perceived as having some power and influence; relative "progressiveness" as measured by institutional services available in the community, educational level of the farmers, and percentage of farmers who listen to the radio regularly; previous history of cooperation and lack of recent conflict; single-biraderi social structure; and a small number of watercourse shareholders. Based on this research, the study makes concrete recommendations for improving the present On-Farm Water Management Pilot Project (including selection of watercourses), and presents a detailed proposal for setting up experimental Water Users Associations and monitoring their progress.

j. Watercourse Improvement Research in Pakistan, by W. Doral Kemper, Wayne Clyma, Gaylord V. Skogerboe and Thomas J. Trout. Water Management Technical Report No. 56.

This research program was funded by USAID, organized by CSU and set out to identify good investments for developing countries in water management. Loss of almost half of the water from watercourses was identified as a primary waste of irrigation water which is a limiting factor in crop production in Pakistan. Physical causes of the loss were identified as high porosity of upper portions of the banks due to burrowing activities of rodents, insects and worms, thin fragile banks near junctions due to borrowing of soil for weekly construction of dams, and rising levels of water in the watercourse due to vegetative growth and sedimentation.

Difficulty in organizing farmers to accomplish regular cleaning and repair was identified as an underlying sociologic cause of the loss.

Experimental masonry and concrete watercourses were built by the government and given to the farmers. They were too expensive and required too much cement to provide a nationwide solution. Moreover, farmers did not appreciate and maintain them because they had no investment therein. Other lined watercourses on which the government paid for materials and the farmers provided labor were better appreciated and maintained, but took longer to build and still required large amounts of cement and were too costly for a national program. Cooperative improvement of the earthen channels by the farmers with the government providing the materials and design for concrete control structures at the junctions was developed as a program which had a benefit:cost ratio of at least 3 to 1 and was eagerly accepted by the farmers in a study which involved a series of case histories. Host government and USAID officials were invited to inspect these field studies and consult with participant farmers. They were sufficiently impressed with the product, the farmers' enthusiasm and the data on costs and benefits, that they asked the CSU team and their host country cooperators to assist in development of a national water management improvement program. This type of watercourse improvement became the primary component which "sold" the program and brought benefits to small as well as large farmers.

Subsequent studies indicated that a good and regular cleaning and repair program would save almost as much water and provide higher benefits with much lower government input. However, the watercourse improvement program with its concrete control structures was more eagerly accepted by the farmers.

Full benefits of the improvement program were obtained only by farmer groups who organized themselves to clean and maintain their watercourses regularly. To motivate and facilitate such organization, a well designed education program is needed which would clearly demonstrate and emphasize cause and effect relations between cleaning and repair and reduced losses. Enabling laws are needed to provide authority to elect local leaders to organize the farmers for this purpose and penalize "freeloaders" who do not do their share of the work.

The "research" involved was pragmatic, achieved its purpose, and was highly satisfying to the participants.

k. Optimization of Lengths of Alternative Watercourse Improvement Programs, by John O. Reuss. Water Management Technical Report No. 57.

Abstract

This report is an attempt to establish a sound theoretical basis and develop computational methods for choosing between alternative methods of construction or improvement of watercourse systems that operate on a rotational or turn basis. These methods were developed for use in Pakistan where

losses from some 80,000 watercourses serving over 30 million acres of land have been identified as a major problem. The factors considered in the analysis as controlling the selection of methods includes: annual cost per unit length, the expected water loss associated with each method, and the value of water.

In water distribution systems operating on a rotation basis, various reaches often have vastly different use times, with utilization generally declining from head to tail. These differences in utilization markedly affect the benefits derived from lining or other improvements on any particular section, but have little or no effect on cost of construction. Major conclusions include: first, that net benefits are generally maximized when different methods, such as lining and earthen improvements, are applied to various sections depending on use time. Computational methods are developed for determining the optimum points for changing methods. Secondly, the major beneficiaries to improvement of high use sections are the downstream users that may be located on reaches where high cost improvements may not be economically feasible. Methods for quantifying benefits to improvement accruing to users throughout the system are also given.

l. Watercourse Improvement Manual, by Thomas J. Trout and W. Doral Kemper. Water Management Technical Report No. 58.

Abstract

The purpose of this manual is to assist both national and donor agency planners to determine the need for and carry out a program to improve the tertiary irrigation conveyance systems. Topics covered include evaluating and diagnosing problems in the present channel systems, proposing and testing solutions to the diagnosed problems, combining the solution techniques into improvement strategies, evaluating the improvement strategies and developing the institutions necessary to carry out the improvement programs. The manual deals both with processes, which will be of primary interest to the planners; and techniques, which would be useful to the engineers, economists and sociologists.

m. Field Evaluation of Methods for Measuring Basin Irrigation Performance, by Satyansu S. Kundu and Gaylord V. Skogerboe. Water Management Technical Report No. 59.

Abstract

A detailed description of field procedures employed to obtain necessary data for evaluating basin irrigation performances of several irrigation events is outlined. Two analytical techniques are described and used for calculating infiltrated water depths through station-areas delineated by

a grid system within the basin. Both techniques require an infiltrometer test and infiltration opportunity time of each station-area during an irrigation event.

A modified volume balance technique is described and is used to develop an infiltration equation which should represent the actual infiltration characteristics of the entire basin during an irrigation event. The infiltrated water depth of each station-area is also calculated by using the infiltration equation developed by this method. All three methods are used for measuring basin irrigation performance and their applicability for measuring performance parameters is compared.

n. Training Manual for Agricultural Water Management Specialists, edited by Dwayne G. Westfall. Water Management Technical Report No. 60.

Abstract

This training manual contains the lesson plans and outlines the course of study that the Agricultural Officers, who are members of the On-Farm Water Management Development Project in Pakistan, complete before being assigned to a field team. Although the title Agricultural Officer is used in Pakistan, a more descriptive title is Water Management Extension Specialist. The major objectives of the course are to: (1) develop confidence in the participant's ability to communicate and work with farmers; (2) provide him with the skills necessary to convince the farmers to undertake a watercourse improvement or cleaning and maintenance program and how to supervise these activities; and (3) equip him with the knowledge and skills so he can show farmers how to use their irrigation water more effectively to increase crop production.

This interdisciplinary training program encompasses seven professional areas: Irrigation and Drainage; Agricultural Extension; Agronomy; Soil Science; Farm Power and Machinery; Farm Management; and Rural Sociology. The team of trainers that conduct this course must work closely together because coordinated training is a major component of this course. The lesson plans are developed to be used with an audience that has a B.S. degree or higher. Depending upon the logistical support, from 15 to 25 students can be handled effectively. The course is 103 days in length, of which 71 days are spent in the field where the trainee learns by doing.

o. Analysis of Basin-Furrow Irrigation, by Gideon Peri and Gaylord V. Skogerboe. Water Management Technical Report No. 61.

Abstract

A comprehensive definition and description of basin irrigation was presented in Water Management Technical Report 49B. A procedure was outlined for the design and evaluation

of basin irrigation systems, showing the interactions between the various basin characteristics, the operational parameters, the management parameters, and the performance parameters. A general model was presented that considered infiltration, advance and recession. A simplified model utilized the infiltrated water distribution under basin irrigation.

This report focuses upon the use of furrows in bunded basins, which has both agronomic and engineering advantages. Comparisons between the performance of basin irrigation and basin-furrow irrigation are made. The physical situations analyzed include: nonuniform water advancement due to slope across the width of the basin; delay in water advance time due to nonuniform longitudinal slope; excess ponding and water application depth due to high ground surface spots within a basin; and ground surface irregularities.

p. Matching Cropping Systems to Water Supply Using an Integrative Model, by John O. Reuss. Water Management Technical Report No. 62.

Abstract

This paper describes the process of matching cropping systems to available irrigation water supply.

The Penman and the Jensen-Haise methods for calculation of potential evapotranspiration (E_{tp}) from climatic parameters are presented, along with methods for calculating crop water requirements once E_{tp} is known. The principles of determining irrigation water requirements of single crops and of combinations of crops are given. Examples given are from Pakistan. Due to the complexity of the process a simulation model was developed to match cropping systems to water supply. Model structure is described and examples are shown for both single and multiple cropping systems. Details of the methods of calculation along with program documentation and listings are appended.

The use of the linear programming (L.P.) technique for optimizing cropping mixes within fixed water supply constraints is also presented, again using an example from Pakistan. The two methods are shown to be complementary, with the simulation model providing essential input information for the L.P. optimization.

q. Summary of Skimming Well Investigations, by David B. McWhorter. Water Management Technical Report No. 63.

Abstract

This report summarizes the theoretical, laboratory and field research conducted as part of the Water Management Research Project at Colorado State University. The research

was specifically oriented toward Pakistan problems but much of the material is more generally applicable. Salt water upconing in isotropic and anisotropic aquifers beneath wells was examined using both laboratory and numerical models, and guidelines for the construction and operation of wells to minimize contamination by upconing are provided. A method for determining the maximum safe depth of drains below the water table is also provided.

r. Development and Design of Watercourse Junction Jet Pumps, by Thomas Trout, W. Doral Kemper and Rick Aust. Water Management Technical Report No. 64.

Abstract

Many Pakistan watercourses have insufficient slope to irrigate the higher fields without submerging the canal turnout and thus decreasing the canal water inflow. This problem is especially acute where SCARP tubewells supplement the water supply. Recognizing that the SCARP tubewells discharge 1 to 2 meters above the watercourse, a device was developed based on the turbulent mixing kinetic energy transfer of jet pumps to utilize the excess head of the tubewell water to raise the level of the canal water by 20 to 30 cm. The Jet Juncture Manual describes the development process and recommended low cost designs for these watercourse structures.

s. Development Process for Improving Irrigation Water Management on Farms

Executive Summary, by Gaylord V. Skogerboe, Max K. Lowdermilk, Edward G. Sparling and Jacob E. Hautaluoma. Water Management Technical Report No. 65A.

Abstract

The Executive Summary is a synopsis of the three-phase development process for improving irrigation water management on farms. Each phase of this development process is detailed in a separate manual: (1) Problem Identification Manual, Water Management Technical Report No. 65B; (2) Development of Solutions Manual, Water Management Technical Report No. 65C; and (3) Project Implementation Manual, Water Management Technical Report No. 65D.

t. Problem Identification Manual, by Max K. Lowdermilk, William T. Franklin, James J. Layton, George E. Radosevich, Gaylord V. Skogerboe, Edward W. Sparling and William G. Stewart. Water Management Technical Report 65B.

Abstract

Problem Identification is the first of three phases in the development process, with the other phases being the Development of Solutions and Project Implementation. The Problem Identification phase consists of two subphases; namely, Reconnaissance and Problem Diagnosis. The Reconnaissance subphase consists of: setting preliminary program objectives; developing a general overview of the irrigation system; conducting reconnaissance field investigations of the plant environment, farm management practices, water supply and removal, and institutional linkages; prepare a preliminary listing of problems; and refine the program objectives. The Problem Diagnosis subphase consists of: designing diagnostic studies; conducting diagnostic field studies; analyzing and interpreting the findings; identifying criteria for the selection and ranking of problems according to program objectives; and reporting findings of priority problems and their apparent causes.

u. Development of Solutions Manual, by Edward W. Sparling, W. Doral Kemper, Jacob E. Hautaluoma, Max K. Lowdermilk, Gaylord V. Skogerboe, William G. Stewart. Water Management Technical Report 65C.

Abstract

The Development of Solutions phase is the second of three phases in the development process for improving irrigation water management on farms. The first phase is Problem Identification and the final phase is Project Implementation. The Development of Solutions consists of three subphases: identification of plausible solutions; testing and adaption of solutions; and assessment of solution packages. The Identification of Plausible Solutions subphase consists of: generating potential solutions to priority problems; screening of potential solutions and discarding implausible solutions; and ranking of plausible solutions. The Testing and Adaption of Solutions subphase consists of: development of a work plan; performing tests; conducting demonstrations and field days; obtaining feedback from clients and refining solutions by phasing the withdrawal of team resources. The Assessment of Solutions Packages subphase consists of: assessing solutions according to program objectives; determining which solutions are acceptable; synthesis of acceptable solutions into alternative solution packages; and reporting of alternative solution packages.

v. Project Implementation Manual, by Jacob E. Hautaluoma, David M. Freeman, W. Doral Kemper, James J. Layton, Max K. Lowdermilk, George E. Radosevich, Gaylord V. Skogerboe, Edward W. Sparling and William G. Stewart. Water Management Technical Report 65D.

Abstract

The third and final phase of the development process for improving irrigation water management on farms is called Project Implementation. This final phase consists of three subphases: (a) Project A thorization; (b) Project Organization; and (c) Project Operation. This manual describes the process of selecting which of several solutions will be developed into a proposal for funding. The basic points about writing and negotiating a proposal are discussed. After authorization of the project, the next steps are designing the project's organization, and selecting and training the field staff. The benefits and means of achieving teamwork are emphasized. The project manager must prepare to accomplish the project's goals, and to establish linkages with organizations that will be affected by the project. This manual stresses the necessity of setting goals, and correcting the progress of the project through monitoring, evaluation, and refinement. To ensure that the improved on-farm practices will persist after the project finishes, the institutionalization of the project into the normal activities of the farmers' organization and the government extension service is discussed.

w. Improving Irrigation Water Management on Farms, Final Report, by Gaylord V. Skogerboe, John O. Reuss and W. Doral Kemper. Water Management Technical Report 66.

Abstract

This final report includes a summary of accomplishments, dissemination and utilization of research results, and lessons learned from the inception of the project on March 28, 1968 to its termination on May 31, 1980. The U.S. AID Evaluation of the CSU Water Management Research Project is discussed, along with the "Development Process for Improving Irrigation Water Management on Farms."

2. Theses

a. Infiltration as Affected by Compaction of Soil and the Pressure and Water Content at the Time of Compaction, by Mohammad Akram. M.S. thesis, Summer, 1979.

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 textered soils, reduced infiltration rates to less than 0.1 percent 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 percent.

The low infiltration rates following compaction were increased by wetting and drying although several cycles of setting 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.

b. Training for and Analysis of Essential and Comprehensive Water Management, by Muhammad Mohsin Wahla. M.S. thesis, Spring, 1980.

Abstract

The objective of this research project was to determine if properly trained and supervised para-professionals (field assistants) could conduct a watercourse improvement program using semitechnical techniques. Training materials were developed with special focus on simplified essential

skills. Four field assistants were trained in these skills, of which three supervised the improvement of watercourses. Their job pe formance was evaluated on the basis of a watercourse design using highly technical engineering skills and engineering specifications.

Field assistants performed the essential improvement program and helped the Pakistani farmers to increase their irrigation water delivery efficiencies on three watercourses. They organized the farmers and trained and motivated the watercourse executive committee (WCEC) in watercourse improvement. The elected WCEC motivated the farmers to perform the improvement program.

The benefits achieved through the essential improvement program were variable. The average increase in delivery efficiency on one watercourse was slightly better than those reported by the On-Farm Water Management Development Pilot Project while the other two were 42% and 50% of these values. The cost per meter of improved watercourse under the essential improvement program is similar to the cost per meter improved under the comprehensive improvement program.

In order to reap the total benefit of increased water supply through watercourse improvement, the field assistants need to be trained in other aspects of crop and water management. Only after total crop production from an improved watercourse is increased will the ultimate benefit of watercourse improvement be realized.

This simplified technique of watercourse improvement looks very promising. Further investigations need to be made before a final evaluation of its applicability can be made. When one considers the limited availability of highly trained college graduate engineers and others, this program using para-professionals becomes very attractive.

c. Soil Compaction and Water Content Effects on Cotton Seed Germination and Emergence, by Zahid Saeed Khan. M.S. thesis, Spring, 1980.

Abstract

In an effort to find practical solutions to the problems of stand establishment of cotton, this research was initiated to determine: 1) the effect of initial water content on germination and emergence of cotton; 2) the effect of compaction applied to the soil on water movement and uptake; and 3) the effect of compaction of the soil on germination and emergence of cotton.

Higher initial soil moisture was found to improve early germination of cotton. To lower soil water content from 25 percent to 12 percent delayed germination by about

one day. Soil down to a depth of 20 cm contributes water which helps seeds planted 3 cm below the surface remain moist long enough to germinate when evaporation is taking place from the soil surface. Emergence rates and final seedling stands were greatly affected by high daily soil temperature. Practically no seedling emergence occurred under these high temperature conditions, when seeds were planted at 0.7 to 0.8 times field capacity, and maximum daily temperatures were 45°C. The highest rate of germination and emergence appeared to occur when the compacting force was between 125 and 250 grams per square centimeter. Compaction of soil immediately below the seeds caused higher water contents and conductivity of the resulting dense layer.

Compacting the soil above the seed layer increased the rate of water absorption by the seeds when evaporation was prevented. However, when evaporation was allowed, germination and emergence decreased in the compacted soils indicating that greater conductivity of the compacted soil above the seed was allowing more rapid increase of soil water stress in the seed zone.

Germination and emergence of seeds planted at 0.8 to 0.9 times field capacity ranged from 65 to 70 percent, depending to a large extent on how the soil below and above the seed zone was treated. Germination and emergence are increased by: increasing the initial water content of the soil (up to field capacity), compacting the soil beneath the seed and pressing the seed into the compacted soil with pressure of about 125 grams per square centimeter, and leaving the soil above the seeds loose.

d. Optimal Watercourse Improvement in the Pakistan Punjab: A Mixed Integer Programming Model, by Barkat Ali. M.S. thesis, Spring, 1980.

Abstract

Linear and mixed integer programming are used to analyze the choice of techniques for reducing conveyance losses in watercourse channels in the Pakistan Punjab. It appears that at present costs even partial lining of watercourses is not profitable as long as earthen improvements are an alternative. Sensitivity analysis shows that if costs of lining are reduced by just 10 percent, the lining of upper reaches does become profitable. It argued that priority should be given to lowering the cost of lining because lining of upper reaches will have benefits over and above those measured in this study. In particular, such lining is beneficial to those on upper reaches because it reduces local waterlogging which damages crops adjacent to the upper reaches. This is important because otherwise farmers on upper reaches receive little additional water as a result of watercourse improvement, making them reluctant to cooperate in maintenance

of improvement of the watercourse. Furthermore, lining upper reaches reduces the size of the groups which need to organize for improvement and maintenance of lower reaches.

e. Irrigation-Nitrogen Management Studies on Sorghum, Corn and Wheat, by Khalid H. Gill. Ph.D. dissertation, Spring, 1980.

Abstract

Three research projects were conducted involving irrigation water and nitrogen fertilizer. One greenhouse experiment was conducted at Colorado State University, Fort Collins, Colorado (USA), and one corn and one wheat field experiment at the Punjab Agricultural Research Institute (PARI), Faisalabad (Pakistan). The ultimate goal was to investigate the irrigation-nitrogen interaction as it influences crop yields.

In the greenhouse experiment when soils were subjected to different wetting and drying cycles or incubated at field capacity moisture or under continuous flooding, sorghum dry matter yield and tissue nitrogen concentration were significantly affected. Incubation at field capacity and continuous flooding produced the maximum yields. The nitrogen concentration was maximum under continuous flooding treatment. The dry matter yield, total nitrogen concentration and uptake were lower under alternate wet and dry conditions and where the crop residue was added.

The irrigation-nitrogen study on corn revealed that weekly irrigations produced better yields as compared to biweekly irrigations or irrigations applied according to the consumptive use as calculated by the Jensen-Haise equation. A historical weather data base from 1976 was used to determine consumptive use for 1977. Appropriate corrections in the evapotranspiration for the growing season were not made and a moisture stress occurred which resulted in the lowest yield under consumptive use. Maximum yields were obtained at 165 kg N/ha under weekly irrigations. Analysis of the soil profile nitrate-nitrogen at harvest revealed that there was more nitrate present in the surface layers under the consumptive irrigation treatment as compared to the weekly or biweekly irrigations. When flood and furrow methods of irrigation were compared, no significant differences in yield were obtained.

In the irrigation-nitrogen study on wheat, irrigations scheduled according to consumptive use calculations produced maximum yields. Regression analysis using yield models made it evident that the peak yields were obtained by applying 120 kg N/ha and 40 cm of water. The maximum net return was also associated with this combination of nitrogen and water. Under the higher irrigation levels, nitrate accumulation occurred in the lower profile while the reciprocal was found true for lower irrigation intensities.

f. Irrigation and Nitrogen Management in Paddy Rice, by Muhammad Hanif. Ph.D. thesis, Summer, 1980.

Abstract

Studies were conducted in the laboratory to investigate the kinetics of various processes involved in the loss of nitrogen. In addition, three crops of Starbonnet rice were grown in the greenhouse during 1978-1979 to study the effect of various irrigation and nitrogen management practices on yield of rice and on the extent of nitrogen loss in paddy soils. Under alternate flooding and drying, the oxidation of NH_4^+ to NO_3^- during drying and subsequent reduction of NO_3^- during flooding provide conditions conducive to repeated loss of N. In continuously flooded soils, the presence of oxidized and reduced layers lead to simultaneous nitrification-denitrification processes. It was observed that the thickness of the oxidized layer in flooded cropped soils was confined to the surface in contrast to the classical concept of 1 to 2 cm thickness.

The recovery of fertilizer N ranged from 12 to 78 percent. Alternate flooding and drying resulted in a recovery of 12 to 28 percent while continuous flooding resulted in N recoveries ranging from 56 to 78 percent. The gaseous loss of applied N ranged from 21 to 84 percent. The highest loss of 111 ug N/g soil was observed when nitrogen was broadcast in alternately flooded and dried soils. The loss of applied N was 25 to 50 percent lower under continuous flooding or similar irrigation treatments involving a 15-day dry spell around flowering than under alternate flooding and drying.

Alternate flooding and drying resulted in the lowest yield of total dry matter. Under continuous flooding or similar irrigations, the yield of total dry matter was 22 to 46 percent higher than under alternate flooding and drying in crops 1 and 2. In crop 3 this amounted to 131 to 157 percent. The difference in crop 3 arose from the intensity of moisture stress applied under alternate flooding and drying. The large gaseous loss of nitrogen under alternate flooding and drying depleted the soil of available N, restricting the yield of total dry matter below the potential production.

The pH of the water and soil profile ranged from 7.6 in the flood water to 6.6 at a depth of 25 cm below the soil surface at the end of the experiment. The pe + pH value ranged from 15.4 to 3.1 across the same profile. Nitrogen mineralization under flooded conditions amounted to 4 percent of the total soil nitrogen or 26 ppm per one percent organic matter.

3. Journal Articles

a. Procedure for Evaluation and Improvement of Irrigation systems, by Gideon Peri, Gaylord V. Skogerboe and David Karmeli. Presented at the 1979 summer meetings of ASAE and CSAE, June, 1979. ASAE Technical Paper No. 79-2089.

Abstract

Poor water delivery and application efficiencies (ICID, 1978) may lead to some unfavorable effects resulting in lower yield per unit of area and per unit of water, less total area irrigated, and detrimental environmental effects, as well as lower returns from the irrigated crops. The need for the improvement of irrigation systems has been well established. The introduction of new technologies has been accelerated due to requirements for higher yields, as well as the need for reducing water applications and energy consumption. The evaluation of presently operating irrigation systems is conducted for the purpose of decision-making in relation to the level of required system improvement.

A comprehensive procedure for the evaluation and improvement of irrigation systems is suggested. The procedure is based on the analysis of the performance of the system for an individual application, along with the irrigation management regime (intervals and depths of application), resulting in an analysis for the whole irrigation season.

b. Operational Evaluation of Village Level Irrigation Conveyance Systems, by Thomas J. Trout and S. A. Bowers. Presented at the 1979 winter meeting of ASAE, December, 1979. ASAE Technical Paper No. 79-2567.

Abstract

The primary methods used to measure irrigation canal conveyance losses are inflow-outflow, ponding, and with seepage meters. All three of these methods measure what is often termed "seepage" losses, or the infiltration of water into the canal wetted perimeter when the system is operating under steady state conditions.

In most canal systems the large majority of the total conveyance loss is steady state seepage. However, in small intermittently used irrigation channels (laterals, ditches, watercourses), there can be a significant transient loss component that is not measured in steady state measurements.

In this study of five village level watercourse systems in Pakistan, total operational conveyance losses, including transient losses, were measured using an adaptation

of the inflow-outflow method. The objectives were to determine the extent of the transient losses and to quantify the types of watercourse losses so that techniques to increase conveyance efficiencies could be evaluated.

c. Consequences of and Farmers' Reactions to Indus Basin Water Management Constraints, by Alan C. Early, David M. Freeman and Max K. Lowdermilk. Presented at the 1979 summer meetings of ASAE and CSAE, June, 1979. ASAE Technical Paper No. 79-5054.

Abstract

The Indus Basin Irrigation System of Pakistan represents one of the great agricultural resources of the world. The integrated system serves more than 12 million hectares and has fertile alluvial soils, a climate favorable to year-round cropping and a large farm population capable of intensive cultivation. With these potentially productive resources in place, the system however has many constraints that prevent the potential from being achieved. Despite the irrigation infrastructure, a maldistribution of supply exists: some areas have water deficiencies, others nearby have large water excesses and large areas of the system remain without water for up to half of the year as nonperennial command areas. In the past 15 to 18 years the farmers of Pakistan have recognized the value of water and have installed approximately 120,000 private, small discharge tubewells with capacity of 10 to 30 liters per second. During this same period the government has undertaken the Salinity Control and Reclamation Projects (SCARP) with the intention of lowering the water table with a large number of large tubewells widely spaced across the pilot areas. The public tubewells number appropriately 8000 currently in operation and have capacities that range from 90 to 140 liters per second serving as an important secondary water source. The emphasis in these developments along with the later stages of the Indus Basin Replacement Project have been the augmentation of supply or the development of new supplies.

The research undertaken by the Colorado State University Field Team in Pakistan has attempted to look at the water use end of the system rather than the water source. This water use subsystem is the on-farm component of water management and assumes the primary and secondary subsystems at the given level of management. The hypothesis behind this approach is that the current water supply could be used more efficiently at the tertiary level of the system where the effect of a new water supply could have the greatest impact on food and fiber production. The village social setting, the interrelations between farmers and the institutional services that they receive from the government agencies provide the background for production that determines the acceptance of new technology and the speed with which it is delivered to the end user.

d. Irrigation Scheduling in Punjab of Pakistan, by Mushtaq A. Gill and Alan C. Early. Presented at the 1979 summer meeting of ASAE and CSAE, June, 1979. ASAE Technical Paper No. 79-5052.

Abstract

A farm water management research project was conducted to determine practical irrigation scheduling techniques, demonstrate the potential for water scheduling for cool season and hot season crops and to evaluate the potential for improving on-farm irrigation application efficiency through closely controlled irrigation. The Class A evaporation pan with locally verified crop coefficients is recommended for practical irrigation scheduling in Pakistan.

Practical irrigation schedules on leveled land for wheat saved up to 10 centimeters of water, improved irrigation application efficiency by more than 20% and resulted in increased crop yields by 0.88 ton/hectare. For maize fodder up to 10 centimeters of water was saved, irrigation application efficiency improved by up to 38% and the increased crop yield was 24 tons of forage per hectare.

e. Development of Improved Water Management Practices in Pakistan, by Gaylord V. Skogerboe, W. Doral Kemper and John O. Reuss. Submitted for publication to the International Journal of Water Supply and Management.

Abstract

Efforts have been underway since 1970 to develop improved techniques for rehabilitating watercourses, precision land leveling, and improved agronomic and irrigation practices on farmers' fields in Pakistan. Since 1976, an On-Farm Water Management Pilot Project has been underway wherein these technologies will be applied on 1500 watercourses. The long-term effectiveness of these technologies will be largely dictated by the ability of farmers on each watercourse to work together cooperatively for their common good, which will require a formalized water users association on each watercourse.

f. Watercourse Improvement Strategies for Pakistan, by John O. Reuss, Gaylord V. Skogerboe and Douglas J. Merrey. Submitted for publication to the International Journal of Water Supply and Management.

Abstract

After discussing the magnitude of watercourse losses in Pakistan, the first section of this paper discusses and compares the costs and potential benefits of three basic

strategies for watercourse improvement. The second section discusses various possible institutional arrangements for water management programs. The final section presents a number of recommendations concerning watercourse improvement strategies and institutional development.

4. Brochure

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

APPENDIX 1

A METHOD FOR ACID DELINTING COTTONSEED[1]

L. Nelson[2]

Cottonseed is often delinted before planting to improve overall seed quality and to facilitate passage through a planter box. Cottonseed may be delinted mechanically with delinting saw gins or by treatment with concentrated sulfuric or hydrochloric acids. At this time, the Agricultural Development and Supply Corporation in Pakistan does not have the facilities for delinting cottonseed. Thus, agronomists and farmers who plan to sow cottonseed with mechanical planters must be capable of delinting their own seed.

The acid delinting method described below was used to delint over 100 kg of cottonseed for field experiments conducted on Mr. Raja Aslam's farm near the Mona Reclamation Experimental Project (MREP). Cottonseed delinted by this method were virually free of lint, while boll worms infesting the seed lot were killed by the acid. In addition, acid delinting of the cottonseed facilitated the removal of immature and broken seed and chaff. The percent germination of cottonseed used in the field studies at Mr. Raja Aslam's farm was improved from 45% for lint seed to 70% for cleaned acid delinted seed.

Materials

Cottonseed - 15 to 20% more than is desired for planting
Plastic sieve or woven basket
Measuring glass - either glass or plastic
Plastic tub - should be large enough to mix 5 kg (5 seers) of cottonseed without spillage
Concentrated sulfuric acid - 1 kg acid for each 5 kg of cottonseed
One pair of rubber gloves - the heavy duty type used in industrial work
Safety goggles
Blue litmus paper - optimal
Matting or cement slab for drying seed

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[1]Modified from a method of acid delinting cottonseed reported by Danishmand and Company, Karkhawa Bazar, Lyallpur.

[2]Graduate Research Assistant, Department of Agronomy, Colorado State University, Fort Collins, CO.

Procedure

All of the materials listed above are available in the larger communities of Pakistan. Use extreme caution when handling commercial sulfuric acid. Avoid contact of the acid with exposed skin. If the user inadvertantly comes in contact with acid, he should immediately wash the acid off with water. If burning persists, a doctor should be consulted at once. It is advisable to wear protective goggles and old clothing when acid delinting seed as the acid is highly reactive with any material other than glass and plastic. Finally, demonstrate the danger involved with handling acid to the non-informed person. Simply pour a small amount of the acid into a glass or a plastic container. Have the person drop a small piece of cloth, metal or plant material into the container. The rate at which these materials are consumed will convince him of the dangers involved with handling the acid.

All of the materials listed above should be assembled near a source of clear running water. The ratio of acid to seed used for delinting is approximately 1:10, but this ratio may vary according to the lint content of the seed. Place 5 kg (5 seers) of cottonseed in the plastic tub. Put the rubber gloves on and carefully measure 1/2 kg (1/2 seer) of acid in the measuring glass. Slowly pour the measured quantity of acid over the cottonseed. Vigorously mix and rub the acid into the seed for 3-4 minutes. The seed will begin to turn a dark color and become quite warm as the acid reacts with the organic components of the lint and seed coat. Between the 3rd and 4th minute, the cottonseed will exhibit a black shiny appearance. Immediately pour clean water over the seed making sure to wash the acid and dissolved lint from the gloves. Pour the contents of the plastic tub into the sieve or woven basket and rinse the seed with clean water for 4 to 5 minutes. It is most important that all of the acid is removed or it will continue to react with the seed coat and eventually damage the embryo. This may be determined by testing the seed for acid content with the tongue or by placing a strip of blue litmus paper on the wet seed. If acid is on the seed, they will taste sour, or the blue litmus paper will turn red. When all acid has been removed, spread the seed on a mat or concrete slab to air dry. Repeat this process until the desired quantity of delinted seed is obtained.

After drying, inspect the seed for broken and unfilled seed. The milling processes used in Pakistan results in a large number of broken seed and detection of unfilled seed is nearly impossible until after acid delinting. The unfilled seed and chaff are easily removed by winnowing.

Immature seed and broken grains, however, may require physical removal. In addition, a germination test should be made to determine the percentage of viable seed.

APPENDIX 2

A FIELD STUDY OF TRADITIONAL AND IMPROVED METHODS OF COTTON CULTURE

Larry Nelson, Abdul Kareem
and C.J. deMooy1/

INTRODUCTION

Cotton, until recently, was the major source of foreign exchange for Pakistan. Average seed cotton yields and acreage planted to cotton have declined sharply since 1972. While the Government's price policies may have been partially responsible for the decline in cotton production, average acreage yields have declined from 1,000 lbs. seed cotton per acre in 1971 to less than 800 lbs. per acre in 1976 (Billy M.Waddle, et al. 1977).

Investigations of cotton production in Pakistan suggested that the problems associated with declining yields have developed from: 1) varietal deterioration, 2) a lack of insect control, 3) poor seed quality, 4) low seeding rates, 5) flooding during the monsoon season, 6) level basin culture and 7) unleveled fields (Billy M. Waddle, et al. 1977).

During the 1976-77 growing season a cooperative cotton production trial was conducted on the farm of Mr. Raja Aslam, Tubewell 62, which is located near the Mona Reclamation Project Colony, Bhalwal, District of Sargodha, Pakistan. The purpose of this field study was to compare the recommended cotton variety AC-134 with a high yielding cotton variety, Delta Pine 25, brought into Pakistan in the mid 60's. In addition, the study was designed to compare raised bed cultivation of AC-134 with the "traditional" basin methods of cotton culture.

METHODS AND MATERIALS

The farm of Mr. Raja M. Aslam, Tubewell 62, was selected as the site for this study. The farm is 187 acres in area, of which 100 acres are cultivated by tenants and 87 acres are cultivated by Mr. Aslam and his brother. Previous experience with Mr. Aslam had shown him to be an ideal cooperator for projects requiring farmer input.

1/Graduate Research Assistant, Department of Agronomy, Colorado State University; JRO, Agricultural Engineering, Mona Reclamation Experimental Project, Pakistan; Professor, Department of Agronomy, Colorado State University, respectively.

An eight and one-half acre field was selected by Mr. Aslam during the early part of February. The field was precision leveled by the Mona reclamation projects personnel during the first week of April.

A completely randomized design consisting of four treatments with four replications, was chosen for the study. The treatment dimensions were 50 feet by 450 feet. The treatments selected for this study were:

A) Delta Pine - 25 grown on ridge furrows with furrow to furrow spacings of 30 in.
B) AC-134 grown on ridge furrows with furrow to furrow spacing of 30 in.
C) AC-134 grown on broadbeds (double-row beds) with furrow to furrow spacing of 60 in.
D) AC-134 grown in basins by the farmers "traditional" methods.

All of the labor and physical inputs used in treatments A, B, and C were provided by the water management project. All of the labor and physical inputs, with the exception of seed, used in treatment D, were provided by Mr. Aslam.

The two varieties of cotton selected for the trial were AC-134 and Delta Pine 25. AC-134 is a synthetic variety of cotton and was recommended for cultivation in the Punjab region of Pakistan by the Agricultural Policy committee. Delta Pine 25 is an American upland cotton variety which has been grown in Pakistan since 1964. Delta Pine 25 is not listed as a recommended variety of cotton by the committee because of the high level of technology and physical inputs required. The seed was acquired through two different sources. Three maunds (247 lbs.) of certified AC-134 cotton seed were purchased from the Agricultural Development and Supply Corporation in Faisalabad. One maund (82.28 lbs.) of Delta Pine 25 cotton seed was purchased from the Punjab Agricultural Research Institute in Multan province. This seed had been purchased by the institute from a farmer in Multan who had been growing Delta Pine 25 for about six years.

Twenty-five seers (50 lbs.) of the AC-134 cotton seed was given to Mr. Aslam for sowing in the basin plots. The remaining AC-134 and Delta Pine 25 cotton seed was acid-delinted according to a method described by Nelson, 1980. The germination of cotton seed was tested prior to and after acid-delinting, by a standard germination test.

On April 12, Mr. Aslam applied a pre-plant (rauni) irrigation to the study area. Nine days later, he considered the field ready for sowing. The cotton seed which he was to plant in the basin plots was soaked overnight and then rolled in a mixture of ashes and cow dung.

The next morning, the study area was worked three times with a tractor-mounted cultivator and planked twice. The boundaries of the basin plots were staked and nitrophos was hand-broadcast at a rate of 46 lbs. of actual N and P_2O_5 per acre. The fertilizer was incorporated with a tractor-mounted cultivator followed by a third planking.

The basin plots were sown by one of Mr. Aslam's tenants with a bullock driven pori hal. A pori hal is a traditional stick plow with a funnel attached to the handle and connected to a 1 inch diameter tube which opens at the heel of the shear. A seeding rate of 8 seers/acre (16 lbs.) was used.

On April 23, urea and single super phosphate were hand-broadcast at a rate of 10 lbs. per acre of N and 60 lbs./acre of P_2O_5 in treatments A, B, and C of th first replication. The ridge furrows and broadbeds were roughly shaped with a set of tractor-mounted listers. A tractor-mounted bedshaper-planter was used to shape the beds and sow the seed. The belt-driven seeder produced a seeding rate of 12 seers per acre (24 lbs/acre) for AC-134 cotton seed and 10 seers per acre (22 lbs/acre) for Delta Pine 25. Ridge-furrow and broadbent treatments in replications II and III were prepared and sown on April 24 and similar treatments in replication IV on April 25.

A pre-emergence irrigation was applied to all broadbed and ridge-furrow treatments in replication I on April 24 and in replications II, III, and IV on April 25. A set of six - 4 inch by 18 inch flumes set at the head of each plot were used to measure the amount of water applied.

A light rain on April 30 produced some soil crusting problems. Four beldars (laborers) from the project were enlisted to break the crust during the next two days. The beldars used kurpas (similar to a hand trawel) to break the crusts.

A side dressing of urea, 50 lbs. per acre of actual N, was broadcast in the furrows of all broadbed and ridge-furrow treatments of replication I and II on June 6 and replications III and IV on June 9. An irrigation was applied immediately after the fertilizer.

Two insecticides, marketed by Ceiba-Geigy, were used to control insect infestations. Nurvacron 40 (0,0-dimethyl-0 (2-methylcarbamoyl-1 methylvinyl) - phosphate), a system insecticide was used to control a relatively broad range of insects throughout the growing season. Nogos 100 EC (0,0 dimethyl-2,2-dichlorovinyl phosphate), a contact-fumigant insecticide, was sprayed in combination with Nurvacron 40, during the flowering and boll formation periods, to improve control of bollworms and sucking insects.

However, after one month of spraying, it was observed that the Nurvacron-40-Nogos 100 EC combination was not controlling bollworms satisfactorily and the Nogos 100 EC was replaced with 25% DDT (dichlorodiphenyl/trichloroethane). The insecticides were sprayed with a Germex 35 cc mist blower purchased through the Punjab Agricultural Department by the Colorado State University Water Management project in Pakistan. A five-gallon compression sprayer marketed by Peco Company in Lahore augmented sprayings with the mist blower. The dates and amounts of insecticide sprayed on each of the treatments are shown in Table 1.

The ridge-furrow and broadbed treatments were weeded twice beginning on May 20 and May 30. Most of the weeding was done with the traditional kurpas, although gooseneck hoes were used occasionally. Mr. Aslam removed weeds from the basin plots by cultivating with a bullock-driven stick plow on June 6.

By the end of July, the AC-134 had grown to heights of 6-7 feet, regardless of treatment. This produced severe problems for the laborers spraying AC-134 in the ridge furrow and broadbed treatments. After consulting with Dr. M Haider of the Mona staff and Dr. John Reuss of the Colorado State University staff, it was decided to split the 50 feet by 450 feet AC-134 broadbed and AC-134 ridge furrow treatments into two treatments 25 feet by 450 feet. Full plots of AC-134 broadbed and AC-134 ridge furrows were left with the plant populations that existed at that time. Skip-row plots of AC-134 ridge furrows were created by removing every third row of cotton from the treatment. Similarly, skip row plots of AC-134 broadbeds were created by removing every fourth row of cotton from the treatment. Access to the 6-7 feet high plants was facilitated by the removal of these rows.

Mr. Aslam irrigated all of the treatments on September 21 and on October 11. Neither of these irrigations was measured.

Six to twenty women from the village of Chak 11 were engaged to harvest the cotton. A total of nine pickings were made on Delta Pine 25 cotton treatments. The dates of the pickings were August 23, September 9, 25, October 8, 18, November 6, 18, December 27 and January 24. The AC-134 ridge furrow and broadbed treatments were picked five times. The dates of the pickings were October 26, November 11, December 1, 27 and January 5. Mr. Aslam's basin treatments were picked six times. The dates of the pickings were October 10, November 6, 16, December 3, January 4 and 19.

Table 1. The dates and amounts of each insecticide applied to the various treatments as liters of insecticide per acre.

Date	Delta Pine 25	Ridge Furrows & Broadbeds	Basin
5/13-14	.45 liters Nurvacron 40	.45 liters Nurvacron 40	-
5/30-31	" "	" "	-
6/2-3	-	-	.45 liters Nurvacron 40
6/17-18	.90 liters Nurvacron 40	.90 liters Nurvacron 40	-
7/1-3	" "	" "	-
7/11-12	" " and .725 liters Nogos	-	-
7/19-20	" "	-	.90 liters Nurvacron 40
7/26	" "	-	-
8/3	-	.725 liters Nurvacron 40 + .725 liters Nogos	-
8/10	.90 liters Nurvacron 40 and 1 liter 25% DDT	-	.90 liters Nurvacron 40 + 1 liter 25% DDT
8/16	" "	-	-
8/19	" "	-	-
8/31-9/5	" "	.90 liters Nurvacron 40 + 1 liter 25% DDT	.90 liters Nurvacron 40 - 1 liter 25% DDT

been a considerable amount of variation in stands obtained within treatments and from year to year. Personal observations during the 1976 Kharif (summer) season suggested that a great deal of the variation in emergence was caused by the methods used to construct and sow raised bed treatments. Ridge-furrows and broadbeds were constructed by hand with the traditional kusees (Pakistani shovel). This activity required one to four days per acre, depending on the availability of labor. The ridge-furrows and broadbeds which resulted were loosely packed, often full of large clods and variable in height. Sowing was either done by hand or with a plot seeder patterned after the pori hal. Neither method resulted in a uniform seed spacing or depth. More importantly, low seeding rates (16 to 20 lbs./acre) of questionable quality cotton seed were used. As a result, low initial plant populations were often subjected to further reductions due to the desiccation of seed sown at shallow depths and to the development of soil crusts on low portions of the beds which were overtopped during pre-emergence irrigations.

Conversations with Niel Dimick, an Agricultural Officer with USAID in Islamabad, revealed that a tractor mounted bedshaper-planter was available in Peshawar. He offered to turn this implement over to the CSU Water Management project provided it was put to use. The acquisition of this implement provided the precision needed for constructing and sowing raised bed treatments on a scale previously unattainable. The potential for conducting a large scale field trial on Mr. Aslam's farm provided an opportunity for an in depth evaluation of traditional and improved methods of cotton culture. In addition, the trial provided an ideal opportunity for farmers in the region to observe some of the improved methods of cotton culture.

A less complicated design was chosen in order to avoid the farmer's confusion with complex field trials. A large plot size was chosen to facilitate the use of tractor equipment and to test the practicality of furrow irrigation in precision leveled fields. The selection of the Delta Pine 25 cotton variety for one treatment developed from its reported success in Multan province, where seed cotton yields of over 3,200 pounds per acre have been reported (M.K. Khakwani, 1973).

Mr. Kareem approached Mr. Aslam about the establishment of a cooperative cotton production trial on his farm in late February. Mr. Aslam discussed the proposal with his family and made a verbal commitment with Mr. Kareem within a few days. Mr. Aslam recommended that the trial be conducted on an eight and one-half acre field which possessed a favorable soil for growing cotton. The field was agreed on after determining that the soil was a relatively fine-textured sandy loam and had a conveniently located lateral along its northern edge. Although Mr. Aslam's primary motive for agreeing to the field trial was to increase the precision leveled acreage of his farm, he was obviously delighted with competitive aspects of the cotton production trial.

Leveling of the Field

Precision leveling of the study site required that approximately 6 inches of soil be cut from the eastern edge of the field and deposited on the western edge. The necessity to sow the cotton as early in April as possible resulted in the termination of the field leveling activities before Mr. Kareem had the opportunity to finish leveling the field. Instead, observations of the levelness of the field were made during the roni irrigation. A few high spots were observed in the center and southwestern portions of the field during this irrigation. The high spots were removed after the first plowing of the study area on April 21.

Seed Preparation

While Mr. Kareem was involved with leveling the study area, the cotton seed was purchased and prepared for sowing. The cotton seed (50 lbs) given to Mr. Aslam was prepared by the traditional methods Pakistani farmers use throughout the Punjab region of Pakistan. Soaking the seed overnight, prior to sowing, is known to improve the overall emergence of cotton seed, particularly when seed beds are low in available soil moisture (Nelson and Schmehl, 1975). After soaking the seed, they were rolled in a mixture of ash and cow dung. The object of this was to paste down the lint fibers to permit easy separation of the seed during sowing. Although seeds prepared in this manner were easily separated, the farmer had little indication of the quality of seed he had prepared for sowing. Visual inspection for immature seed and seed infested with boll worms was severely limited with linters.

Cotton seed used in raised bed treatments was acid delinted to improve the seeds passage through the seed box. Prior to acid delinting, the germination of linters was tested with a standard germination test. The average germination of AC-134 and Delta Pine 25 linter cotton seed was 45 and 53%, respectively. The low germination percentages suggested that a large portion of the seed, hidden by the lint, was of inferior quality.

Large amounts of immature seed, dead seed, twigs and broken seed coats were removed during the acid delinting process. Most of this material was washed away during the rinsing process. After rinsing, the cotton seeds were spread over a concrete slab to dry. Closer inspection of the AC-134 cotton seed revealed that 10 to 15% of seed were infested with pink boll worms and nearly 15% of the seed

Data collected during the season included soil moisture, stand counts, soil temperatures during the emergence period, amount of water applied for two irrigations, inputs required for each treatment, boll counts, plant heights, and seed cotton yield. In addition, records of spraying activities and weeding activities were kept for evaluating the effectiveness of the methods used.

An analysis of variance was performed on the seed cotton yields and orthagonal comparisons were used to determine significant treatments. In addition, a record of production costs was kept during the growing season. The information was used to determine the most profitable treatment for the farmer.

RESULTS AND DISCUSSION

Preliminary Preparations

The selection of a farm for a cooperative cotton production trial involved identifying a farmer who was both capable of and willing to venture into a cooperative trial with the WAPDA-CSU Water Management project. This required that the farmer be willing to accept a certain amount of risk with the crop. He had to be willing to provide some of the inputs and to spend more time with the field trial than normally expected. Lastly, he had to be prepared for a constant stream of local and foreign experts who would be touring the various cooperative projects of the Water Management program.

Previous association with Mr. Raja Aslam had shown him to be an ideal candidate for such a project. Mr. Aslam had an eight-acre field precision leveled through the project's land leveling program during the previous year. Mr. Abdul Kareem, the engineer responsible for leveling the field, was impressed with Mr. Aslam's cooperativeness and desire to improve his overall farming operations. He therefore suggested the project initiate a cooperative field trial on the Aslam farm.

Mr. Aslam's desire to increase the precision-leveled acreage of his farm precipitated the establishment of a cooperative herbicide trial on wheat during the 1975-76 season. Unfortunately, birds ravaged the seedbed during the emergence period, nullifying any effects the herbicide treatments mav have had. However, the project was encouraged by the personal involvement of Mr. Aslam, his brother and their tenants during the establishment of the trial.

Previous field trials at the Mona Reclamation Experimental Project (Bashir Sabir, et al., 1975-76) indicated that raised bed cultivation improved overall stands and yields of both field corn and cotton. However, there had were immature. Lesser amounts of immature and boll worm infested seed were observed in the Delta Pine 25 cotton seed, but nearly 20% of this seed had been damaged during the ginning process. Apparently, the large size of the Delta Pine 25 seed resulted in many of the seed being cracked by the rollers during the ginning process.

It was necessary to improve the overall seed quality, before sowing, by physically removing obviously inferior cotton seed. An attempt to find a wire mesh screen with sufficient diameter openings to grade out the immature seed met with little success. Upon hearing about our troubles, Mr. Aslam's wife, along with other women of Chak II, volunteered to clean the seed by hand. After cleaning, a second germination test revealed the germination of AC-134 and Delta Pine 25 had been improved to 70 and 73%, respectively.

It was very disappointing to discover that cotton seed of such poor quality, particularly certified AC-134 cotton seed, was sold to the farmers. At Rs. 81.51 per maund (82 lbs.), it was understandable that farmers in this region were reluctant to purchase their seed from the Agricultural Development and Supply Corporation. Subsequent conservations with Mr. Aslam and other farmers of the area revealed their reservations about Government organizations responsible for supplying many of the agricultural inputs required for crop production.

Mr. Aslam was favorably impressed by the overall quality of the cotton seed which had been acid-delinted and cleaned. This was demonstrated later, when he asked to be shown how to acid delint cotton seed (AC-134) he had purchased for sowing on another six-acre field. The method was demonstrated to him and some of the other farmers early one morning. After the demonstration, Mr. Aslam acid-delinted all of the seed required for sowing. His satisfaction suggests this method should be made available to farmers choosing to cultivate cotton as a cash crop. Extension agents who could demonstrate the acid delinting technique would most certainly gain credibility with the farmer.

Initial Field Preparations and Sowing

Mr. Aslam considered the field to be in "wattar" on April 21. "Wattar" is a term used throughout Pakistan, to describe a field in which the soil moisture is sufficient for seedbed preparation but not too dry for proper seedling emergence.

It was at this point that the realization of Mr. Aslam's intentions to compete with the project became apparent. Mr. Kareem inspected the field and felt it would not reach "wattar" for two to three more days. He suggested that Mr. Aslam intended to sow the cotton before "wattar" in order to improve his changes of a better stand.

The next day, the basin plots were laid out after the study area had been plowed and planked. Bunds were built around the basin plots with a tractor-mounted ridger and two of Mr. Aslam's tenants broadcast the fertilizer by hand. The amount and type of fertilizer applied to the basins was left to Mr. Aslam. Farmers in this region appear to have little understanding of inorganic fertilizers. Some, like Mr. Aslam, are aware that different nutrients are available, but they have little awareness of fertilizer grades. Mr. Aslam's choice of nitrophos applied at a rate of 46 lbs. actual nitrogen and 46 lbs. actual P_2O_5 per acre probably resulted from the dealer selling him the equivalent of one bag of urea and three bags single super phosphate in the form of nitrophos.

After the fertilizer was applied Mr. Aslam "plowed" and planted the basin in a single operation. Subsequent conversation with Mr. Aslam indicated that the field had received an extra plowing because of his lack of experience with experimental plots.

Late that afternoon Mr. Aslam's tenant sowed the basin plots with a bullock-driven pori hal. His tenant attempted to sow the cotton seed in 30 inch rows along most of the length of each basin. However, the bullocks swerved some and actual row spacing varied from as little as 20 inches to 36 inches. A seeding rate of 8 seers/acre (16 lbs./acre) was used. This seeding rate was said to be 2 to 4 seers higher than seeding rates used by farmers in the area.

The shear of the pori hal leaves a small open furrow which is approximately 3 inches wide and 3 inches deep. Seed sown with the pori hal varied in depth and spacing. Seeding depth varied from near the surface to depths of 2 inches below the base of the furrow. The seed was spaced from a few inches to 36 inches.

Broadbed and ridge-furrow treatments of replication I were constructed and sown the next day. A basal fertilizer application of 10 lbs. of N per acre as urea and 50 lbs. of P_2O_5 per acre as single superphosphate, was broadcast by hand. The low rate of nitrogen was used to reduce excessive vegetative growth. Broadbeds on 60 inch centers and ridge furrows on 30 inch centers were constructed with a set of listers. After construction, the raised beds were shaped and sown with a tractor-mounted bed-shaper planter. A seeding rate of 12 seers per acre (24 lbs. per acre) was used for AC-134 cotton seed. The slightly larger seed size of Delta Pine 25 resulted in a lower seeding rate of 11 seers per acre (22 lbs. per acre).

A certain amount of difficulty was incurred when constructing the raised beds in replication I, due to the high soil moisture content. Therefore, the construction of broadbeds and ridge-furrow plots of replications II, III, and IV were postponed for a day. A fourth plowing, prior to plot construction was used to facilitate the drying of the soil. The construction of the remaining ridge-furrow and broadbed treatments proceeded without incidence on April 24 and 25.

Irrigation

Mr. Aslam did not irrigate the basin plots until September 21. He applied a second irrigation to these plots on October 11. Unfortunately, neither of these irrigations were measured due to the absence of Mr. Kareem and myself.

Conversation with Mr. Aslam, concerning his views about cotton irrigation, revealed some interesting concepts. Withholding irrigations during the vegetative period was though to stimulate root growth, and thus, improved the plant's ability to mine water from greater depths in the soil. More importantly, soil moisture stress was said to reduce excessive vegetative growth, which made hand harvesting easier. While the effect of soil moisture stress on vegetative growth is well understood by agronomists, research conducted by Howard M. Taylor and Betty Klepper, 1973, has shown that as soil moisture tension neared 1 bar, both the vegetative and root growth of cotton ceased. Nevertheless, Mr. Aslam's cotton averaged over 8 foot by mid-October, suggesting that the long vegetative period (120 days for AC-134), monsoon rains and the basal fertilizer application of 46 lbs. of actual nitrogen, undermined his efforts to prevent rank growth with a period of soil moisture stress.

Supplemental surface irrigations were used to maintain proper soil moisture regimes in all of the broadbed and ridge-furrow treatments. Soil moistures were monitored gravimetrically, to a depth of two feet, in all treatments during the first eight weeks. However, improper handling of the soil samples collected after the sixth week was not corrected and gravimetric soil moisture collection proved impractical. Subsequent irrigation needs were monitored by observations of the cotton plants. A dark blue green coloration of the leaf indicated the plants' need for additional water.

A pre-emergence irrigation was applied to all broadbed and ridge furrow treatments two days after sowing. The purpose of this irrigation was to provide an ideal moisture regime and to reduce high soil temperatures. An average of 2 inches of water was applied. The average application time was 2 hours for ridge furrow treatments and 3 hours for broadbed treatments. Another 4 to 6 hours was required before the water subsided from the furrows

The entire surface area of the ridge furrows were wet through by the pre-emergence irrigation. The surface of broadbeds was wetted 5 to 6 inches past the seed row and 2 inch subsurface samples showed that the wetting front reached 8 to 10 inches beyond the seed row.

A second irrigation varying from 2 to 2½ inches was applied to the broadbed and ridge furrow treatments in replications I and II on June 5 and in replications II and IV on June 9, 6 to 7 weeks after planting. Gravimetric soil moisture samples at 1 foot and 2 foot depths, taken prior to the irrigation, average 8 and 10% soil moisture content, respectively.

A side dressing of urea, at 50 lbs. of nitrogen per acre, was hand broadcast into the furrows of all broadbed and ridge-furrow treatments before the irrigation was applied. This was intended to be one of two side dressing applications, but the rank growth that resulted from this application discouraged further nitrogen fertilization of the plots.

The water requirements of the cotton were supplied by monsoonal rains from the second week of June through the second week of September. Four days of rain during the first week of July and two days of rain during the third week of July flooded all of the plots with 1 to 1-1/2 inches of water for periods of 2 to 4 days. The water subsided from the basin plots within 2 days but remained in the furrows of the broadbeds and ridge furrows up to 4 days. No apparent damage was observed in any of the treatments.

On September 21, Mr. Aslam's tenant applied an irrigation to the basin plots. Unfortunately, the tenant misunderstood the directions and irrigated all of the ridge-furrow and broadbed treatments along with the basin plots.

Mr. Aslam irrigated all of the treatments again on October 11. The irrigation of broadbed and ridge-furrow treatments was not scheduled as it was assumed that the cotton harvesting would not extend beyond the end of November. The necessity of this irrigation became apparent later, when it was learned that the cotton harvest actually extended into late January.

Seedbed Soil Temperatures

The soil temperatures observed in broadbed, ridge furrow and basin treatments on April 26 are shown in Table 2. The maximum soil temperatures occurred at 1:15 p.m. Soil temperatures of seed level in broadbed treatments were observed to be 12 to 14°F lower in the seed rows than in the center of the bed. Slightly lower temperatures were

Table 2. Air and subsurface soil temperatures (degrees fahrenheit) in broadbed, ridge furrow, and basin treatments as observed over a four-hour period on April 26.

Time	Air Temperature	Broadbed (2 inch depth) Seed Row	Broadbed (2 inch depth) Center	Broadbed (2 inch depth) Seed Row	Ridge Furrow (2 inch depth) Seed Row	Basin (1 inch depth) Seed Row	Basin (2 inch depth Seed Row
12:20	98	97	104	95	92	106	94
12:45	99	95	106	97	92	106	95
1:15	99	96	107	94	92	107	96
2:13	99	96	105	93	89	106	96
3:03	97	89	104	91	89	105	96
3:30	96	89	101	87	89	105	96
4:05	95	87	98	85	87	100	95
4:45	92	84	96	86	84	98	93

observed in the broadbed and ridge-furrow treatments. Temperatures at 1-inch depth in basin plots were similar to those observed in the center of broadbed treatments. Unfortunately, soil temperature measurements had to be abandoned because of cool, cloudy weather during the next four days. Nevertheless, the temperatures that were observed demonstrated the importance of pre-emergence irrigations as a method of lowering high soil temperatures. If there had been two to three more days of high day time temperatures, the basin treatment temperatures of seed level would have been comparable with those observed in the center of the broadbeds.

Stand Establishment

In 1976, the Agricultural Policy Committee of the Pakistan Federal Government, recommended that an ideal stand of AC-134 cotton in the Punjab region was 15,000 to 20,000 plants per acre (Recommendations of Cotton Production, 1976). Cotton stands of less than 15,000 plants per acre were said to result in lower yields. Field surveys conducted in the Mona Reclamation Project area over a period of 7 years suggested that the vast majority of farmers in this region obtained cotton stands well below those recommended by the committee (Table 3). The average cotton stand observed in the farmers fields was 8,600 plants per acre and only 12% of the 559 farmers surveyed had average stands of 18,500 plants per acre.

In the humid southeastern and dry southwestern areas of the United States, cotton stands vary from 35,000 to 60,000 plants per acre (Martin, et al., 1976). Because of high labor costs, the practice of thinning stands to specific plant populations has been abandoned throughout the cotton growing regions of the United States. Seed cotton yields vary from 2,000 lbs. per acre to over 5,000 lbs. per acre.

It was of some consternation to learn that the cotton stands recommended by the Agricultural Policy Committee were considerably lower than those recommended in the United States. But even more surprising was the fact that farmers cotton stands were considerably less than those recommended by the committee. It was therefore of interest to learn the effect that high plant populations would have on the average seed cotton yields of AC-134 and Delta Pine 25.

The average cotton stands obtained in the various treatments are shown in Table 4. Mr. Aslam's "traditional" basin plots ranged from a low of 5,900 plants per acre to a high of 11,300 plants per acre, with an average treatment stand of 8,975 plants per acre. With the exception of the stand in the basin plot of replication II, Mr. Aslam appeared to be quite satisfied with the plant populations he had obtained.

Table 3. The average plant populations and seed cotton yields of 550 farmer's fields in the Mona Reclamation Projects area from surveys conducted n 1966 through 1973 (Muhammad Fazil Sabir, 1975).

Average Plant Population	Farms Surveyed: Number of Farmers	Farms Surveyed: % of Total Farms	Average Yield in lbs. Per Acre
3,600	113	20	500
6,300	143	26	600
8,600	145	26	700
10,900	62	11	780
14,000	30	5	860
18,500	66	12	855

Table 4. Average cotton stands observed in each treatment and overall average stands for each treatment.

	Replication				Average Treatment Stand
	I	II	III	IV	Plants/Acre
Ridge Furrow (AC-134)	53,000	52,800	51,200	46,400	50,850
Broadbed (AC-134)	48,800	47,100	35,600	52,600	46,025
Ridge Furrow Skip Row (AC-134)	35,330	35,160	34,100	30,900	33,875
Broadbed Skip Row (AC-134)	39,750	35,325	26,700	39,450	35,300
Ridge Furrow (Delta Pine 25)	35,100	34,100	30,100	36,300	33,900
Basin (AC-134)	8,900	5,900	9,800	11,300	8,975

The stands of AC-134 in the ridge furrow treatments were consistently higher than any other treatment. The average stand of AC-134 in the ridge-furrow treatments were 50,850 plants per acre. A stand of 35,600 plants per acre in replication III of the broadbed treatments lowered the overall average plant population of AC-134-broadbed treatments to 46,025 plants per acre. The latter 1/3 of this treatment was improperly leveled and was from 2 to 3 inches higher than the rest of the field. As a result, the pre-emergence irrigation was not uniform and emergence in this portion of the plot was poor.

The rank growth of AC-134 during the month of July posed a serious threat to the success of the experiment. By the end of July it was obvious that something had to be done to broadbed and ridge-furrow treatments or insecticide applications would have to cease. Dr. M. Haider of the Mona Reclamation project suggested that alternate rows of the AC-134 be removed in order to facilitate insecticide applications. It was, therefore, decided to split AC-134 broadbed and ridge furrow treatments into two separate treatments of 25 by 450 foot each. Full plots of AC-134 broadbed and ridge-furrow treatments were left with the original plant populations previously discussed. Skip row plots of AC-134 broadbed treatments were created by removing every fourth row of cotton. Similarly, skip row plots of AC-134 ridge-furrow treatments were created by removing every third row of cotton. It was felt that the Germix 35 cc mist blower would provide adequate insecticide coverage of either two or three rows.

The removal of every fourth row of cotton in broadbed skip-row treatments resulted in an overall average stand of 35,300 plants per acre (Table 4). The lowest plant population observed in this treatment was 26,700 plants per acre in replication III. The removal of every third row of AC-134 in ridge furrow treatments resulted in an average treatment stand of 33,875 plants per acre (Table 4).

The stands of ridge furrow treatments sown with Delta Pine 25 were consistently lower than those observed in similar treatments sown with AC-134. The plant populations of Delta Pine 25 varied from 30,100 to 36,300 plants per acre with a treatment average of 33,900 plants per acre (Table 4). A lower rate of sowing (10-11 seers/acre) was responsible for the reduction in plant populations of Delta Pine 25. The lower sowing rate developed when the seeder was calibrated for sowing AC-134. The larger seed size of Delta Pine 25 was overlooked during the seeder calibration. As a result, sowing rates of Delta Pine 25 were 1 to 2 seers lower than similar treatments sown with AC-134.

Plant Height

During the first 1-1/2 months, the growth of cotton in all treatments appeared to be normal. Although Mr. Aslam applied a basal fertilizer application of 46 lbs. of nitrogen per acre, the plant heights of AC-134 basin plots were similar to those observed in ridge-furrow and broad-bed treatments. Withholding irrigations in the basin treatments probably limited excessive growth of the AC-134 during this period. However, the growth of AC-134 in basin treatments commenced with the start of the monsoon season and by the first week of September, the AC-134 in basin treatments averaged 8 foot 3 inches (Table 5).

The rank growth of Delta Pine 25 (Table 5) was obviously a result of varietal deterioration. The seed purchased for this study represented the sixth generation of the original Delta Pine 25 seed brought into Pakistan. The rank growth of AC-134 treatments (Table 5), however, raised serious questions about not only the variety but also the fertilizer recommendations made by the Agricultural Policy committee (Table 5). The nitrogen applied to AC-134, irrespective of treatment, was nearly 60, 40, and 15 lbs. per acre less than that recommended for poor, medium and rich soils (Recommendations of Cotton Production, 1966). By the first week of September, the average height of AC-134 for all treatments was 8 foot, 7 inches (± 1 foot). The sandy loam soil on which this trial was conducted was not a rich soil nor was it an ideal soil for cotton production. With observations such as these, the validity of the recommendations made by the committee was doubtful.

Weed Control

It appeared that the average Pakistani farmer in the Mona Reclamation project area viewed weeds as a secondary crop used to supplement the fodder needs of his livestock. The weeds were allowed to grow until they were 6 to 10 inches tall, where upon they would be harvested daily as feed for the livestock. While most farmers seemed to realize that this practice lowered crop yields, their perception of the importance of livestock and seasonal shortages of fodder took precedence over timely weed control.

Mr. Aslam, however, had the means to supply his family's meat and dairy needs and considered the few head of livestock he owned as a nuisance one tolerated in order to keep the family peace. Although timely weed control was considered to be important, Mr. Aslam was frustrated by the methods of seed control that were available to him. Hand weeding or any other activity that required extra field laborers was viewed with contempt. His reasons, also shared by other farmers in the region, were: 1) the availability of the

Table 5. The average height of cotton plants measured during the first weeks of October (in feet and inches).

	Replication				Average Height for Treatment
	I	II	III	IV	
Ridge furrow (AC-134)	8'5"	8'3"	8'4"	8'11"	8'6"
Broadbed (AC-134)	8'9"	9'4"	8'8"	9'0"	8'11"
Ridge Furrow (Delta Pine 25)	6'5"	5'3"	4'11"	5'3"	5'6"
Basin (AC-134)	8'3"	8'9"	8'11"	7'6"	8'3"

local labor force did not coincide with peak period of need, 2) the field laborers were generally indifferent with the tasks they were paid to perform, 3) the field laborers had to be constantly supervised if one expected them to do a fair day's work. But the lack of accessory equipment for tractors and quality sprayers for herbicides limited Mr. Aslam's choice of weeding methods to either hand weeding or cultivation with the relatively inefficient stick plow. He chose the latter method for weeding the basin plots on June 5. The share of the stick plow is only about 4" wide at its widest point. Thus, a large number of passes were required to cultivate the field. The tapered point of the share had little effect on the weeds, most of which were shoved to either side of the share as it moved through the soil. Observations of the basin plots after they were cultivated indicated that approximately 60% of the weeds were removed. Two weeks later, Mr. Aslam and his tenants removed the remaining weeds by hand.

All ridge-furrow and broadbed treatments were hand-weeded two times. The first weeding was started on May 20 and required ten days before all of the treatments were completed. From 2 to 10 laborers were involved with the weeding. The laborers, armed with kurpas (similar to a hand trawel) squatted between the rows and chopped the weeds just below the ground surface. Although this method of weed control appeared to be effective, it required too much time to seed areas over an acre in size. By the time the laborers started to weed the last two replications, the weeds were nearly 6 inches tall and a second crop of weeds had started to grow in the first replications. Another ten days were required to weed the ridge-furrow and broadbed treatments a second time. The second weeding provided adequate weed control for the remainder of the season.

Insect Control

Observations of farmers in the Mona Reclamation Project area indicated that insecticides were rarely applied to field crops. The farmers understanding of insect pests and the damage they caused was limited to a few insect species such as stemborers and corn earworms. Insect infestations often went unnoticed until the crop appeared "sick". By this time, major damage to the crop had occurred.

The Extension service personnel of the Mona Reclamation Project and the Federal Government appeared to be fairly competent at diagnosing insect problems and prescribing the correct insecticides. However, support for these services was minimal and extension agents were forced to provide assistance to farmers on a request basis. As a result, very few of the farmers in the area benefited from extension programs.

Because sprayer equipment, even the small compression sprayers, were extremely difficult to obtain in Pakistan; Mr. Aslam had never applied insecticides to cotton. The acquisition of the Germix 35 cc mist blower by the water management project prompted Mr. Aslam to provide some insect control in the basin treatments. He was, however, unable to identify many of the insect pests that attacked his cotton and therefore, tended to wait until the cotton was damaged before he sprayed. As a result, Mr. Aslam only sprayed the basin plots four times, two of which were during the more critical boll formation period. Although white flys and jasids damaged the cotton during the vegetative period, the plants appeared to recover rapidly after insecticide applications. However, better insect control during the boll formation period may have improved Mr. Aslam's seed cotton yield by two to three maunds per acre (160 to 200 lbs./acre).

It was originally intended to provide all-season prophylactic insect control in all broaded and ridge-furrow treatments. Bi-weekly spraying of Nurvacron 40 were planned for the vegetative period and weekly sprayings of Nurvacron 40 plus Nogos were scheduled for the boll formation period. The bi-weekly spraying of Delta Pine 25 were adhered to during the vegetative period (Table 1). However, observations of AC-134 in basin plots suggested that prophylactic insect control for AC-134 in the vegetative period was not as critical as originally thought. Therefore, it was decided to reduce some of the input costs for the AC-134 broadbed and ridge furrow treatments by permitting some insect damage during the vegetative period. As a result, insecticides were not applied to the AC-134 broadbed and ridge-furrow treatments during the month of July (Table 1). The insect damage appeared to be minimal and probably had little effect on the cotton.

The use of Nurvacron 40 plus Nogos insecticides provided some boll worm control but as the season progressed it became apparent that the insecticides were not providing the control desired. Nogos was therefore replaced by 25% DDT in early August (Table 1). Although this initially improved boll worm control, the rank growth of Delta Pine 25, previously described, seriously limited proper insecticide coverage. Better insecticide coverage would have probably improved the seed and cotton yields of Delta Pine treatments by 4 to 5 maunds per acre (329 to 411 lbs. per acre).

Prophylactic insect control during the boll formation period of AC-134 broadbed and ridge furrow treatments was never started because of the rank growth, described previously. The AC-134 broadbed and ridge-furrow treatments were split into full plots and skip row plots on August 1 and 2 in an attempt to improve sprayer accessability. Unfortunately, the removal of cotton rows in the skip row treatments merely provided a temporary solution to the problems encountered with spraying. These plots were sprayed once on August 3 before the skip rows were filled in with lateral branches and lodging cotton plants. As a result, the AC-134 ridge-furrow and broadbed treatments were only sprayed one more time during the season. At least four maunds per acre (329 lbs./acre) of seed cotton were lost to boll worms during this period.

Treatment Yields

The first cotton was harvested from the Delta Pine 25 treatments on August 23. A total of nine pickings were made before the harvest of Delta Pine 25 treatments were completed. The harvest covered a period of 154 days and ended on January 24, 276 days after sowing. The first AC-134 cotton was harvested from the traditional basin plots on October 10 and from ridge-furrow and broadbed treatments on October 24. A total of six pickings in the basin plots and five pickings in the ridge-furrow and broadbed plots were made. The last of the cotton was harvested from basin plots on January 19 and from ridge-furrow and broadbed plots on January 5. The total growing season for these treatments was 273 and 258 days, respectively.

The Delta Pine 25 variety, sown on ridge-furrows, produced significantly higher yields than the AC-134 variety, sown on various bedding treatments (Table 6). The average seed cotton yield on Delta Pine 25 was over 700 lbs. per acre greater than that of AC-134 treatments. While better insect control accounted for some of the yield differences obtained, boll counts taken earlier in the season indicated that there was a wide disparity between the potential yields of the two cotton varieties. Based on these boll counts, the average potential seed coton yield at the Delta Pine 25 treatment was over 2,400 lbs. per acre which was from 600 to 900 lbs. greater than potential yields of AC-134 treatments.

Unfortunately, the rank growth of Delta Pine 25 decreased the effectiveness of insecticide applications and the potential seed cotton yields of 2,400 lbs. per acre were not obtained. A great deal of the rank growth would have been eliminated had it been possible to obtain pure Delta Pine 25 cotton seed. However, government restrictions on the importation of foreign cotton seed nullified any thoughts of purchasing Delta Pine cotton seed from the United States. Furthermore, the relatively narrow row spacing (30 inches) increased the potential for rank growth as the season progressed. The use of a wider row spacing (36 to 40 inches) would have promoted more lateral branching and decreased the potential of excessive top growth. This would have improved the insecticide applications.

Within AC-134 treatments, seed cotton yields of ridge-furrow and broadbed skip-row treatment were significantly higher than all other bedding treatments (Table 6). The removal of every third row of cotton in ridge-furrow skip row treatments and every fourth row of cotton in broadbed skip-row treatments improved the light penetration into the lower branches of AC-134. As a result, more bolls developed on the lower branches of AC-134 cotton plants in skip row treatments. Boll counts of AC-134 treatments, during the week of October 9th, showed that ridge-furrow and broadbed skip row treatments averaged 22.0 and 24.3 bolls per foot of row, respectively. Similar boll counts of ridge furrow and broadbed treatments only averaged 13.3 and 14.4 bolls per foot of row, respectively. The increase in the number of bolls produced by AC-134 in skip-row treatments more than compensated for the reduction in plant populations. In fact, boll counts of AC-134 treatments indicated that ridge-furrow and broadbed skip row treatments had a higher yield potential than any of the other bedding treatments. The average predicted seed cotton yield of these treatments was 1,595 and 1,980 lbs. per acre, respectively.

Table 6. The seed cotton yield obtained in each treatment and the average treatment yield.

	Seed Cotton (lbs/acre) Replications I	II	III	IV	Average Seed Cotton Yield (lbs/acre)
Ridge furrow (Delta Pine 25)	1935	1748	2023	1930	1909**
Ridge furrow (AC-134)	924	1161	1053	1293	1108
Broadbed (AC-134)	1080	1178	948	1590	1199
Ridge furrow skip row (AC-134)	1227	1334	1289	1377	1307*
Broadbed skip row (AC-134)	1217	1334	1168	1398	1279*
Basin (AC-134)	973	926	1280	1336	1129

* Differs from basin irrigation treatment at 0.05 level.
** Differs from all AC-134 treatment at 0.05 level.

The seed cotton yields of the "traditional" basin treatments were comparable to those obtained from ridge-furrow and broadbed treatments (Table 6). Mr. Aslam indicated that the average seed cotton yield of the basin treatments was 400 to 600 lbs. per acre higher than he had obtained in the past. He attributed the higher yields to the use of insecticides and an improved cotton stand.

Mr. Aslam was somewhat surprised by the rank growth of AC-134 in the basin plots. However, the excessive vegetative growth was not harmful and may have improved the seed cotton yields in the basins. The individual plants averaged over 8 foot in height and were from 4 to 6 foot in diameter. Because of the low plant density, competition among plants was minimal and the plants were heavily laden with bolls throughout the boll formation period. As a result, boll counts averaged 13.9 bolls per foot of row and were comparable with those observed in ridge-furrow and broadbed treatments.

The seed cotton yields obtained in this field trial suggested that little benefit was gained from raised bed cultivation of AC-134. However, any positive effects of the raised bed cultivation of AC-134 were nullified by the rank growth that occurred in these treatments. This is suggested by the observation that potential yields of raised bed treatments, based on boll counts, were 100 to 200 lbs. greater than those of basin treatments.

Economic returns

The production costs and returns for "traditional" basin, Delta Pine 25, AC-134 broadbed and AC-134 ridge-furrow treatments are shown in Tables 7, 8, 9, and 10. The production costs of AC-134 ridge-furrow and broadbed skip-row treatments were similar to those of the ridge-furrow and broadbed treatments and will be discussed within the text.

The costs of the physical inputs reflects the prices paid by the Water Management Research project in 1976. Labor costs were based on the wages paid by WAPDA for daily laborers and are somewhat higher than those paid by Mr. Aslam. Mr. Aslam paid daily field workers Rs. 6.80 per day and provided them with one meal. In addition, field laborers working for Mr. Aslam were expected to work from sunrise to sunset, whereas WAPDA laborers were in the field from 7:30a.m. to 3:30p.m. As a result, labor costs, particularly for sowing, replanting and weeding, were higher than would be normally expected. Tractor time was based on the rate charged by local contractors. Picking costs were based on the rate Mr. Aslam paid the local women for this activity. Miscellaneous costs such as food, petrol and transportation were covered by adding 5% of the gross returns to the production costs.

The government authorized price for AC-134 seed cotton was Rs. 138.00 per maund (82.28 lbs.) in 1977. Although the Pakistan Government discouraged the growth of Delta Pine cotton varieties, it set the authorized price for the extra long staple varieties, such as Delta Pine 25, at Rs. 160.00 per maund of seed cotton. Gross returns were therefore based on the prices set by the Pakistan Government.

The total production costs for the "traditional" basin plots were Rs. 693.19 per acre (Table 7). An average yield of 1129 lbs. of seed cotton per acre (13.2 maunds/acre) resulted in a gross return of Rs. 1893.14 and a net profit of Rs. 1199.95 per acre. For every Rs. 1.00 invested in the "traditional" basin treatments, Rs. 2.73 were returned.

Table 7. The production costs for AC-134 "traditional" basin treatments.

Seed, 8 seer - (Rs. 2.04/seer)	Rs. 16.32
Fertilizer	
46 units of nitrogen and 46 units of P_2O_5 nitrophos	70.00
Insecticide	
7 lbs. Nurvacron 40 (4 sprays)	144.41
2 liters DDT 25% (2 sprays)	19.26
Tractor time (Rs. 40.00/hr) 2-1/2 hours	100.00
Irrigation water (29% efficiency for 2 in. = 1.58 in root zone at Rs. 20/in = Rs. 31.60/ irrigation) 4 irrigations	126.40
Labor: (Laborer - Rs. 8.00/day)	
Sowing - Fertilizer etc. (1/2 man day)	4.00
Bullocks for sowing and cultivation	30.00
Weeding x (1/2 man day)	4.00
Irrigation (4 irrigations at 1 hr/irrigation is 1/2 man day)	4.00
Spraying (2 hrs/acre - 4 sprays)	18.00
Tractor labor (Rs. 2.00/hour)	5.00
Irrigation canal maintenance (cleaning 2 x /year for 200 ft. length requires 2 man days/ year and cotton season is 9 months)	12.00
Picking costs (1/16 yield at 13.7 mds/acre at a rate of Rs. 138.00/md.)	118.00
5% miscellaneous costs for food, petrol, transportation, etc.	95.00
Total	Rs. 693.19
Production 13.7 mds at 138.00/md[2]	1893.14
Production costs (total)	693.19
Net Profit	Rs. 1199.95
Return on Investment	Rs. 2.73

1. Rs. 1.00 ≈ $0.10
2. One maund is 82.28 lbs.

The production costs for the Delta Pine 25 treatments were Rs. 1550.29 per acre and nearly 2-1/4 times those incurred for the "traditional" basin plots (Table 8). But the gross returns of Rs. 3744.00 per acre and the net profit of Rs. 2193.71 per acre, were nearly double those of the traditional basin treatments. The return on investment for Delta Pine 25 treatments was a respectable Rs. 2.41.

Larger investments in seed, fertilizer, insecticide, and labor increased the production costs of AC-134 ridge furrow and broadbed treatments to Rs. 1058.86 and Rs. 1072.79 per acre, respectively (Tables 8 and 9). As a consequence of the rank growth of AC-134, potential seed cotton yields were lowered. The yields that resulted in these treatments were comparable to those of "traditional" basin treatments. But due to the higher inputs costs, the net profits of ridge-furrow and broadbed treatments were only Rs. 804.14 and Rs. 942.01 per acre. In turn, the return on investment for these two treatments was lowered to Rs. 1.76 and Rs. 1.87, respectively.

The removal of selected rows of AC-134 cotton plants in skip row treatments resulted in higher seed cotton yields (Table 6). Because the production costs of these treatments were similar to those of ridge-furrow and broadbed treatments, net profits of skip-row treatments increase to Rs. 1085.34 and Rs. 1046.94. In addition, the return on investment for ridge-furrow and skip row treatments were increased to Rs. 1.98 and Rs. 1.95, respectively.

SUMMARY AND CONCLUSIONS

A cooperative cotton production field trial was conducted on the farm of Mr. Raja Aslam (Tubewell 62) in the Mona Reclamation Project area. A completely randomized design, replicated four times, was used to compare bedding treatments of Delta Pine 25 and AC-134 cotton varieties with "traditional" basin cultivated AC-134 cotton on a precision level and eight-acre field.

Stand Establishment:

The stands of certified AC-134 cotton variety in "traditional" basin treatments averaged 8,975 plants per acre and ranged from 5,900 to 11,300 plants per acre. The low plant populations resulted from: 1) a low seeding rate (16 lbs. cotton seed per acre), 2) the inferior quality of the cotton seed which had an average germination of 35%, 3) the variable seeding depths obtained by sowing cotton seed with the traditional bullock driven pori hal, 4) low seedbed soil moisture regimes and high seed level temperature regimes.

Table 8. The production costs and returns for Delta Pine 25 treatments.

Seed, 15 seer - (Rs. 1.95/seer)	Rs. 29.25
2 lbs. Commercial Sulphuric acid (Rs. 3.50/lb)	7.00
Fertilizer	
60 units of nitrogen as Urea (Rs. 1.36/lb or nitrogen)	81.60
60 units of P_2O_5 as Single Super Phosphate (Rs. .90/lb.) of P_2O_5	54.00
Insecticide	
20 lbs. Nuvacron 40 (11 sprays)	412.63
7 liters DDT 25%	67.41
Tractor time (Rs. 40.00/hr) 2-1/2 hrs	100.00
Irrigation water (29% efficiency for 2 in = 1.58 in root zone at Rs. 20/in - Rs. 31.60/irrigation) 4 irrigations	126.40
Labor: (Laborer - Rs. 8.00/day)	
Sowing - Fertilizer etc. (1 man day)	8.00
Replanting and weeding (8 man day)	64.00
Weeding 2 x (16 man days)	128.00
Irrigation (4 irrigations at 3 hrs/irrigation is 1-1/2 man days)	12.00
Spraying (2 hrs/acre - 11 sprays)	22.00
Tractor labor (Rs. 2.00/hr)	5.00
Irrigation canal maintenance (cleaning 2 x /year for 200 ft. length requires 2 man days/year and cotton season is 9 months)	12.00
Picking costs (1/16 yield at 23.4 mds/acre at a rate of Rs. 160.00/md)	234.00
5% miscellaneous costs for food, petrol, transportation, etc.	187.00
Total	Rs. 1550.29
Production 23.4 mds at 160.00/md[2]	3744.00
Production costs (total)	1550.29
Net Profie	Rs. 2193.71
Return on Investment	Rs. 2.41

1. Rs. ≙ $0.10
2. One maund is 82.28 lbs.

Table 9. The production costs and returns for AC-134 Broadbed treatments.

Seed, 15 seer - (Rs. 204/seer)	Rs.	30.60
2 lbs. Commerical Sulphuric acid (Rs. 3.50/lb)		7.00
Fertilizer		
60 units of nitrogen as Urea (Rs. 1.36/unit of nitrogen)		81.60
50 units of P_2O_5 as Single Super Phosphate (Rs. .90/unit of P_2O_5)		45.00
Insecticide		
9-1/2 lbs. Nurvacron 40 (6 sprays)		196.00
2 liters DDT 25% (2 sprays)		19.26
Tractor time (Rs. 40.00/hr) 2-1/2 hours		100.00
Irrigation water (29% efficiency for 2 in = 1.58 in root zone at Rs. 20/in - Rs. 31.60/irrigation) 4 irrigations		126.40
Labor: (Laborer - Rs. $8.00/day)		
Sowing - Fertilizer etc. (1 man day)		8.00
Replanting and Weeding (8 man day)		64.00
Weeding 2 x (16 man days)		128.00
Irrigation (4 irrigations at 3 hrs/irrigation is 1-1/2 man days)		12.00
Spraying (2 hrs/area - 6 sprays)		12.00
Tractor labor (Rs. 2.00/hr)		5.00
Irrigation canal maintenance (cleaning 2 x /year for 200 ft. length requires 2 man days/year and cotton season is 9 months)		12.00
Picking costs (1/16 yield at 14.6 mds/acre at a rate of Rs. 138.00/md).		125.93
5% miscellaneous costs for food, petrol, transportation, etc.		100.00
Total		1072.79
Production 14.6 mds at Rs. 138.00/md[1]		2014.80
Production costs (total)		1072.79
Net Profit	Rs.	942.01
Return on Investment	Rs.	1.87

1. Rs. 1.00 ≈ $0.10
2. One maund equals 82.28 lbs.

The stands of AC-134 obtained in respective ridge-furrow and broadbed treatments averaged 50,850 and 46,025 plants per acre, while stands of Delta Pine 25 averaged 33,900 plants per acre. The high plant populations were achieved as a result of: 1) the physical separation of inferior quality seed from the seedlot after acid delinting, which improved the average germination of AC-134 and Delta Pine 25 cotton seed from 35 to 45% to 70 and 73%, respectively, 2) the higher sowing rates of 22 and 24 lbs. of seed cotton per acre, 3) a uniform seeding depth of 1-1/2 inches, made possible with the use of a tractor-mounted seeder and 4) favorable seed moisture and soil temperature regimes. The latter was made possible by sowing the cotton seed on ridge-furrows and broadbeds. This permitted the application of a pre-emergence irrigation, which raised seedbed soil moistures to field capacity and lowered high daily seed level soil temperatures to levels near the cardinal germination temperatures for cotton.

Subsequent investigations concerned with raised bed cultivation of field corn in severely crusted soils showed that one irrigation, applied to soften surface crusts, improved the emergence of seedlings by nearly 35% and improved average grain yields by over 800 lbs. per acre (L. Nelson and Jack deMooy, 1980). Both of these studies have provided ample evidence in support of raised bed cultivation of cotton and field corn for improving the stand establishment and yields of these crops.

Irrigation:

A two-inch irrigation applied to ridge-furrow and broadbed treatments required an average application time of 2 and 3 hours, respectively. Heavier textured soils in the Punjab region, with lower infiltration rates, would require longer irrigation periods. Thus, adaptation of raised bed cultivation of corn and cotton may require that farmers apply less water more frequently. However, once the furrows have been filled, the irrigation stream can be cut back to a level that will supply the rate of infiltration. The excess stream would then be available for the next field. With proper planning, a farmer could irrigate a series of fields during an irrigation turn.

Insecticide applications:

The use of a Germix 35 cc mist blower provided adequate sprayer coverage of Nurvacron 40 during the vegetative period. Rank growth of the inbred Delta Pine 25 reduced the effectiveness of insecticides applied during the boll formation period. The seemingly unrelenting growth of AC-134 cotton in other treatments not only reduced the effectiveness of insecticides applied but caused the termination of spraying activities during the critical boll formation period. As a result, boll worm infestations substantially reduced seed cotton yields in all treatments.

Seed Cotton Yields:

Although rank growth of the Delta Pine 25 indicated varietal deterioration, the overall performance of this variety was superior to that of the AC-134 cotton variety. The average seed cotton yield of Delta Pine 25 treatments was 1909 lbs. per acre and over 600 lbs. per acre higher than highest average treatment yield of AC-134. It is believed that higher yields of seed cotton would have resulted with the use of a wider row spacing. A row spacing of 36 to 40 inches would have reduced the tendency for rank growth, improved light penetration into the lower branches and increased the efficiency of insecticide applications.

The rank growth of the certified AC-134 cotton variety raised serious questions about the variety, fertilizer, and row spacing recommendations made by the Pakistan cotton council. The average plant height in ridge furrow broadbed and "traditional basin" treatments was 8'6", 8'11", 8'3", respectively. The amount of nitrogen applied to these treatments was below that recommended by the cotton council. The excessive vegetative growth of AC-134 treatments suggests that the variety had seriously deteriorated since its introduction in 1959.

In "traditional" basin plots, with low plant populations, the rank growth of AC-134 may have improved seed cotton yields. The average seed cotton yield for basin treatments was 1,129 lbs. per acre. But, rank growth in ridge-furrow and broadbed treatments reduced light penetration into the lower branches. As a result, fewer bolls developed and the average seed cotton yields for these treatments were similar to those obtained in "traditional" basin treatments.

The removal of selected rows of cotton in ridge furrow and broadbed skip-row treatments demonstrated the importance of a wider row spacing. Improved light penetration significantly increased the number of bolls formed in skip-row treatments and the average yield of skip-row treatments was substantially higher than the average yield obtained in other AC-134 treatments.

Within AC-134 treatments, the economical analysis showed that Mr. Aslam was better off with the "traditional" methods of cotton culture. But, with increased inputs, principally insecticides, Delta Pine 25 grown on ridges nearly doubled net profits. These results suggest that cotton research in Pakistan must focus on varietal

Table 10. The production costs and returns for AC-134 ridge furrow treatments.

Seed, 15 seer - (Rs. 2.04/seer)	Rs. 30.60
2 lbs. Commerical Sulphuric Acid (Rs. 3.50/lb)	7.00
Fertilizer	
60 units of nitrogen as Urea (Rs. 1.36/unit of nitrogen)	81.60
50 units of P_2O_5 as Single Super Phosphate (Rs. .90/units of P_2O_5)	45.00
Insecticide	
9-1/2 lbs. Nurvacron 40 (6 sprays)	196.00
2 liters DDT 25% (2 sprays)	19.26
Tractor time (Rs. 40.00/hr) 2-1/2 hrs.	100.00
Irrigation water (29% efficiency for 2 in = 1.58 in root zone at Rs. 20/in - Rs. 31.60/irrigation) 4 irrigations	126.40
Labor: (Laborer - Rs. 8.00/day)	
Sowing - Fertilizer etc. (1 man day)	8.00
Replanting and weeding (8 man day)	64.00
Weeding 2 x (16 man days)	128.00
Irrigation (4 irrigations at 3 hrs/irrigation is 1-1/2 man day)	12.00
Spraying (2 hrs/acre - 6 sprays)	12.00
Tractor labor (Rs. 2.00/hr)	5.00
Irrigation canal maintenance (cleaning 2 x/year for 200 ft. length requires 2 man days/year and cotton season is 9 months)	12.00
Picking costs (1/16 yield at 13.5 mds/acre at a rate of Rs. 138 00/md)	119.00
5% miscellaneous costs for food, petrol, transportation, etc.	93.00
Total	1058.86
Production 13.5 mds at Rs. 138 .00/md	1836.00
Production Costs (total)	1058.86
Net Profit	Rs. 804.14
Return on Investment	Rs. 1.76

1. Rs. 1.00 $0.10
2. One maund equals 82.28 lbs.

improvement, row spacing, plant populations and fertilizer rates. In addition, agencies responsible for maintenance of varietal integrity and extension services must be given more support or cotton production will continue to decline.

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APPENDIX 3

IMPROVING FIELD CORN STANDS IN SERIOUSLY CRUSTED SOILS

by

Larry J. Nelson and C. J. deMooy[1]

Research on soil crusting, conducted at the Colorado State University Agronomy Farm in 1978, was continued in the Grand Valley of western Colorado during the 1979 growing season. The problems associated with irrigated agriculture in this valley are somewhat analogous to those observed in Pakistan. Approximately one-third of the valley's irrigated area has been degraded by waterlogging and salt accumulations. Soil crusting problems are particularly troublesome on many of the poorly structured, high silt-content soils. In addition, the arid climate of the valley is particularly conducive to field studies involving soil crusting.

GEOLOGIC HISTORY

The Grand Valley, approximately 49,200 hectares in area, was carved in the Mancos Shale formation by the Colorado and Gunnison rivers and their tributaries. The valley floor, which is at an elevation of 1,370 meters, is surrounded by the Little Book Cliffs (elevation 3,050 meters) to the southeast and the Uncompahgre Plateau (elevation 2,740 meters) to the southwest. The geologic formations exposed in the canyon walls and escarpments of the surrounding topography have played an important role in soil development and the drainage characteristics of the valley. A review of the geological events leading to the formation of the valley, taken from Lohman (1965), follows.

Most of the Grand Valley rests upon metamorphic and igneous deposits laid down during several different periods of the Precambrium Era (Fig. 1). Uplift during the Paleozoic Era, produced an erosional period which extended into the early Mesozoic Era. This erosional period removed all signs of the Paleozoic Era from the Grand Valley area.

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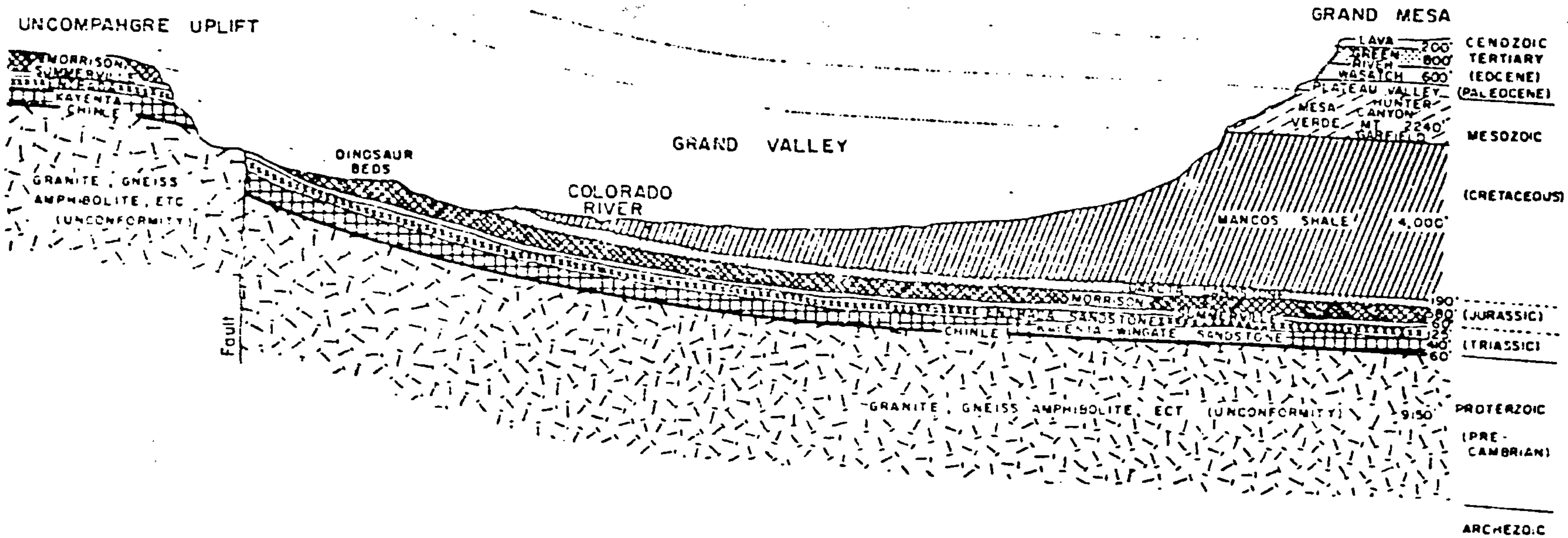

Figure 1. Geology of the Grand Valley. (U.S. Department of Agriculture, 1955)

Chronolithologically, the majority of formations present in the Grand Valley originated during the Mesozoic Era (Fig. 1). The earliest formations, the Chinle Kayenta-Windgate, Entrada and Morrison, were of continental origin. The alluvial and eoleon nature of these deposits suggests that there were wide climatic differences during this period. Sandwiched in-between and lying above these deposits are a number of marine formations indicating at least three periods of invasion by prehistoric seas. The most dominant of these is the Mancos Shale, which now commands the floor of the valley (Fig. 1). This formation was derived from marine mud deposited in the shallow waters of a late cretaceous sea. Because of its marine origin, the shale contains a very high percentage of water soluble salts. The salts, mostly calcium sulfates with lesser amounts of sodium chloride, sodium sulfate, magnesium sulfate and calcium and magnesium carbonates, are quite visible in the open joints and fractures of weathered shale (Evans et al., 1978). The importance of this formation in relation to soils and water quality merits further discussion.

Above the Mancos Shale deposits lie a series of marine sandstones, lagoonal deposits and coal swamps of the Mesa Verde Group. The nature of this deposit indicates that an advance and retreat of the inland sea occurred several times.

Renewed uplift during the early Cenozoic Era, raised the Colorado Plateau well above sea level. Gentle down-warping in the Grand Junction area created a large basin in which fluvial deposits of the Plateau Valley and Wasatch were formed (Fig. 1). The down-warping continued throughout the northern part of the Colorado Plateau, eventually leading to the formation of a huge lake, called the Green River or Uinta Lake. A remarkable sequence of sediments, including papery shale, marlstone, and oolite, eventually filled the lake. Numerous beds of lean to rich oil shale, also deposited in the Green River formation, have generated commercial interest.

Volcanic activity in the post-Green River Age formed the thick basalt flows which now cap the Grand Mesa. Increased uplift and deformation of the Colorado Plateau during the mid- to late-Cretaceous Period probably aided the establishment of the ancestral Colorado River on the lava beds. Subsequent erosion of these formations by the Colorado and Gunnison rivers and their tributaries sculptured the valley and associated canyons as they appear today.

SOILS

Nearly 90% of the soils surveyed in the Grand Valley are of alluvial origin. This allvium represents a wide range of materials derived from several, previously discussed formations. The soils are frequently high in lime, gypsum, sodium, potassium, magnesium and other calcium salts. Because of their relatively recent origin, there is a noticeable lack of argillic and calcic horizons common to the more weathered soils of the region. In addition, the arid climate of the valley has restricted the growth of natural vegetation. Thus, undisturbed soils often have organic matter contents of less than 1% with associated low levels of nitrogen.

Most of the Grand Valley is underlain by the easily eroded Mancos Shale formation (Fig. 1). Lying just above the Mancos Shale is a large cobble aquifer extending north from the Colorado River and for most of the width and length of the valley. The aquifer, which is under slight artesian pressure, is overlain by a thick mantle of alluvium derived principally from the Mancos Shale. A second aquifer or perched water table lies within this alluvium, separated from the cobble aquifer by a thin, often discontinuous, confining layer of clay and shale gravel. The boundaries of the perched water table extend well beyond those of the cobble aquifer, its areal extent being largely determined by the relatively impermeable nature of the Mancos Shale formation and the amount of water feeding the aquifer.

Neither aquifer contributed significantly to the development of saline and saline sodic soils in the valley or to the salt-loading of the upper Colorado River Basin until after the establishment of irrigated agriculture in the early 1880's. However, the construction of approximately 286 km of canals, 1,640 km of head ditches and 600 km of laterals, during the late 1800's and early 1900's, permitted the agricultural development of 28,650 hectares of land (Evans et al., 1978). Excessive quantities of water, attributed to seepage from the conveyance system and inefficient irrigations, increased the flow of saline water into the aquifers. A corresponding rise in the water table followed. Consequently, by the mid-1940's, nearly one-third of the irrigated area of the valley had either been abandoned or was only marginally productive. In addition, the Grand Valley became one of the largest salt contributors (estimated at 450,000 to 800,000 metric tons, annually) to the Colorado River Basin (Evans et al., 1978).

Although the salinity problems associated with irrigated agriculture in the Grand Valley have changed relatively little since the mid-1940's, a number of research projects are providing information necessary for large-scale salinity control programs. Of interest are some of the recommendations that have resulted from eight years of salinity control research in the Grand Valley (Evans et al., 1978a,b, and Walker et al., 1978). Of several programs recommended for salinity control in the valley, the most cost-effective were concrete lining of laterals and on-term irrigation system improvements. Head ditch lining or installations of gated pipe and/or automated cutback furrow irrigation were found to be the most cost-effective on farm improvements. A salinity control program concentrating on the above improvements and emphasizing efficient irrigation through water scheduling and educational programs would be the most effective in reducing salinity problems. In addition, conversion from furrow irrigation to other more efficient irrigation systems, such as sprinkler, trickle and level border irrigation, were found to be highly effective programs for limited areas of the valley.

The areas of the Grand Valley most affected by waterlogging and salt accumulations are those soils formed on the alluvial mantle or Mancos Shale. Of particular interest are the heavy textured silty clays and silty clay loams which form the Billings series. These poorly structured, fine-grained soils occupy nearly one-third of the valley's area and vary in depth from 14 meters to less than one meter. Because of the marine origin of their parent material (Mancos Shale), they contain moderate to high levels of salts. The removal of these salts by leaching is made difficult by poor internal drainage characteristics and a shallow water table. Furthermore, proper irrigations are made all the more difficult by low infiltration rates and the ease with which this soil puddles. Upon drying, the puddled soil forms an extremely hard crust which can seriously impede emergence and damage cultivating implements.

Because of the severe crusting problems associated with these soils, farmers have been reluctant to switch from furrow irrigation to the more efficient sprinkler irrigation systems common elsewhere in the state. In 1977, however, the SEA-ARS began a pilot study to determine the suitability of flat and furrowed level basin irrigation in the Grand Valley (Kincaid and Kruse, 1980). Three years of cropping with corn, barley and alfalfa have shown that level basin irrigation is a practical alternative for significant areas of the valley. The reduced labor inputs, increased precision with which water can be applied and the elimination of surface runoff will enhance acceptability by local farmers.

CLIMATE

The monthly range in temperature and distribution of precipitation for Grand Junction is shown in Figure 2. The climate of the lower valley is characterized by hot, dry summers and cool winters. Precipitation occurs as snow in the winter and rain from thunderstorms in the summer.

Although it is not uncommon for daily summer temperatures to range as high as 40.6 degrees C (105 degrees F), the usual range is the middle to low--30 degrees C--with night-time lows around 15 degrees C. The relative humidity is usually low during the growing season, with the average daily relative humidity ranging from 20 to 45%.

The Grand Valley receives an annual precipitation of only 211 mm (8.29 in.). The precipitation is fairly evenly distributed throughout the year. Because of the low annual precipitation, the valley is totally dependent on the nearby high mountain snowpacks for irrigation and community water needs.

The natural constriction of DeBeque Canyon on the upper northwest end of the valley limits the movement of cold and warm air masses into and out of the valley. This provides early and late fall frost protection and results in an average growing season of 190 days.

METHODS AND MATERIALS

The Mesa College Agricultural Farm, located near Grand Junction, was selected as the site for this study. The farm, recently obtained from the State Home, now functions as a field training center for Mesa College students majoring in vocational and general agriculture programs.

The field selected is located south of the main entrance road and directly west of the Power Lineman Training facilities. It had been cropped with barley the previous year.

The soil, a Billings silty clay loam, is an important soil of the valley, occupying nearly one-fifth of the area. In general, this weakly structured soil is described as having a low infiltration rate, poor internal drainage and moderate to high levels of salts. Susceptability to water logging and/or further salt accumulation is enhanced by the presence of a shallow water table. The soil is easily puddled when irrigated. The extremely hard surface crust, developed upon drying, seriously impairs the emergence of field crops and makes tillage difficult. As a result, this soil is termed "adobe" by the local farmers.

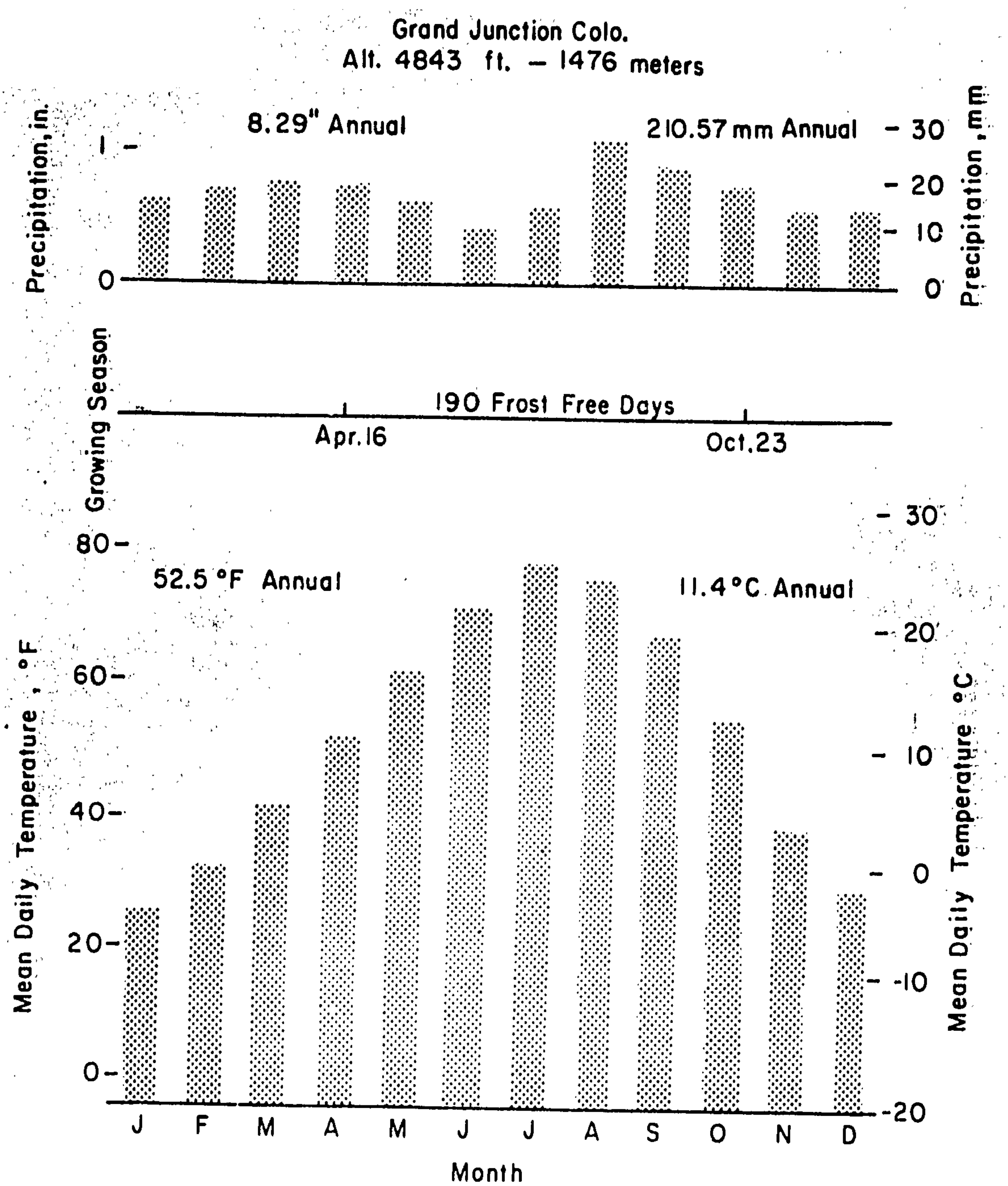

Figure 2. Normal precipitation and temperature at Grand Junction, Colorado (U.S. Department of Commerce, 1968).

A surface sample of this soil, collected during the fall of 1978, was prepared for minerological analysis according to procedures presented in Black (1965). The lime and organic-matter-free sample was separated into fine sand, two silt and one clay size fractions. Petrographic identification of sand fraction minerals was made. The mineral suites in the less than 2μ clay were identified by x-ray defraction analysis with calcium and potassium saturated clays, given ethylene glycol, humidity and heat treatments. Cation exchange capacity determinations and surface area measurements were made for semi-quantitative estimates of the clay mineral suite.

A 3 x 3 split plot design, replicated four times was chosen for the study. The main plots were 12.2 by 12.2 meters (40 x 40 ft), and the subplots were 4.6 meters (15 ft) wide by 12.2 meters long. The treatments included:

Main plots--Initial seed moisture content at sowing (ISMC).

A. 9% ISMC (air dry seed)

B. 23% ISMC (The seed was soaked 4 hours prior to sowing.)

C. 31% ISMC (The seed was soaked 12 hours prior to sowing.)

Subplots--Post-plant seedbed treatments

1. Crusted (Crust formed by sprinkler irrigation two days after sowing.)

2. Soil mulch (Crusts were broken by a sugar beet crust breaker three days after sowing.)

3. Pre-emergence irrigation (Crusts were softened by a furrow irrigation seven days after sowing.)

Before the construction of the plots, 54 soil samples (2 samples/subplot) from the upper 15 cm were collected from the first 3 replications. The samples were dried, composited into a set of 27 samples (one sample/subplot) and stored for subsequent chemical analysis. After harvest, all of the samples, except those of main plot A of replication 1, were composited into a single sample per main plot. These 11 composited samples were sent to the Soil Testing Service at Colorado State University for determination of NO_3-N, P, K. soluble cations and anions, pH, EC, and cation exchange capacity.

Prior to plot selection, a student from Mesa College incorporated ammonium phosphate and muriate of potash in the study area to equal a total of 30, 77 and 56 kg per hectare of N, P_2O_5 and K_2O, respectively. Field preparation included an additional 166 kg of N per hectare, as urea, applied with a gandy fertilizer spreader and incorporated with a roller harrow.

Before the urea was applied, the field was chisel-plowed to a depth of 20 to 25 cm. After incorporation of the fertilizer, raised double-row bed (broadbeds) were constructed with a set of two tractor-mounted listers. A furrow spacing of 152 cm (60 in.) was used. Furrow depths ranged from 15 to 20 cm (6-8 in.).

A 90-day modified single-cross variety of field corn, Grand Valley SX 121, was chosen for the study. All treatments were sown on June 14 with a tractor-mounted, hand-fed disk seeder, capable of sowing a specific population of 69,190 seeds per hectare (28,000 seeds/acre). Seeds were raised to 23 and 31% initial seed moisture contents by soaking in a bucket of clean water for a period of 4 and 12 hours, respectively.

After sowing, a series of 48 plastic beads were buried 5 cm deep and approximately 20 cm apart in the seed rows of all crust (A) subplots. The beads were 5 mm in diameter. A steel wire (piano wire), 15 cm long, was threaded through each bead and crimped on the end. The wire was extended above the soil surface 10 cm, and bent to form a hook.

A semi-portable sprinkler irrigation system, powered by a PTO driven pump, was used to induce surface crusting. Three laterals (10.2 cm diameter) were set along the north-south ends and center of the experimental area, producing an 18 meter spacing between laterals. Rainbird (#35 TNT, with 0.56 cm nozzle openings) sprinkler heads on 60 cm risers were spaced at 12 meter intervals along the laterals. The sprinkler system was operated at a suboptimal pressure of 50 $lbs/in.^2$. Two hundred and sixteen plastic cups, set in a grid pattern throughout the experimental area, were used to evaluate the efficiency of sprinkler application.

All treatments were sprinkler-irrigated on the morning of June 16, 1979. On June 17, a hand-operated sugar beet soil crust breaker was used to mulch all soil-mulch treatments (B). On June 21, a furrow irrigation was applied to all pre-emergence irrigation treatments (C).

Surface soil temperatures at 1 cm and subsurface soil temperatures at seed level (5 cm) were monitored with thermocouples during the first 14 days of emergence. A SEA-ARS weather station, approximately 1,000 meters northeast of the experimental areas, provided additional climatic information.

Four 9.1 meter rows in the center of each subplot were staked for data collected. Daily stand counts were made on each row, beginning on day six after sowing and for 10 days thereafter. A final stand count was taken at harvest.

The physical impedance of soil crusts were measured in crusted treatments over a four-day period, beginning one day after the sprinkler irrigation. To measure physical impedance, a wood stand 83 cm high and 64 x 64 cm wide was placed directly over a buried bead. A 2.54 cm pulley attached to the center of a crossbar on the top of the stand served as a fulcrum for a 1.5 meter nylon line. A loop at one of the nylon line was attached to the wire hook extending from the buried bead. A one-liter plastic carton was attached to the other end of the nylon line. Water was carefully poured into the plastic carton until the bead was pulled through the soil crust. The volume of water was measured. This volume was then converted to a force measurement.

A total of 48 beads were pulled each day, 12 beads per plot, beginning one day after sprinkling and for four days thereafter. In addition, four penetrometer readings were taken within close proximity of each bead. The four penetrometer readings were averaged as a comparative measurement of physical impedance.

Soil moisture was monitored to a depth of 1.5 meters at 30 cm intervals with a neutron probe. In addition, 0-15 cm and 15-30 cm soil samples were collected throughout the season for gravimetric moisture determinations. During the first 6 weeks, irrigations were scheduled when 50% of the plant-available soil water had been used. But, it was observed that plants wilted severely before this level of soil moisture extraction was reached. Irrigations were, therefore, scheduled when 25% of the plant-available soil water had been used.

During the growing season, nine furrow irrigations, not including the pre-emergence irrigation, were applied. The irrigation system was installed so that each irrigation could be evaluated from data collected during the irrigation. The data are presently being coded for computer analysis.

All treatments were harvested on October 19 and 20. Four rows, 9.1 meters long in each subplot, were hand harvested for grain and silage. Harvest data included stand counts, numbers of barren stalks and stalks with two ears, moisture contents of corn and grain, and silage yields.

Stand counts and harvest data were analyzed by a 3 x 3 factorial analysis of variance. Significant data were subjected to an LSD mean separation tests. All LSD values were calculated at the 0.05 level.

RESULTS AND DISCUSSION

SOIL ANALYSIS

The results of the mineralogical analysis of the Billings silty clay loam are presented in Tables 1 and 2. The total sand, silt and clay fractions amounted to 20, 48, and 32%, respectively. The grains of the very fine sands are predominantly quartz with some potash feldspar and mica. The mineral suite of the <0.002 mm clay fraction is dominated by vermiculite, smectite (montmorrilonite), kaolinite and illite with lesser amounts of chorite and quartz. Comparable soils of the Punjab region of Pakistan have higher silt contents and the mineral suites of the clay fraction are principally illite and chlorite with smaller amounts of smectite (montmorillonite) and vermiculite (Schmehl and Franklin, 1972).

Table 1. Organic matter and lime free separates of the Billings silty clay loam soil.

% Clay	% Silt		% Sand				
<0.002 mm	0.002-0.02 mm	0.02-0.05 mm	0.05-0.1 mm	0.1-0.25 mm	0.25-0.5 mm	0.5-1 mm	1-2 mm
31.9	28.5	19.7	14.0	4.7	0.4	0.6	0.2

Table 2. Semi-quantitative estimates of the clay mineral suite.

Mineral	Fraction of mineral suite	CEC meg/100 g	Surface area m^2/g
Kaolinite	0.20	1.6	9
Illite	0.17	4.3	29.8
Vermiculite	0.25	43.7	110.0
Smectite	0.21	21.0	168.0
Chlorite	0.12	3.0	21.0
Quartz	0.05	0.1	1.3
		73.7	339.1

The experiment was originally designed with three replications and planted during the latter part of May. However, an untimely rain 8 days after sowing, substantially improved the emergence of seedlings in the crusted treatments. The experiment was, therefore, terminated and a second experiment of similar design was planted. Due to the variable emergence of seedlings within treatments, a fourth replication was added to the second experiment.

Since soil samples were collected for laboratory analysis prior to the establishment of the first experiment, they are only representative of the first three replications. All of the soil samples, except those of treatment A in replication 1, were composited into one sample per main plot. Because plant growth was poor, this treatment was selected for more complete analysis.

The results of the laboratory analysis, shown in Table 3, indicate this is a saline-sodic soil. The average electrical conductivity of saturated paste extracts was 8.5 mmhos/cm and ranged from 6.4 to 12.5 mmhos/cm. The calculated exchangeable sodium percentage varied from 7.2 to 27%, averaging 12.1%. Calcium, magnesium, chloride and sulfate levels were elevated.

The high gypsum content initially suggests that reclamation of this field by leaching would be beneficial. However, the high levels of salts and poor structure of this finely grained soil result in poor infiltration and internal drainage characteristics. A fluctuating water table, varying from 1 meter to 2 meters below the surface, further complicates water application. Thus, reclamation of this soil would require efficient irrigation applications along with intensive management practices aimed at improving soil structure.

The levels of nitrate, potassium and phosphorus are considerably higher than normally expected (Table 3). The high levels of these nutrients resulted from the application of ammonium phosphate and muriate of potash to the study area prior to plot selection. The levels of iron and zinc appear to be adequate for proper plant growth.

SEED BED ENVIRONMENT

Air and soil temperatures for a 12-day period beginning 4 days after sowing are presented in Table 4. Daily maximum air temperatures were in the low 30 degrees C for most of the emergence period. However, cloudy weather on the 6th and 7th day lowered the air temperatures to the low 20 degrees C. Surface soil temperatures at 1 cm depth increased

Table 3. Soil analysis of experimental area.

Rep	Main Plot	Sub Plot	pH	Cond. mmhos/cm	% Organic Matter	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Ca meq/l	Mg meq/l	Na meq/l	K meq/l	HCO_3 meq/l	Cl meq/l	SO_4 meq/l	SAR	CEC meq/100g
		1	8.0	12.5	1.8	91	25	286	1.8	19.0	27.0	41.2	97.4	2.3	1.0	54.1	102.8	16.7	--
	A	2	7.8	6.6	3.0	165	82	494	44.7	32.1	21.0	25.9	42.1	3.1	1.4	20.2	59.2	7.9	--
I		3	8.0	12.2	1.4	124	10	196	1.9	14.8	27.8	36.8	86.5	1.1	0.8	35.6	91.5	15.2	--
	B	-	7.8	10.0	1.9	111	42	306	4.5	25.0	29.3	31.6	54.3	1.9	1.3	26.2	78.8	9.9	--
	C	-	7.8	8.4	2.2	37	52	531	5.0	26.3	30.8	28.9	36.5	4.8	2.2	32.3	68.2	6.7	13.8
	A	-	7.8	8.4	2.1	113	40	328	3.3	27.0	31.4	26.6	42.2	2.1	0.9	20.7	64.5	7.8	--
II	B	-	7.8	8.1	2.0	116	33	310	22.5	25.0	31.3	24.4	36.6	1.8	1.1	19.3	61.5	6.9	15.5
	C	-	7.9	9.6	1.9	72	37	295	15.6	20.4	29.7	28.8	53.0	1.9	1.3	32.9	68.2	9.8	--
	A	-	7.9	6.7	2.0	42	46	306	8.3	28.3	28.8	23.4	33.3	1.8	1.3	15.5	61.5	6.5	--
III	B	-	7.3	6.4	1.9	99	48	314	21.9	28.1	31.8	22.0	26.1	1.7	1.2	9.6	57.0	5.0	15.6
	C	-	7.9	7.7	1.8	71	34	254	2.0	21.3	33.0	25.1	36.5	1.5	1.3	17.0	66.8	6.8	--
Mean			7.8	8.5	2.0	87.5	41.2	329.9	11.1	24.8	30.5	27.3	43.7	2.2	1.3	23.3	67.9	8.1	15.0
Standard Deviation			0.05	1.5	0.1	33.2	6.4	78.5	8.0	3.0	1.5	4.1	14.9	1.0	0.4	9.2	8.7	2.5	1.01

Table 4. Daily air temperatures recorded at the SEA Weather Station and daily averaged maximum soil temperatures al 1 cm and 5 cm depths.

	Days after Planting											
Temperature Variable	4	5	6	7	8	9	10	11	12	13	14	15
Air Temperature - Max	31	30	22	24	28	31	32	33	34	34	34	36
°C - Min	16	19	8	19	14	12	11	14	18	19	16	16
Maximum Soil Temperature at 1 cm °C	19	37	43	--	49	50	47	37	32	47	47	47
Soil Temperature Variation	5	5	6	--	7	6	6	5	5	5	6	5
Maximum Soil Temperature at 5 cm °C	18	24	30	--	34	35	36	32	28	33	33	33
Soil Temperature Variation	5	5	5	--	5	6	5	5	5	5	5	6

from a low of 19 degrees C, two days after the sprinkler application, to the high 40 degrees C. Soil temperature at seed level (5 cm) also increased from a low of 18 degrees C, two days after the sprinkler application, to the low 30 degrees C. Maximum surface and seed level temperatures observed were 56 and 41 degrees C, respectively.

The physical impedance of crusted treatments was measured by two different methods. The first method simulated the amount of force necessary for an emerging seedling to penetrate or remove an overlying crust ped. This was accomplished by determining the amount of force required to pull a 5mm bead through the crust ped. A total of 48 beads, 16 per plot, were removed each day during a four-day period following the sprinkler applications. Secondly, the physical impedance of the crusts were measured with a penetrometer. Four penetrometer readings within close proximity of each bead were averaged.

Previous research has shown the mean thrust of corn seedlings to be 2.9×10^5 dynes (Taylor, 1971). It is probable that crusting strengths much greater than this would adversely affect the emergence of corn seedlings. The emerging shoots contacting such crusts tend to bend and elongate in a horizontal direction. The chances of successful emergence of these seedlings depend on the horizontal distance the seedling has to travel. Seedlings emerging under small peds normally emerge through the cracks between the peds, while those under large peds expend seed food reserves before reaching the cracks.

The distribution of the forces required to pull a bead through a crust ped are shown in Table 5. The least amount of force required to break through a crust occurred on the second day after sprinkling and was 2.0×10^5 dynes. The largest force measured occurred on the following day and was 4.6×10^6 dynes. The wide distribution of measured forces, shown in Table 5, resulted from the random development of the crust peds. Some beads were centered below a crust ped, others near the edge and a few lay in cracks between peds. The distribution of the forces required to pull a bead through a crust remained fairly constant throughout the four-day period (Table 5). However, a slight increase in the number of beads which broke through crusts, at forces greater than 3.0×10^6 dynes, was observed between the first and second day. The same trend occurred with penetrometer readings at forces exceeding 2.0×10^6 dynes.

A larger number of measurements were made with the penetrometer due to the ease of measurement. The penetrometer

Table 5. Frequency distribution of forces indicated in table heading measured using the bead method (B) and the penetrometer (P) during a four-day period following sprinkler application.

Days after sprinkling		10^6 dynes								
		0-0.5	0.5-1.0	1.0-1.5	1.0-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	>4.0
1	B	2	10	14	4	11	6	1	--	--
	P	--	7	58	96	26	5	--	--	--
2	B	1	5	8	12	9	4	5	--	2
	P	--	--	2	5	81	51	25	4	3
3	B	2	9	8	9	7	4	5	2	2
	P	--	--	4	53	75	32	18	6	2
4	B	2	10	7	8	5	7	3	--	3
	P	--	2	10	31	57	51	16	11	1
Total B		7	34	37	33	32	21	14	2	7
Total P		--	9	74	185	39	139	59	21	6

readings ranged from a low of 0.75 x 10^6 dynes on the first day to a high of 4.2 x 10^6 dynes on the third day.

The daily distribution of penetrometer readings indicated that crusting strength increased up through the second day and changed very little thereafter (Table 5). The overall averaged daily penetrometer readings of 1.62 x 10^6, 2.48 x 10^6, 2.25 x 10^6 and 2.32 x 10^6 dynes, respectively confirm this observation. Similar overall averaged daily values from bead force measurements were 1.82 x 10^6, 2.17 x 10^6, 2.22 x 10^6 and 2.08 x 10^6 dynes, respectively. The agreement between the daily mean values obtained by two entirely different methods is fairly close, considering that the sample size of the bead force method was 1/4 of that for penetrometer measurements.

STAND ESTABLISHMENT

A field study conducted in Fort Collins during the previous season showed soil mulching treatments to be a highly effective method for improving the stand establishment and yield of field corn in weakly crusted soils (Nelson and deMooy, 1979). Other investigations by Kemper and Miller (1970) indicated that near normal stands of field crops were obtainable if soil crusts were kept moist during the emergence period. The use of double row beds (Broadbeds) and ridge furrows could provide the farmer with an opportunity to soften crusts with surface irrigations. Since water is delivered to farms in Pakistan on a weekly rotation, it is doubtful that more than one pre-emergence irrigation could be applied by a farmer during the emergence period. Therefore, it was of interest to determine what effect soil mulching and a pre-emergence irrigation would have on the stand establishment of field corn in a severely crusted soil.

Both the soil mulching and pre-emergence irrigation treatments substantially improved the emergence of seedlings over those observed in crusted treatments. Overall, final stands of the soil mulch, pre-emergence irrigation and crusted treatments were 37.9, 32.2 and 21.4 plants per 9.1 meter row, respectively. Closer inspection of the data revealed some of the improvement in stands of soil mulched and pre-emergence irrigation treatments resulted from sowing prehydrated seed. Further discussion of seedbed treatments are presented in sections on initial seed moisture content.

Prehydrating seed, prior to sowing, was demonstrated as a practical method for improving the stand establishment and yield of field corn in a weakly crusted soil (Nelson and deMooy, 1979). Therefore, it was of interest to determine the effect of sowing prehydrated seed on the emergence and yield of field corn in a severely crusted soil. Three initial seed moisture contents were chosen for this purpose. Normal air dry seed sown at 9% ISMC were compared with prehydrated seed sown at 23 and 31% ISMC. The prehydrated seeds were raised to their respective seed moisture contents by soaking in water for periods of 2 1/2 and 12 hours.

The initial emergence of seedlings began on the 5th day after sowing in treatments sown with seed at 31% ISMC. The overall effect of higher initial seed moisture content on emergence was only found to be significant during the first 9 days after sowing. The improved emergence of prehydrated seed during this period occurred primarily in soil mulched and pre-emergence irrigation treatments (Figure 3).

The removal of soil crusts by soil mulching permitted normal emergence of seedlings. Increased rates of emergence of prehydrated seed in this treatment were similar to those observed in a previous field study (Nelson and deMooy, 1979). Although sowing prehydrated seed in mulched soil improved final stands, they were not considered to be significantly better than similar treatments sown with seed at lower ISMC (Figure 3).

Softening surface crusts with a pre-emergence irrigation increased the daily accumulated emergence of seedlings irrespective of initial seed moisture content. However, the emergence of prehydrated seed at 31% ISMC was consistently higher than that observed for seed at lower ISMC. The final stands of plants, sown at different ISMC in pre-emergence irrigation treatments, are shown in Figure 3. While differences due to ISMC are not considered to be significant at the 0.05 level, the average stand of pre-emergence irrigation treatments was improved by over 10% when sown with seed at 31% ISMC.

A slight, but significant improvement in the emergence of prehydrated seed was observed in crusted treatments up to the 8th day after sowing, after which little deference due to ISMC was observed (Figure 3). The initial difference in emergence of prehydrated seed occurred as a result of earlier emergence through cracks between crust peds. Similar emergence of seed at lower ISML occurred, but at slower rates.

The final stands of 9, 23 and 31% ISMC treatments in crusted plots were only 62, 62 and 54% of those observed in soil mulched treatments sown with air dry seed. The poor performance of ISMC treatments in crusted plots, was a result of the development of severe crusts, which occurred prior to emergence. Apparently, low seedbed temperatures (Table 4), after the sprinkler application, delayed emergence. A similar study in Fort Collins identified low

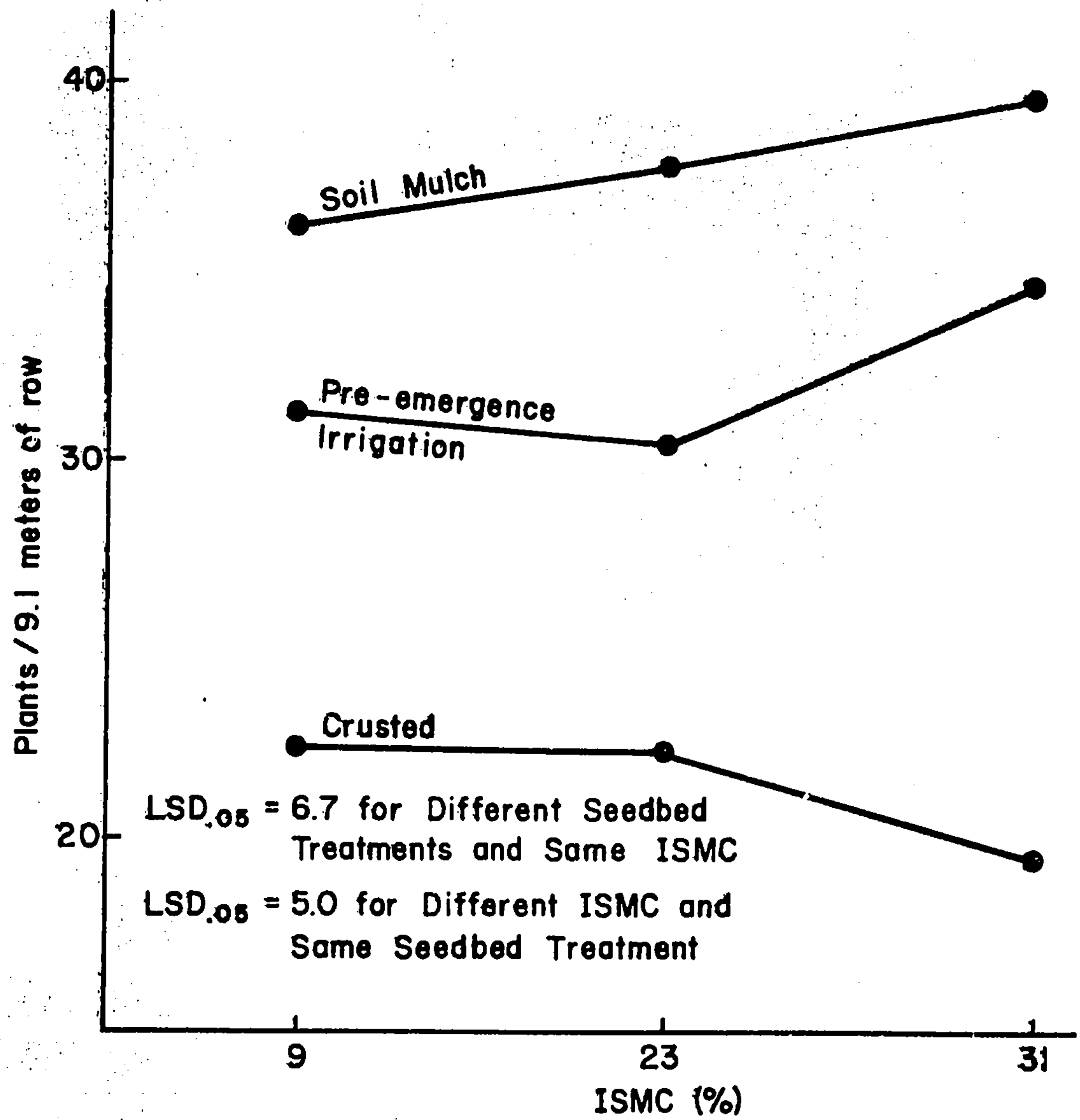

Figure 3. The effect of initial seed moisture content and the final stand of crusted, pre-emergence irrigation and soil mulch treatments.

seedbed temperatures as the main cause of delayed emergence of corn seedlings in sprinkler-irrigated treatments (Nelson & deMooy, 1979). The high salinity levels of this soil certainly stressed seedlings during the initial period of establishment and probably contributed to the slower rates of emergence in all treatments.

YIELD RESULTS

The average grain yields of crusted, soil mulch and pre-emergence irrigation treatments were 3,454, 4,354, and 4,430 kg per hectare, respectively. Mean separation tests revealed that there were no significant differences in grain yield between mulched soil or pre-emergence irrigation treatments, but both treatments were significantly different from crusted treatments.

The average grain yields of 9, 23, and 31% ISMC treatments were 4,186, 4,121, and 3,929 kg/ha, respectively. Although the yield differences were not considered significant, close inspection of the data revealed some interesting relationships between ISMC and seedbed treatments (Figure 4). The average grain yields of crusted treatment were virtually the same, regardless of ISMC. This would be expected as plant population of these treatments were nearly identical (Figure 3). The average grain yields of pre-emergence irrigation treatments were increased by more than 260 kg/ha when sown with seed at 30% ISMC. A higher average plant population in this treatment easily explained the higher grain yields (Figure 3). However, the average grain yields of soil mulched treatments decreased with increasing ISMC. The average yield decreased by 213 kg/ha when ISMC was increased to 23%, and by 1,047 kg/ha when it was increased to 31%. The plant populations of these treatments were similar, indeed slightly higher as seed moisture content increased (Figure 3). A similar phenomenon was observed in a previous study conducted at Fort Collins. The yield of a soil mulched treatment in that study was decreased by 297 kg/ha when ISMC was increased from 9% to 23% (Nelson and deMooy, 1979).

The results of total dry matter yields were similar to those of grain yields. The average total dry matter yields of crusted, soil mulch and pre-emergence irrigation treatments were 6,632, 8,804, and 8,713 kg/ha, respectively. Again, soil mulch and pre-emergence irrigation treatments were significantly different from crusted treatments, but not from each other.

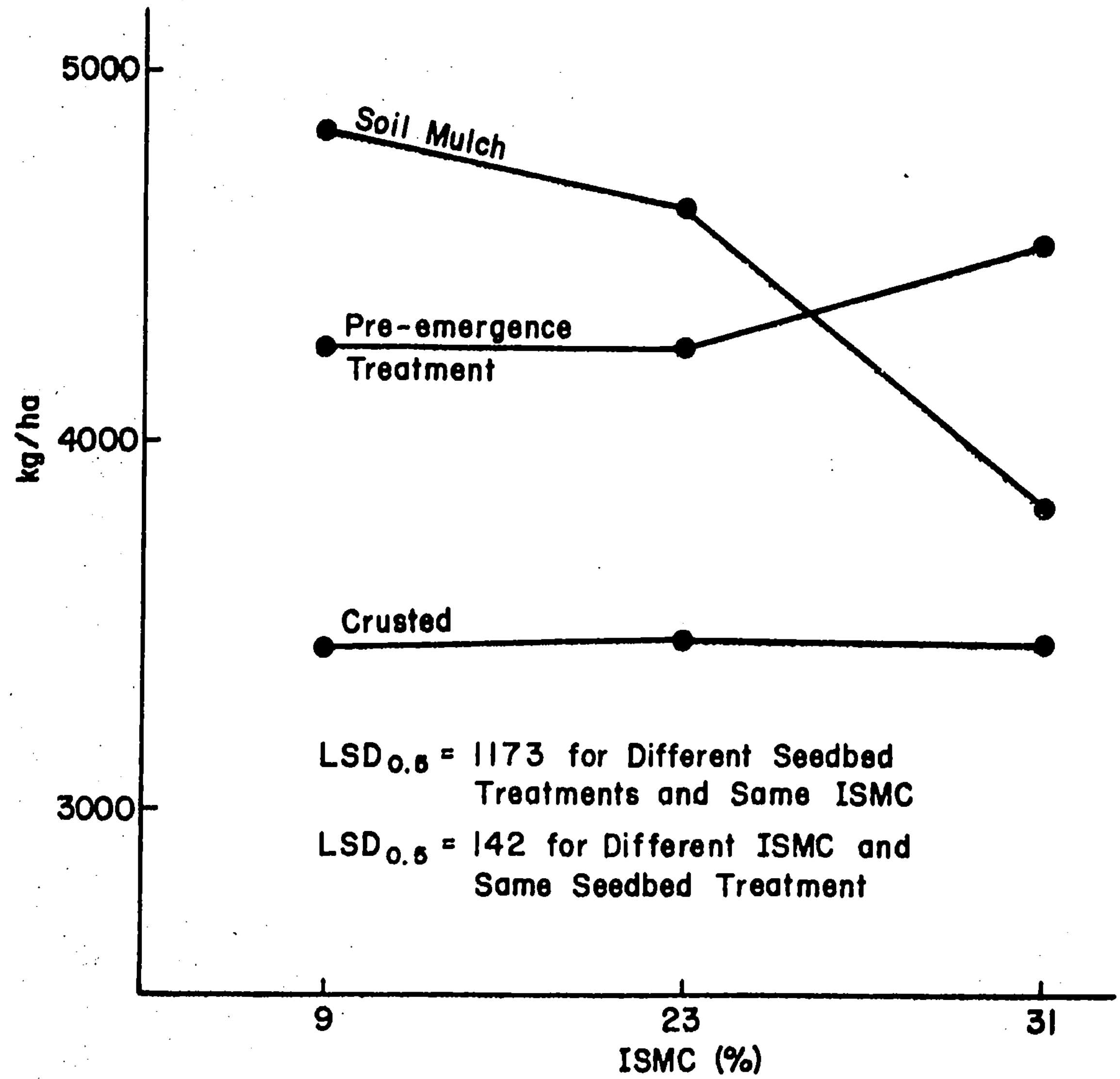

Figure 4. The effect of initial seed moisture content on the grain yields of crusted, pre-emergence irrigation and soil mulch treatments.

Closer inspection of the data revealed similar relationships between ISMC and seedbed treatments. Total dry matter decreased with increasing initial seed moisture content in mulched treatments. The total dry matter yields decreased from 8,407 to 8,169 and 6,932 kg/ha as ISMC increased. Total dry matter increased by nearly 300 kg/ha in pre-emergence irrigated treatments sown with 31% ISMC over similar treatments sown with seed at lower ISMC. However, total dry matter yields of crusted treatments were decreased by over 500 kg/ha when sown with seed at 31% ISMC.

SUMMARY AND CONCLUSIONS

A field trial concerned with stand establishment of field corn in a severely crusted soil was conducted at the Mesa College farm near Grand Junction, Colorado. The soil, a Billings silty clay loam, had a total sand, silt and clay content of 20.48 and 32%, respectively. The mineral suite of the $<$ 0.002mm clay fraction was dominated by vermiculite, smectite (montmorrillonite), kaolinite and illite with lower amounts of chlorite and quartz.

Soil analysis revealed that this was a saline-sodic soil, with an average electrical conductivity of the saturated paste extract of 9.0 mmhos/cm and an exchangeable sodium percentage ranging from 7.2 to 27%. The soil was also found to be highly gypsiferous, but reclamation by the application of leaching treatments might be difficult because of poor infiltration and internal drainage characteristics and a water table varying from 1 to 2 meters below the soil surface.

A 3 x 3 factorial design, replicated 4 times, was used to test the effects of prehydrated seed and seedbed treatments on the stand establishment and yield of field corn. Pre-plant initial seed moisture contents (ISMC) were 9, 23, and 31%, respectively. Two days after sowing, an average of 2.8cm of water was applied to the study area with a semi-portable sprinkler irrigation system. After the sprinkler irrigation, the experimental area was subdivided into subplots consisting of crusted, soil mulched and pre-emergence irrigation treatments. Soil mulch subplots were mulched three days after sowing and pre-emergence irrigation subplots were irrigated seven days after sowing.

The physical impedance of crusts in crusted treatments was measured by two different methods. Both methods demonstrated that maximum crusting strength occurred on the fifth day after sowing. Force measurements, simulating resistance to shoot emergence through crusts, varied from a low of 2.0

$x\ 10^5$ dynes to a high of 4.6×10^6 dynes. More traditional measurements with a penetrometer varied from 7.5×10^5 dynes to 4.2×10^6 dynes. The agreement between the daily averaged values obtained by the two methods was fairly close.

Although significant improvements in the emergence of seed at higher ISMC were observed for the first eight days after sowing, prehydrated seed treatments did not improve overall emergence in crusted treatments. The initial emergence of prehydrated seed in crusted treatments was slowed by low seedbed temperatures and high salinity levels. There were no significant differences due to ISMC in final stands. Neither grain yield or total dry matter was found to vary with ISMC.

Soil mulching of crusted treatments increased the final stands by 43%. The application of a pre-emergence irrigation to crusted treatments improved final stands by 33%.

Grain yields of soil mulched, pre-emergence irrigation, and crusted treatments were 4,430, 4,354 and 3,454 kg/ha, respectively. Similar total dry matter yields were 7,836, 7,731 and 6,134 kg/ha, respectively.

The grain yields of pre-emergence irrigated treatments were increased by over 250 kg/ha when sown with prehydrated seed at 31% ISMC. But, grain yields of soil-mulched treatments decreased by 200 kg/ha, when ISMC was increased from 9% to 23%. Furthermore, a reduction in yield of more than 1,000 kg/ha occurred when ISMC was raised to 31%.

The data from this study reveals soil mulching to be the most effective method for improving stands and grain yields of field corn grown in severely crusted soils. A pre-emergence irrigation application, to soften crusts, was also shown to increase both stands and grain yields of field corn. Further improvements in stands and grain yields may result with two or more pre-emergence irrigation applications.

Prehydrating seed prior to sowing did not improve stands or yields of field corn grown in a severely crusted soil. Although prehydrated seed was observed to improve the stands and yields of pre-emergence irrigation treatments, a large decrease in the yields of soil mulch treatments occurred with increasing preplant seed moistures. Thus, prehydrating seed prior to sowing does not appear to be a feasible method for improving stand establishment and yields of field corn in severely crusted soils.

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APPENDIX 4

A HAND OPERATED CRUST BREAKER[1]

L. Nelson[2]

A hand operated crust breaker has been found to perform well in both weakly and severely crusted soils (Fig. 1). The use of this implement in soil crusting experiments indicates a farmer could break soil crusts on 3 to 4 acres per day.

To operate the crust breaker, it is first centered over a seed row and then pushed at near normal walking speed. By simply exerting a slight downward force, the operator can break through more severely crusted portions of the field. Where crust strengths are too severe for normal operation of the implement, it may be necessary to tie weights on the lower handle to exert more downward force. The 4 to 4 1/2 inch band of soil mulched by the crust breaker will permit normal emergence of seedlings.

The crust breaker could be constructed in any town in Pakistan where a welder is available. The materials needed for construction are widely available throughout Pakistan.

Materials Needed

Quantity	Description
1	12 x 8 inch piece of 1/8 inch thick steel plate
1	1 x 2 inch hardwood hoard 5 feet in length
1	8 inch length of 5/8 diameter steel rod
2	1 3/4 inch length of 1 inch inside diameter pipe
2	2 inch wood screws
2	1 inch cotter pins or 5/8 inch nuts
4	2 inch washers with 11/16 inch holes

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[1]The crust breaker was originally designed for use in sugar beet experimental plots by USDA personnel, Fort Collins, CO.

[2]Graduate Research Assistant, Department of Agronomy, Colorado State University, Fort Collins, CO.

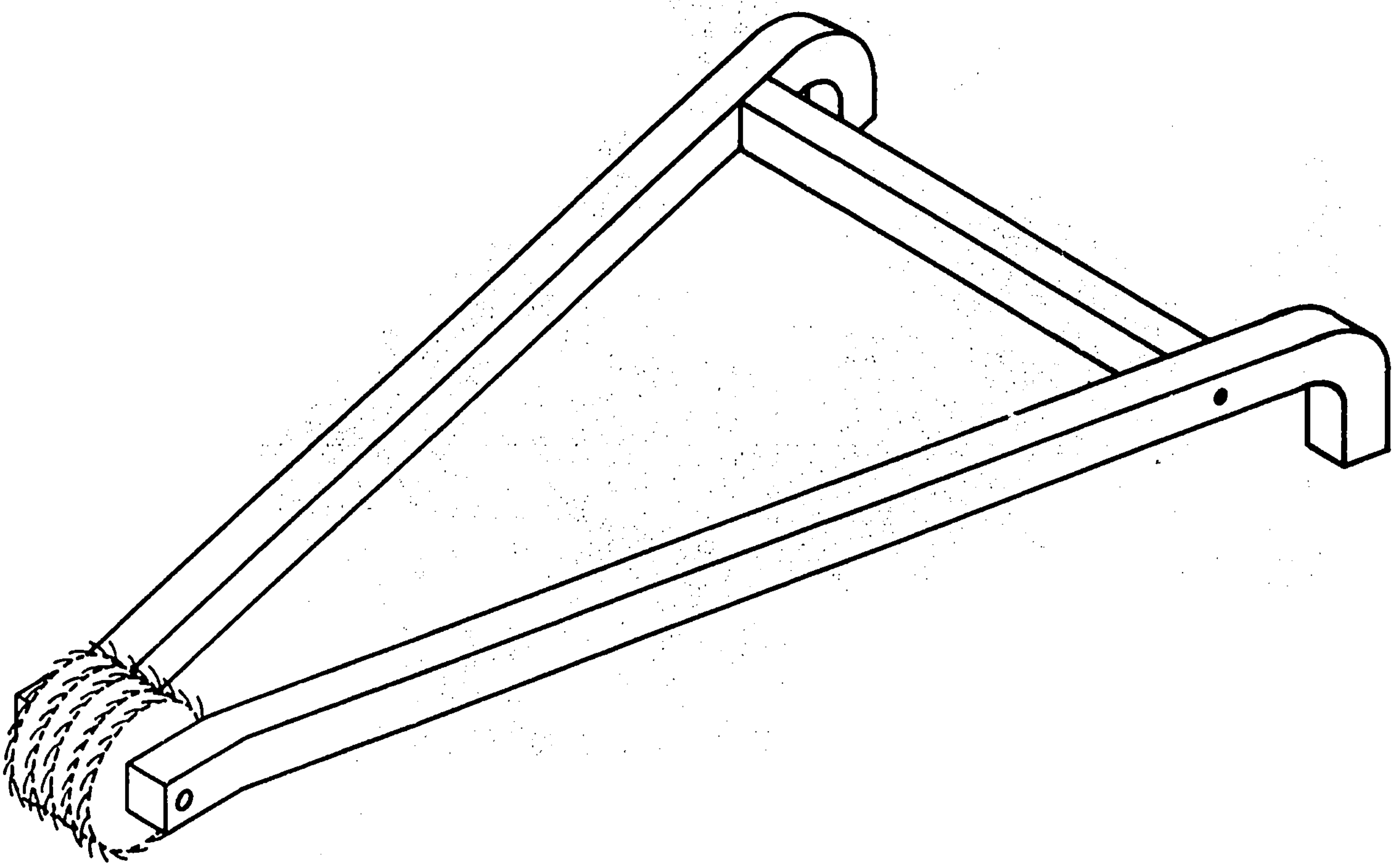

Figure 1. A hand operated crust breaker.

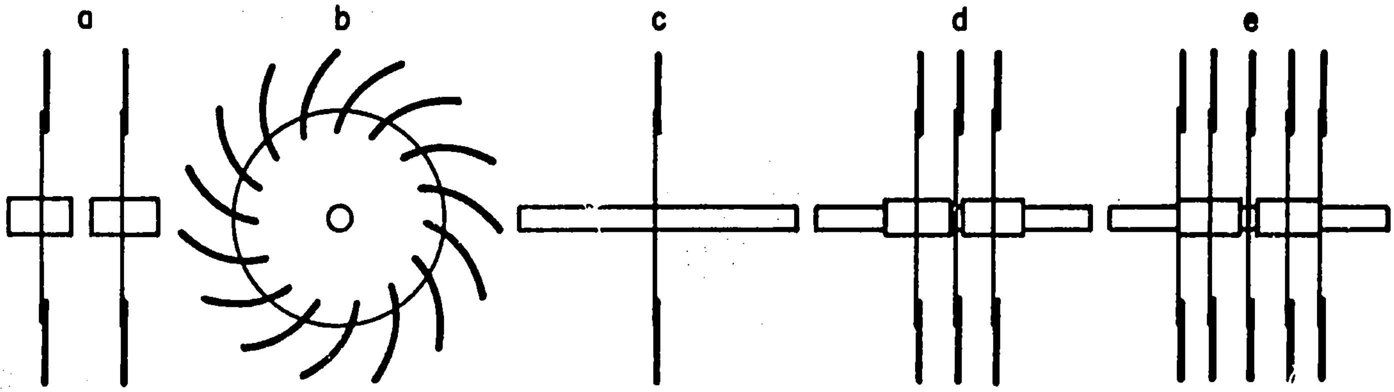

Figure 2. The rotary hoe assembly, including, a) the free rotating rotary blade, b) the rotary hoe blade, c) the central fixed rotary blade, d) the free rotating rotary blades position on either side of the fixed blade, and 3) the rotary hoe assembly.

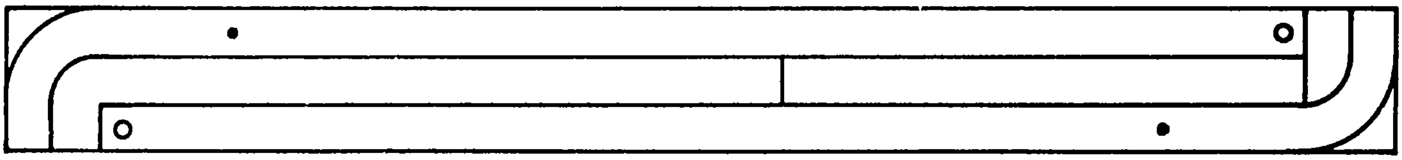

Figure 3. The handles and crossbar.

The rotary hoe assembly is constructed from a 8 1/2 inch long, 5/8 inch diameter steel rod; a 12 x 18 inch steel plate and a total length of 170 inches of 1/4 inch diameter steel rod. Five 6-inch diameter rotary hoe blades are cut from the steel plate and a 1 1/4 inch diameter hole is drilled through the center of two of the blades. A pipe, 1 3/4 inches long is centered in the hole of each blade and welded in place (Fig. 2a). The two blades are called free rotating rotary hoe blades. The 1/4 inch diameter rod is cut into seventy-five 2 1/2 inch sections for the rotary hoe tines. Each tine is bent slightly and the end of the tine is filed at a 30° angle to form a cutting edge. Fifteen of the tines are welded on the outer edges of each of the five rotary hoe blades, 1 1/4 inches apart and 5/8 of an inch from the outer edge of the blade (Fig. 2b). A 5/8 inch diameter hole is drilled in the center of the other three undrilled rotary blades. One of the blades is welded to the center of the 8 inch long axle (Fig. 2c). The two free-rotating rotary hoe blades are placed on either side of the central fixed-rotary hoe blade (Fig. 2d). The two remaining are welded on either side of the free-rotating blades with a 2 inch spacing between the blades and the central fixed blade (Fig. 2e).

The handles and the cross bar are cut from the 5-foot long 1 x 6 inch wide hardwood board as shown in Figure 3. After cutting, the handle grips are shaped by trimming the rough edges. Two-inch wood screws are used to fasten the the 22 1/2 inch long crossbar to the handles. The rotary hoe assembly is attached to the handles with either cotter pins, or nuts, if the axle ends are threaded. Washers placed on the axle to either side of the handles keep the axle from binding and protects the handle from excessive wear (Fig. 3).

APPENDIX 5

INFLUENCE OF STUBBLE AND TILLAGE ON MOISTURE AND NITROGEN CONSERVATION UNDER MONSOONAL CONDITIONS

by

M. A. R. Farooqi, C. J. deMooy and J. Olson[1]

INTRODUCTION

Pakistan's dryland agriculture is characterized by cultural practices which lead to excessive loss of moisture and nitrogen. Conservation of these could increase the crop yields. There is a general practice of increased plowing and planking among the farmers in Pakistan. Research has shown that frequent tillage operations are rarely beneficial and frequently detrimental in addition to being costly (Arnon, 1972). Studies have indicated that tillage operation wastes water by exposing moist soil to sun and wind. Soil surfaces loosened by tillage often lose all moisture to depth of tillage (Hanway, 1976). Smika (1976) reported that standing stubble was more effective in reducing soil water loss than where all residue was flat, probably because stubble reduced wind velocity at the soil surface. Further, stubble has been found to reflect 9% more incident solar radiation than bare soil, thereby reducing evaporation.

Most studies showing conservation of moisture due to decreased tillage and stubble maintenance have been conducted in areas where snow catchment is a major problem. To study the influence of tillage and stubble on moisture and nitrogen conservation under monsoonal conditions, the present study under rainfall condition was undertaken.

OBJECTIVE

1. To study the conservation of residual soil water unused by crop as affected by stubble mulch and tillage.

2. To investigate the moisture conservation by stubble and tillage under monsoonal condition.

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[1]Graduate Research Assistant, Professor and Laboratory Assistant, respectively, Department of Agronomy, Colorado State University, Fort Collins.

3. To determine the movment and distribution of nitrogen as influenced by moisture.

4. To determine the effectiveness of tillage and chemical control on weed growth.

MATERIALS AND METHODS

One site each under short and long stubble was selected during the summer, 1978, by cutting the standing wheat to the required height for short and long stubble treatment. The field plot design was split-split plot with the following treatments:

Stubble conditions (main plot)

1. Stubble, short - 9 cm high
2. Stubble, long - 45 cm high

For this purpose the stubble was cut to the desired height.

Tillable (subplots)

For Objective 1 (conservation tillage for soil residual moisture)

1. Sweep after harvest (SH).
2. Chisel after harvest (CH)
3. Initial sweep and sweep after thunderstorm of about 1" (ST)
4. Initial chisel and chisel after thunderstorm of about 1" (CT)
5. No till - chemical control (NT)

For Objective 2 (moisture conservation during and after monsoon)

1. Sweep at "wattar"* (SW)
2. Chisel at "wattar" (CW)
3. Sweep at "wattar" and after thunderstorm (SW-ST)

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*Wattar - proper soil moisture condition when implement could first turn.

4. Chisel at "wattar" and after thunderstorm (CW-CT)

5. No till - chemical control (NT)

The field layout plan is given in Figure 1.

RESULTS AND DISCUSSION

There is an indication that more moisture was conserved under long stubble than short stubble conditions. Weed growth was controlled to a great extent by use of herbicide in the no till treatment compared to the tillage operation. The results of this study could be well applied in rainfed areas of Pakistan. The monsoonal precipitation could be conserved by manipulating stubble and tillage conditions to achieve effective weed control and minimizing evapotranspiration and reduce evaporative losses by creating a mulch.

A follow-up greenhouse experiment is in progress with the following treatments:

Main

1. Short stubble

2. Long stubble

Subtreatment

1. No till - chemical weed control

2. Tilling after 6" accumulative rainfall

3. Tilling after '" rainfall

Sub-subtreatment

1. 0 - 0 - 0

2. 50 - 0 - 0

Sacrifice one replication for moisture and nitrogen analysis after 12" irrigation

Remaining

Total number of pots = 2 x 2 x 3 x 3 = 36

The subtreatment of tillage was provided because of the physical limitation of the experiment.

Initial results indicate that long stubble conserved more water than short stubble.

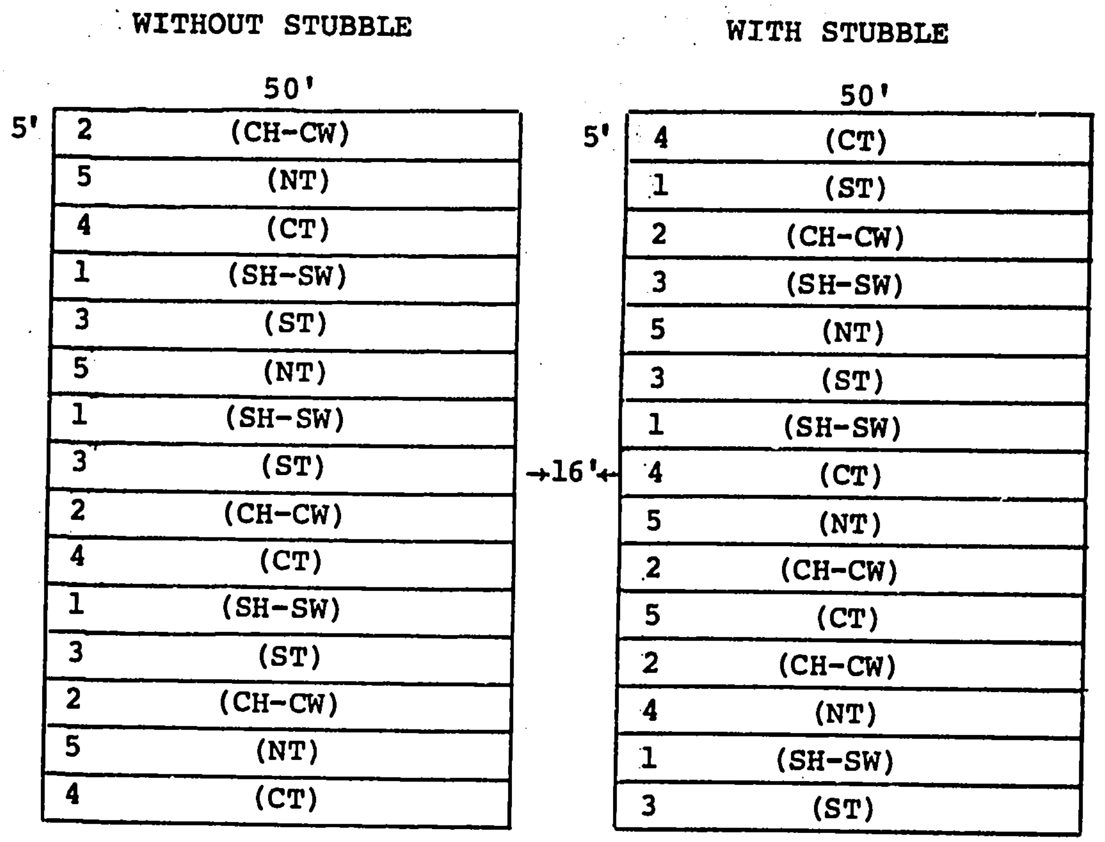

Figure 1. Field layout plan.

APPENDIX 6

IRRIGATION SCHEDULING IN PUNJAB OF PAKISTAN[1]

by

M. A. Gill[2] and A. C. Early[3]

ABSTRACT

A farm water management research project was conducted to determine practical irrigation scheduling techniques, to demonstrate the potential for water scheduling for cool season and hot season crops, and to evaluate the potential for improving on-farm irrigation application efficiency through closely controlled irrigation. The Class A evaporation pan with locally verified crop coefficients is recommended for practical irrigation scheduling in Pakistan.

Practical irrigation schedules on leveled land for wheat saved up to 10 centimeters of water, improved irrigation application efficiency by more than 20%, and resulted in increased crop yields by 0.88 ton/hectare. For maize fodder up to 10 centimeters of water was saved, irrigation application efficiency improved by up to 38% and the increased crop yield was 24 tons of forage per hectare.

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[1]Paper presented at the American Society of Agricultural Engineers Joint Meeting with the Canadian Society of Agricultural Engineers, June 25-27, 1979, at the University of Manitoba, Winnipeg, Manitoba, Canada.

[2]Deputy Director, On-Farm Water Management Improvement Project, Government of Punjab, Lahore, Pakistan.

[3]Associate Agricultural Engineer, Irrigation Water Management Department, International Rice Research Institute, Los Banos, Philippines, both formerly associated with the Colorado State University, Water Management Research Project in Pakistan under USAID contracts AID/ta-c-1100 and AID/ta-c-1411. All opinions are those of the authors and not necessarily those of the funding agency, the United States Government, Colorado State University, the Government of Pakistan or the International Rice Research Institute.

INTRODUCTION

Agriculture in Pakistan is heavily dependent upon the world's largest integrated irrigation system, the Indus Basin System. More than 100 years of development have resulted in a system with more than 96,000 kilometers of canals commanding approximately 13.3 million hectares of land and supplemented by approximately 120,000 private and public sector tubewells.

The emphasis in the past 20 years of development and partial replacement of the system have been largely concentrated on expanding the water supply available, with the 4 million end-user farmers left to look after the tertiary level irrigation activities. The recent recognition of the importance of farm water management (Corey & Clyma, 1974 and Clyma & Corey, 1974) in the nearly 80,000 tertiary units or watercourse command areas has given emphasis to the improved management of existing resources. The water saved at the farm level through improved management is likely to be equivalent in total volume to the capacity of the large storage dams built at tremendous cost to Pakistan and the donor countries.

Recent Research Results

Recent research by the Colorado State University Water Management Field Farm in Pakistan has indicated the current state of farm level water management through a survey of 40 watercourses across the irrigated districts of Punjab and Sind (Lowdermilk, et al., 1975 and Early, et al., 1978). Those results indicated the tertiary level watercourse command has a mean conveyance efficiency of approximately 60% and that the farm application efficiency averages 75%. These two efficiencies provide a net subsystem or tertiary level mean efficiency of 45%, considerably less than the estimates of the earlier studies (Gibb, 1966).

The Indus Basin System has a mean annual flow of approximately 17.3 million hectare meters (MHM) of water, of which 11.1 MHM are diverted to the irrigation system annually (Figure 1). The estimated losses in the conveyance system between the storage dams and diversion weirs to the tertiary level turnout are assumed to be 33%. With this level of losses, this leaves 7.4 MHM available to the watercourse command areas. However, within the watercourse commands, 8,000 public tubewells pumping at an average rate of 100 l/sec and 120,000 private tubewells pumping at average rate of 20 l/sec provide an input of nearly 50% of that available from the canal system making 11.1 MHM available at the head

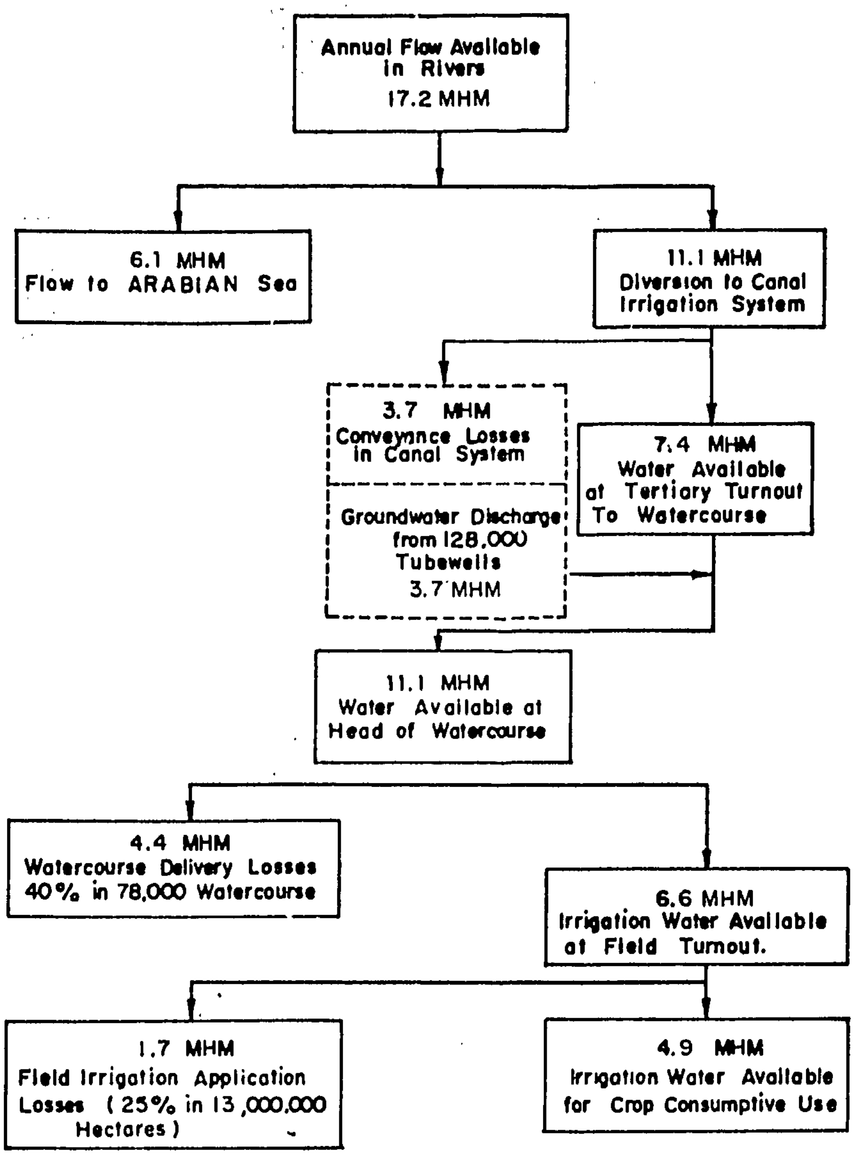

Fig. 1. Pakistan's Indus basin water budget (after Early, 1975).

of the watercourse tertiary level system. With 60% conveyance efficiency this makes 6.7 MHM available at the field and 75% application efficiency makes 5.0 MHM available for crop consumptive use. The losses in the tertiary level subsystem have become the research target in two combined theses on the topic of farm water management. The first was concerned with the conveyance losses and land leveling improvements as previously reported by Shafiq, et al., (1978). This research concerns the losses in field application and the benefits to be demonstrated by scientific irrigation scheduling.

Research Objectives

The objectives of the research were stated in the following questions: What is the most practical method for prediction of potential evapotranspiration as basis for irrigation scheduling in Punjab of Pakistan?

What are practical irrigation schedules for wheat grown in cool season and maize fodder grown in the hot season?

What is the potential for improving the on-farm irrigation application efficiency when timing of water and quantity applied are closely controlled?

The research was conducted using the case study method on a selected watercourse command area near Lahore. The research application was made to precision land leveled fields with a tolerance ± 1.5 cm within an area of 0.1 to 0.2 hectare and control fields under farmer management.

MATERIALS AND METHODS

The primary determinant of crop water needs is atmospheric demand for water due to radiation, humidity and wind factors. Secondary factors are the crop, growth stage, rooting depth and soil moisture availability (Chang, 1968). Methods of determination of crop consumptive use of water, herein assumed equivalent to actual evapotranspiration, have been developed and were compared in extensive specific location field tests reported by Jensen, et al., (1973).

Two particular methods of prediction of potential evapotranspiration (PET) which have received particular attention are the Penman equation and the Jensen-Haise equation both based on the combined effects of radiant energy and the aerodynamic effect of wind movement, (Jensen and Haise, 1963). In addition the U.S. Weather Bureau

Class A evaporation pan has received much attention as a meteorological instrument, the exposure pan has received much attention as a meteorological instrument, the exposure of which in an irrigated area tends to integrate the major factors affecting crop consumptive water use.

The determination of actual evapotranspiration (AET) from PET predictions requires knowledge of a proportionality factor, called the crop consumptive use coefficient (CC). The CC is a factor that depends on the crop type, spacing and height as a three dimensional surface intercepting energy and varies with the age of the crop as the vegetation density changes. The AET is determined as the product of CC and PET and expressed as a function of time. Numerous observers (Jensen, et al., 1973 and Chang, 1968) have summarized CC factors from numerous crops at many locations. Haider, et al., (1975) and De Mooy, et al., (1975) have summarized preliminary CC coefficient results for Pakistan conditions.

The recent growth in irrigation scheduling services and the advantages in water saving due to controlled water application were chronicled by Gill (1977). The application of scientific irrigation scheduling to the fixed irrigation delivery schedule of Pakistan indicated the method by which soil, crop, previous irrigation date and water availability schedule could be integrated into a program requiring field verification (Early, 1975).

The methodology employed in this research included four stages. First was the selection and establishment of the research site with available paired precision leveled and unleveled fields and a meteorological station at the site. The instruments included a recording and non-recording rain gauge, an evaporation pan, a hygrothermograph, a minimum-maximum thermometer, annemometer, and a net radiation device, which never gave satisfactory results. At this stage detailed soil moisture sampling and characterization was conducted. The soil moisture parameters are tabulated in Table 1.

The second stage corresponded to the establishment and monitoring of a cool (rabi) season maize crop in December. Measurements included intensive soil moisture sampling and determination by the gravimetric method, measurement of agrometeorological parameters to predict PET (Israelsen and Hansen, 1962) and measurement of all water inputs to the plots by cutthroat flumes. The monitoring of soil moisture was done 1 day before and 2 days after each irrigation to apply the moisture balance (Figure 2) and minimize losses as surface runoff and deep percolation. Soil moisture depletion

Table 1. Summary of Mean Available Moisture Percentage for Experimental and Control Plots

	Hakeem Farm Expt. Plot #1	Mehtab Farm Expt. Plot #2	Liaqat Farm Control Plot #1	Majeed Farm Control Plot #2
1. Field Capacity (% on weight basis)	21.9	22.2	22.9	18.5
2. Permanent wilting point (% on weight basis)	8.9	8.5	7.3	8.8
3. Available soil moisture (% on weight basis)	13.0	13.7	15.6	9.7
4. Mean Dry Bulk Density (apparent specific gravity)	1.2	1.4	1.2	1.4
5. Available Moisture (% on volume basis)	16.2	19.0	19.5	13.6
6. Available Soil Moisture (cm/30cm depth)	4.9	5.8	5.9	4.1

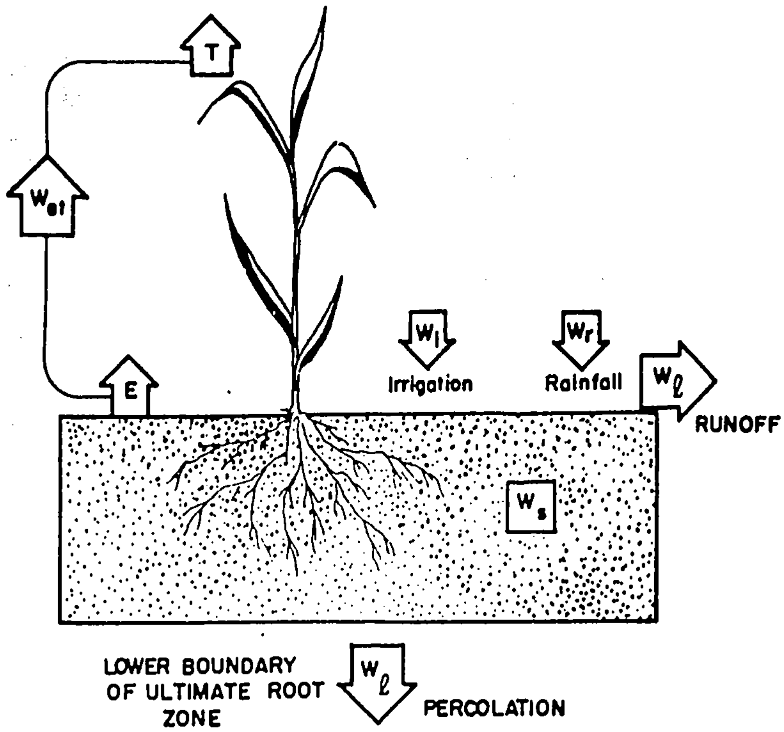

Fig. 2. Sketch for water balance equation.

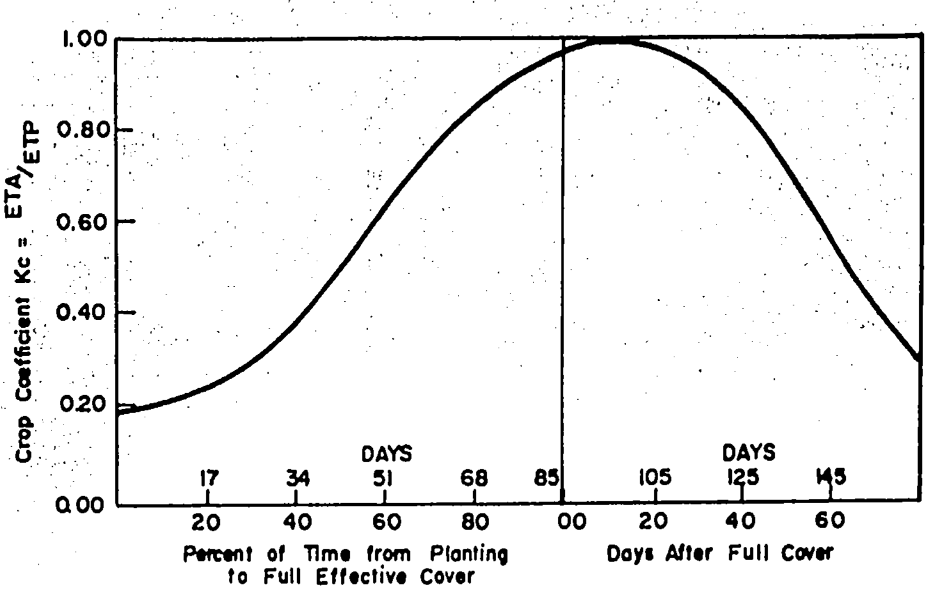

Fig. 3. Crop coefficients for maize (after Jensen and Haise, 1963)

to 180 centimeters between irrigations and samplings was taken as the standard of actual evapotranspiration, AET. Potential evapotranspiration was calculated according to the equation of Penman (calculated using modified constants for arid areas suggested by Maier (1969), Jensen-Haise and compared to the Class A pan. Irrigation scheduling was done using the crop consumptive use coefficient of Jensen, et al. (1973) in Figure 3. Irrigation application efficiency was calculated using the equation

$$E_a = \frac{SMD}{D_i} \times 100$$

where SMD is the accumulated soil moisture deficit below field capacity for the root zone just prior to irrigation and D_i is the depth of irrigation water applied. Crop yield samples were made at randomly selected crop cutting sites.

The third stage corresponded to the establishment and monitoring of a hot (kharif) season maize crop in May, with full implementation of the irrigation scheduling technology tested in the previous season. The methodologies and measurements corresponded to those used on the wheat crop. The methodology used the crop coefficients of Jensen, et al., (1973) and the maize crop rooting depth with time assumption of Figure 4.

The fourth stage was the analysis of data and conclusion of the questions posed as objectives.

RESULTS AND DISCUSSION

The results obtained from the research are detailed soil moisture depletion versus time traces for experimental and control plots, comparison of cumulative potential evapotranspiration curves by various methods, determination of crop consumptive use coefficients as ratios of AET to PET by various methods, tabulation of irrigation application through the season, and tabulation of experimental results of water use, efficiency and crop yield as a result of the irrigation scheduling and precision land leveling.

Wheat Crop

Detailed traces of the available soil moisture depletion versus time and in response to the rainfall and irrigation inputs for 2 experimental and 2 control plots are shown in Figures 5-8. The traces are shown by increments of 15 and 30 centimeter depth intervals to 180 cm maximum depth of

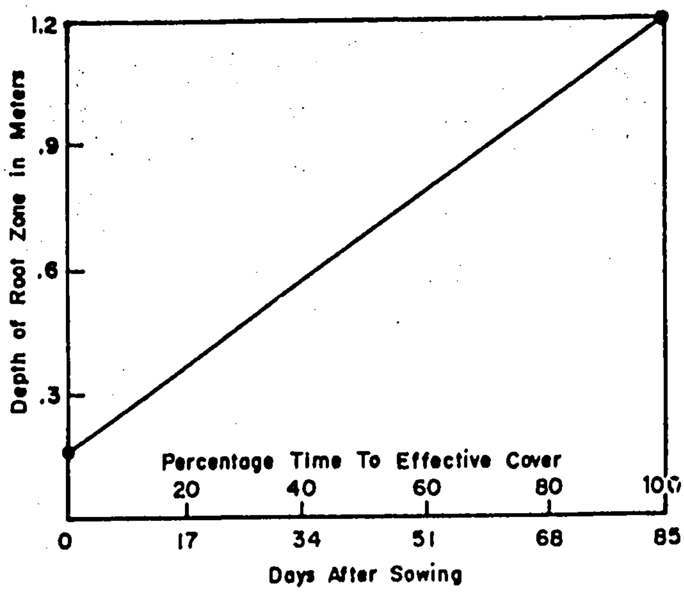

Fig. 4. Assumed root zone accumulated depth over time for maize (after Kincaid and Heerman, 1974).

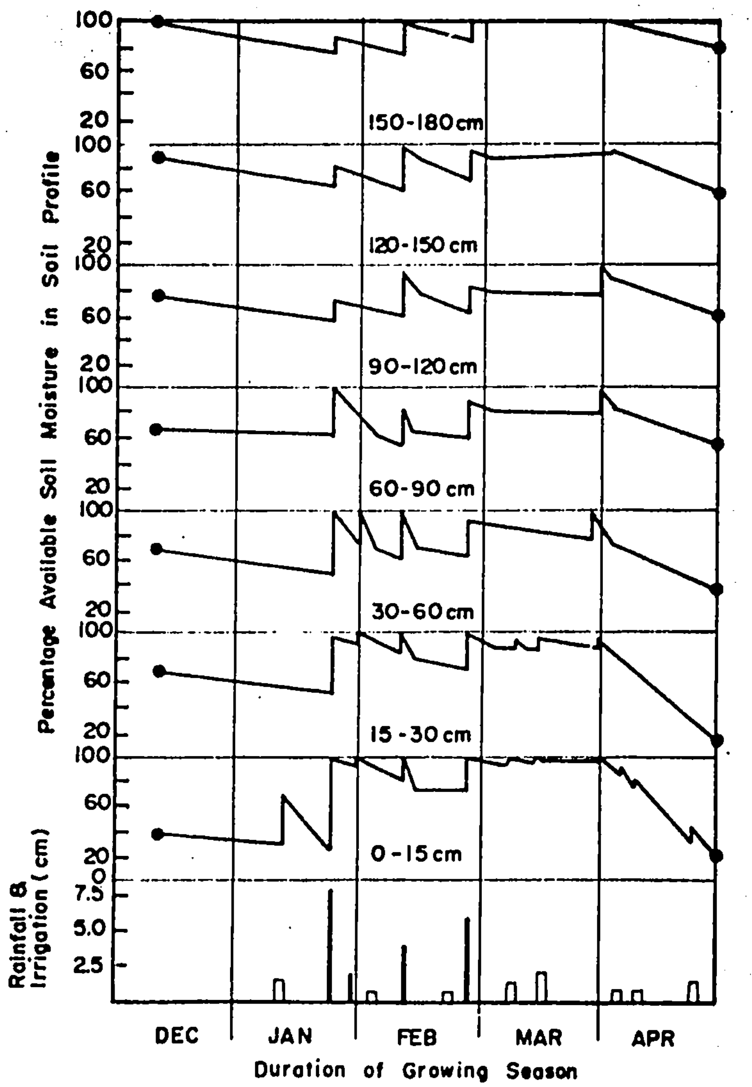

Fig. 5. Available soil moisture with respect to time in experimental plot number one at Hakeem farm.

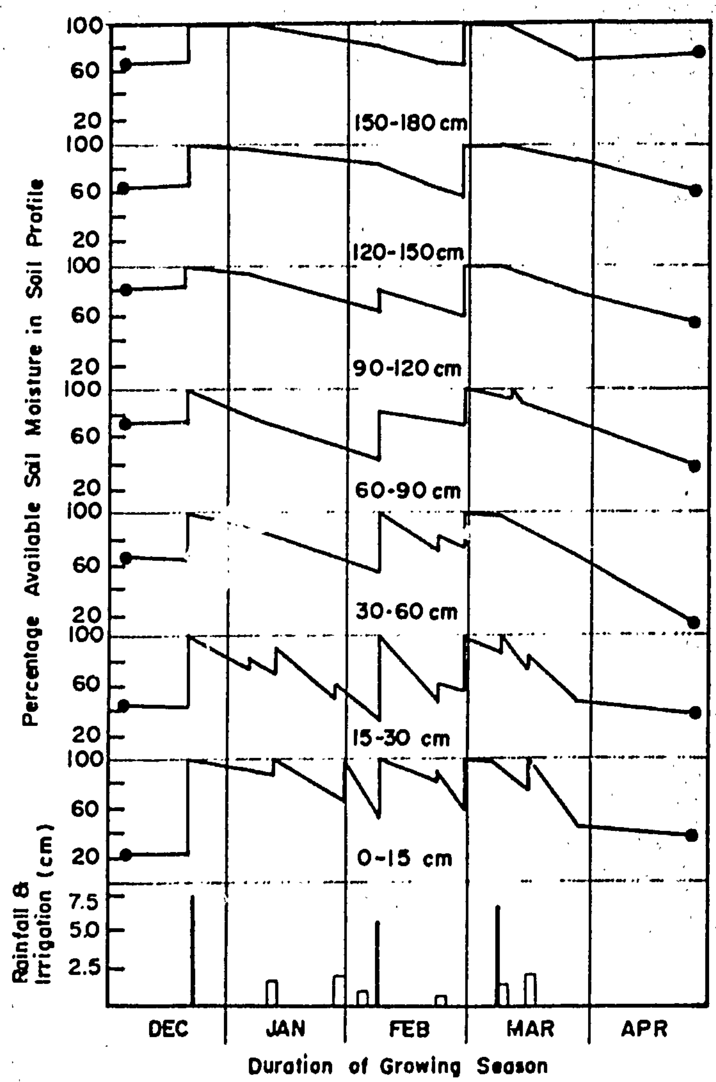

Figure 6. Available Soil Moisture with Respect to Time in Experimental Plot Number Two at Mehtab Farm

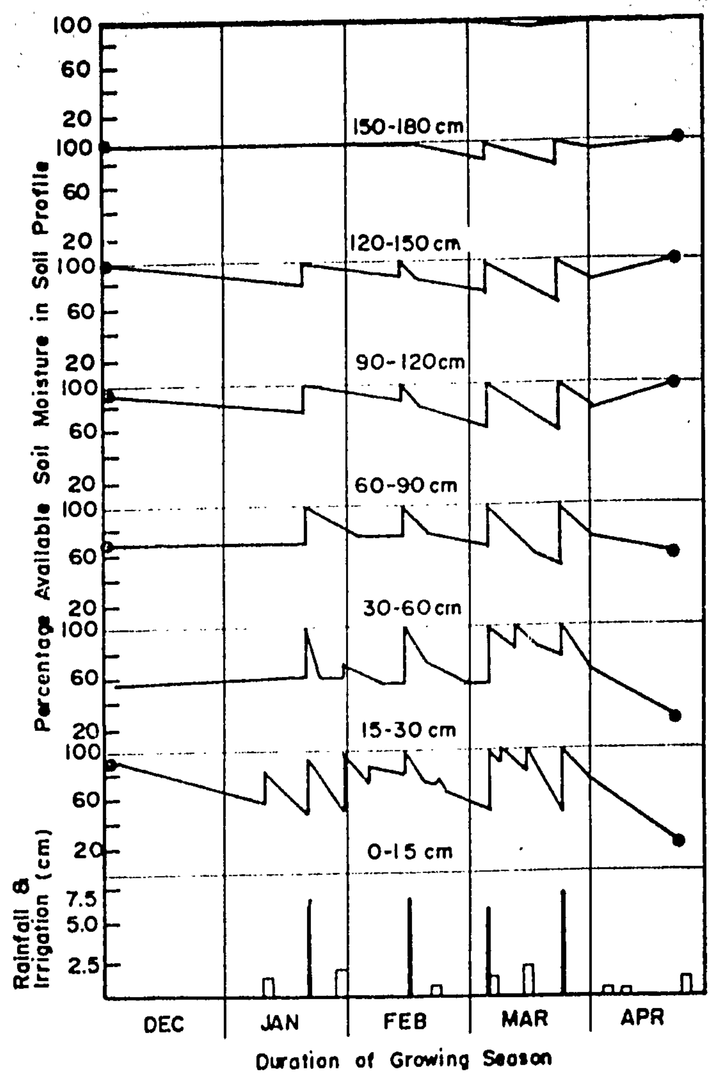

Fig. 7. Available soil moisture with respect to time in control plot number one at Liaqat Farm.

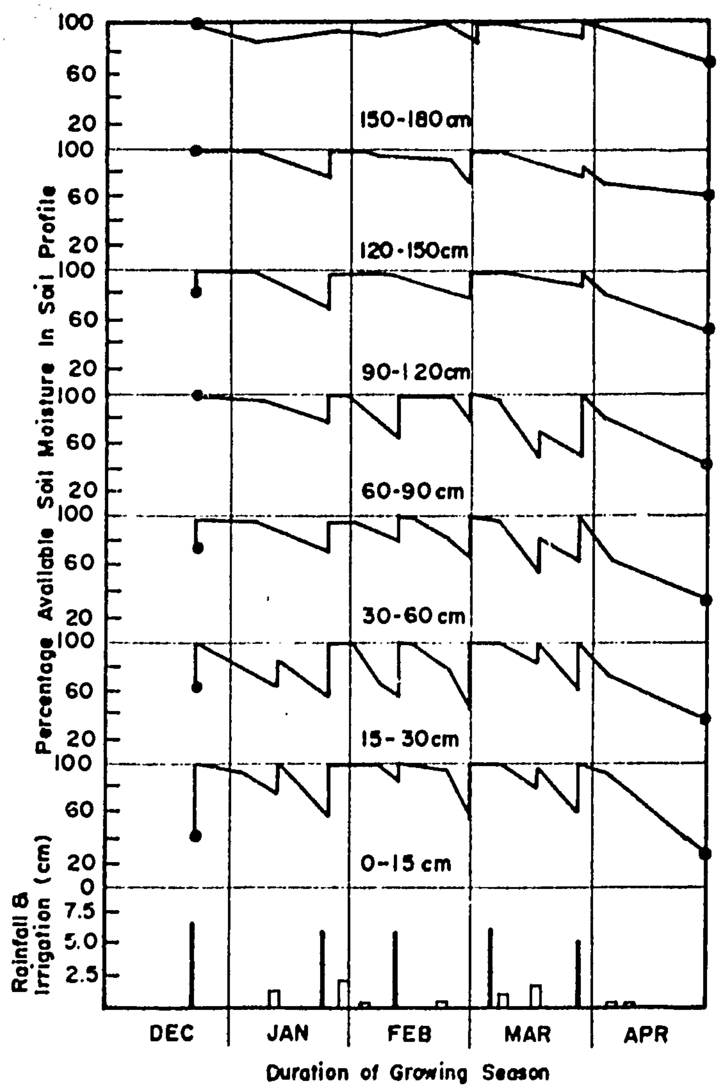

Fig. 8. Available soil moisture with respect to time in control plot number two at Majeed farm.

sampling. The less frequently irrigated experimental plots indicate greater soil moisture depletion at each interval than do the more frequently irrigated farmer controlled plots.

The comparison of methods of predicting PET are shown in Figure 9. A close correspondence is shown between the Jensen-Haise, adopted Penman and Class A evaporation pan estimates. The accumulated actual evapotranspiration (AET) curve falls below the PET curves and the Penman estimate using humid region coefficients lags significantly below even the AET curve.

When the AET data is compared to the PET data for pan evaporation Jensen-Haise estimates, the results are shown in Figures 10 and 11 respectively. The daily actual rates in mm/day for the wheat growing season are shown in Figure 12 and the consumptive use coefficients obtained as a function of time are shown in Figure 13. These values show a remarkable similarity to Figure 3 from the literature. This further confirms the non-necessity of further consumptive use experiments around the world as long as some testing of crop varietal response and soil moisture depletion rates are provided locally.

The potential evapotranspiration accumulated in the interval between irrigations, rain occurring, soil moisture depletion just prior to irrigation, water applied and application efficiency for experimental and control plots are shown in Tables 2 and 3, respectively.

The summary of the wheat crop is shown in Table 4. Irrigation applied for wheat on experimental plots averaged 23.5 centimeters with 9.9 centimeters of rain occurring during the season. The farmer controlled plots received an average 33.1 centimeters of irrigation, nearly 10 centimeters of excess.

The mean irrigation application efficiency for experimental plots was 63% while for farmer plots was 43%, a 20% differential. The mean experimental plot yields were 3.60 tons/ha, while the control plot mean was 2.86 tons/ha. The maximum difference between plots was 0.88 ton per hectare.

Maize Fodder

The crop consumptive use coefficients for the maize fodder crop are shown as a function of time in Figure 14. Table 5 contains a summary of the measured AET estimated PET and calculated CC, crop coefficients. The later results demonstrate a near linear function with the passage of time.

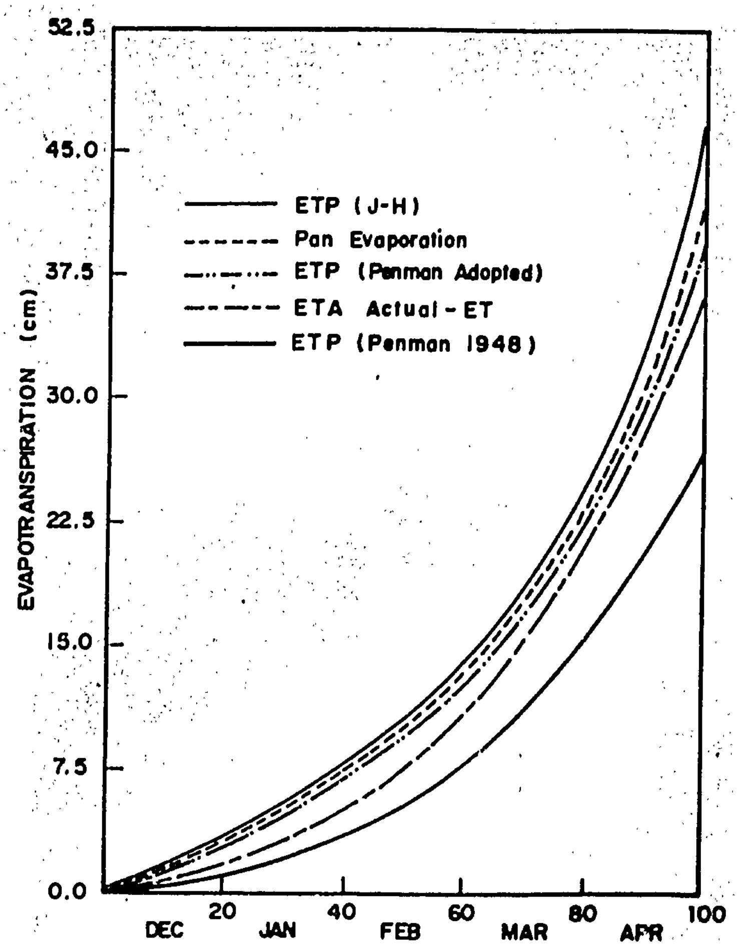

Fig. 9. Cumulative actual and potential evapotranspiration in wheat growing season 1975-76 at Kanjra.

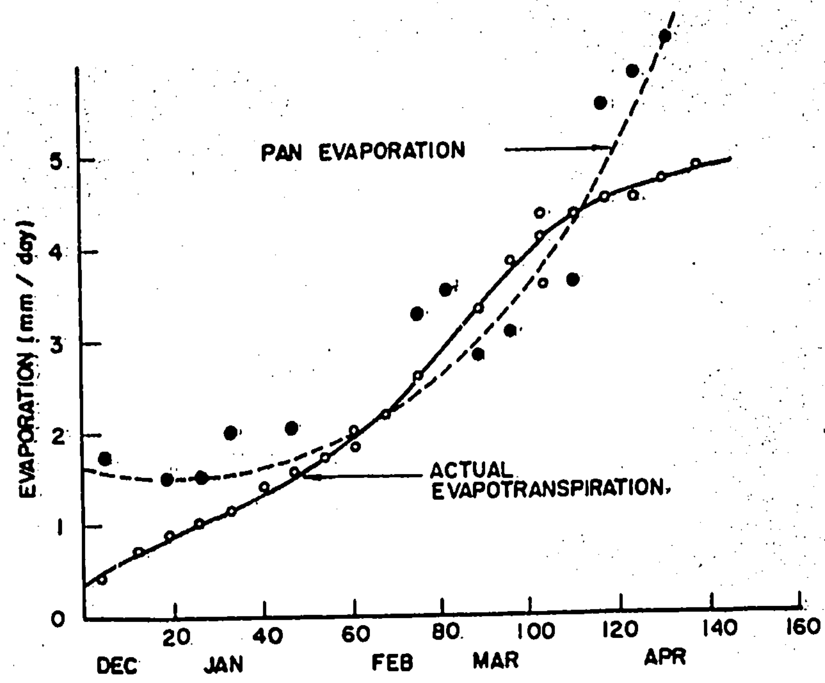

Fig. 10.Relationship between daily pan evaporation and actual evapotranspiration for wheat 1975-76 at Kanjra.

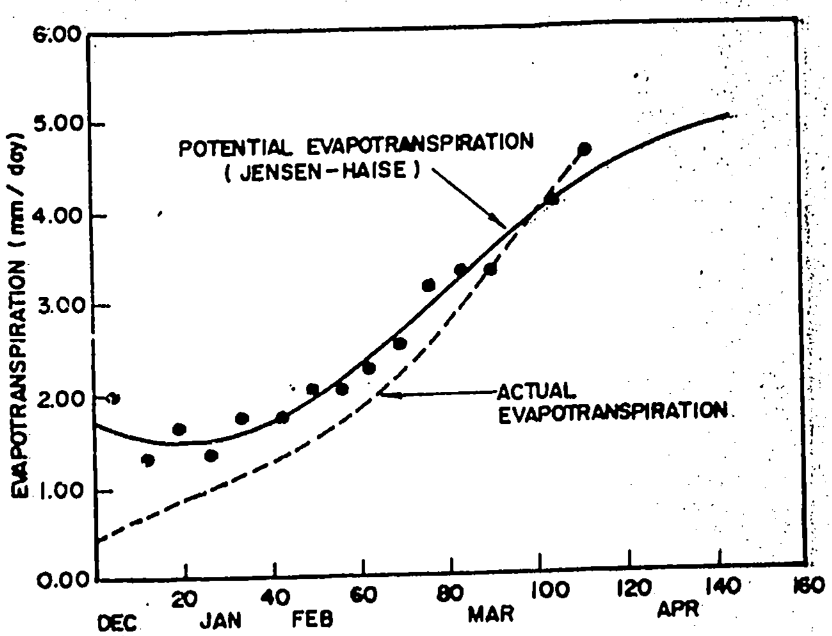

Fig. 11. Daily potential (Jensen-Haise) and actual evapotranspiration for wheat 1975-76.

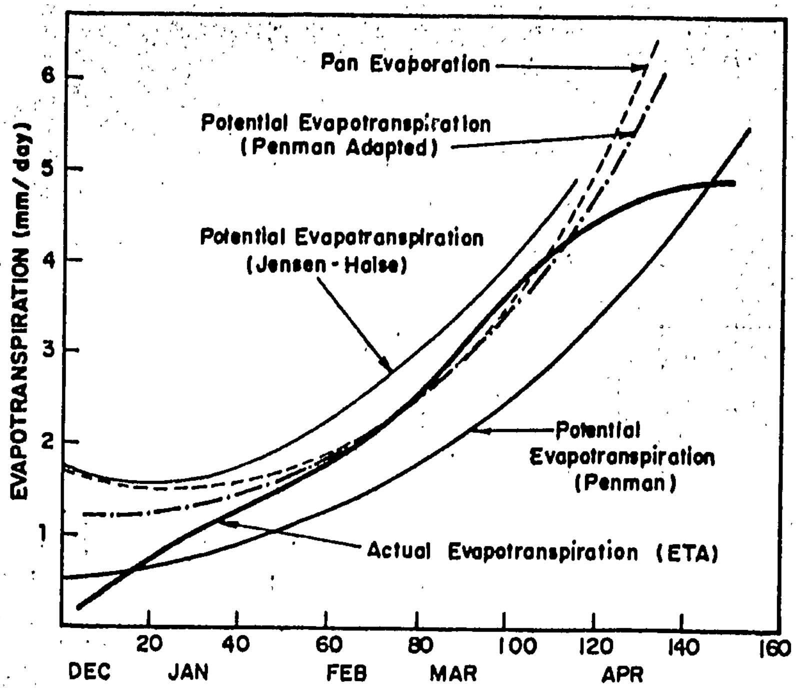

Fig. 12. Comparison of methods of evapotranspiration determination during wheat growing season 1975-76 at Kanjra.

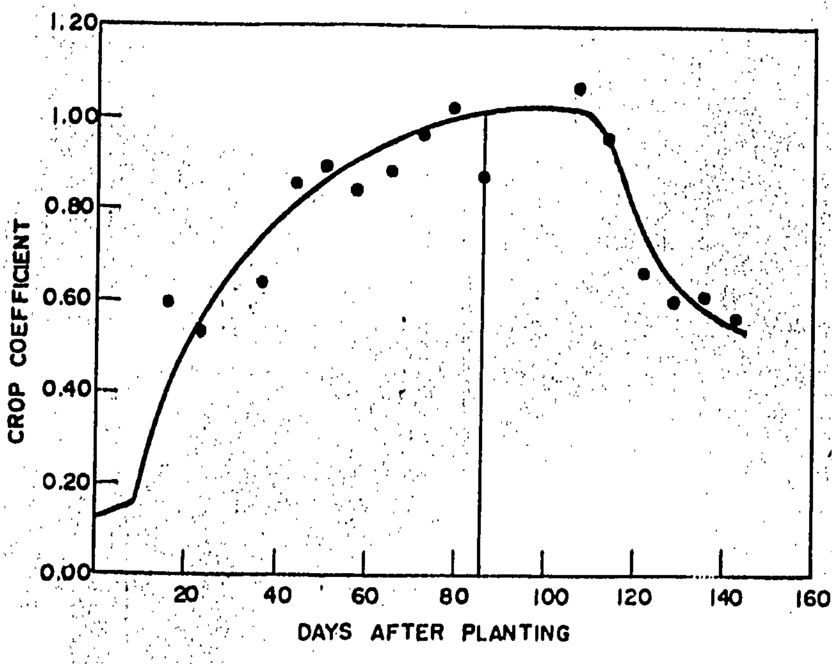

Fig. 13. Experimental crop coefficients for late growing Mexican wheat crop by Jensen-Haise equation.

Table 2. Application Efficiencies on Experimental Fields at Kanjra Watercourse during Rabi 1975-76.

Date Inspected	Days since last irrigation (*after sowing)	Evapotranspiration during Irrigation Interval (cm)	Rainfall during Irrigation Interval (cm)	Soil Moisture Deficiency (cm)	Water Applied (cm)	Application Efficiency E_a (%)
			EXPERIMENTAL FIELD #1			
1/24/76	44*	5.36	1.19	4.17	8.00	52.1
2/14/76	22	4.80	1.83	2.97	4.04	73.6
2/28/76	14	3.56	1.14	2.41	5.72	42.2
3/27/76	27	8.92	2.82	6.10	6.10	100.0
				Seasonal E_a = 67.0%		
			EXPERIMENTAL FIELD #2			
12/22/75	19*	1.45	-	1.45	5.13	20.2
2/8/76	48	6.83	3.18	3.66	5.46	66.9
3/1/76	22	5.03	1.27	3.76	4.57	82.2
				Seasonal Ea = 59.20%		
			Overall Mean Ea = 63.10%			

Table 3. Application Efficiencies on Farmers Control Fields at Kanjra Watercourse during Rabi 1975-76

Inspected	Days since last irrigation (*after sowing)	Evapotranspiration during Irrigation Interval (cm)	Rainfall during Irrigation Interval (cm)	Soil Moisture Deficiency (cm)	Water Applied (cm)	Application Efficiency E_a (%)
12/22/75	19*	7.45	-	1.45	5.92	24.5
1/23/76	50	5.59	1.27	4.32	6.91	62.5
1/25/76	33	3.78	1.27	2.51	5.72	44.0
1/28/76	5	0.89	0.51	0.38	5.08	7.1
2/8/76	13	2.18	1.83	0.36	5.72	6.2
2/18/76	20	3.81	2.29	1.52	6.91	22.0
2/21/76	21	4.80	1.27	3.53	6.50	54.3
3/3/76	15	4.01	0.76	3.25	6.22	52.2
3/7/76	7	1.96	-	1.96	5.64	34.7
3/26/76	21	8.00	2.79	5.21	7.11	73.2
3/28/76	20	6.60	2.79	3.81	4.72	80.6

Seasonal Application Efficiency = 42%

Table 4. Results of On-Farm Water Management Technology Applied at Kanjra Watercourse Area for Wheat Crop in 1975-76 RABI(Cool) Season

Field (Owner and Number	Total irrigation Water Applied during the Crop Growing season (cm)	Total Effective Rainfall during the Season (cm)	Seasonal Application Efficiency E_a (%)	Average E_a (%)	Crop Yield (t/ha)
		Wheat Season 1975-76			
Experimental Field #1 (Hakeem Farm)	23.85	9.91	67.0	63.1	3.55
Experimental Field #2 (Mehtab Farm)	23.29	9.91	59.2		3.65
Control Field #1 (liagat Farm)	32.18	9.91	43.6	42.6	2.96
Control Field #2 (Majeed Farm)	34.06	9.91	41.9		2.77

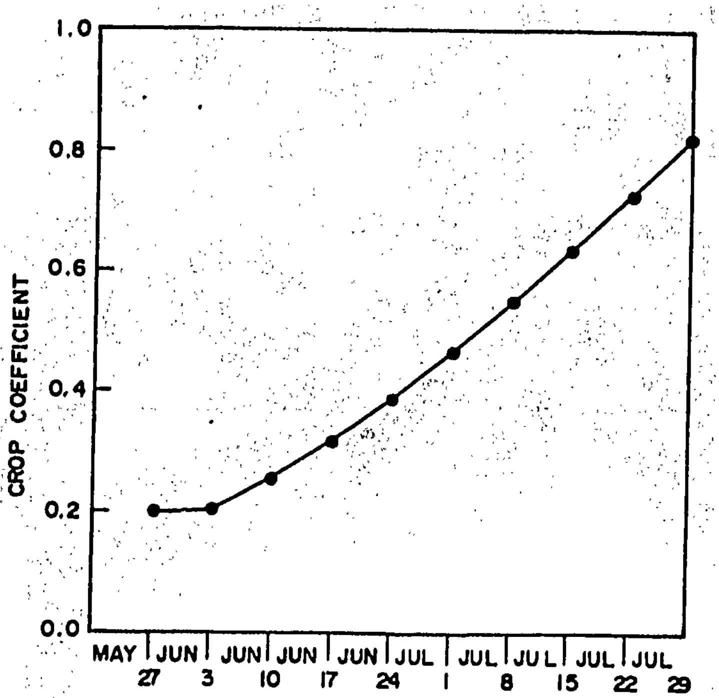

Fig. 14. Experimental crop coefficients for maize fodder crop by Jensen-Haise equation.

Table 5. Daily Evapotranspiration and Crop Coefficients for Maize Fodder at Kanjra by Jensen-Haise Method

Period	Potential Evapotranspiration (ETP) cm/day	Crop Coefficient Kc	Actual Evapotranspiration (ETA) cm/day
May 24-30	1.07	0.20	0.22
June 31- 6	1.14	0.20	0.23
7-13	0.96	0.25	0.24
14-20	0.80	0.30	0.24
21-27	1.03	0.38	0.39
28- 4	0.89	0.45	0.40
July 5-11	0.68	0.56	0.38
12-18	0.60	0.64	0.39
19-25	0.62	0.72	0.45
26-31	0.61	0.82	0.50

The irrigation application efficiencies measured on experimental and control plots are shown in Tables 6 and 7 respectively.

The seasonal irrigation scheduling summary reports for each of the three experimental maize crop plots are shown in Tables 8, 9, and 10. The report indicates date of inspection, average AET, projected root zone depth, available soil moisture in the root zone, allowable depletion assumed at 50% available water in the root zone, actual depletion to date and the projected date of irrigation and amount of irrigation needed. This is the condensed information from the entire period of observation of June and July. The summary of total irrigation, total effective rainfall, seasonal application efficiency, and crop yields are in Table 11.

The mean total irrigation for the experimental plots was 20.8 centimeters with 20.6 centimeters of estimated effective rain during the season. The mean application efficiency was 87% and the crop yield ranged from 30 to 42 tons per hectare with a mean of 36.2 tons/per hectare. For the control plots the comparable field was #2 (the Feroze farm) with 31.2 centimeters of water applied and 24.0 centimeters of water applied as rain. The first control field received excessive rains due to later planting and harvest. The mean control application efficiency was 49% and the mean crop yield was 23 tons per hectare.

The water saved due to irrigation scheduling and precision land leveling was approximately 10 centimeters or 33% of the control depth. The application efficiency was 24 tons while the difference between mean yields was 13 tons of fodder per hectare.

SUMMARY AND CONCLUSIONS

The comparison of methods of predictions of potential evapotranspiration provided close correspondence between Jensen-Haise, Adapted Penman and the Class A pan. The latter is recommended as an irrigation scheduling tool in conjunction with a non-recording rain gauge and soil moisture sampling, for practical application in Pakistan. The determination of consumptive use coefficients as ratios of actual to potential evapotranspiration indicates good agreement with published literature sources for both wheat and maize and leads to the conclusion that further detailed consumptive use research is unwarranted.

Table 6. Irrigation Application Efficiencies on Irrigation Scheduling Experimental Fields at Kanjra Watercourse during Maize Growing Season 1976

Date Inspected	Available Nakka Discharge (li/sec)	Amount of Water Applied (cms)	Moisture Deficiency in rootzone (cms)	Irrigation Application Efficiency Percentage
		Experimental Field #1 Hakeem Farm (head of the Watercourse)		
6/24/76	79.2	6.43	5.87	91.3
7/13/76	80.7	7.01	6.73	95.5
			Seasonal E_a = 93.4%	
		Experimental Field #2 Chirag Farm (MIddle of the Watercourse)		
6/11/76	47.8	5.33	4.04	75.7
6/26/76	71.3	8.38	7.37	87.9
7/6/76	70.8	7.44	6.99	94.2
			Seasonal E_a = 85.93%	
		Experimental Field #3 Rashid Farm (End of the Watercourse)		
6/21/76	59.4	7.11	5.46	76.8
6/30/76	62.3	7.44	6.53	87.7
7/11/76	56.6	6.76	5.49	81.4
			Seasonal E_a = 82.0%	

Table 7. Irrigation Application Efficiencies on Farmer Controlled Fields at Kanjra Watercourse during Maize Growing Season 1976

Date Inspected	Available Field turnout Discharge (li/sec)	Depth of Water Applied (cms)	Moisture Deficiency in rootzone (cms)	Irrigation Application Efficiency (%)
6/21/76	49.5	8.03	4.67	58.2
7/5/76	62.3	8.13	9.35	100.0
7/13/76	5.94	7.87	3.58	45.5
7/19/76	73.6	7.37	2.24	30.3

Seasonal Application Efficiency = 68%

Table 8. Scientific Irrigation Scheduling for Maize Fodder 1976 on Experimental Plot #1 Hakeem Farm

Soil Type - Silt Loam
Date of sowing - May 29, 1976
Moisture content at field capacity
(weight basis) = 21.9 Percent
Moisture content at permanent wilting point
(weight basis) = 8.9 Percent

Date Inspected	Average Evapotranspiration Rate ET (cm/day)	Root-zone Depth (cm)	Available Water Holding Capacity in rootzone (cm)	Allowable Depletion in root-zone (cm)	Available Water in rootzone (cm)	Depletion to date (cm)	Irrigation needed	
							Date	Amount (cm)
6/13	0.24	45.7	7.44	3.73	3.48	3.96	6/14	4.19
6/21	0.31	60.9	10.11	5.05	4.88	5.23	6/22	5.54
7/3	0.38	76.2	12.95	6.60	12.01	0.94	7/16	6.86
7/13	0.42	91.4	14.99	7.49	8.23	6.76	7/14	7.11

Table 9. Scientific Irrigation Scheduling for Maize Fodder 1976 on Experimental Plot # 2 Chirag Farm

Soil Type - Silt loam
Date of sowing - May 27, 1976
Moisture content at field capacity
(weight basis) = 21.5 Percent
Moisture content at permanent wilting point
(weight basis) = 8.5 Percent

Date Inspected	Available Evapotranspiration Rate ET (cm/day)	Root-zone Depth (cm)	Available Water Holding Capacity in rootzone (cm)	Allowable Depletion in root-zone (cm)	Available Water in rootzone (cm)	Depletion to date (cm)	Irrigation needed Date	Irrigation needed Amount (cm)
6/10	8.24	30.5	5.72	2.87	1.93	3.78	6/13	4.09
6/12	0.24	61.0	8.56	4.29	7.32	1.24	6/24	4.29
6/24	0.40	76.2	14.58	7.29	8.15	6.43	6.26	7.37
6/28	0.40	76.2	12.80	6.40	5.64	0.76	7/12	6.35
7/1	0.39	76.2	13.41	6.68	8.64	4.78	7/5	6.60
7/5	0.39	91.5	15.75	7.87	9.47	6.27	7/8	6.10
7/8	0.40	106.7	18.39	9.19	11.40	6.99	7/14	8.89

Table 10. Scientific Irrigation Scheduling for Maize Fodder 1976 on Experimental Plot #3 Rashid Farm

Soil Type - Silt Loam
Date of sowing - May 31, 1976
Moisture content at field capacity
(weight basis) = 21.5 Percent
Moisture content at permanent wilting point
(weight basis) = 8.5 Percent

Date Inspected	Average Evapotranspiration Rate ET (cm/day)	Root-zone Depth (cm)	Available Water Holding Capacity in rootzone (cm)	Allowable Depletion in root-zone (cm)	Available Water in rootzone (cm)	Depletion to date (cm)	Irrigation Needed	
							Date	Amount (cm)
6/18	0.31	45.7	8.69	4.34	4.42	4.27	6/19	4.57
6/23	0.40	61.0	11.40	5.72	7.70	3.71	6/28	5.72
6/28	0.40	61.0	10.82	5.41	5.87	4.95	6/29	5.72
7/7	0.40	76.2	14.07	7.04	10.80	3.28	7/16	7.11
7/16	0.41	91.4	16.56	8.28	12.65	3.91	7/28	7.62

Table 11 . Results of On-Farm Water Management Technology Applied at Kanjra Watercourse Area for Maize Fodder Crop in 1976. KHARIF (hot) season

Field (Owner and Number)	Total irrigation Water Applied during the Crop Growing season (cm)	Total Effective Rainfall during the Season (cm)	Seasonal Application Efficiency E_a (%)	Average E_a (%)	Crop Yield (t/ha)
		Maize Fodder - 1976 Irrigation Scheduling Program			
Experimental Field #1 (Hakeem Farm)	19.81	19.56	93.4	87.1	42.3
Experimental Field #2 (Chirag Farm)	21.16	19.56	85.9		36.5
Experimental Plot #3 (Rashid Farm)	21.31	22.61	82.0		29.8
*Control Field #1 (Pervez Farm)	12.57	50.29	30.3	49.1	18.3
Control Fiel #2 (Feroze Farm)	31.24	24.03	67.9		27.7

*Control Field #1 was sown 3 weeks later than the others and received much more of the monsoon rains.

Irrigation scheduling in conjunction with precision land leveling has resulted in substantial savings of 10 centimeters of water for both wheat and maize representing a 33% savings of water applied on farmer controlled fields.

The application efficiency improvement for wheat was more than 20% and for maize was up to 38%. Crop yield improvement under intensive management was 0.88 tons per hectare of wheat and 24 tons per hectare for maize fodder.

The level of obtained incremental improvements and produc ion are of a magnitude that is of interest to farmers and wh ch is highly likely to have good economic justification. ractical irrigation scheduling has a potential complementary sole to the new water management improvement technology of watercourse improvement and precision land leveling.

Recommendations

Water is limiting factor in food production fc. Pakistan. Management of water in the tertiary or watercourse command area is important because over-irrigation in quantity and frequency contributes to waterlogging and under-irrigation results in salinity accumulations in the arid excess-evaporative demand climate. The resultant low irrigation application efficiencies and incomplete irrigations are partially due to unleveled farmers' fields, traditional methods and concepts of water requirements, fixed irrigation schedules and responses to uncertainty of water supply. The key to water management improvements remains however in the hands of the farmers acting in their own best interest, individually and collectively (Radosevich, 1975).

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APPENDIX 7

SCARP TUBEWELL PUMPING PLANT PERFORMANCE IN MONA RECLAMATION EXPERIMENTAL PROJECT AREA

By

Muhammad Akram, Dwayne Konrad, Norman Illsley, Muhammad Munir Chaudhry1/

I. INTRODUCTION

Salinity Control and Reclamation Project (SCARP) tubewells are installed to lower or stabilize the high ground water table that threatens and destroys valuable cropland and to provide more water to irrigators. The tubewells could be used to reclaim salinized soils.

Most of the 148 tubewells under this study were drilled and completed in 1964-65. The range in depth of the wells in the Mona Project area is from 250 to 400 feet. Static water levels are quite uniform at about 10 feet and specific capacities range from near 40 to over 100 gallons per minute per foot of drawdown (gpm/ft.). The tubewells were properly designed, pumps were laboratory tested and, apparently, construction was adequately supervised. The well construction and pump records for the SCARP tubewells are quite complete.

Tubewell casing and screen were manufactured to the type and slot size selected for the aquifer conditions. Generally, the screen was placed only next to the more permeable portion of the aquifer. Electric motors used to drive the pumps range in horsepower from 20 to 30 horsepower. Pump discharges range from 2 to 4 cusecs.

The SCARP tubewell program has been plagued by many problems and is being criticized daily for these problems. WAPDA reported in 1971 (1) that pumping costs for the Mona-SCARP tubewells were 40 to 50% higher than for private tubewells in the same area. It was also reported that the initial estimated tubewell life of up to 40 years was actually closer to 15 years. Utilization of public tubewells was said to be low due to repairs, down time and general mismanagement.

II. MONA PROJECT AND SCARP TUBEWELLS

The 148 SCARP tubewells under study have been administered and controlled by Mona Project since completion. Normally,

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1/Junior Agricultural Engineer, MREP, Irrigation Engineer and Agricultural Engineers, Colorado State University, and Project Director, MREP, respectively.

the SCARP tubewells are turned over to the Irrigation Department by WAPDA after their completion. The 148 tubewells are available for research and demonstration in all phases of water management. Recently, another 170 public tubewells have been added to Mona Project management.

Twenty-three of the 148 electrically driven tubewells have been shut down permanently due to brackish or highly saline water that has intruded from below because of pumping effects. Little is known concerning the actual salt content of the pumped water and how it varies throughout the seasons or years. Generally, the tubewell water is mixed with higher quality canal water at the head of the watercourse so that the entire commanded area receives groundwater when it is being used.

Until recently, pumping plant repair and maintenance was determined by observable need. For example, if the pump was vibrating badly, bearings were replaced or, if a motor overheated and burned out, the overload problem was located and the motor was repaired. Downtime and the farmer's needs for water were not of highest priority.

III. OBJECTIVES OF THE MONA PROJECT PROGRAM FOR TUBEWELL PERFORMANCE TESTING

The present research program for tubewells calls for a procedure that will increase the effectiveness of tubewells and increase their useful life at least cost. Rather than indiscriminately repair pumps, as the previous program suggested, a research program is devised that will allow each tubewell pumping plant to be numerically tested and evaluated. That is, the pumping plant will be rated in terms of how well or how poorly it is performing its assigned duty of pumping a desired quantity of water at a designed head. This rating is called tubewell "pumping plant performance."

The concept for using plant performance testing as a basis for repair is based upon the theory that, if a pumping plant is operating at its initial high efficiency, 70% for example, that plant is in good condition and should not be shut down for routine repair. At the same time, if a certain plant is visually operating smoothly but is found to be operating at only 40% efficiency, this plant should be carefully inspected and pump impellers adjusted for clearance. If adjustment does not increase performance significantly, the plant needs to be further analyzed and pump change, pump repair or well renovation should be considered.

It is desirable to devise an economical and practical method for determining least cost of maintaining and operating tubewells while providing a reliable water supply. Tubewell performance testing has become acceptable worldwide as a method of conserving energy and keeping pumping costs at a minimum.

A further objective of this program is to define the kinds of problems that are occurring within the tubewell itself. Problems of encrustation, corrosion and sand pumping have already been cited but little has been done to combat the problem on a country-wide basis. Pakistan can ill afford to lose the service of expensive tubewells. Research and adoption of standards for operating and maintaining tubewells is vital to both the public and private sector as relates to salinity control and water supply.

Table 1 shows that operation and maintenance costs of pumping per acre-foot have tripled in the past nine years and increased nearly sixfold since first use. Percent utilization of the tubewells has declined from 67% to 42% since 1970 and total acre-feet pumped has decreased by 47% for this group of 148 SCARP tubewells. For reasons unclear, 34% of the decreased production occurred between 1970 and 1972.

A. Procedure for Tubewell Performance Testing

The performance testing program involved measuring static water level, water level drawdown while pumping, pump discharge, and input horsepower. Attempts were made to simulate actual or normal operating conditions.

Pumping lifts and static water levels were measured by lowering an electrical 2-wire conductor wire into the well until the ammeter showed conductor contact with the water surface. Pressure head was measured by the use of a manometer tube in the discharge line ahead of the orifice place. Pipe friction losses in the pump column and discharge pipe were estimated. Pumping lift and pressure head were then added to determine total operating or dynamic head. Pump discharge was measured with the use of a 6.5-inch sharp-edged orifice plate. Discharge was taken directly from the calibration table for this particular orifice plate.

Pumping plant performance was calculated as water horsepower divided by input horsepower multiplied by 100 to express it as a percentage. That is,

$$\text{Efficiency} = \frac{\text{Output Horsepower}}{\text{Input Horsepower}} \times 100,$$

Where, Output = Water Horsepower = $\frac{Q \times H}{3960}$

and Input = $\frac{VI\ \sqrt{3}\cos\phi}{746}$

COST OF TUBEWELL O & M, WATER PUMPED
AND PERCENT UTILIZATION IN MONA PROJECT AREA

Table 1.

Year	Total Operation and Maintenance Cost (Rupees)	Pumpage (acre-feet)	Cost* (Rupees/acre-feet)	Percent Time Utilization
1965-66	4,66,058	83,736	5.6	39.7
1966-67	9,76,303	1,20,027	8.1	37.5
1967-68	17,01,644	1,38,231	12.3	43.1
1968-69	14,17,442	2,04,127	10.8	63.8
1969-70	23,35,259	2,15,107	10.0	67.3
1970-71	23,32,207	2,07,531	11.2	64.9
1971-72	22,76,810	1,43,158	15.9	44.6
1972-73	23,82,014	1,17,576	20.2	36.8
1973-74	24,98,374	1,22,245	20.4	39.9
1974-75	27,96,253	1,34,583	20.8	48.2
1975-76	31,69,679	1,11,708	28.4	40.7
1976-77	35,40,000	1,26,186	28.0	47.2
1977-78	36,76,030	1,13,935	32.3	41.9

*Cost includes only direct O & M charges.

Where, Q = discharge, gallons per minute
H = total dynamic head, feet
V = average voltage per motor leg
I = average amperage per motor leg
Ø = phase angle, cos Ø of 0.8 assumed

The field formula for calculating plant efficiency becomes,

$$E = \frac{Q \times H}{7.36\ V\ I}$$

V. RESULTS AND DISCUSSION OF 1979 TUBEWELL PLANT PERFORMANCE TESTING

A. Pumping Plant Efficiency

Average pumping plant efficiency for 106 SCARP tubewells tested in the Mona Project was 48 percent. Highest plant efficiency determined was 76% on MN-52. Lowest efficiency was 27% on MN-76 (Appendix A). Tubewell plant performance, by numbers of tubewells is as follows:

Percent Efficiency	No. of Tubewells
> 70	2
60-69	11
50-59	32
40-49	44
30-39	12
< 30	5

A reasonably well designed and new electrically driven pumping plant can attain a 70 to 75% efficiency. In fact two plants, MN-52 and MN-136 reached, or exceeded that goal. However, it is unrealistic to expect all plants to reach that efficiency when, in fact, some of the plants may not have been 75% efficient when new.

Peak expected efficiency for a 25 to 30 horsepower electric motor is about 90%. Peak efficiency of a 2-stage vertical turbine pump is 84% or slightly less. The electric motor is capable of sustaining its efficiency. The pump is subject to wear from cavitation, sand particles and inadequate adjustment. Only in rare cases would the pump retain its peak initial efficiency. Under these assumptions, a reasonable expected plant efficiency for a group of 100 plus SCARP tubewells would be about 60%. Thirteen percent of the tubewells met that goal.

Depending upon the cost of electrical energy, a plant efficiency as low as 50% may be permissible. In that case, only 42% of the tubewells met that goal. At 50% efficiency the cost of energy is 10% above what is reasonable and achievable. Eighty-eight percent of the plants are below the 60% efficiency level. At current and projected competition and costs for energy, it is vital that irrigated agriculture make the best use of energy regardless of whether tubewells are heavily subsidized by the public or not. The SCARP tubewell program will finally live or die depending upon its benefit to Pakistan.

The efficiency of the hollow-shaft, 3-phase electric motor is quite constant. That is, efficiency of the motor will not drop off without a drastic effect on the windings and life of the motor itself. This, in turn, indicates that the reasons for low plant efficiency lie mainly with the turbine pump. Within the pump can be found several common problem areas that can account for poor efficiency. (3)

1. The impellers and bowls are worn by sand or maladjustment.

2. The bearings in the shaft are worn through improper lubrication, misalignment of shaft, etc.

3. The impellers are out of adjustment.

Pump impeller adjustment was attempted by the Mona tubewell staff after performance testing. One of the problems encountered during the adjustment process was that the motor amperage rose. The adjustment was attempted on only a few pumps. However, when this condition of overload by adjustment arises, two possibilities exist: (1) adjustment is in error and results in drag of the impeller or (2) the impeller is responding to adjustment by pumping more water at a higher degree of efficiency. Unfortunately, the motor overload may require that impeller clearance be changed back to the "inefficient" setting. The remedy for (2) is to either increase motor size so that pump efficiency can be increased or re-select a slightly smaller pump when the pump is finally pulled for repair.

The Mona tubewell staff reported that impeller adjustment was limited by the very small amount of side seal that existed within the pump. This problem should be discussed with pump manufacturers since pump life and performance can be tied closely to the opportunities for impeller adjustment.

B. Specific Capacity of Tubewells

Specific capacity is a useful calculation in determining whether or not the tubewell itself is functioning as it should or as it did in the past. It is defined as rate of flow per unit of drawdown (gpm/foot). Appendix A lists the tubewells studied and the trend in specific capacity. Even though static water tables have dropped very slightly (1 to 4 feet) since well completion in most of the area, the specific capacities have declined quite drastically on many of the sample wells. Average decline of specific capacity in 15 years was 32%. The effect of this decline is that the pump must act against a greater pumping lift and in turn, the pump will react by pumping less water since pump speed is constant. Fortunately, the vertical turbine pumps selected compensate quite well to this change in operating lift.

The decline in specific capacity indicates that either of two changes have occurred. (2)

1. The entrances into the well screen or perforations are partially plugged or plugged in certain sections.

2. The porous sections of the aquifer are either becoming plugged or dewatered.

Plugging or encrusting is often accelerated by excessive pumping rate. Precipitation of salts occurs at the screen where a water pressure differential exists. Previous literature documents the fact that encrustation is a problem in Pakistan tubewells. There is no reason to doubt this occurrence in light of water quality. In some cases, fine sand particles migrate towards the well screen and are trapped in the nearby aquifer or gravel pack. Whatever the reason(s) for decline of specific capacity, the decline represents a direct threat to the useful life of the tubewells. In the meantime, it causes waste of electrical energy as well as a decrease in water supply to farmers.

C. Static Water Levels

A primary purpose of the SCARP tubewell program is to decrease waterlogging by lowering the water table and allowing the soil salts to be flushed downward. Data collected on these wells indicate that the static water level dropped an average of 3.2 feet on 103 tubewells since installation. Even though this decline rate is only 0.2 feet/year, it shows the value of pumping where, formerly, the water table was rising. This also strengthens the argument for maintaining these tubewells and offering schemes to avoid pumping brackish water. The range of water level declines was from zero to 7.4 feet. Twelve tubewells showed a water table rise that averaged only 0.66 feet over 15 years. The reasons for this rise could not be readily determined. In effect, the aquifer recharge to those areas is greater than pumping or outflow.

D. Tubewell Discharge

Tubewell plant performance tests on 106 wells showed that pump discharge rates have decreased 20% since installation. A small fraction of the decline may be due to additional head imposed on the pump by the use of the orifice plate itself. The average pumping rate is about 2.8 cusecs, a loss of 0.53 cusecs. Listing average losses does not show the real effect of discharge decline since, within the 106 tubewells, 16 have lost one cusec or more. MN-4 pump discharge has declined 40% and MN-93 declined 52% since pumping began. Incidentally, performance efficiencies for both of these plants was 37% and 31% respectively. Without further analysis in the field, it is impossible to determine whether low plant efficiency has caused decreased discharge or vice versa. In several instances, the drastic decline in specific capacity indicates that the tubewell itself is failing.

E. Motor Loading

Performance testing showed that 24% of the tubewell motors were drawing more than rated motor current Generally, overloads less than 10% are permissible (not desirable). Fourteen motors were loaded 10% or less. The highest percent overload was 17%. The 10 plants showing excess overload need to be reinspected immediately and determinations made as to the cause of overload. Overloads of 10 to 20% will cause motor insulation to break down and will cause motor failure. Either the impellers are dragging on the bowls, the bearings are worn, or the pump is too large for that motor. In general, overloading was less severe than expected.

F. Motor Protection

It is not uncommon for tubewell transformers and/or motors to "burn out" in the Mona Project area. Wiring standards were questionable and terminal wires in the control box were often loose. In some cases, the tubewell operator had tapped into the control box to take electricity for his personal use. Motor protection or fusing often consisted of various gages of wire in the same control box. In effect, motor protection is haphazard. If something drastic does occur within the pump, the motor can often draw enough current to burn out the motor, transformer, or both. No strict tabulations were kept in regard to motor protection and wiring.

VI. RESULTS OF PUMP REPAIR

As a follow-up to the tubewell performance testing program, eight of the poorest performing plants were chosen for pump pulling and repair. All work was conducted by the

Tubewell Operation and Maintenance section of the Mona Project. The type of repair needed was determined by inspection of the pump parts. Repair ranged from replacing pump bearings to refacing impellers. The average cost of repair per pump was Rs. 4221 and included only the cost of materials used. Highest repair cost for a pump was Rs. 7819 (MN-66)

Follow-up performance tests (Table 2) showed that, as a result of repair, efficiency was increased by an average of 20%. However, these tests point out that repair by observation did not bring performance up to the desired 70%. Instead, final efficiency averaged only 51%. A logical conclusion, therefore, is that there is some other obstacle barring the way to higher plant efficiency that was not found by mechanical inspection. Since motor efficiency is not the only cause of inefficiency, either the pump impellers needed replacing or the impellers are not correct for the existing conditions. More testing and analysis is needed before repair is undertaken. Impeller adjustment should be carefully undertaken and performance should be evaluated versus the pump curve (characteristics) for that pump. The correct analysis of pump problems cannot be overemphasized. Analysis is best done with the pump in place.

Total downtime for the tubewell repair was approximately four days. Since pumping time is vital to the irrigator, plant performance testing and necessary repair or alterations should be scheduled during periods of low water demand.

VII. COST OF PLANT PERFORMANCE TESTING

Pumping plant performance testing is only worthwhile if it returns more than it costs. One of the main objectives of the Mona Project testing program was to pinpoint pumping plant problems before complete plant failure occurred. Cost effectiveness of performance testing versus no testing can best be done by comparing operating costs, tubewell utilization rates, acre-feet pumped and farmer attitude over a longer period of time.

Generally, a testing crew included a junior agricultural engineer, a tubewell serviceman, and two assistants. Transportation included a Jeep-type vehicle with driver. The crew could run a standard test in about one hour. Lost time was incurred due to local power outages and impassible roads. Additional time was required to allow static water levels and pumping water levels to stabilize before measuring. One crew can average about six performance tests per day. The value of testing is not in the test itself but in the correct interpretation of test data collected. Interpretation involves careful analysis and decision-making and, in many instances, will require more time than the field test.

TUBEWELL PUMPING PLANT EFFICIENCIES
BEFORE AND AFTER REPAIR, MONA PROJECT AREA

Table 2.

Tubewell No.	Efficiency (%) Before Repair	Efficiency (%) After Repair	% Increase
28	29.0	52	23
29	37.0	42	5
32	39.0	58	19
59	29.3	57	28
66	32.2	52	20
69	27.6	50	22
76	26.7	52	25
77	28.3	45	17
Average	31.1	51	22

VIII. CONCLUSIONS

The average tubewell pumping plant efficiency for 106 SCARP wells was 48%. Only 13% of the plants had efficiencies above the chosen standard of 60%. An attainable plant efficiency is 75%. The effect of low plant efficiency is that cost of electrical energy is 12-15% higher than required. Generally, tubewell plant maintenance costs will be above normal on inefficient plants.

Specific capacity of the tubewells has dropped an average of 32% in 15 years. Maximum decrease in specific capacity was 62% (MN-62). Six tubewells showed a small increase in specific capacity since pumping began. Tubewell plant efficiency does not appear to be closely correlated to the degree of specific capacity change. However, the group of tubewells performing above 60% generally have specific capacities that are within 24% of original. Many of the original specific capacities were in the range of 95 to 115 gpm/ft. and are not 50 to 80 gpm/ft. Encrustation of the tubewell screen (or perforations) is a likely cause for decreased specific capacities in these tubewells.

Tubewell production or discharge rate is about 80% of original discharge. This decrease does not include the complete closure of 23 tubewells because of highly saline water. It is not unreasonable to believe that the decrease in pumping rate, coupled with the decrease in percent utilization of the tubewells, could seriously affect or even reverse the favorable downward trend of the water table. The irrigators would welcome the additional water for their crops that they, apparently, have lost.

The study did not include a compilation of ground water quality as was originally planned. An inventory of well screen depths showed that, of 13 tubewells that have been closed due to brackish water pumped, 12 of the wells have screens to depths of 320 to 365 feet. Earlier reports indicate that the practice of deep pumping at high pumping rates can result in salt water intrusion from below, as is likely occurring with the SCARP-Mona tubewells. There may be tubewells in current use that produce water with unacceptable salinity.

Motor overload was not a common problem with the SCARP-Mona tubewells with only 10 plants on excess overload (10% above rated load). Motor and transformer burnout are probably due to mechanical failure at the pump and lack of motor protection from excess current.

IX. RECOMMENDATIONS

The 1979 test results are, in effect, a benchmark for tubewell plant performance. A program for future testing operation and maintenance of these public tubewells would include the following:

1. Perform plant efficiency tests on the tubewells tested in 1979 to determine any changes in performance and conditions.

2. Assemble the pump impeller curves that coincide with each tubewell to determine if the installed pump is reasonably correct. For tubewells performing below 49% a cost analysis should be done to determine the net return due to changing pumps and/or motors. Actual energy costs should be used instead of the subsidized costs.

3. Single out all tubewells that tested below 40%. Analyze these to determine if the pump impeller is the correct size and cut. Pull and repair the pump, if necessary. Test the pumping plant after reinstallation.

4. Assemble data on each tubewell regarding hours of down-time at critical water use periods and acre-feet pumped.

5. Work with electrical advisors on proper electrical protection for motors.

6. Initiate a program for monitoring quality of the pumped water. Determine, through cooperation with the soils specialist, whether any of the tubewells are pumping water that will cause losses in crop yield because of salinity. Where water quality is unsuitable or questionable, several alternatives exist:

   a) cease pumping the tubewell
   b) reduce hours of pumping
   c) reduce rate of pumping
   d) attempt to case or close off the deeper (usually more saline) part of the aquifer

7. Attempt to reestablish, if possible, some of the SCARP tubewells that are now closed due to brackish water. First, determine the quality of existing water, how it can be used and the value of water to the farmers. If feasible, set up a pumping plant to pump from shallower depths and at much lower rates than the original tubewell (1.0 to 1.5 cusecs). This program will require cooperation and agreement from the landowners using the water.

8. Retest the group of tubewells that show large decreases in specific capacity. If the tubewell is constructed of durable and acid resistant materials, devise an acidization treatment to rehabilitate the tubewell

from encrustation. Test tubewell performance before and after any treatment. Dynamite treatment may be used where blasting experts are available. Treatment can result in complete failure of a tubewell and is not recommended as a common practice. The most common acids used for encrustation are hydrochloric acid and sulfamic acid.

REFERENCES

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TUBEWELL PERFORMANCE TESTING DATA, MONA PROJECT AREA

Appendix A.

Tubewell No.	Static Water Level (ft)	Drawdown (ft)	Original Discharge (gpm)	1979 Discharge (gpm)	Original Spec. Capacity (gpm/ft)	1979 Spec. Capacity (gpm/ft)	Overall Plant Efficiency (%)
MN - 1	—	—	1574	1469	104	—	54.0
MN - 2	—	—	1554	1424	81	—	52.0
MN - 3		22.8	1473	1193	73	52.4	44.9
MN - 4		33.5	1613	974	87	29.0	36.6
MN - 5		16.8	1194	1131	72	67.5	48.6
MN - 6	—	—	1270	—	99	—	—
MN - 7	—	—	1633	—	91	—	—
MN - 8			1493	1362	79	61.9	54.0
MN - 9			1410	1131	62	48.1	60.5
MN - 10		22.7	1574	1280	91	56.5	45.8
MN - 11		20.0	1431	1393	92	69.7	47.0
MN - 12		19.4	1513	1512	115	78.1	44.0
MN - 13		14.2	1613	1362	82	92.3	46.2
MN - 14		16.0	1493	1878	96	86.1	58.1
MN - 15		26.5	1574	951	98	360	46.9
MN - 16		22.2	1554	1017	107	45.7	48.7
MN - 17		25.0	1240	1156	114	46.2	61.2
MN - 18		16.0	1245	1175	94	73.4	66.6
MN - 19		13.0	1442	1017	115	78.2	48.8
MN - 20		19.2	1534	1017	110	52.9	51.6
MN - 21		14.0	1294	1280	107	91.4	52.2
MN - 22	—	—	1431	—	110	—	—
MN - 23		16.8	1318	1346	74	80.4	52.0
MN - 24		22.0	1534	1409	92	64.0	56.8
MN - 25		25.8	1633	1469	105	56.9	46.5
MN - 26		13.2	1270	1156	108	87.2	48.8
MN - 27		20.1	1270	1280	91	63.6	40.2
MN - 28		21.0	1652		109	63.4	29.0
MN - 29		10.0	1613		123		37.0
MN - 30		—	1574	(B/W)	164	—	

Tubewell Performance Testing Data, Mona Project Area (cont.)

Tubewell No.	Static Water Level (ft)	Drawdown (ft)	Original Discharge (gpm)	1979 Discharge (gpm)	Original Spec. Capacity (gpm/ft)	1979 Spec. Capacity (gpm/ft)	Overall Plant Efficiency (%)
MN - 31		16.2	1613		129	90.5	60.0
MN - 32		13.3	1613		131	84.1	39.0
MN - 33-41	--	—	--	(B/W)	—	—	—
MN - 42		22.0	1387	928	72	42.2	56.0
MN - 44	--	--	1742	--	130	--	--
MN - 45	--	—	1294	--	147	--	--
MN - 46		15.2	1725	1119	134	73.9	38.8
MN - 47			1514	1193	93		60.2
MN - 48-51	--	--	--	(B/W)	—		
MN - 52		17.5	1622	1498	96	85.6	76.0
MN - 53	--	--	1594	(B/W)	90	--	—
MN - 54		19.5	1554	1409	105	72.2	44.2
MN - 55		14.0	1260	1017	103	72.6	44.6
MN - 56		21.4	1564	1280	107	59.7	44.9
MN - 57		17.0	1593	1099	106	64.6	41.9
MN - 59		16.0	1725	1017	127	63.6	29.4
MN - 60	—	—	1680	--	122	—	—
MN - 61		16.0	1270	974	110		38.4
MN - 62		26.7	1725	1175	114	44.0	47.2
MN - 63	—	—	1318	—	108	—	--
MN - 64	--	--	1613	1313	91	—	49.6
MN - 65	—	—	1613	1512	104	—	48.0
MN - 66		12.0	1622	1017	98	84.8	32.2
MN - 67	—	—	1743	—	110	—	--
MN - 68		20.5	1534	1246	92	60.0	50.7
MN - 69		14.5	1652	1156	106	79.8	27.6
MN - 70		29.5	1282	1175	98	39.8	50.7
MN - 71		19.5	1670	1649	113	84.6	53.5
MN - 72		217.	1725	1687	131	77.9	46.4
MN - 73		19.2	1795		123	62.0	43.5
MN - 74	—	—	1594	(B/W)	90	—	—

Tubewell Performance Testing Data, Mona Project Area (cont.)

Tubewell No.	Static Water Level (ft)	Drawdown (ft)	Original Discharge (gpm)	1979 Discharge (gpm)	Original Spec. Capacity (gpm/ft)	1979 Spec. Capacity (gpm/ft)	Overall Plant Efficiency (%)
MN - 75		30.5	1670	1131	85	37.0	51.3
MN - 76		20.2	1294	1059	88	52.5	26.7
MN - 77			1594	1194	78		28.3
MN - 78			1195	(M)	71		58.0
MN - 79		23.5	1633	1156	88	49.2	48.7
MN - 80	—	—	1232	(B/W)	84	—	—
MN - 81		25.8	1670	1499	99	58.0	42.2
MN - 82			1688	1131	98		48.0
MN - 83	—	—	1169	(B/W)	51	—	—
MN - 84	—	—	1534	(B/W)	88	—	—
MN - 91			1141	1212	80		38.1
MN - 92	—	—	1632	(B/W)	97	—	—
MN - 93			1633	790	93		30.8
MN - 94	—	—	1688	(B/W)	115	—	—
MN - 95		16.0	1688	1131	98	70.7	43.9
MN - 96	—	—	1539	1297	95	—	36.6
MN - 97	—	—	1554	1156	110	—	40.2
MN - 98	—	—	1593	1662	112	—	54.9
MN - 99	—	—	1462	1483	112	—	43.0
MN - 100	—	—	1707	—	105	—	—
MN - 101		21.2	1652	1687	108	79.4	51.4
MN - 102		14.5	1622	1439	124	99.2	50.9
MN - 103		18.0	1410	1346	110	74.8	53.0
MN - 104		25.0	1245	1211	69	47.5	48.1
MN - 105		21.5	1220	1280	73	59.5	65.2
MN - 106		22.0	1270	1175	71	53.4	69.3
MN - 107		22.5	1574	1079	95	48.0	38.0
MN - 108		25.0	1574	1636	79	65.4	57.8
MN - 109		19.0	1245	1099	75	57.8	47.0
MN - 110		24.0	1220	951	69	39.6	47.8

Tubewell Performance Testing Data, Mona Project Area (cont.)

Tubewell No.	Static Water Level (ft)	Drawdown (ft)	Original Discharge (gpm)	1979 Discharge (gpm)	Original Spec. Capacity (gpm/ft)	1979 Spec. Capacity (gpm/ft)	Overall Plant Efficiency (%)
MN - 111		21.0	1564	1211	72	57.7	52.0
MN - 112		24.0	1554	1373	69	58.0	54.9
MN - 113		22.0	1113	1097	40	50.0	52.4
MN - 114	--	--	1472	(B/W)	73	--	--
MN - 115	--	--	1458	(B/W)	53	--	--
MN - 116	--	--	1513	(B/W)	78	--	--
MN - 117		23.0	1554	1393	83	60.6	48.1
MN - 118		19.0	1270	1211	87	63.7	50.0
MN - 119		18.5	1574	1269	74	79.4	50.0
MN - 120		21.5	1574	1393	81	64.8	56.2
MN - 121		10.6	1593	1119	74		32.7
MN - 122		22.9	1760	1346	104	58.8	54.0
MN - 123		24.5	1670	1454	93	59.4	47.0
MN - 124		16.2	1688	1498	97	92.2	45.4
MN - 125		26.0	1670	1280	101	54.6	47.1
MN - 126		23.2	1220	1209	87	55.0	60.0
MN - 127		24.0	1633	1498	81	62.4	45.5
MN - 128		21.8	1688	1409	105	64.8	53.0
MN - 129	--	--	1534	1556	69	--	44.0
MN - 130		19.5	1593	1393	79	71.4	34.1
MN - 131		19.0	1294	1211	87	63.7	42.2
MN - 132		26.0	1652	1346	96	51.8	42.1
MN - 133		--	1725	1492	116		48.5
MN - 134		23.0	1220	1059	82	46.0	43.0
MN - 135		15.0	1530	1540	82	102.7	62.8
MN - 136			1594	1454	92		74.9
MN - 137		10.2	1594	1409	109	73.2	60.6
MN - 138		24.2	1232	1017	102	41.9	54.8
MN - 139		14.5	1514	1330	97	91.7	53.7
MN - 140			1574		108		57.3

Tubewell Performance Testing Data, Mona Project Area (cont.)

Tubewell No.	Static Water Level (ft)	Drawdown (ft)	Original Discharge (gpm)	1979 Discharge (gpm)	Original Spec. Capacity (gpm/ft)	1979 Spec. Capacity (gpm/ft)	Overall Plant Efficiency (%)
MN - 141	--	--	1472	--	123	--	--
MN - 142		16.0	1511	1280	100	80.0	42.9
MN - 143		26.0	1462	1346	91	51.5	67.2
MN - 144			1194		111		50.5
MN - 145		47.0	1127		83		47.2
MN - 146			1220		90		49.6
MN - 147			1127		79		44.7
MN - 148			1155		73		53.6

APPENDIX 8

A PONDING STUDY OF FACTORS WHICH AFFECT WATERCOURSE WATER LOSSES[1]

Tom Trout, Zahid Saeed Khan, Hayat Ullah Khan, Abdul Khaliq, Mohd. Akram, Azeem Cheema, and Mohammad Munir[2]

INTRODUCTION

Recent studies of Pakistan watercourse conveyance losses by WAPDA Master Planning, Mona Reclamation Experimental Project, faculty of the College of Agricultural Engineering at the University of Agriculture, Faisalabad, the Punjab Agriculture Department's On-Farm Water Management Development Project, and Colorado State University Water Management Research Project, have indicated that water losses are in the range of 30 to 50% of the inflow at the "mogha" (watercourse inlet); (Ashraf, et al., 1977; Lowdermilk, et al., 1978; Ali, et al., 1978; Trout, et al., 1977; Clyma, et al., 1975, and Punjab On-Farm Water Management Development Project, 1978). All of these conveyance loss studies utilized the inflow-outflow method of loss measurement. Water measurement flumes were installed at the entrance and exit of a long channel section and the loss was calculated as the difference in the flows measured in the two flumes. Such high losses indicate a large potential to deliver more water to the farmers' fields through making the watercourse conveyance system more efficient. Reducing watercourse losses by 5 percentage points (5 percent of the inflow) would result in more extra water supply at the farmers' fields than is delivered from Tarbella Reservoir.

Previous to these recent studies it was generally believed that watercourse losses were small, often estimated at about 10% of the inflow (Gibb, 1966). This belief was partially based on ponding water loss measurements conducted by the Irrigation Research Institute, Punjab (n.d.) and Hunting Technical Services Ltd. (1965). The conflicting results between the inflow-outflow measurements and the ponding loss data created questions about the measurement methodologies.

This ponding loss study was undertaken to attempt to clear up the existing conflict between the two sets of findings, and to study, in depth, the earthen watercourse to determine the causes of water losses and to develop design techniques to reduce these losses.

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2/The authors are CSU Water Management Research Project and Mona Reclamation Experimental Project Agricultural Engineers and the MREP Project Director.

METHODOLOGY

Data Collection

Measuring water channel losses by the ponding method involves filling a section of channel closed at both ends and determining the decrease in the volume of water in the section over time. This volume decrease is determined by measuring the area of the surface of the ponded water (top width times the section length) and the rate of recession of the water surface. The water surface width times length times depth change in a unit of time results in a rate of water leaving the channel, or a water loss rate in liters per second (lps) (or cubic feet per second (cfs)). To make the results comparable to other loss measurements from different section lengths, the loss rate is taken per unit of distance (lps per 100 meters (cfs/1000 ft)). (NOTE: Loss rates in cfs/1000 ft are roughly 1/10 of loss rates in lps/100 m.)

The test sections were selected to be representative of existing watercourse channels. Often two or more adjoining sections were studied to determine the variability in the results. No changes were made to the natural state of the channel such as sealing leaking insect holes or disturbing the vegetation.

The section lengths varied from 20 to 40 meters (60-120 ft). Such short lengths were studied so that the ponded water depth at each end of the section would not vary due to the slope of the section more than one centimeter (one-half inch) from the normal flow depth.

Staff gages were firmly inserted into the bottom of the channel to measure the water depth changes. The gage was normally installed in the channel before the study began and while water was flowing normally in the section to determine the normal operational supply level (osl). An attempt was always made to determine the current normal flow depth as accurately as possible. As will be explained later, the operating level will change over time with changing vegetative growth and silt deposition and the operational supply level will not always remain the same.

Once the channel had ceased being used, compacted earthen bunds were built at the ends of the selected sections. The downstream bund was constructed first while the test section was being filled to 4 to 6 cm above the measured osl, then the section was closed at the upper end. An attempt was made to maintain the water at the increased depth for a short time (½ to 1 hr) to wet up the banks, but this was not always possible.

Five evenly spaced water surface width measurements were made in each section during the initial water surface level gage readings and at least twice later during the water level recession. The average of the five readings along with the staff gage reading at the time of the measurement was used as a measure of the top width at various depths.

Staff gage and time readings were taken after about each one-half centimeter of drop of the water surface. They were continued usually until the water level had dropped about 10 cm below the recorded osl. Occasionally recessions were recorded until the channel was nearly empty.

Any visible leakage which passed through the bank and appeared outside the watercourse was noted and often volumetrically measured.

During or after the recession data collection, other parameters which describe the condition of the test section were measured. The elevation of the water surface at osl relative to the elevation of the surrounding field surfaces was measured with a surveyor's level. The width of each bank at the osl depth was estimated at five places with a tape measure sighted across the bank top. A visual assessment was made of the condition of the channel wetted perimeter to determine whether it was clean or grassy, whether insect and rat holes were visible, and the general cross-sectional shape. An estimate or flume measurement was made of the normal flow rate in the section. The time water flows in the channel section each week was determined from a warabundi (irrigation turn rotation) schedule or by questioning the farmers, and the distance of the section from the mogha (watercourse inlet from the canal), and whether the channel was sarkari khal (government authorized primary channel) or farmer's branch was determined. Soil type was estimated by visual assessment. All data were recorded on a data collection sheet such as is shown in Figure 1.

Loss Rate Calculations

Loss rates were determined from a graphical analysis of the recession and top width data. Depth gage readings were plotted versus time as is shown in Figure 2. The measured osl (operational supply level) gage reading is also marked on the graph and gage readings are noted relative to the osl reading. The water surface recession rate at any depth relative to osl is determined by measuring the slope of the curve at that depth.

Average water surface widths were plotted on the same graph versus gage readings, with widths listed along the top of the graph (see Figure 2). The average width at any gage reading was interpolated from the graph.

Figure 1.

PONDING LOSS MEASUREMENT

DATA SHEET

(Always note measurement units)

Date ____________________
Experimenter ________________

Purpose for measurement ______________________________
Location of Watercourse ______________________________
Location of test section (sq #/Ac#) ______________________
Gauge reading at full supply level (FSL) __________________
Time channel was full before testing began __________ hours
Channel section length __________________

Water Surface Recession Data:

Time	Gauge Reading	Time	Gauge Reading	Time	Gauge Reading

Comments: ____

Channel Section Water Surface Width:

	Gauge Reading	Width	Ave. Width
Initial:	______	____, ____, ____, ____, ____,	______
	______	____, ____, ____, ____, ____,	______
Near FSL:	______	____, ____, ____, ____, ____,	______
	______	____, ____, ____, ____, ____,	______
Final:	______	____, ____, ____, ____, ____,	______

Additional Information:

1. Bank width at FSL
   Left Bank ____, ____, ____, ____, ____, Average ______
   Right Bank ____, ____, ____, ____, ____, Average ______

2. Elevation difference between FSL and surrounding fields:
   BM. rod reading ________ BM. description ______________
   FSL (rod reading) ______________________________
   Right side field rod reading ____, ____, ____, Ave ____, Δ Elev ___
   Left side field rod reading ____, ____, ____, Ave ____, Δ Elev ___
   Remarks (adjoining roads, etc.) ______________________

3. Cross-sections: Draw a typical cross-section giving top width and depth; include banks in drawing

Figure 1. (Cont'd)

4. How many days or hours per week does water flow in this section? ____________________

5. How far is the section from the mogha? ____________
   Is the section in the Sarkari Khal or on a farmer's branch? ____________________

6. Flow rate: What is the measured or estimated flow at the section? ____________ cusecs.

7. Bank material: Estimate the soil type: ____________
   Measure the bulk density: Sample Vol. ________; Sample dry wt. ____
   Bulk Density ________.

8. Is there any visible leakage? ______ From what type of hole? ____________

   Measure leakage volumetrically at different gauge readings and record gauge reading when leakage stopped. ____________

type leak	gauge reading	loss rate (units)

9. Adjoining crop losses:

   Area of land adjoining the test section where crops have been damaged by seepage: ____________________; crop: ____________

10. Describe the condition of the wetted perimeter; i.e., whether it is grassy or clean, the presence of rat or insect holts, etc: ____________
____
____
____

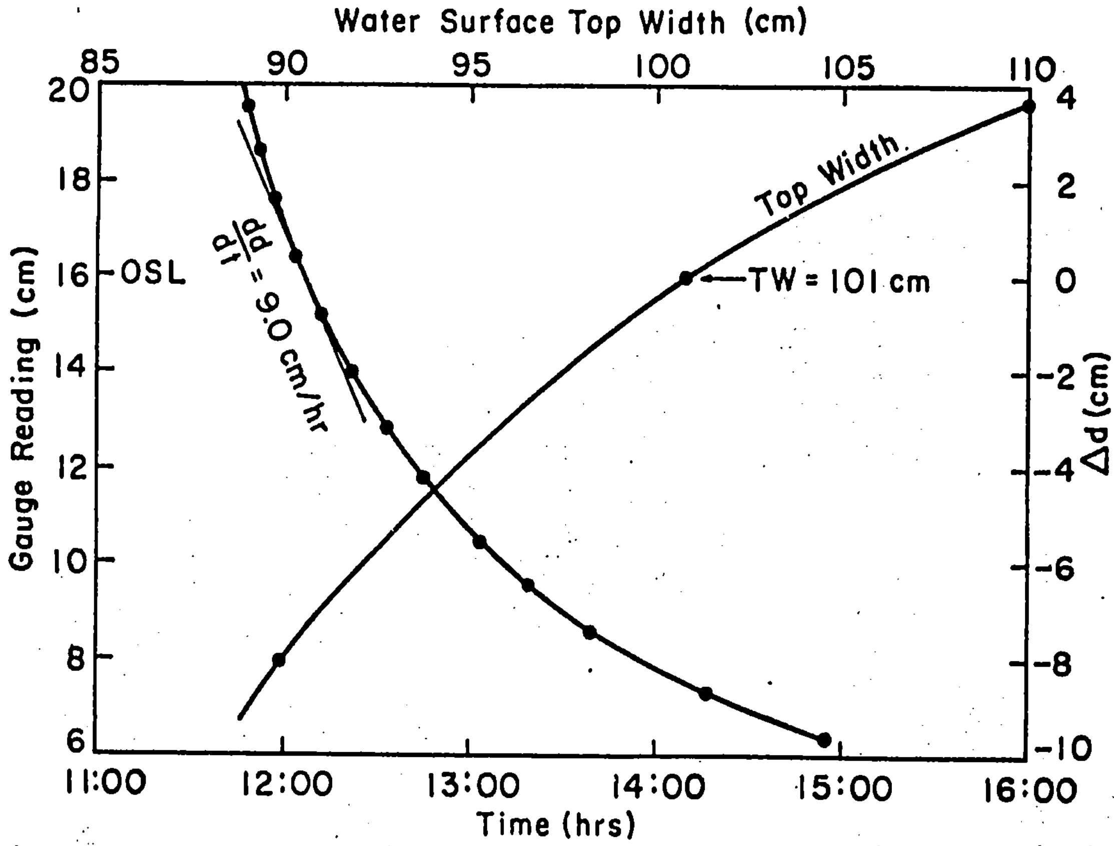

Figure 2. Gauge reading vs. time and water surface top width.

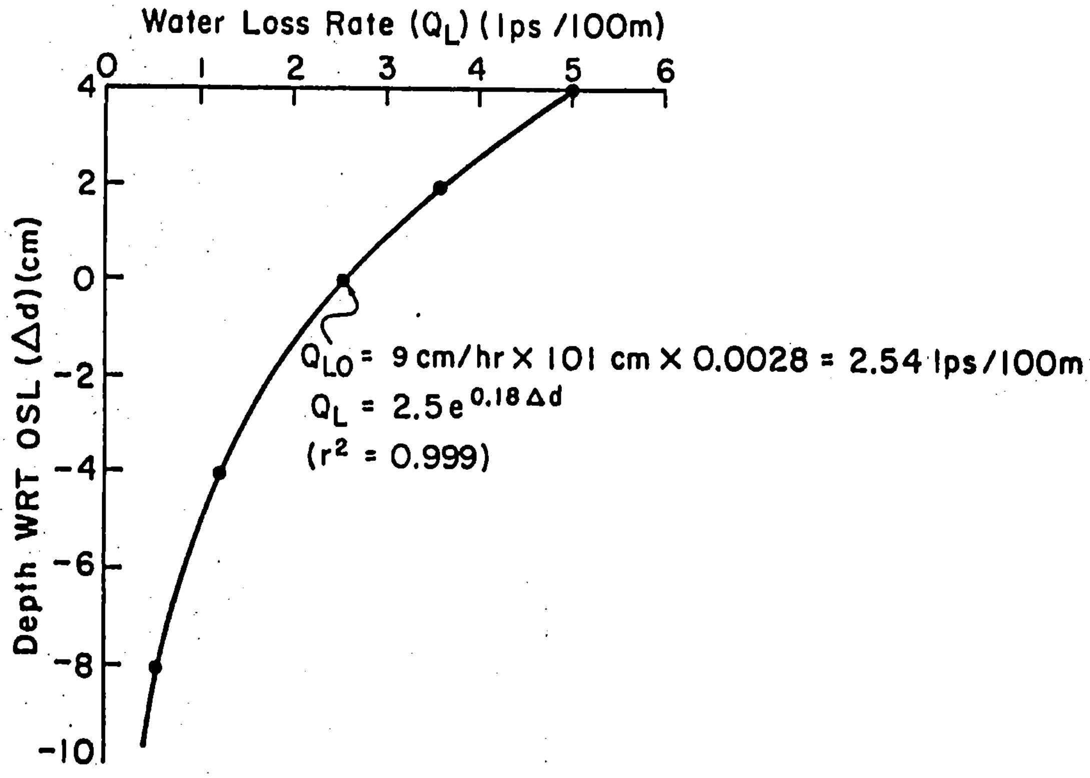

Figure 3. Loss rate as a function of depth.

Multiplying the water surface recession rate times the interpolated average water surface width, with the correct unit conversions, results in a water loss rate per unit of length;

$$(Q_L)_{d_i} = \left(\frac{dd}{dt}\right)_{d_i} \times (TW_A)_{d_i} \times C \qquad (1)$$

Where:

$(Q_L)_{d_i}$ = water loss rate at depth d_i (lps/100m),

$\left(\frac{dd}{dt}\right)_{d_i}$ = water surface recession rate at depth d_i (cm/hr),

$(TW_A)_{d_i}$ = average water surface top width at depth d_i (cm),

C = conversion factor = $\frac{1}{1000}$ (liters/cm^3) x $\frac{1}{3600}$ (hr/sec) x 100 (cm/m) x 100 m length = .0028.

This calculation was repeated at various depths. The overall results were plotted on a graph of water loss rates versus depth relative to osl, as is shown in Figure 3.

A factor which would affect the water surface recession rate is the water surface evaporation during the test. Water surface evaporation will vary with the season, climatic conditions, etc. Gibb (1966) lists annual evapotranspiration rates for various areas in the irrigated Indus Basin between 5 and 7 feet per year (150-215 cm/yr). If we convert an intermediate value of 180 cm/yr to the equivalent loss rate from a channel 100 cm wide and 100 m long, the result is 0.006 lps/100m. If this average value is increased four times to allow for tests during daylight hours on hot days, the equivalent loss rate is still only 0.024 lps/100m. Since this value is about 1 percent of the average measured loss rate, the surface evaporation factor was ignored.

<u>Analysis of the Data</u>

In order to better understand the factors which influence watercourse losses, it was attempted to determine the functional relationships between the various watercourse descriptive parameters such as flow depth, bank width, normal flow rate, etc., and the loss rate.

The first factor which affects loss rates is indicated in Figure 3. Loss rate consistently varied significantly with the depth of flow. It was recognized from graphs, such as Figure 3, that this relationship was curvilinear with a positive second derivative and could usually be represented by an exponential relationship of the form:

$$Q_L = Q_{LO}e^{b(\Delta d)} \tag{2}$$

Where;

Q_L = water loss rate (lps/100 m),

Q_{LO} = water loss rate at the osl ($\Delta d=0$) (lps/100 m),

b = an empirically derived exponent (cm^{-1}), and

Δd = water depth relative to the osl depth (cm).

The values of Q_{LO} and b were determined by running an exponential regression analysis on the values of Q_L and Δd taken from the graphs (such as Figure 3). The coefficient of determination (r^2) of the regression analysis was taken as the measure of the accuracy of the derived exponential relationship in describing the data. Normally the relationship was very good with r^2 values above 0.95 in 2/3 of the samples, and the derived Q_{LO} value was nearly always within 5 percent of the actual measured water loss rate at osl.

The derived coefficient and exponent of the loss vs. depth relationship, Q_{LO} and b, were then accepted as parameters which describe the water loss rate in the channel. The value Q_{LO} gives the normal loss rate in the test section and b is a measure of the sensitivity of that loss rate to fluctuations in flow depth. The exponent can be interpreted mathematically as the fractional change in loss rate with a unit change in depth, since:

$$\frac{\frac{dQ_L}{dd}}{Q_L} = \frac{bQ_{LO}e^{b\Delta d}}{Q_{LO}e^{b\Delta d}} = b, \tag{3}$$

Where:

$\frac{dQ_L}{dd}$ = rate of change of loss rate with depth.

The exponent was utilized as a factor only for those samples with r^2 values above 0.95.

An attempt was then made to relate the other measured descriptive parameters to these derived Q_{LO} and b values. It was realized that there were many factors which could not be measured or controlled which affect loss rates and it would not be possible to directly derive the desired functional relationships, so a multiple linear regression analysis was made between Q_{LO} and b and the quantifiable factors of:

1. operational supply level elevation with respect to the elevation of the adjoining field surfaces (ΔE) (cm),

2. average bank width at osl (BW) (cm),

3. normal flow rate in the channel (Q) (lps),

4. the percentage of time the section is full (T) (%),

5. the distance of the section from the mogha inlet (D) (m), and

6. the side slope of the inner bank at the osl (Z)(cm/cm).

The osl with respect to field elevation was selected as a relevant factor because it would partially determine the hydraulic gradient which would push water out through insect and rodent holes. Average bank width could affect the chances of rodent and insect holes or other leaks passing completely through the banks. The normal flow rate in the channel will indicate whether loss rates are higher in larger channels or remain fairly constant with channel size. The percentage of time a water channel is utilized could affect the insect and rodent activity in the banks below osl and consequently the loss rates. The distance of the test section from the mogha will often determine the amount of silt which is deposited in the channel and silt deposition could affect infiltration rates.

The side slope of the wetted perimeter will affect the amount of silt deposition on the sides of the banks. Nearly vertical sides (small Z value) often collect little silt. The factor Z is defined as horizontal divided by vertical distance. It was calculated from the slope of the water surface width vs. depth graph shown in Figure 2.

In addition to these six quantifiable factors, there were several nonquantitative characteristics which were also noted. The six nonquantifiable factors were:

1. Whether the watercourse was augmented by a public tubewell supply or not (SCARP/non-SCARP (S/NS));

2. Whether the section was sarkari khal or farmer's branch (SK/FB);

3. Whether the section had been recently rebuilt or not (Improved/Unimproved (I/U));

4. Whether the section's wetted perimeter was generally clean or full of grass and vegetation (Cl/GR);

5. Whether the banks had been thoroughly wet or not before the data collection began (Wet/Dry(W/D)); and

6. Soil type: Sandy (Sa), Sandy Loam (SaL), Loam (L), Silt Loam (SiL), and Clay Loam (CL).

In a few cases, attempts were made to select sections where most of the above listed factors could be controlled or held constant. This allowed one of the factors to be compared directly with the loss rate parameters. This was done in the case of ΔE and BW factors.

The statistical analysis of the data was complicated by intercorrelations between the measured parameters. Most of these intercorrelations were inherent in the physical system. For example, SCARP tubewell supplemented watercourses tend to have higher flow rates than non-SCARP watercourses, and sarkari khal channels are used more often than farmers' branch channels. It was, because of these intercorrelations, not always possible to establish a direct cause and effect relationship.

Because of the intercorrelations, the qualitative and quantitative parameters were analyzed together in one regression analysis. Qualitative parameters were inserted as dummy variables with values of 1 or 0.

RESULTS

Table 1 lists the data collected in 122 ponding loss measurements. The first digit of the data set identification number (I.D. No.) indicates whether the watercourse is non-SCARP (1) or SCARP (2). The second digit is the same within each subset for all tests made on the same watercourse. The third digit is the same within each watercourse group for tests made at the same time on adjoining sections. The final digit identifies the section. Sixty-five measurements are complete in all quantitative data. Because of inadequate number of samples with measured soil types, no analysis was made between soil type and loss rate.

The loss rates at operational supply level (Q_{LO}) and the exponential coefficient, b, were determined by the curve fitting procedure described in Chapter 4. The coefficient of determination (r^2) for each derived curve is given.

There is a wide variability in the measured loss rates. The mean derived loss rate at operational supply level (Q_{LO}) was 2.32 lps/100m (0.25 cfs/1000 ft) with a standard deviation of 1.95 lps/100m for 122 sets of data. The loss rate values range from 0.01 to 12.93 lps/100m (0.001 to 1.39 cfs/1000 ft). Part of the variability is the result of the non-quantitative parameters and a portion can be related to the quantitative variables as discussed in the regression

Table 1. Ponding Loss Data Including Qualitative and Quantitative Variables and Loss Rates.

I.D. NO.	QUALITATIVE VARIABLES						QUANTITATIVE VARIABLES QM (LPS)	D (M)	T (%)	Z	BW (CM)	DE (CM)	LOSS RATE QLO (LPS/100M)	B (1/CM)	RSQ
1111.	NS	U	SK	CL	D	SAL	31	448	50	1.35	63	28	.10	.341	.962
1112.	NS	U	SK	CL	D	SAL	31	448	50	1.25	64	27	.09	.341	.980
1113.	NS	U	SK	CL	D	SAL	31	512	45	.82	104	18	[illegible]	.331	.970
1121.	NS	U	FB	GR	W	SAL	28	384	2	.99	66	11	1.45	.211	.972
1122.	NS	U	FB	GR	W	SAL	28	384	2	.45	60	11	.83	.180	.995
1123.	NS	U	FB	CL	W	SAL	28	448	1	1.40	66	10	.49	.130	.960
1124.	NS	U	FB	CL	W	SAL	28	448	1	.54	71	16	.74	.128	.986
1211.	NS	U	FB	CL	D	SA	34	1600	4	.76	50	20	3.93	.057	.943
1212.	NS	U	FB	CL	D	SA	34	1600	4	.90	50	20	4.83	.051	.965
1221.	NS	U	FB	GR	D	SAL	57	320	10	1.40	72	30	2.38	.189	.998
1311.	NS	U	SK	GR	D	L	65	64	70	.22	68	8	.09	.089	.941
1312.	NS	U	SK	GR	D	L	65	64	70	.90	77	4	.01	.245	.997
1321.	NS	U	SK	GR	D	L	65	64	14	2.00	72	11	.19	.224	.997
1411.	NS	I	SK	CL	D		113	3840	7	.45	127	24	.14	.249	.980
1412.	NS	I	SK	CL	D		113	3840	7	1.50	101	26	.23	.168	.999
1413.	NS	I	SK	CL	D		113	3840	7	.71	107	31	.30	.019	.956
1421.	NS	U	SK	GR	D		113	4160	18	.63	64	21	.67	.056	.961
1422.	NS	U	SK	GR	D		113	4160	18	1.21	63	19	.58	.069	.968
1431.	NS	U	FB	GR	W		113	1408	4	1.47	49	25	1.03	.466	.819
1511.	NS	U	FB	GR	D		34	64	21	.75	35	17	.19	.605	.411
1512.	NS	U	FB	GR	D		34	64	5	1.60	28	11	.58	.195	.973
1521.	NS	U	FB	GR	W	SAL	23	256	4	1.20	34	11	.39	.237	.876
1522.	NS	U	FB	GR	W	SAL	20	192	3	2.80	41	15	1.28	.286	.977
1531.	NS	U	FB	GR	D		23	64	3	.45	28	10	1.08	.127	.991
1532.	NS	U	FB	GR	D		28	64	6	.67	35	20	.45	.169	.989
1611.	NS	U	SK	CL	W		48	640	13	2.34	82	20	.49	.128	.596
1612.	NS	U	SK	GR	W		48	704	10	1.20	88	7	.68	.149	.941
1613.	NS	U	SK	GR	W		48	768	10	1.25	112	9	.71	.208	.907
1711.	NS	U	SK	GR	W		76	384	7	1.16	143	30	1.03	.177	.974
1712.	NS	U	SK	CL	W		76	384	7	1.95	144	17	1.42	.187	.989
1811.	NS	I	SK	CL	D	SIL	40	2240	8	1.50	97		.55	.215	.995
1821.	NS	U	FB	GR	W	SIL	40	1728	2	1.33	50		.28	.174	.950
1831.	NS	I	SK	CL	D	SIL	48	320	36	.55			.22	.172	.827
2711.	S	I	SK	CL	W	CL	141	2880	25	.86	88	49	2.51	.188	.940
2721.	S	U	FB	CL	W	CL	170	320	8	.60	64	13	4.64	.182	.990
2211.	S	I	SK	GR	W	CL	85	1408	7	1.04	88	34	1.11	.156	.997
2221.	S	U	SK	GR	W	CL	85	1280	5	.65	76	14	3.43	.152	.998
2811.	S	U	FB	GR	W	L	85	64	14	.92	49	21	2.69	.098	.930
2611.	S	I	SK	CL	W	CL	57	1600	7	.63	61	6	1.86	.199	.980
2511.	S	U	FB	CL	W	SIL	99	448	5	.30	71	19	.56	.203	.950
2512.	S	U	FB	CL	W	SIL	99	448	5	.55	75	25	1.02	.192	.950
2513.	S	U	FB	CL	W	SIL	99	512	5	.24	78	23	1.30	.146	.990
2411.	S	U	FB	CL	W	SA	79	64	7	3.30	122	4	3.25	.050	.910
2412.	S	U	FB	CL	W	SA	79	64	7	.49	105	3	1.86	.021	.460
2413.	S	U	FB	CL	W	SA	79	128	7	.92	82	-5	4.55	.275	.930
2421.	S	U	SK	GR	D	SAL	79	64	5	.70	107	-42	.46	.170	.950
2422.	S	U	SK	GR	D	SAL	79	64	5	.50	95	-33	.37	.160	.920
2423.	S	U	SK	GR	D	SAL	79	128	5	1.00	100	-20	.28	.171	.960
2431.	S	U	SK	GR	D	SAL	79	128	11	1.60	134	24	3.06	.115	.960
2432.	S	U	SK	GR	D	SAL	79	128	11	2.00	130	26	3.43	.281	.970
2311.	S	I	SK	GR		CL	127	64	10	.68	96	30	3.46	.203	.940
2312.	S	I	SK	GR		CL	127	64	10	.88	96	36	1.79	.161	.984
2321.	S	I	SK		W		127	64	10	.56		32	5.57	.140	.990
2322.	S	I	SK		W		127	64	10	1.20		35	4.83	.165	.990
2323.	S	I	SK		W		127	128	10	1.11		35	3.43	.127	.990
2324.	S	I	SK		W		127	128	10	.93		49	2.32	.169	.950
2331.	S	I	SK		W		113	768	5	1.11		14	1.79	.037	.884
2332.	S	I	SK		W		113	768	5	.80		6	1.80	.109	.803
2333.	S	I	SK		W		113	832	5	1.00		0	1.12	.098	.926
2334.	S	I	SK		W		113	832	5	1.43		15	3.04	.167	.905
2111.	S	I	SK		W		113	1920	12	1.00		11	1.98	.103	.990
2112.	S	I	SK		W		113	1920	12	.83		16	3.25	.113	.990
2113.	S	I	SK		W		113	1984	12	.55		18	2.69	.110	.990
2114.	S	I	SK		W		113	1984	12	.71		39	2.60	.044	.950
2115.	S	I	SK		W		113	2048	12	.81		18	2.13	.084	.920
2121.	S	I	SK	CL	D		113	1856	18	.94	127	10	1.26	.121	.984
2131.	S	I	SK	CL	D		113	2368	12	.96	101	25	2.23	.134	.994
2132.	S	I	SK	CL	D		113	2368	8	1.03	116	22	3.26	.119	.973
2231.	S	U	FB	CL	D	SIL	99	256	1	.60	71	21	2.35	.084	.987
2232.	S	U	FB	CL	D	SIL	99	256	1	.50	60	28	4.19	.074	.997
2233.	S	U	FB	CL	D	SIL	99	320	1	.30	57	26	2.83	.062	.936
2141.	S	U	FB	CL		SIL	99	256	1	.50	60	28	3.62	.056	.995
2142.	S	U	FB	CL		SIL	99	256	1	.50	60	28	5.15	.064	.997
2151.	S	I	SK				113	2560	9	.75	24	86	.69	.123	.953
2161.	S	U	FB	GR	W		113	1536	2	.83	68	23	12.93	.163	.988
2162.	S	U	FB	GR	W		113	1536	2	.85	72	23	5.52	.059	.986
2163.	S	U	FB	GR	W		113	1600	2	1.25	99	23	7.40	.070	.991
2621.	S	I	SK	CL	D		57	1024	38	1.08	125	16	1.14	.150	.984
2622.	S	I	[illegible]	CL	D		57	1088	38	.82	118	19	1.17	.118	.999
2623.	S	I	[illegible]	CL	D		57	1152	38	1.30	125	34	1.14	.127	.989
2624.	S	I	SK	CL	D		57	1216	38	1.02	112	39	.98	.121	.998

Symbols

NS = Non-SCARP
S = SCARP
U = Unimproved
I = Improved
SK = Sarkari Khal
FB = Farmer's Branch
CL = Cleaned
GR = Grassy
D = Dry

W = Wet
SA = Sand
SAL = Sandy Loam
L = Loam
SIL = Silty Loam
CL = Clay Loam
QM = Inflow (Q_M)
D = Distance from mogha

T = Time used (%)
Z = Side Slope
BW = Bank Width
DE = Elevation above field (ΔE)
QLO = Derived Loss Rate at osl (Q_{LO})
B = Derived exponent (b)
RSQ = r^2 of derived equation

Table 1. Ponding loss data including qualitative and quantitative variables and loss rates. (Cont'd.)

2171.	S	I	SK		D				1.25		2.69	.124	.957
2172.	S	I	SK		D				1.25		2.90	.066	.985
2173.	S	I	SK		W				1.10		1.11	.084	.900
2174.	S	I	SK		W				1.20		1.04	.103	.926
2181.	S	U	FB		D				.90		2.12	.170	.945
2182.	S	U	FB		D				.40		1.45	.113	.945
2183.	S	U	FB		W				1.15		1.45	.113	.960
2184.	S	U	FB		W				.61		1.20	.110	.980
2191.	S	U	FB	GR							3.78	.050	.940
2195.	S	U	FB	CL							2.78	.066	.961
2192.	S	U	FB	GR							3.85	.085	.994
2196.	S	U	FB	CL							3.11	.081	.907
2193.	S	U	FB	GR							.54	.156	.980
2197.	S	U	FB	CL							1.44	.153	.962
2341.	S	I	SK	GR							3.00	.163	.988
2345.	S	I	SK	CL							2.42	.127	.993
2342.	S	I	SK	GR							2.52	.147	.996
2346.	S	I	SK	CL							3.18	.131	.995
2343.	S	I	SK	GR							1.62	.226	.987
2347.	S	I	SK	CL							1.96	.186	.989
2911.	S	I	SK							30	5.20	.096	.910
2921.	S	I	SK							60	5.48	.125	.900
2931.	S	I	SK							90	6.40	.188	.980
2912.	S	I	SK							30	6.87	.144	.990
2922.	S	I	SK							60	6.22	.190	.930
2932.	S	I	SK							90	4.83	.130	.885
2913.	S	I	SK							30	3.53	.055	.890
2923.	S	I	SK							60	3.43	.071	.970
2933.	S	I	SK							90	2.41	.065	.980
2941.	S	I	FB								2.05	.303	.985
2942.	S	I	FB								2.51	.170	.787
2943.	S	I	FB								2.01	.244	.913
2944.	S	I	FB								5.24	.100	.970
2945.	S	I	FB								5.20	.116	.940
2601.	S	U	SK			23	1152	15			1.32	.190	.996
2541.	S	U	FB			40	320	8			.80	.055	.910
2951.	S	I	SK								1.35	.089	.968
2961.	S	I	SK								2.23	.134	
2962.	S	I	SK								3.25	.119	
2971.	S	I	SK								4.73	.127	.940
2351.	S	I	SK								1.95	.076	.900

Symbols

NS = Non-SCARP
S = SCARP
U = Unimproved
I = Improved
SK = Sarkari Khal
FB = Farmer's Branch
CL = Cleaned
GR = Grassy
D = Dry

W = Wet
SA = Sand
SAL = Sandy Loam
L = Loam
SIL = Silty Loam
CL = Clay Loam
QM = Inflow (QM)
D = Distance from mogha

T = Time used (%)
Z = Side Slope
BW = Bank Width
DE = Elevation above field (ΔE)
QLO = Derived Loss Rate at ofl (Q_{LO})
B = Derived exponent (b)
RSQ = r^2 of derived equation

analysis section. A large portion of the variability (over 50%) could not be related to the measured parameters.

The data strongly supported the hypothesis that the loss rate is exponentially related to the depth. For two-thirds of the data sets, the relationship between loss rate and depth fits the exponential Equation 2 with a coefficient of determination (r^2) above 0.95. In only 11 of the 122 total data sets did the relationship have an r^2 value below 0.90.

The exponent coefficient, b, which was considered only for those cases where the equation r^2 value was greater than 0.95, was also widely variable. The mean for 81 cases was 0.150 with a standard deviation of 0.069. Values varied from 0.019 to 0.605. Although part of the variability is related (later in this section) to the measured parameters, over half remained unexplained.

Regression Analysis

Regression analysis of the data indicated only three parameters which significantly affected loss rates:

1. whether the channel was SCARP or non-SCARP (Sc/NS),
2. whether it was sarkari khal or farmer's branch (SK/FB), and
3. the normal flow rate (Q).

The derived regression equation is:

$$Q_{LO} = 0.79 + 1.33\ Sc - 1.64\ SK + 0.018Q \qquad (4)$$

coefficient of determination (r^2) = 0.39

standard error of estimate (S.E.E.) = 1.61

F factor = 16.53

Adding other factors to the regression increased the r^2 value very little and, in fact, increased the standard error of estimate.

Equation 4 indicates that SCARP watercourses lose 1.33 lps/100m more water than non-SCARP channels, loss rates in sarkari khal sections are 1.64 lps/100m less than in farmers' branches, and that loss rates increase 0.018 lps/100m for each liter per second increase in the normal flow rate.

Further analysis of the data indicated that the influence of flow rate on loss rate is less in non-SCARP than in SCARP watercourses. The derived regression equation is:

$$Q_{LO} = 1.32 - 0.54\ Sc - 1.47\ SK + 0.006\ Q + 0.024\ (QxSc) \quad (5)$$

$$r^2 = .415$$

$$S.E.E. = 1.59$$

This model indicates that the influence of the flow rate (Q) on the loss rate (Q_{LO}) is four times larger in SCARP than in non-SCARP channels, and that the higher loss rates measured in SCARP channels is primarily a result of the higher flow rates and the stronger influence of flow rates on loss rates. Figure 4 graphically depicts the derived regression equation (Eq.5).

The data analysis of the total data set did not indicate a relationship between loss rate and usage time, T, as has been reported by other authors (Bowers et al., 1976, Cheema et al., 1976). It is probable that this relationship is partially hidden by the SK/FB factor, since T is highly intercorrelated with this factor. The six sets of measurements made on non-SCARP, unimproved, sarkari khal sections, where this intercorrelated factor is held constant, indicates that an inverse relationship does exist between loss rate and usage time. The data and derived regression equations are shown in Figure 5. For this data subset, T is by far the most important parameter affecting loss rates. There was not enough variability in usage times of the SCARP, sarkari khal sections to allow derivation of a significant relationship.

Elevation of the watercourse operational supply level with respect to the elevation of the surrounding land surface (ΔE) did not significantly affect loss rates in the total data set. However special measurements designed specifically to determine the influence of ΔE on Q_{LO} by holding most other factors constant, did indicate that a direct relationship exists. These measurements (I.D. #2321-2334 and 2411-2432 in Table 1) are plotted in Figure 6 and indicate that loss rates increase about 0.04 lps/100m for every one centimeter increase in ΔE.

Five parameters were related in the stepwise linear regression analysis to the exponential coefficient b. They are listed along with the derived coefficients in the order of their insertion into the regression equation, in Equation 6.

$$b = 0.19 - 0.000072Q + 0.0011T - 0.000029D - 0.055Sc + 0.037SK \quad (6)$$

$$r^2 = .45$$

$$S.E.E. = .056$$

$$F = 8.33$$

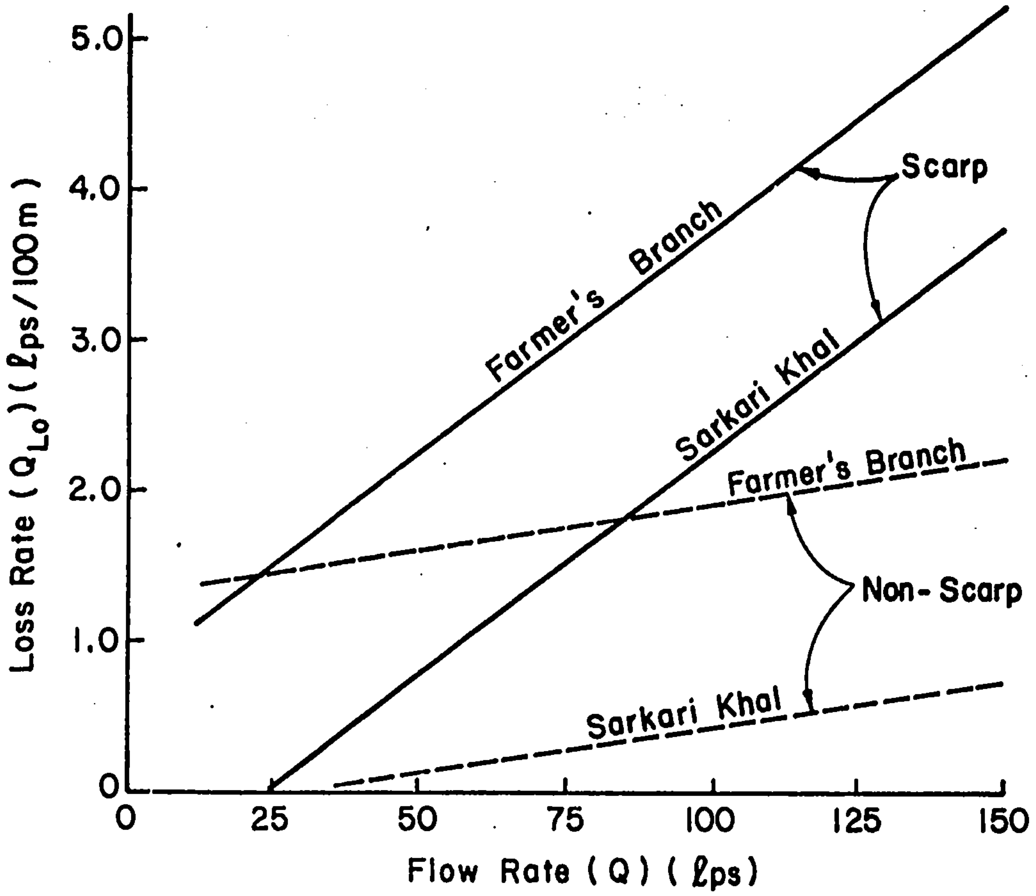

Figure 4. Loss rate as a function of flow rate (Q) for SCARP and non-SCARP, and sarkari khal and farmer's branch channels, according to derived regression Equation 5.

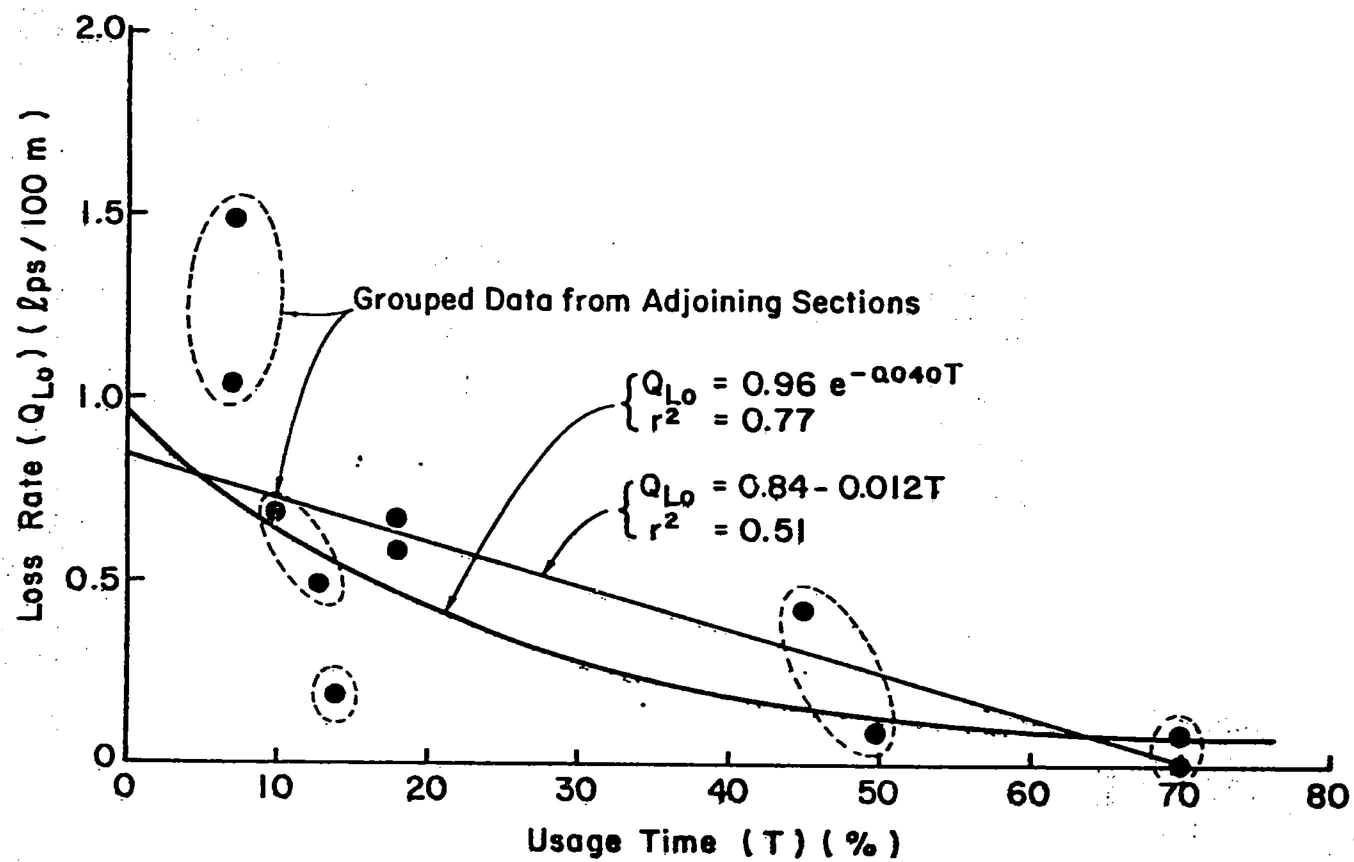

Figure 5. Loss rate as a function of usage time (T) for measurements from non-SCARP unimproved sarkari khal (NS,U,SK) sections.

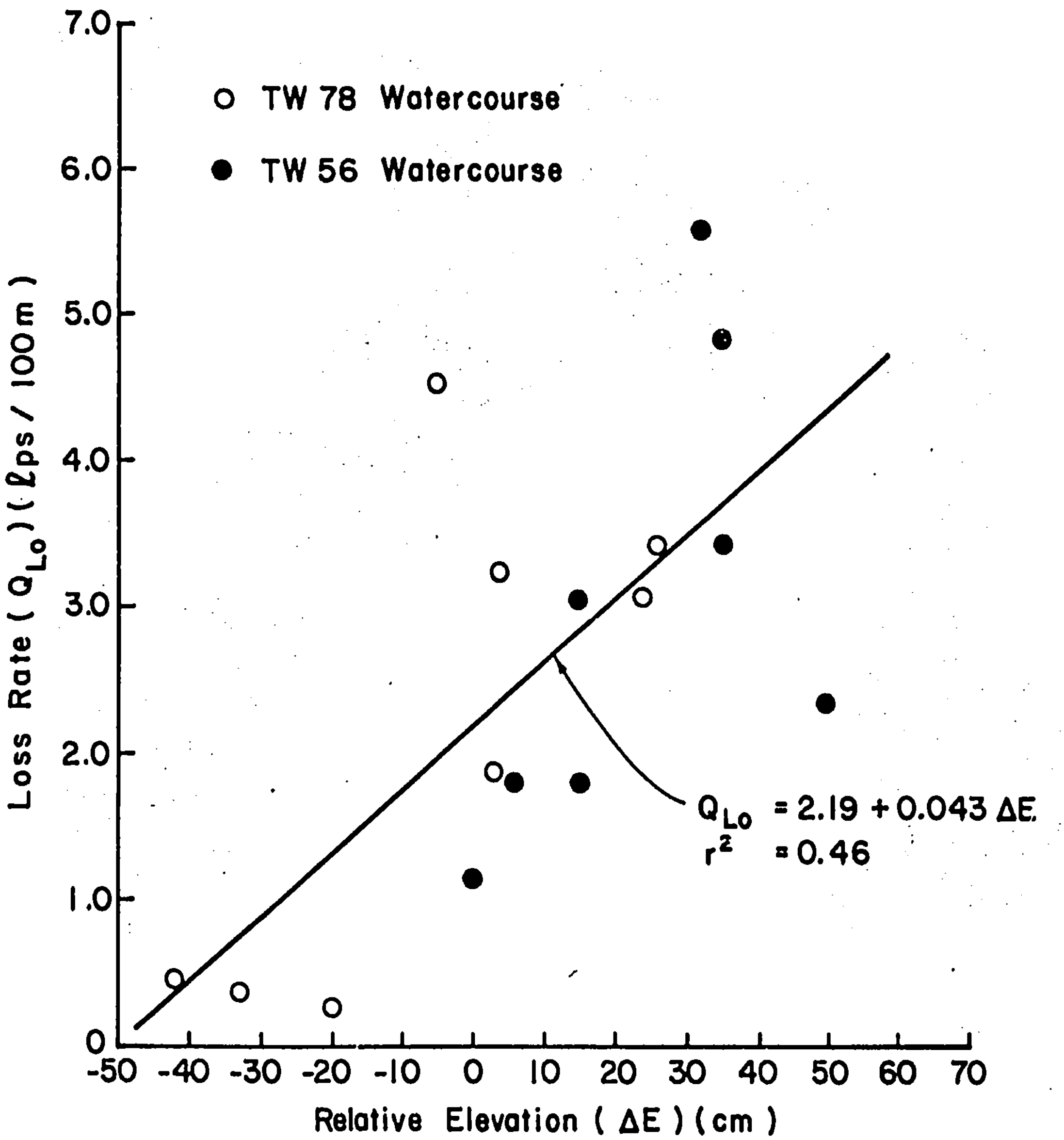

Figure 6. Loss rate as a function of the operational supply level elevation relative to the elevation of the surrounding land surface (ΔE) for channel sections on two watercourses.

The loss rate, Q_{LO}, was included as a parameter in the regression but was not a significant factor. The equation indicates that b values decrease slightly with increasing normal flow rate and distance from the mogha, increase with increasing usage time, and are higher in non-SCARP and sarkari khal sections.

DISCUSSION OF THE FINDINGS

A Comparison of the Present Results with Previous Findings

The ponding loss data indicate that water loss rates in Pakistan watercourses average about 2.3 lps/100m (0.25 cfs/ 1000 ft) with a very wide variability. This loss rate would result in 42% losses on a watercourse where the average distance to the field is 1400 m (4600 ft)(Ali et al. 1978), and the inflow rate is the average of those in this study (77 lps (2.8 cfs)). The average loss rate measured in SCARP watercourses was 2.87 lps while that in non-SCARP channels was 0.84 lps/100m. Various inflow-outflow loss measurements have found loss rates in the same range. Lowdermilk et al. (1978) measured 40 watercourse systems where the average loss rate was 3.3 lps/100m (0.36 cfs/ 1000 ft). Operational conveyance loss measurements found average steady state loss rates on six watercourse systems, two of which were SCARP, to be 1.92 lps/100m (0.21 cfs/ 1000 ft)(Ali et al., 1978). Clyma et al. (1975), found average loss rates from watercourses from six areas of the Punjab to be 1.79 cfs/100 (0.19 cfs/1000 ft). On-Farm Water Management Development Project (1978) measured loss rates from 66 watercourses (all non-SCARP) in Sahiwal Tehsil which averaged 0.75 lps/100 m (0.08 cfs/1000 ft). All of these inflow-outflow data sets also had a large amount of variability.

In 18 of the channels where ponding losses were measured, independent inflow-outflow measurements have also been made. The data collected from these sections and presented in Table 2 allow a direct comparison of ponding and inflow-outflow measurements.

In all cases, the individual ponding measurements were made on short 20 to 40 meter channel sections which were located on the longer branches (400-800 m) where the inflow-outflow measurement was made. If all of the branch were divided into ponding loss sections and tested, the total losses should be comparable between the two methods. The true ponding loss tests are a small sample of the total (about 5%) and the exhibited variability would be expected, although the aggregate of several samples should approach the true value.

Wide variability is displayed between the two sets of data for specific channels, but the differences in the overall averages is not large. The average ponding loss

Table 2. Comparison of loss rates measured in the same watercourse branches by the inflow-outflow method and by ponding.

Non-SCARP	Loss Rates (lps/100 m)					
	By Ponding					By Inflow-Outflow
Branch	Individual measurements				Mean	
1	0.10	0.09	0.42		0.20	0.46
2	1.45	0.83	0.49	0.74	0.88	0.74
3	3.93	4.83			4.38	8.35
4	2.38				2.38	2.88
5	0.09	0.01			0.05	0.74
6	0.19	0.09			0.14	0.65
7	0.22				0.22	0.56
Ave.					1.18	2.05
SCARP						
1	2.51				2.51	1.86
2	1.86				1.86	3.34
3	3.06	3.43			3.25	2.60
4	1.98	3.25	2.69		2.53	2.78
5	1.26	2.23	3.26		2.25	2.78
6	0.69	2.69	2.90		1.70	1.76
7	3.78	2.78			2.58	2.78
8	1.32				1.32	3.06
9	1.35	3.27			2.31	1.76
10	2.23	3.25	4.73		3.40	2.78
11	1.14	1.17	1.14	0.98	1.11	2.32
Ave.					2.26	2.53
Overall Ave.					1.84	2.34

measurement is 20% less than the average inflow-outflow measurement. The difference is larger in non-SCARP watercourses.

Two characteristic differences between ponding and inflow-outflow measurements could cause the above difference. The first is that required head loss in the downstream flume utilized in inflow-outflow measurements increases the flow depth in the test section. The amount of depth increase depends upon the head loss in the flume (which normally varies from 3 to 9 cm) and the hydraulic characteristics of the channel which determine the backwater curve of the water surface. The present study has indicated increasing the flow depth will increase the loss rate. An analysis of this effect in Ali et al. (1978) indicates that this flume induced depth increase will often cause flume loss measurements to overestimate actual loss rates by 5 to 30% of the loss rate.

The second factor which would cause ponding loss measurements to be less than inflow-outflow measurements is the silt deposition from ponded water. Canal water normally carries a heavy sediment load, much of which is transported to the field in normally flowing water. When the water is ponded, part of this suspended sediment will deposit on the wetted perimeter of the test section. This sediment deposition is aggravated by the building of the earthen bunds at both ends of the section which often adds large quantities of sediment to the ponded water.

Deposits of fine sediments usually have lower infiltration rates than the channel bed and bank materials. Also, the deposition of larger sediment particles (derived from the bund soils) than normally deposit in a channel can plug larger pores and even some of the smaller size insect holes and cracks. Both of these factors will lead to reduced infiltration rates in ponded sections and will cause ponding loss measurements to underestimate true loss rates.

Consequently, the true steady-state water channel loss rate would be expected to lie somewhere between that measured by ponding and inflow-outflow methods.

It should also be mentioned that both methods have normally been used only to measure steady state loss rates, which will underestimate true operational loss by about 7 percent of the inflow (Ali et al., 1978). Operational losses include, in addition to these steady-state losses, transient losses such as dead storage, wetting up of dry channels, and occasional breaks in banks and bunds.

Ponding loss rates measured in the earlier studies by the Punjab Irrigation Research Institute and Huntington Technical Services averaged about 0.23 lps/100 m (0.025 cfs/100 ft) and 0.37 lps/100 m(0.04 cfs/1000 ft) respectively.

Both studies combined made measurements in 23 channel sections. Several explanations for why these previous results were so much lower (about 1/3 of the non-SCARP average in the present study) than more recent measurements are discussed in Ashraf et al. (1977), and include:

1. Straight, uniform sections with no visible leakage were purposely chosen such that potential rather than actual loss rates could be demonstrated.

2. Less attention was paid to the normal operational supply level. In the 150 m (500 ft) sections used, if the channel slopes averaged 0.0005, the difference in depth from one end to the other end of the section would be about 8 cm. An 8 cm drop in depth will, according to the present study, cause a 70% reduction in loss rate. The IRI study reported the "average" loss rate over a period of time when the water level receded about 15 cm (6 in). Again, the findings of this study indicate that such an "average" reading would be only about 1/4 as large as the loss rate at the initial depth.

3. The Huntington Technical Services study refilled the same section three times and the average of all three measurements was reported. It was noted that measured loss rates were reduced with each remeasurement. This remeasurement process would be expected to result in reduced loss rates due to the siltation effect previously mentioned and due to microbiological growth on the wetted perimeter that would tend to decrease infiltration rates (Allison, 1947).

Analysis of the Reasons for the High Loss Rates

These ponding loss measurements support the referenced inflow-outflow data which indicate that watercourse losses are high. Once this fact is established, the next task is to determine what is causing the high loss rates so that methods to reduce losses can be formulated. As an initial effort to establish these causes, it was attempted to relate various measurable parameters to the loss rate.

Loss Rate as a Function of Flow Depth

The first parameter analyzed was depth of flow relative to the normal flow depth or operational supply level. It was established that loss rate is strongly related to depth and the relationship is generally described by the exponential equation:

$$Q_L = Q_{LO}e^{b\Delta d} \qquad (2)$$

The exponential coefficient b averaged 0.15 cm^{-1} for the total data set. This implies that loss rates will double with each 5 cm increase in flow depth and triple with an 8 cm increase.

Depth of flow in a given channel is influenced by several factors. Depth will increase as more water flows in the channel, as grasses and vegetation grow in the channel increasing the channel roughness, when silt deposits build up on the bed, or whenever a farmer is irrigating a high field or allows a water buffalo or a log to lie in the watercourse partially blocking the flow. The depth increase resulting from these last two factors can be calculated with iterative backwater curve calculations which depend upon the increased depth at the obstruction or field and channel hydraulic characteristics. Such a calculation has been done previously in Ali et al. (1978) to predict induced losses with flume installations. Table 3 adapted from Table 17 of that report uses the backwater curve calculation and the exponential loss rate-depth relationship with b = 0.15 to predict increased losses as a result of increasing the flow depth at one place in a channel.

Inflow-outflow measurements on two watercourse systems supported this finding by indicating that loss rates increased significantly when higher fields were being irrigated (Trout et al., 1977). Of three other watercourses studied in the same fashion by Ali et al. (1978), two exhibit a similar field elevation-loss rate relationship.

The effect of changes in channel roughness or inflow rate on flow depth can be determined from Manning's equation for a given channel cross-sectional shape. For an optimum (minimum wetted perimeter) rectangular, triangular, trapezoidal, or semi-circular shaped channel, the explicit relationship between depth and these factors is:

$$d = a\left(\frac{1}{\sqrt{S}}\right)^{3/8} (Q)^{3/8} \quad (n)^{3/8}, \tag{7}$$

Where:

d = flow depth (m)

a = a constant: a = 0.92 for an optimum rectangular channel (depth = ½ bottom width), 1.30 for a triangular channel (Z=1), 0.97 for an optimum trapezoidal channel, and 1.00 for a semi-circular channel

S = channel slope (m/m)

Q = inflow rate (m^3/sec)

n = Manning's roughness coefficient

Table 3. Ratio of average loss rate in a watercourse section with an obstruction which creates a given depth increase, to the loss rate without the obstruction (Adapted from Table 17 of Ali, et al., (1978) with b = 0.15).

Depth Increase at Obstruction (cm)	Channel Slope (m/m)	Section Length (m) 150	300	600	900	1200	1500	1800	2400
3	.0002	1.52	1.44	1.33	1.26	1.21	1.17	1.14	1.10
	.0005	1.42	1.30	1.17	1.11	1.09	1.07	1.06	1.04
	.0008	1.29	1.19	1.10	1.06	1.05	1.04	1.03	1.02
6	.0002	2.43	2.27	1.95	1.74	1.59	1.49	1.41	1.31
	.0005	2.10	1.79	1.47	1.32	1.24	1.19	1.16	1.12
	.0008	1.92	1.58	1.30	1.20	1.15	1.12	1.10	1.07
9	.0002	3.83	3.44	2.86	2.45	2.16	1.96	1.81	1.49
	.0005	3.28	2.63	1.96	1.66	1.49	1.39	1.33	1.25
	.0008	2.84	2.15	1.60	1.40	1.30	1.24	1.20	1.15

More commonly encountered watercourse cross-sectional shapes can often be described by a power curve of the form:

$$d = u(TW/2)^p \qquad (8)$$

Where:

d = depth (m)

TW = top width (m)

u = an empirical constant

p = an empirical exponent

An example of such a cross section where u = 2.5 and p = 3 is shown in Figure 7. The relationship between depth and Q and n for this cross-sectional shape can be closely approximated by an equation of the form of equation 7. For the shape in Figure 7 the coefficient value, a, is 1.26 and the exponent value 0.54. The coefficient of determination of the fit is 0.99995. After testing many cross-sectional shapes, it was determined that for most watercourses, the relationship between normal depth of flow and flow rate and roughness coefficient, could be closely approximated by an equation of the form:

$$d = a\left(\frac{Qn}{\sqrt{S}}\right)^c \qquad (9)$$

where a and c are empirically defined constants which vary with channel shapes and sizes, but are usually in the range of 1.1 to 1.4, and 0.45 to 0.55 respectively. This relationship is shown in Figure 8 for a = 1.2 and c = 0.50, and three slope values.

Equation 9 can then be combined with equation 2 to develop a relationship between the change in loss rate with changes in Q or n.

$$Q_L/Q_{LO} = e^{b(\Delta d)} = e^{b(d-d_o)} = \exp\left\{ba\left[\left(\frac{Qn}{\sqrt{S}}\right)^c - \left(\frac{Q_o n_o}{\sqrt{S}}\right)^c\right]\right\} \qquad (10)$$

Equation 10 is depicted graphically in Figure 9 for four initial values of the flow rate-roughness coefficient product ($Q_o n_o$). As an example to demonstrate the use of the figure assume a watercourse presently has a flow rate of 50 lps (about 1.75 cfs) and a roughness coefficient of 0.04, giving a $Q_o n_o$ value of 2. Assume the slope of the channel, is a moderate 0.0005. It is desired to increase the mogha flow by 20%. The figure predicts by moving out the S = .0005 curve which passes through Q_L/Q_{LO} = 1 at (Qxn) = 2, until the (Qxn) value of 2.4 (120% of 2) is reached on the ordinate, that the new loss rate will be about 1.7 times greater than

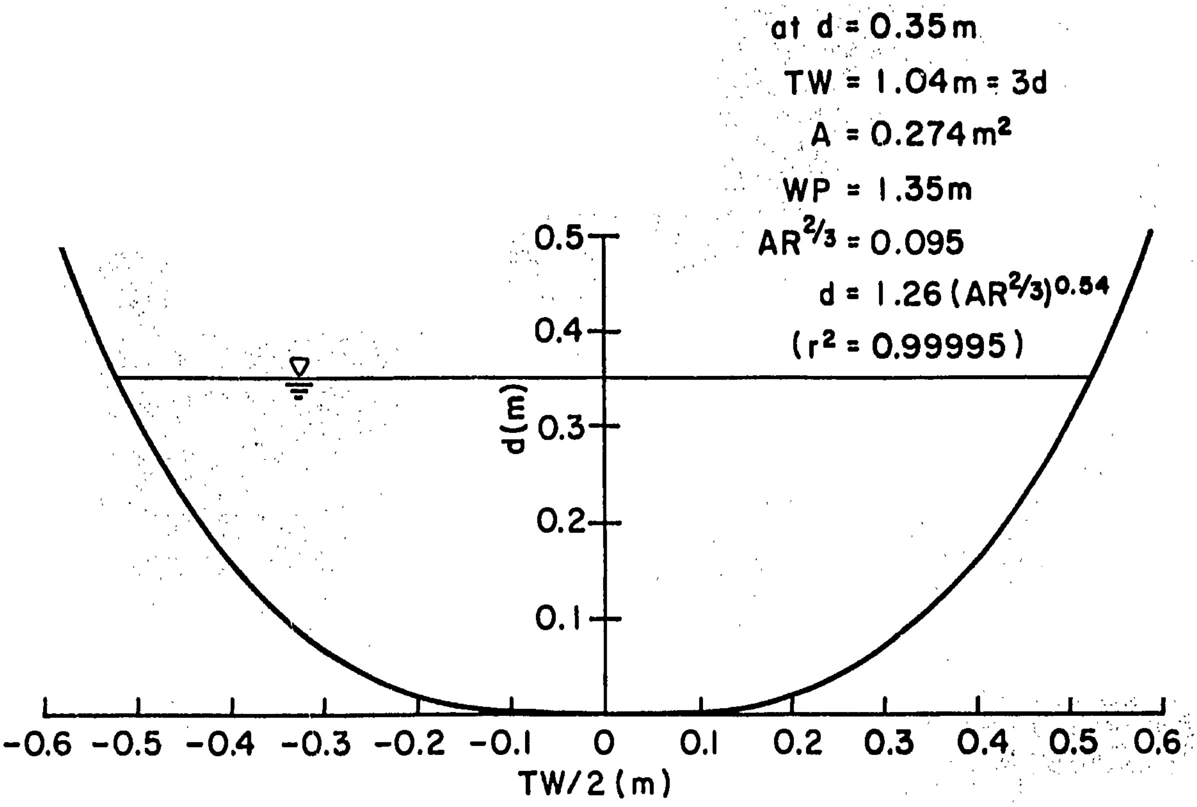

Figure 7. Watercourse cross-sectional shape model defined by Equation 8, with u = 2.5 and p = 3.

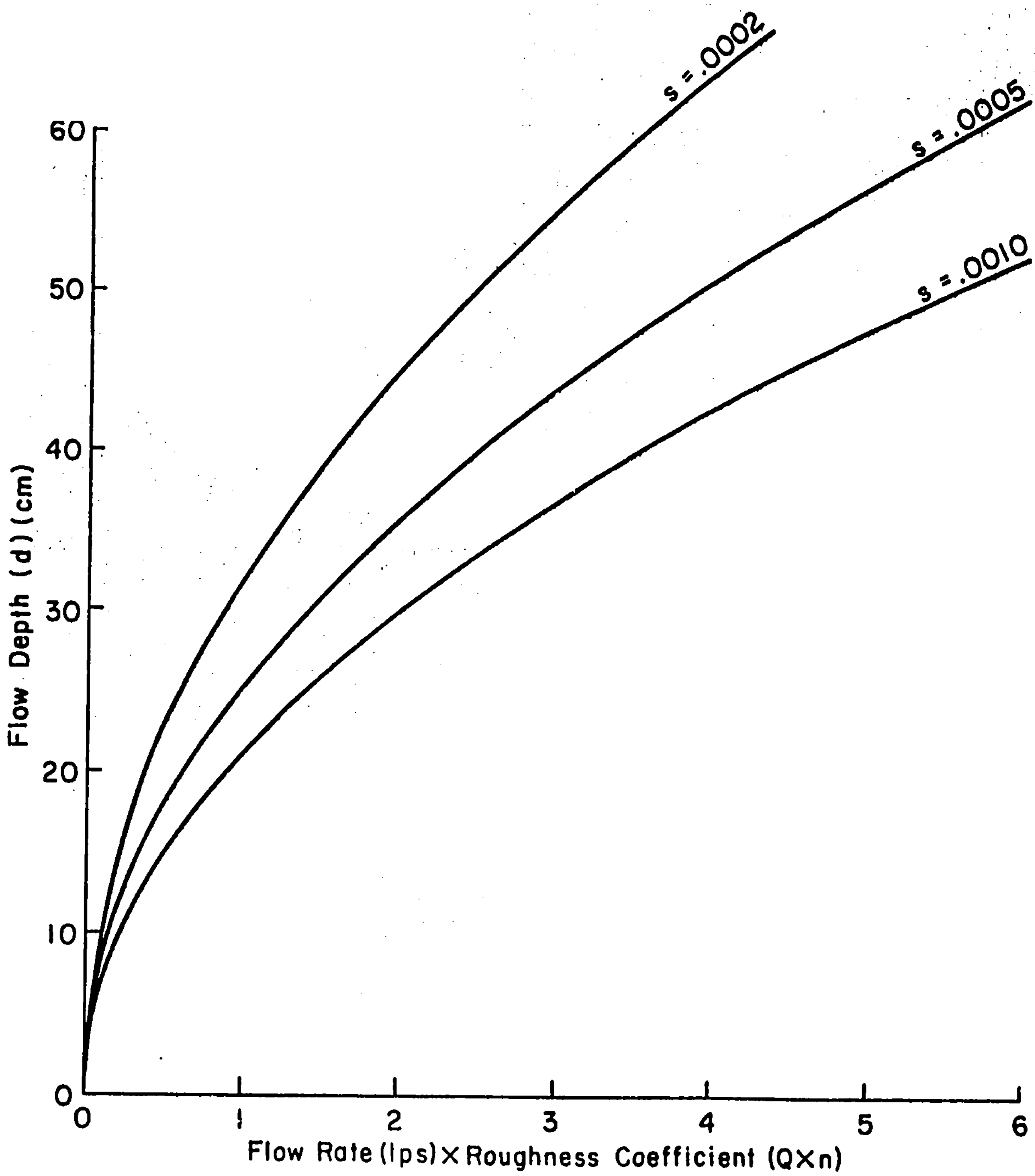

Figure 8. Flow depth (d) as a function of flow rate times roughness coefficient (Qxn) for a channel when a = 1.2 and c = 0.5 in Equation 9.

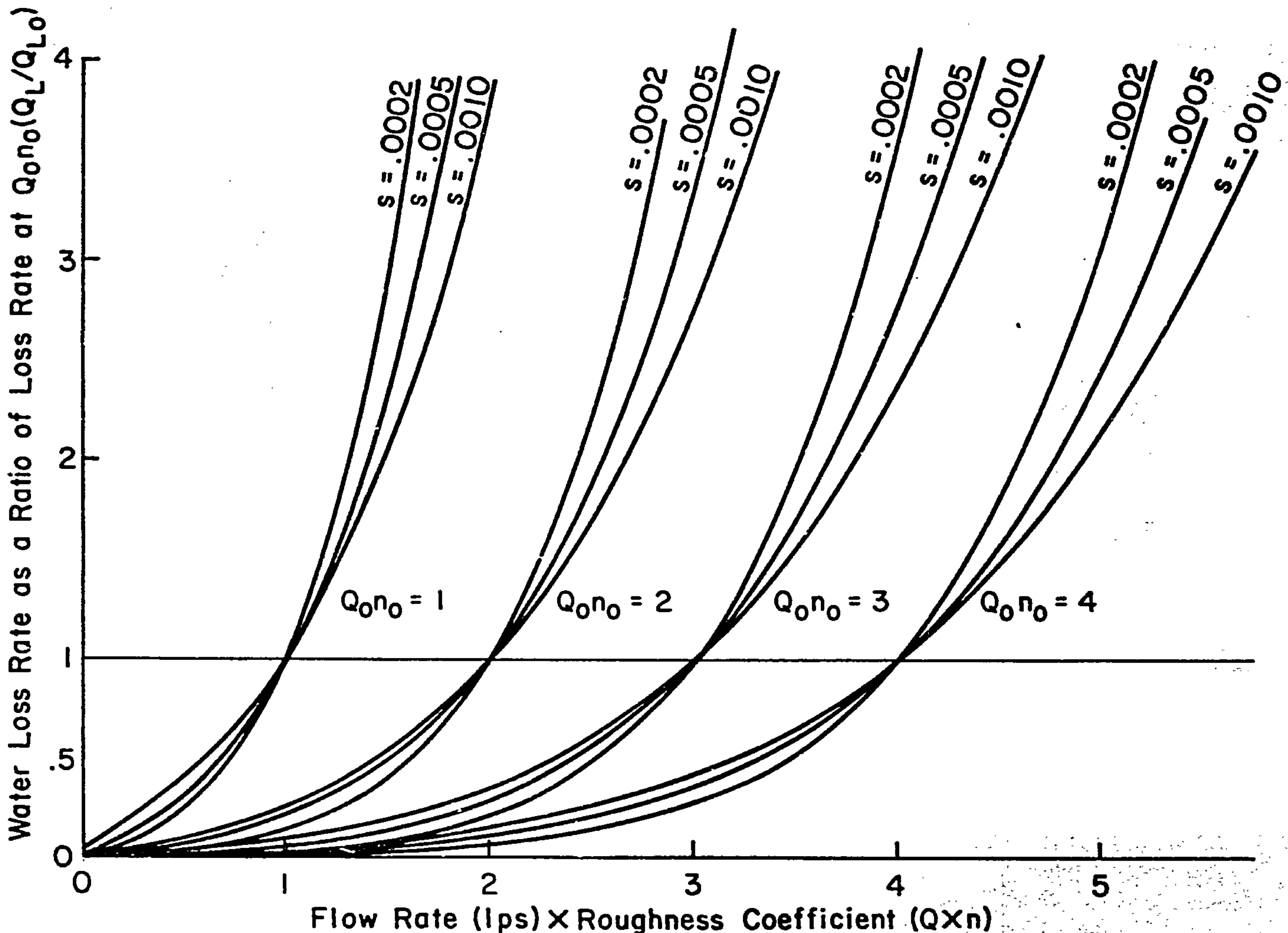

Figure 9. Relative change in loss rates with a relative change in the product of flow rate and roughness coefficient.

the previous loss rate. However, if the channel is cleaned and maintained such that an n value of 0.025 is achieved, the new (Qxn) value will be 1.5 (60 lps x .025) and the loss rate will actually be reduced to about half of its previous value. To extrapolate between given values of $Q_o n_o$, move along the x-axis to the proper value and then move up or down parallel to the nearest line for the appropriate slope value until the proper (Qxn) value is reached.

From the figure the sensitivity of loss rate to changes in inflow rate or roughness coefficient is graphically pointed out. It indicates the importance of redesigning and enlarging watercourses if an increase in inflow is anticipated, the possible benefit of splitting larger flows into two channels, and the importance of maintaining the channels in a clean condition with relatively low and constant roughness coefficient values.

Evidence for the validity of this curvilinear relationship with a positive second derivative is given in Bowers et al. (1976) and Ali et al. (1978) where exponential models with positive coefficients best fit collected inflow-outflow loss rate vs. flow rate change data.

It should be restated that the changes in roughness and flow rates referred to here are fluctuations over short periods of time. It would be assumed that a watercourse channel would evolve over time to long term changes. For example, if a decision is made to permanently split a water supply into two channels, the steady state loss rates would initially be drastically reduced (more than proportionally) as depicted in Figure 9. However, this new flow rate would, over time, establish a new normal flow depth to which the watercourse would evolve, and the eventual loss rate decrease would probably be governed more by the relationship between loss rate and normal flow rate (discussed later), which is less than proportional.

The measured change in loss rate with depth is the secondary result of two other factors which are changing with flow depth. The first is the changing length of the wetted perimeter through which seepage is taking place, and the second is the changing average rate of seepage into the wetted perimeter. Since the change in loss rate is occurring much more rapidly than both the change in wetted perimeter and an expected change in seepage rate resulting from the change in pressure head, it must be assumed that water seeps into watercourse bank soils at a much higher rate than into the bed soils.

The loss rate is made up of the sum of the seepage rates (s) into each section of the wetted perimeter. If both seepage rate and wetted perimeter length are taken relative to depth, then:

$$Q_L = s(d_n) \times (WP(d_n) - WP(d_{n-1})) + s(d_{n-1}) \times (WP(d_{n-1}) - WP(d_{n-2})) + \ldots + s(d_1) \times (WP(d_1) - WP(d_o)) \quad (11)$$

Where:

$s(d_n)$ = the seepage rate into the banks at height d_n above the channel bottom per unit of channel length

$(WP(d_n) - WP(d_{n-1}))$ = the length of wetted perimeter from depth d_n to depth d_{n-1}

As this incremental equation is taken to its limit, it reduces to:

$$Q_L = \int_o^{d_n} s(d) \frac{dWP}{dd} dd \quad (12)$$

If the derivative is taken of both sides, the seepage rate at any depth, s(d), can be determined.

$$s(d) = \frac{dQ_L}{dd} / \frac{dWP}{dd} \quad (13)$$

The numerator of this equation can be calculated from slope of the line of the loss rate vs. depth relationship shown in Figure 3 at any depth, or from the derivative of equation 2. The denominator can also be determined graphically by measuring the slope of a line depicting the relationship between the length of wetted perimeter and depth, at any depth, or, if the relationship can be mathematically modeled, by the derivative of the equation.

Figure 10 depicts the seepage rate as a function of depth determined graphically from the data for a sample watercourse section. Figure 11 shows the seepage rate as a function of depth calculated mathematically for a hypothetical watercourse whose cross-section is shown in Figure 7 and whose loss rate is represented by equation 2 with Q_{LO} = 2.0 lps/100 m and b = 0.15 cm^{-1}. Both figures indicate that the seepage rate into the higher banks is much greater than that into the bed and lower banks. Although the influence of the variation in pressure head on seepage rate has not been considered, for the ranges of pressure heads which apply, the effect on seepage rate should not normally be greater than 10 to 30%. Adjustment for this factor would have the effect of adjusting the seepage rate scale somewhat, but would not change the overall conclusion.

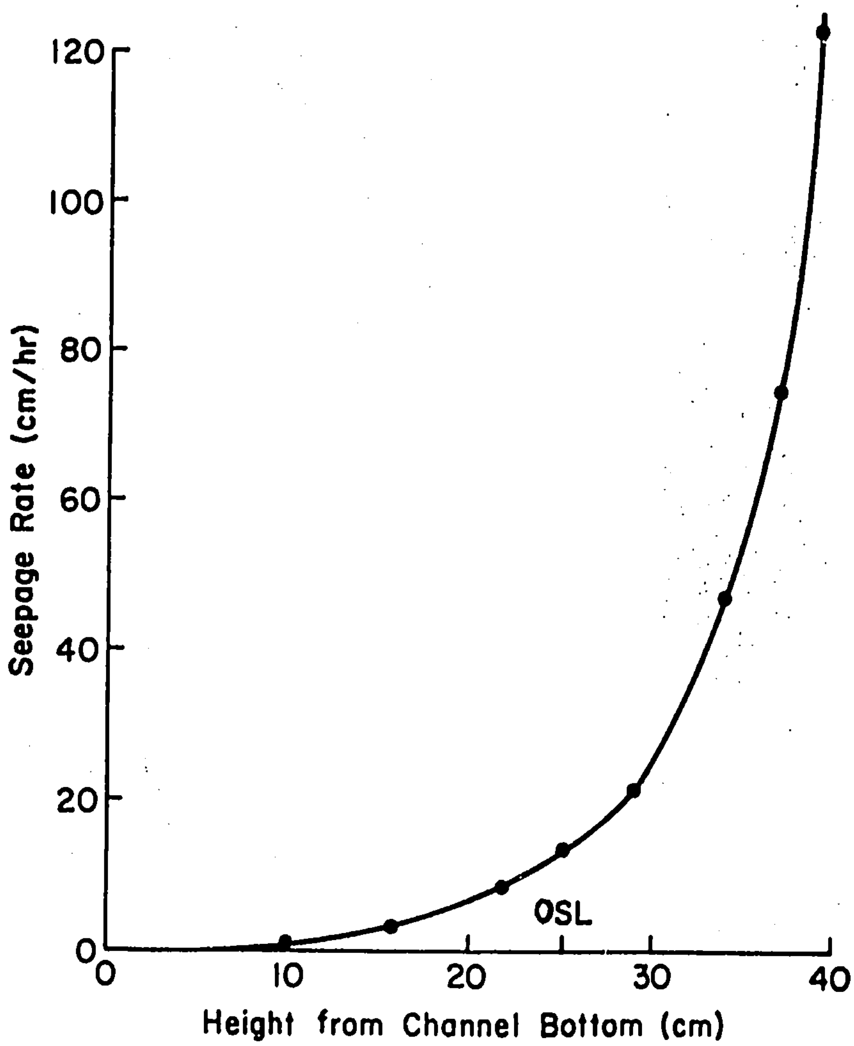

Figure 10. Seepage rate into watercourse bank soils at various heights up the banks from the channel bottom (determined graphically from ponding loss data for a sample section).

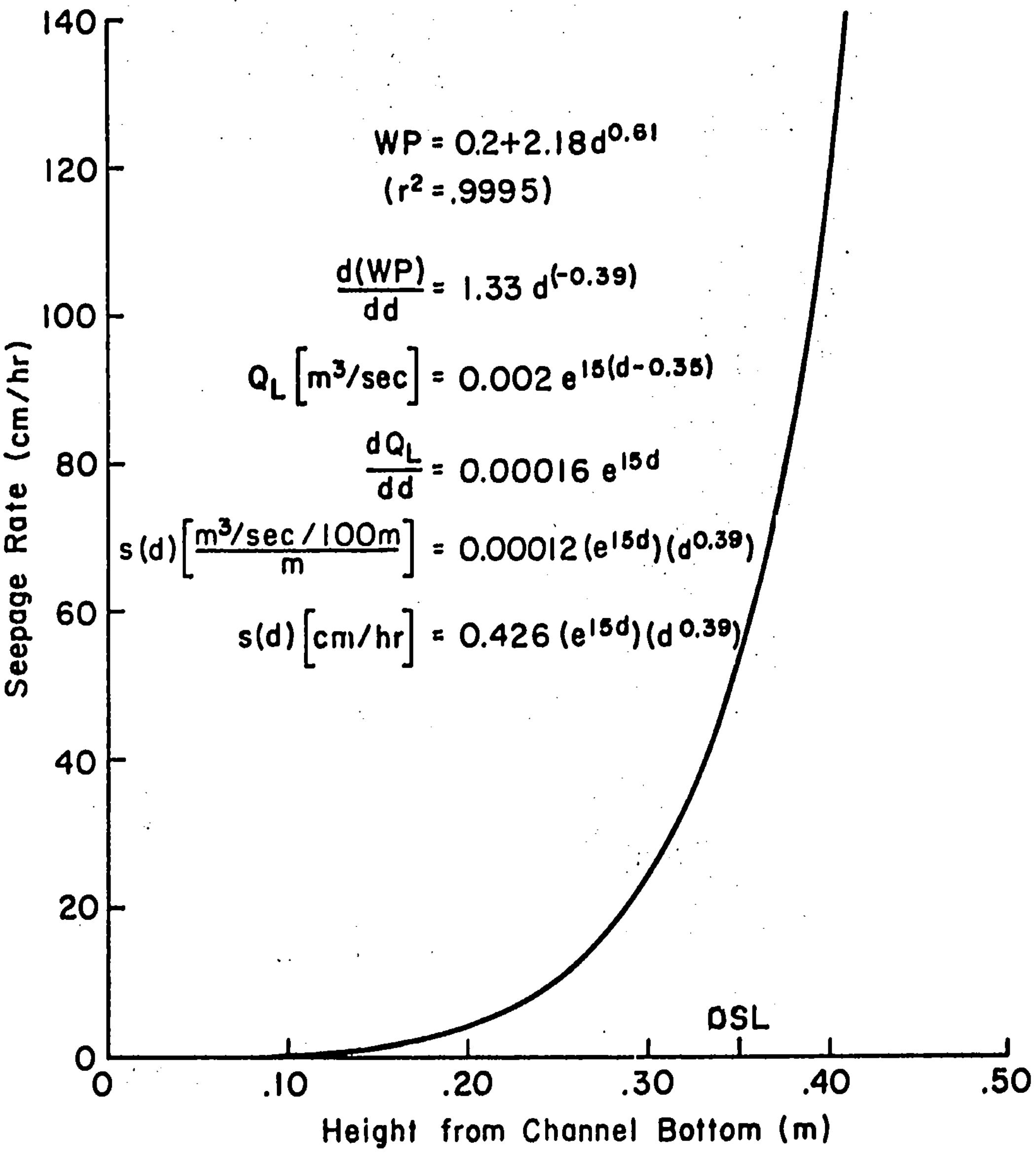

Figure 11. Seepage rate into watercourse bank soils at various heights up the banks from the channel bottom (calculated from Equation 13 for a hypothetical channel).

There are several possible reasons why the seepage rate into the highly permeable banks might be as much as 100 times higher than into the bed. The slope of the bank sides inhibit sediment deposition which can seal the bed. Also silt which does deposit on the bed is often left to build up over time, while that on the bank is periodically shaved away with grasses and vegetation during cleaning and maintenance activities. The bed often has dead storage water standing in it for a high percentage of the time which can facilitate microbial activity which can tend to seal pores and lower seepage rates.

But these reasons do not explain why seepage rates into the upper banks are 20 to 100 times higher than infiltration rates into the surrounding fields. A phenomenon in addition to seepage resulting from normal soil permeability must be taking place.

One such phenomenon observed in nearly every watercourse bank are the "macropores" resulting from the activity of burrowing insects and rodents. Banks are often riddled with a network of tunnels dug and utilized perimarily by rats and ant colonies. Both are usually found in the upper portions of the bank, often near and above the normal operational supply level.

Burrowing insects and rodents are naturally attracted to the watercourse bank habitat because:

1. its soils are often undisturbed for decades,

2. bank soils contain probably the most organic matter and support the most verdant, permanent supply of vegetation (and consequently food supply) of any soils in the area,

3. water from the watercourse is absorbed into the banks and provides moisture to soften soils for digging and reduces soil temperatures,

4. in a basin irrigated area, watercourse banks are often the only soil mass of sufficient volume which is permanently above water.

An ant or rat burrow filled with water is obviously of no use to its maker, so they are generally sealed toward the inside of the watercourse, and are often built near or just above the normal operational supply level. However, leaks and breaks do occur, especially in the many abandoned burrows, and because of the interconnections, one leak can fill an extensive system of these macropores, which sometimes lead down, out and under surrounding fields. Water filled burrows have the effect of increasing the effective wetted perimeter of the watercourse many times.

This extensive system of macropores could explain the high seepage rates into watercourse banks, and the extreme sensitivity of this seepage rate with height along the banks. It could also explain the extreme variability in measured ponding loss rates and the low percentage of the variability which can be explained by the measured parameters. Even when most parameters were held constant, the measured rates were still extremely variable. Table 4 lists the measured loss rates at osl (Q_{LO}) for various sets of measurements where either the same section was measured several times over time or adjoining sections were measured at one point in time. In most cases, the standard deviation of the sets of 3 or 4 measurements is 1/3 to 1/2 of the mean. This variation, like the high seepage rates, cannot be explained by normal variations in permeability but could be explained by point sources of seepage through macropores.

Loss Rate as a Function of the Measured Parameters

The effects of depth of flow relative to the normal osl on loss rates can be held constant by comparing the loss rates which occur only at the operational supply level, allowing the influence of the other measured parameters to be studied. Any interaction between the other parameters and the depth factor should be indicated by their relationship with the b variable which expresses the sensitivity of the depth-loss rate relationship.

The data clearly indicate that SCARP watercourses have higher loss rates than non-SCARP watercourses. This finding supports previous similar conclusions of inflow-outflow loss studies reported in Lowdermilk et al. (1978) and Clyma et al. (1975). Lowdermilk's comprehensive survey of 40 watercourses found that median loss rates on SCARP systems were 82% higher than for non-SCARP watercourses (2.97 lps/100 m vs. 1.62 lps/100 m (0.32 cfs/1000 ft vs. 0.175 cfs/1000 ft)). Clyma's data indicate that SCARP watercourse loss rates are at least double those found in non-SCARP watercourse systems. This ponding loss data indicate the difference is more than double, although about 2/3 of the difference is a result of larger flow rates in SCARP watercourses.

Probably an important reason for the higher loss rates is the fact that the SCARP watercourses were never redesigned and rebuilt to carry the increased flow from the combined canal and public tubewell supply, with the result that was discussed previously of increasing the flow and consequently the flow depth in a watercourse. It would be expected that the watercourse channels would evolve over time as a result of cleaning and maintenance activities to carry the increased flow more efficiently, but this apparently has not completely taken place yet in the 15 years since the SCARP II public tubewells have been installed. Because the farmer's flow at the field has been increased in spite of the higher losses, perhaps he has

Table 4. Comparison of measured loss rates in test sections where most conditions are constant.

A. Measurements in the Same Section over Time

Section	Time from first measurement	Individual measurements	Mean	Standard Deviation
		Loss Rates (Q_{LO})(lps/100m)		
1	0,3,15 days	4.19 3.62 5.15	4.32	0.77
2	0,3,16 months	1.35 3.27 1.45	2.02	1.08
3	0,0,10,25 months	5.75 3.71 1.86 3.45	3.70	1.60
3(a)	0,0,10,25 months	8.35 6.31 2.78 1.79	4.81	3.06

B. Measurements in Adjoining Sections

Set	Sec 1	Sec 2	Sec 3	Sec 4	Mean	Standard Deviation
	Measured Loss Rates (Q_{LO})(lps/100m)					
1	12.44	5.75	8.35		8.85	3.37
2	2.34	4.19	2.83		3.12	0.96
3	12.90	5.57	7.43		8.63	3.81
4	1.14	1.17	1.14	0.98	1.11	0.08
5	0.56	1.02	1.30		0.96	0.38
6	5.57	4.83	3.43	2.32	4.04	1.45
7	1.79	1.80	1.12	3.04	1.94	0.80
8	3.25	1.86	4.55		3.22	1.35
9	0.46	0.37	0.28		0.37	0.09
10	3.78	3.85	0.54		2.72	1.89
11	2.78	3.11	1.44		2.44	0.88
12	3.00	2.52	1.62		2.38	0.70
13	2.42	3.18	1.96		2.52	0.62
14	5.20	6.87	3.53		5.20	1.67
15	5.48	6.22	3.43		5.04	1.44
16	6.40	4.83	2.41		4.55	2.01
17	0.10	0.09	0.42		0.20	0.18
18	1.45	0.83	0.49	0.74	0.88	0.41
19	0.14	0.23	0.30		0.22	0.08
20	0.49	0.68	0.71		0.62	0.12

not been as willing to upgrade his channels to more efficiently carry the increased flow. Another factor which would tend to result in higher loss rates on SCARP watercourses is the relatively less cleaning and maintenance activity observed on public tubewell augmented watercourses (Mirza et al., 1975).

Another possible reason for SCARP watercourses to have higher loss rates than non-SCARP ones is that, with the added clear tubewell water, the tendency for the silt in the canal water to deposit in the channel which could in turn reduce the seepage rates, is greatly reduced. However, at least 25% of the time, the tubewell is turned off and silt deposition from the canal water should be normal.

Loss rates increased with increasing normal flow rates, or larger capacity watercourses had higher loss rates. The loss rates tended to vary slightly less than proportionally with normal flow rates. Loss rate as a percentage of flow rate is more nearly constant than absolute loss rates. The inflow-outflow data collected by Lowdermilk et al. (1978), Clyma et al. (1975), and On-Farm Water Management (1978), also indicate that loss rates increase with inflow rates, but percent loss rates decrease slightly as flow rates increase. Trout (1979) found that loss rates increase about 80% as fast as normal inflow rate.

A second design parameter which also increases, but less than proportionally, with flow rate is the length of wetted perimeter. The relationship between wetted perimeter and flow rate can often be expressed as a power curve relationship with an exponent usually less than 0.5:

$$WP = f(Q)^{g} \qquad (14)$$

Where:

WP = length of wetted perimeter (m)

f and g = empirical constants depending upon channel cross-sectional shapes and hydraulic parameters.

Trout (1979) fit equation 14 to cross-sectional data from 10 watercourses and derived an exponent value of 0.4. Since the increase in loss rate with flow rate is much more rapid than the increase in wetted perimeter with flow rate, loss rate is not proportional to wetted perimeter length as has been assumed in many seepage measurements made in the past.

The positive relationship reported above and supported by the referenced data, would predict that, if more than one smaller watercourse were designed to carry the same total aggregate flow as one previous watercourse, the total losses would increase slightly (this assumes delivery lengths are not changed). But if increasing the number of watercourses also results in significantly shorter delivery distances, then total losses should be reduced. It should be noted that this referred to flow rate change is not the same as that previously discussed which influences flow depths, because appropriate channel design changes are also assumed, which result in the changed rate being a new normal flow rate.

A second important finding that supports previous results, is that farmers' branches have higher loss rates than sarkari khal sections. Trout (1977) and Ali et al. (1978) found similar results in four out of five watercourses where operational conveyance losses were determined by inflow-outflow. In fact, for the five studied watercourses, average steady state loss rates per unit length in farmers' branches were double those measured in sarkari khal sections (Ali et al., 1978). This difference is even more significant when it is considered that average flow rates in the farmers' branches were lower due to losses in the sarkari khal sections.

One of the primary reasons for the higher loss rates in the farmers' branches might be that they are used much less often than the sarkari khal sections, and percent usage (T) correlates inversely with loss rates. This factor can explain a large part of the difference. Less usage could lead to less silt deposition, more vegetative growth and more opportunity for burrowing rodents and insects to dig holes lower in the banks below the normal operational supply level.

Other possible reasons for the difference include less maintenance of farmers' branches, since they are the sole responsibility of the user or users and no regular cleaning activities are usually undertaken. Also there is no right-of-way allowance for the branches which often pass through the user's land, and he will often attempt to build as small of channel as possible to minimize the amount of his land that is taken out of production. The lack of freeboard on the under-sized watercourses will force the burrowing insects and rodents further down into the portions of the banks that are normally below osl. Because of field elevation fluctuations, there is often no true normal depth of flow in the farmers' branches. This could also lead to the rodent and insect activity, which normally takes place in the banks primarily above the osl, to extend more often down into the lower regions of the banks.

Watercourse sections which are full of water and in use a higher percentage of the time had lower loss per unit of time in the data shown in Fig. 5. This phenomena was first noticed by Cheema et al. (1976) in inflow-outflow measurements and is supported by this data, which predicts that increasing the time a channel is used by 10 percentage points would reduce loss rates by about one third. This would suggest that splitting the water down two major branches of a watercourse at all times could lead to a reduction in steady state losses.

It is probably the time factor which is largely responsible for the large difference between loss rates in sarkari khal channels, which were used an average of 20% of the time, and those in farmers' branches, which were used only about 1/5 as much.

There are several possible physical explanations for this relationship. Many studies of seepage into soils have shown that seepage rates decrease drastically with the amount of time which water is ponded on the surface, and although the rates rebound during drying and rewetting, they do not rebound to their initial values (Allison, 1947). Consequently, the longer and more consistently a soil is flooded, the lower the seepage rates. Allison blames the decrease primarily on microbial activity on the soil surface which both breaks down surface soil structure and produces biological scums or films which tend to seal the soil surface. This biological activity would be expected to be somewhat less in watercourses than in seepage rings due to the turbidity of the silt laden water.

A second explanation for lower loss rates from often used channels is that the occurrence of water should tend to prevent burrowing insects or rodents from extending their holes below the water level for fear of their holes filling with water. Channels full more often should consequently have fewer macropores below the operational supply level, and lower loss rates.

A third possible reason for the observed lower loss rates is that in high water table areas, it is more likely that a channel which is used most of the time would have more constant seepage and be more likely to have hydraulic contact with the groundwater. If hydraulic contact is established, the hydraulic head and consequently seepage rate will decrease as the water table comes nearer the surface.

In the studies designed to isolate the effects of the relative elevation parameter, ΔE, on loss rates, a direct relationship was indicated. Loss rates increased about 0.04 lps/100m for every one centimeter increase in ΔE. A physical reason for this relationship could be that the additional hydraulic head pushes water into the macropores of the higher watercourses. The hydraulic head would not influence seepage into a partially saturated porous medium, but would have an influence if the seepage water was in hydraulic contact with the groundwater.

The data indicate no difference between loss rates in cleaned or grassy sections. Since the normal osl was usually determined to be that observed immediately before the measurement, and flow depths will be less in a channel when it is cleaned, it would be expected that clean channels would tend to have lower loss rates. Such a result was reported in a ponding loss study conducted by Akram et al. (1978) designed primarily to determine the effects of cleaning on loss rates.

At a given flow depth, the loss rates were observed to both increase (probably the result of silt removal) and decrease (probably the result of hole (macropore) plugging) in the different test sections, but because of a drop in the operational supply level of about 12 cm as a result of the cleaning activity, loss rates at the new osl consistently decreased to about 50% of their values measured before cleaning.

Whether the channel had been wet for a period of time before measurement (usually at least 1 hour) or not did not appear to affect either the loss rates or b values. This result is encouraging in that it indicates even in previously empty watercourses the filling and wetting up procedure took sufficient time that increased initial infiltration rates during the wetting up of dry banks did not appear to affect the results. Unpublished data collected by the authors indicate that this period of increased infiltration rate usually lasts less than 60 minutes and that after only 30 minutes time the infiltration rate into initially dry banks is usually less than 15% greater than the steady state infiltration rate. There were, however, two sets of sections which were measured both in a wet and dry condition where loss rates measured under wet conditions were significantly lower than the dry measurements. Any ponding loss measurement should allow the channel to be filled for sufficient time (one hour should be sufficient) before measurement begins to insure that the loss rates are steady state.

The lack of correlation between improved or existing channels (I/U) and loss rates is unexpected in light of published inflow-outflow data which indicates that loss rates are reduced as much as 50% by renovating the watercourse channels (Bowers et al., 1976, Cheema et al., 1976). It would be expected that rebuilding watercourse banks would destroy macropores and reduce loss rates.

Bank width did not appear to have any effect on loss rates. Obviously, there must be a point where sufficiently thin banks must lead to breaks and leaks, and this situation has been observed in the field; but such visible leakage apparently is a small enough percentage of the total loss rate that, for the tested sections, it was not a significant factor. Two independent ponding loss studies designed to test the effect of bank width on loss rate came to the same conclusion. One involved progressively trimming away the outside of the bank and checking loss rates, and the second involved building banks at various widths to measure their influence on loss rates. Neither procedure appeared to have an effect on loss rates.

Visible leakage which passes through the macropores and appears on the outside of the watercourse test sections was noted and often measured. About 20% of the sections had visible leakage. The measured leakage usually amounted to less than 20% of the total loss rate at the osl, and was very sensitive to depth changes in most sections. Most visible leakage stopped flowing near or slightly below the operational supply level, indicating the importance of the macropores at or above osl. Visible leakage did not seem to occur more often in watercourse sections with thinner banks.

Banks which are thick enough to safely and securely support the conveyed water appear to have no further affect upon water loss rates.

The side slope factor, Z, displayed no consistent influence on loss rate. It is reasonable to expect that steeper bank slopes (lower Z values) would allow less silt deposition on the sides and lead to higher loss rates. This expectation was not supported by the data analysis. Longer wetted perimeters which would be expected from channels with larger Z values might counter the silt deposition effect.

It is more difficult to give physical explanations for the relationships between the parameters and the b value. As watercourse size increases, as it will with increasing normal flow rates, the percent increase in total wetted perimeter with an increase in depth is smaller. Thus, increasing flow depth into the more porous upper banks would be expected to have a relatively smaller effect on the loss rate, as indicated by Equation 6. This could also be the cause of the lower b values in SCARP channels.

Channels used more often tended to have higher b values. This could be the result of the tendency for channels with high T values to develop a more definite and stable osl resulting from their higher usage, less vegetative growth below the operating level, and tendency to be farther from field elevation induced depth changes. Depth fluctuations, when they do occur, would tend to have a more dramatic effect on loss rates.

Channel sections at greater distance from the mogha will normally tend to be closer to the fields and have a less stable osl, with the opposite result as predicted for the usage time factor. By the same reasoning, sarkari khal sections should have a stabler osl and higher b values, as indicated in the regression equation (Eq. 6). It appears that the amount of fluctuation in the water surface of a channel affects the sensitivity of loss rates to these fluctuations, and thus factors which are related to more stable operating supply levels also have lower b values.

MAJOR CONCLUSIONS

1. Loss rates in Pakistan's watercourses are high and will result in average conveyance losses of about 40%.

2. Loss rates are especially high in SCARP watercourses.

3. Ponding loss measurements will measure loss rates somewhat lower than inflow-outflow flume measurements because of silt deposition and flume effects. The true steady-state loss rate will lie somewhere between the two measured values.

4. Loss rates will increase rapidly with increasing flow depth, and thus with increasing inflow rates or vegetation in the channel. No supplemental water should be added to a watercourse channel without enlarging the channel for the increased flow. Cleaning vegetation from channels will lead to lower losses.

5. Seepage rates into watercourse banks are often as much as 100 times greater than seepage into the bed, and several times higher than infiltration rates in the surrounding fields.

6. The high seepage rates, extreme variability in loss rates, and the amount of that variability that cannot be explained by the measured parameters implies that there is a phenomenon involved in addition to normal infiltration, such as point sources of seepage through macropores (insect or rodent burrows).

7. Larger watercourses (higher Q) have higher loss rates but the relationship is less than proportional.

8. Watercourse channels which are used more often have lower loss rates.

9. SCARP channels have significantly higher loss rates than non-SCARP watercourses. Part of the reason is the higher flow rates in SCARP watercourses.

10. Farmers' branches have significantly higher loss rates than sarkari khal sections, partially because of a lower percent usage time.

11. Loss rates in channels with a fairly constant operational supply level are more sensitive to flow depth fluctuations.

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APPENDIX 9

OPERATIONAL EVALUATION OF VILLAGE LEVEL IRRIGATION CONVEYANCE SYSTEMS

Thomas J. Trout and S. A. Bowers[1]

INTRODUCTION

The primary methods used to measure irrigation canal conveyance losses are inflow-outflow, ponding, and with seepage meters (Brockway and Worstell, 1969; Rohwer and Stout, 1948; and Worstell, 1976). All three of these methods measure what is often termed "seepage" losses, or the infiltration of water into the canal wetted perimeter when the system is operating under steady state conditions.

In most canal systems the large majority of the total conveyance loss is steady state seepage. However, in small intermittently used irrigation channels (laterals, ditches, watercourses), there can be a significant transient loss component that is not measured in steady state measurements. Transient losses include:

1. excess infiltrated water which wets up dry channel banks;
2. water seepage and leakage during the time water is being transferred from one field to another;
3. dead storage water left lying in the bottoms of channels after drainage of channel storage into the fields is complete; and
4. losses resulting from short term watercourse breaches and outlet breaks.

In this study of five village level watercourse systems in Pakistan, total operational conveyance losses, including transient losses, were measured using an adaptation of the inflow-outflow method. The objectives were to determine the extent of the transient losses and to quantify the types of watercourse losses so that techniques to increase conveyance efficiencies could be evaluated.

PAKISTAN WATERCOURSE CONVEYANCE SYSTEM

A brief description of the studied systems will aid in understanding the methods utilized and the results. The 13 million hectares (ha) of land commanded by irrigation canals

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in the Indus Basin of Pakistan is divided into more than 78,000 watercourse systems. Each system generally serves between 80 and 350 ha of land farmed by an average of 40 cultivators and divided into 0.1 to 0.4 hectare level basins.

The conveyance system receives a continual supply of approximately 1.0 liter per second (lps) for each 5 ha of commanded land from one canal outlet. The system is usually composed of about 140 m of channel per hectare of irrigated land, of which about one-fifth is government constructed and cooperatively maintained primary channel ("sarkari khal") and four-fifths is individually or jointly owned farmers' branches.

The constantly flowing water is usually delivered to the farmers on a weekly turn rotation. Each farmer receives all the water for a percentage of the week's time according to the percentage of the total commanded land which he owns. The water is rotated through the complex channel system in a regular manner, commencing each week with the fields nearest the canal and moving progressively down each primary channel branch until the tail fields are reached at the end of each rotation. All of the primary channels and about half of the farmers' branches are used during a rotation.

Figure 1 shows the layout of a watercourse system. Table 1 gives summary descriptions of each of the watercourses which were studied.

OPERATIONAL LOSS MEASUREMENT PROCEDURE

An adaptation of the inflow-outflow loss measurement technique was used to determine total operational conveyance losses. In a traditional inflow-outflow study, flow measurements are made only during steady state flow and the loss is computed as a difference in flow rates at two locations on the conveyance system. In this study, the flow rates were monitored continuously, and the data accumulated on flow hydrographs, such as is shown in Figure 2. Integration of the hydrographs allowed computation of the volume of water passing through a given flume rather than just the flow rate. Operational losses were calculated as the difference between the volume of water entering the watercourse at the head and the volume entering the irrigated fields during a complete rotation.

The 20 x 91 cm (8" x 36") Cutthroat flumes (Skogerboe, et al., 1973) used to measure flows were installed at the head of the watercourse, at the junction between the primary and farmers' branches, and at the field outlet for each field being irrigated during a complete irrigation rotation. Flume readings were taken every 5 to 15 minutes (depending on flow fluctuations) by attending technicians from the time water first reached the flume until drainage was complete.

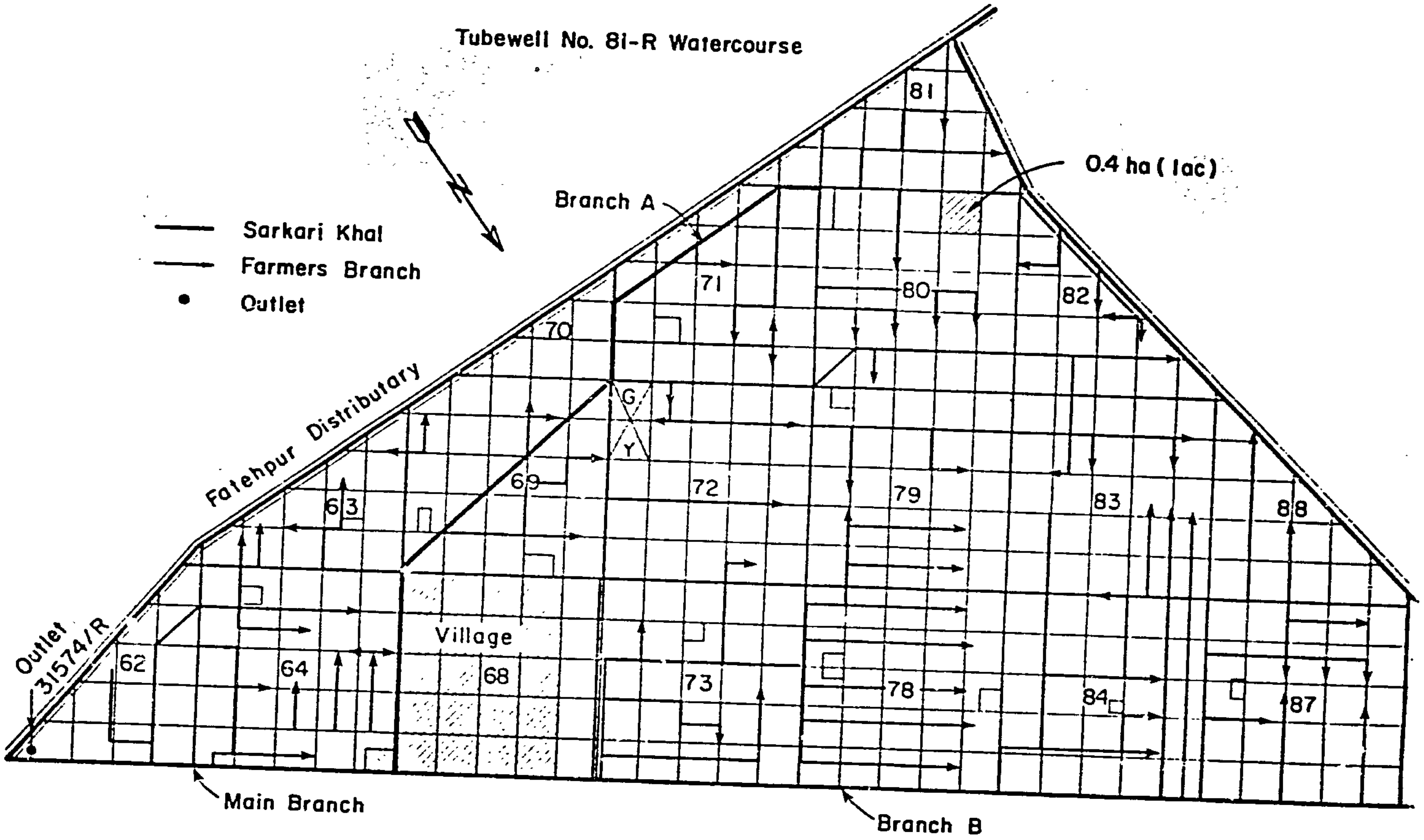


Figure 1. Layout of watercourse TW 81-R, which commands 148 ha of land with 70 lps of flow. The watercourse includes 3350m of primary channel (sarkari khal) and 19,650m of farmers' branches.

Table 1. Summary descriptions of the five studied watercourses.

	Watercourse					
	TW 81-R	TIK #1	MP 6	MP 35	MP 52	Ave.
Outlet Number	31574/R	RD89480/L	RD21000/L	4500-R	8AR/52	
Location (District)	Sarghoda	Faisalabad	Mianwali	Bahawalpur	Moro	
Commanded Culturable Area (ha)	148	166	150	119	129	142
Sarkari Khal Length (m)	3350	4880	3260	980*	4240	3342
Farmer's Branch Length (m)	19,650	25,120	15,000	12,220	12,060	16,810
Total Channel Length (m)	23,000	30,000	18,260	13,200	16,300	20,152
Percent Sarkari Khal (%)	15	16	18	7*	26	17
Length of Channel Per CCA (m/ha)	154	180	122	111	126	139
Number of Farmers	20	91	34	33	42	42
Average Holding Size (ha)	6.0	1.8	4.4	5.2	3.2	4.1
Annual Cropping Intensity (%)	174	174	119	117	136	144
Outlet Design Discharge (lps)	≈30	34	33	35	26	32
Average Measured Discharge (lps)	70**	41***	56	38	37	48
CCA per Design Discharge (ha/lps)	4.9	4.7	4.5	3.4	5.0	4.5
CCA per Measured Discharge (ha/lps)	2.1	4.0	2.7	3.1	3.5	3.1
Tubewells	1 (Gov't.)	2 (Private)	None	None	None	
Soil Type	Silty Loam	Silty Loam	Sandy	Sandy Loam	Silty Loam	
Average Field Infiltration Rate (cm/hr)	≈1.0****	≈1.0****	26	2.3	7.1	

*Main channel length - sarkari khal was not delineated.
**30 lps from the mogha + 40 lps from the Government tubewell.
***Not including tubewell water which was not mixed with the canal water.
****Estimated from data in Precision Land Leveling Project (1974).

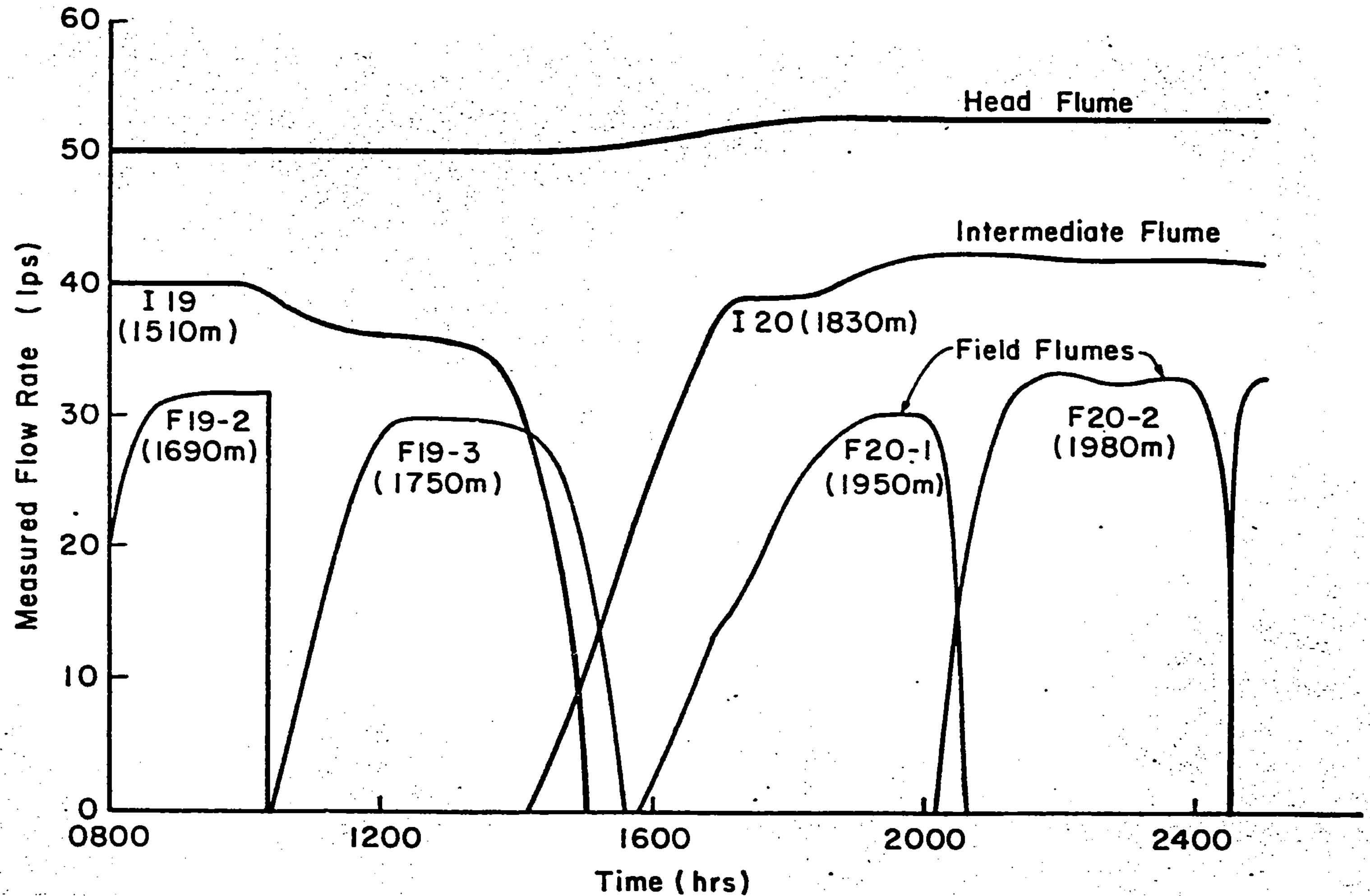


Figure 2. Flow hydrograph showing discharge through the head, intermediate, and field flumes over time during an operational loss study.

Transient conveyance loss was computed as the difference between the total operational loss, computed volumetrically, and the steady state loss determined in the traditional way from flow rate differences. Figure 3 illustrates this calculation.

The transient losses resulting from short-term bank breaches or outlet leaks were also determined from the flow hydrographs by calculating the area of the hydrograph between the previous and following steady state flow rate and the measured depressed flow rate during the break. Figure 4 illustrates this calculation.

The volume of water lost to dead storage left lying in the bottoms of the channels after drainage into the fields is complete was physically measured. The cross section of the dead storage water was estimated with depth and top width measurements at regular intervals along the channels, and dead storage volumes were determined by multiplying this area by the interval length.

The extensive flow measurements involved in an operational study allowed evaluations of other types of losses and some of the factors affecting losses. Least squares regression analysis was used to relate fluctuating flow rates and location on the system to measured loss rates. Intermediate flow measurements allowed losses to be divided between those occurring in the primary channels and those measured in the farmers' branches.

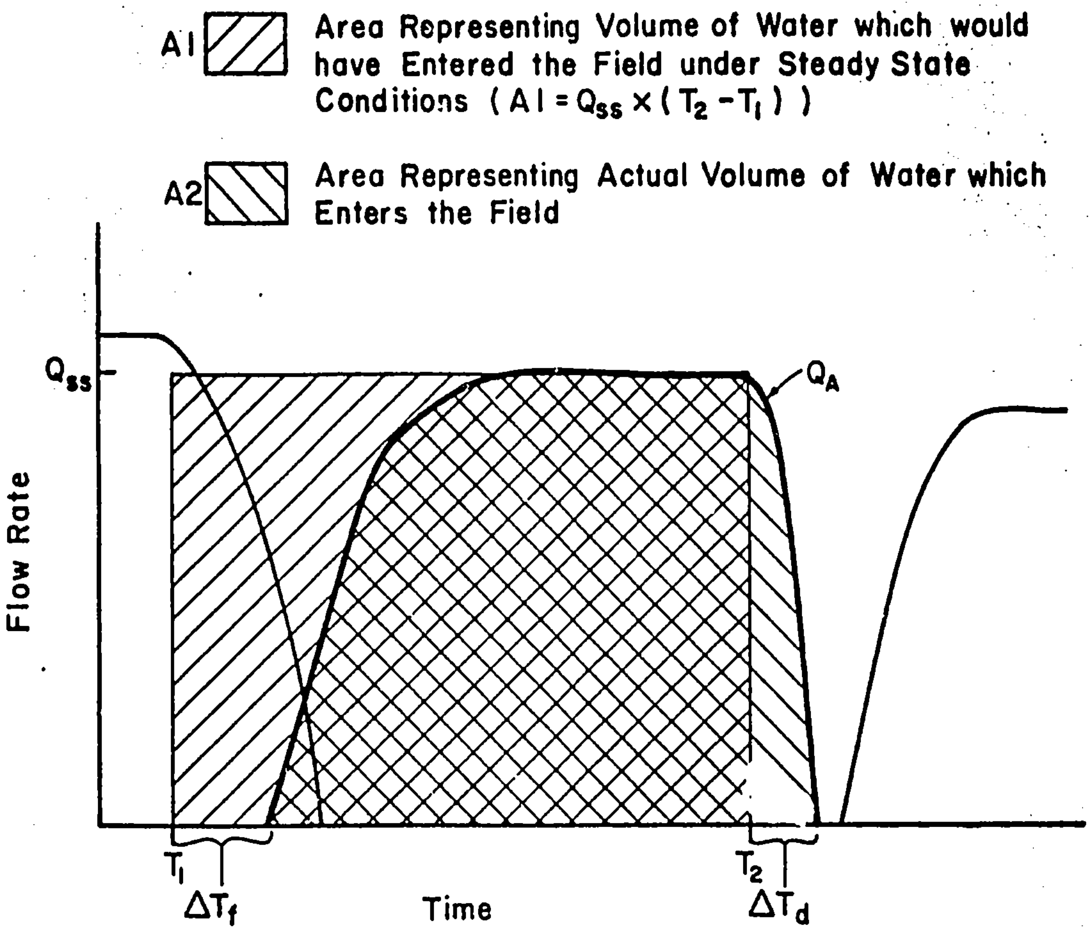
Surface evaporation from the conveyed water surface was estimated by multiplying the local pan evaporation rate by the average water surface width and by the time weighted average length of channel utilized. Visible leakage which flowed over or through banks or leaks through closed outlets was volumetrically measured by collecting a sample of the leakage in a container or small pond.

RESULTS

Total operational conveyance losses on the five studied watercourses varied from 37% to 56% and averaged 45% of the inflow. Of these total losses, 55% occurred on the primary channels. Table 2 lists the losses on each watercourse.

The transient losses on the five watercourse systems varied only from 5.7% to 8.4% of the inflow or 12% to 23% of the losses. Table 3 lists the transient losses for each of the measured watercourses.

The transient losses for each field irrigated on each watercourse correlated well with the length of channel filled and drained in the process of irrigating the field. These regression equations are shown in Table 4. For all five



T_1 = Time Water Flow is Turned from Previous Field
ΔT_f = Time Consumed in Filling the Channel Leading to the Present Field
T_2 = Time Water Flow is Turned to the Following Field
ΔT_d = Drainage Time of Channel into the Field
Q_{ss} = Steady State Flow Rate
Q_A = Actual Flow Rate
Transient Loss (V_{TL}) = A1 − A2

Figure 3. Graphical depiction of the transient loss calculation.

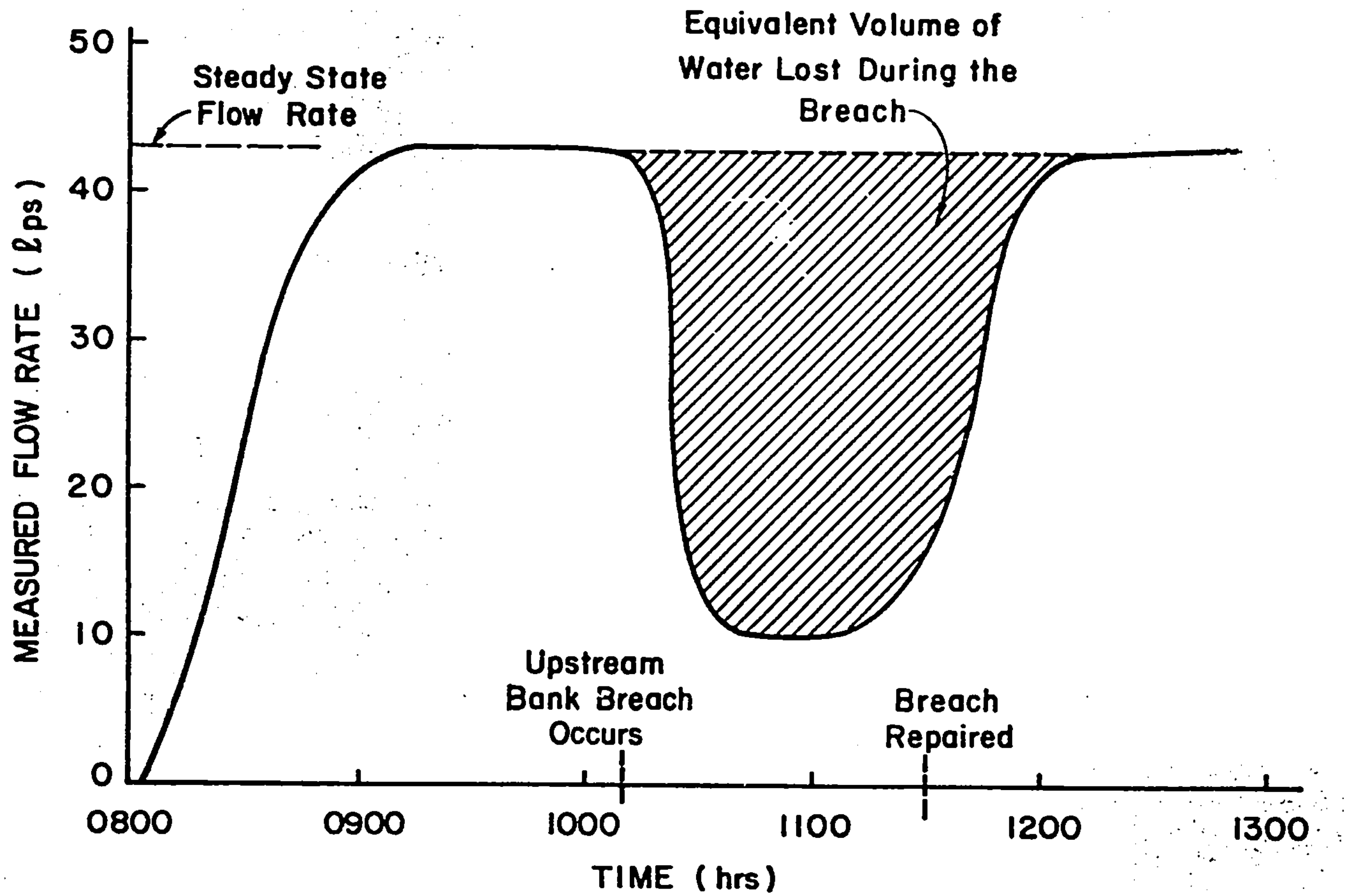


Figure 4. Graphical depiction of the short term bank breach loss calculation from the flow hydrograph.

Table 2. Volumes of inflows and losses and conveyance efficiencies on the five operationally studied watercourses.

Watercourse section	Volume of inflow (m^3)	Conveyance efficiency (%)	Volume of losses (m^3)	Distribution of losses (%)
TW 81-R				
Primary channels	42,970	63	15,840	66
Farmers' branches	27,130	70	8,080	34
Total to fields	19,070	44	23,920	
TIK #1				
Primary channels	24,970	84	4,020	44
Farmers' branches	20,950	76	5,110	56
Total to fields	15,840	63	9,130	
MP #6*				
Primary channels	34,070	81	6,380	47
Farmers' branches	27,690	74	7,150	53
Total to fields	20,540	60	13,530	
MP #35*				
Primary channels	23,290	80	4,560	50
Farmers' branches	18,740	76	4,480	50
Total to fields	14,260	61	9,040	
MP #52*				
Primary channels	20,280	66	6,810	66
Farmers' branches	13,470		3,580	34
Total to fields	9,890	49	10,390	
Average				
Primary channels	29,120	75	7,520	55
Farmers' branches	21,600	75	5,680	45
Total to fields	15,920	55	13,200	

*Average of three weeks (3 rotation cycles) of data.

Table 3. Transient losses on the five operationally studied watercourse systems during one weekly turn rotation.

	Watercourse					Average
	TW81-R	Tik 1	MP 6*	MP 35*	MP 52*	
Total transient losses:						
Total volume (m^3)	2975	2086	2296	1271	1271	1980
Percent of inflow (%)	6.9	8.4	6.7	5.7	6.3	6.8
Percent of total losses (%)	12.4	22.8	17.0	14.0	12.2	16.4
Per channel length (m^3/m)	0.263	0.096	0.197	0.132	0.127	0.163
Per channel length per unit inflow (m^3/m/(m^3/sec))	3.70	2.32	3.50	3.43	3.78	3.35
Dead storage:						
Total volume (m^3)	1308	1283	494	827	1073	997
Percent of inflow (%)	3.0	5.1	1.4	3.6	5.3	3.7
Percent of total losses (%)	5.5	14.0	6.8	10.9	9.8	9.4
Percent of transient losses (%)	44.0	61.5	17.0	65.0	84.4	55.1
Per channel length (m^3/m)	0.116	0.059	0.040	0.086	0.101	0.080
Per channel length per unit inflow (m^3/m/(m^3/sec))	1.63	1.43	0.71	2.23	3.01	1.80
Major Bank and outlet Breaches:						
Total volume (m^3)	nm**	0	822	38	86	237
Percent of inflow (%)		0	2.4	0.2	0.4	0.7
Percent of losses (%)		0	6.0	0.4	0.8	1.8
Percent of transient losses (%)		0	35.8	3.0	6.7	11.4

*Values are the average of three weeks (three rotation cycles) of data collection.

**Not measured.

Table 4. Regression equations describing the relationship between transient losses (V_{TL}) and the length of channel filled (L_W) and drained (L_D) to irrigate each field. All equations are significant at the 99% level.

Watercourse	Regression equation	Coefficient of determination (r^2)
TW81-R	$V_{TL} = -15.0 + 0.31\ L_W - 0.10\ L_D$	0.58
Tik 1	$V_{TL} = 3.1 + 0.14\ L_W - 0.06\ L_D$	0.52
MP 6	$V_{TL} = 0.3 + 0.21\ L_W - 0.04\ L_D$	0.59
MP 35	$V_{TL} = 2.6 + 0.16\ L_W - 0.07\ L_D$	0.77
MP 52	$V_{TL} = 21.0 + 0.15\ L_W - 0.08\ L_D$	0.70

watercourses combined, transient losses also correlated with the average flow rate, which is representative of the relative size of the channels. An average of 0.16 m^3 of water was lost per meter of channel filled and drained, or .0034 m^3/m per liter per second of inflow. Over two-thirds of the transient losses occurred in the farmers' branches.

Dead storage amounted to about half of the transient losses, or 3.7% of the inflow. Short term bank breaks and leaks were highly variable depending upon the maintenance and upkeep of the watercourses, but averaged only about 11% of the transient losses and less than 1% of the inflow.

An average of 63% of the steady state losses occurred in the primary channels, although 80% of the channel usage (80% of the conveyance to the average field) was in these channels. The average steady state flow loss rates (lps/100 m length) in the farmers' branches were double those in the primary branches. The steady state losses on the five systems is summarized in Table 5.

Less than 1% of the losses on the five watercourses could be attributed to surface evaporation. Visible leakage varied with the condition of the channels between 0 to 5% of the losses, or 0 to 3% of the inflow. About half of the visible leakage was from leaky outlets.

The equivalent "infiltration rates" of the steady state losses into the channel wetted perimeters varied from 2.0 to 4.3 cm/hr and did not correlate with the soil type or infiltration rates of the surrounding field soils. In 3 of the 5 cases, the channel infiltration rate was at least double the field rate. This implies that a phenomena other than normal infiltration into channel bank and bed soils is taking place. Ponding loss measurements and other observations lead

Table 5. Steady state losses on the five operationally studied watercourses.

Watercourse section	Steady state losses (%)	Weighted average* inflow rate (lps)	Weighted average* steady state loss rate (lps/100m)	Weighted average* steady state loss rate (%/100m)
TW 81-R				
Primary channels	34	71.0	1.86	2.5
Farmers' branches	23	46.6	2.26	6.4
To the field	49	36.1	2.13	2.9
TIK #1				
Primary channels	16	41.2	0.56	1.2
Farmers' branches	13	34.7	1.58	4.6
To the field	28	30.5	0.74	1.9
MP #6**				
Primary channels	19	56.3	0.79	1.3
Farmers' branches	14	45.8	4.85	10.5
To the field	33	39.3	1.16	2.0
MP #35**				
Primary channels	17	38.5	1.69	3.9
Farmers' branches	15	31.1	1.10	3.6
To the field	33	26.3	1.40	3.6
MP #52**				
Primary channels	34	37.1	1.07	2.8
Farmers' branches	15	24.9	1.36	5.5
To the field	45	21.2	1.12	3.0
Average				
Primary channels	24	48.8	1.19	2.3
Farmers' branches	16	36.6	2.35	6.1
To the field	38	30.7	1.31	2.7

*Time weighted average.
**Values are the average of three weeks (3 rotation cycles) of data.

to the same conclusion (Trout, 1979). The assumption is that "macropores" (insect, worm and rodent holes), primarily in the upper banks, greatly increase the effective wetted perimeter and perhaps lead to more porous strata.

Steady state loss rates were correlated with inflow rate on each of three tested watercourses. As upward fluctuations in the inflow rate occurred, loss rates increased rapidly. Figure 5 shows the relationship between loss rate and inflow rate for one of the watercourses and a linear and exponential regression line fit to the data. Ponding loss measurements showing an exponential relationship between loss rate and flow depth in watercourse channels support this finding (Trout, 1979).

The loss rate data indicated that loss rates in the channels decreased with distance, but not as fast as the flow rate decreased. The loss rate was between being constant with and proportional to the normal flow rate in the channel.

The flow diagram shown in Figure 6 summarizes the flow of water through the measured conveyance systems and the types of losses involved.

IMPLICATIONS OF THE FINDINGS

Extensive steady state loss measurements in Pakistan watercourses have indicated that conveyance losses are in the range of 30 to 50% (Ashraf, et al., 1978; Lowdermilk, et al., 1978). This operational study has shown that, in addition to these steady state losses, an additional 7% of the inflow is lost to transient conditions--a water loss not measured in the steady state measurements.

The transient losses are dependent on the length of channel filled and drained. This suggests that the transient losses in a system can be proportionately reduced by changing the system operation or layout to reduce the total length of channels utilized during a rotation. In Pakistan, the regular water rotation system minimizes channel usage within the system layout, but the small field and holding size requires an extensive channel network which results in the high transient losses.

Channel usage could be reduced by enlarging the fields and/or by reorganizing them into long narrow border strips so that more land is accessible from each branch. Figures 7 and 8 show such a reorganization where total branch length is reduced 50% without enlarging fields. Such a change of course must be balanced against application uniformity decreases resulting from the longer field lengths.

These findings indicate that changing from the existing rotation to a demand system where water is moved through the

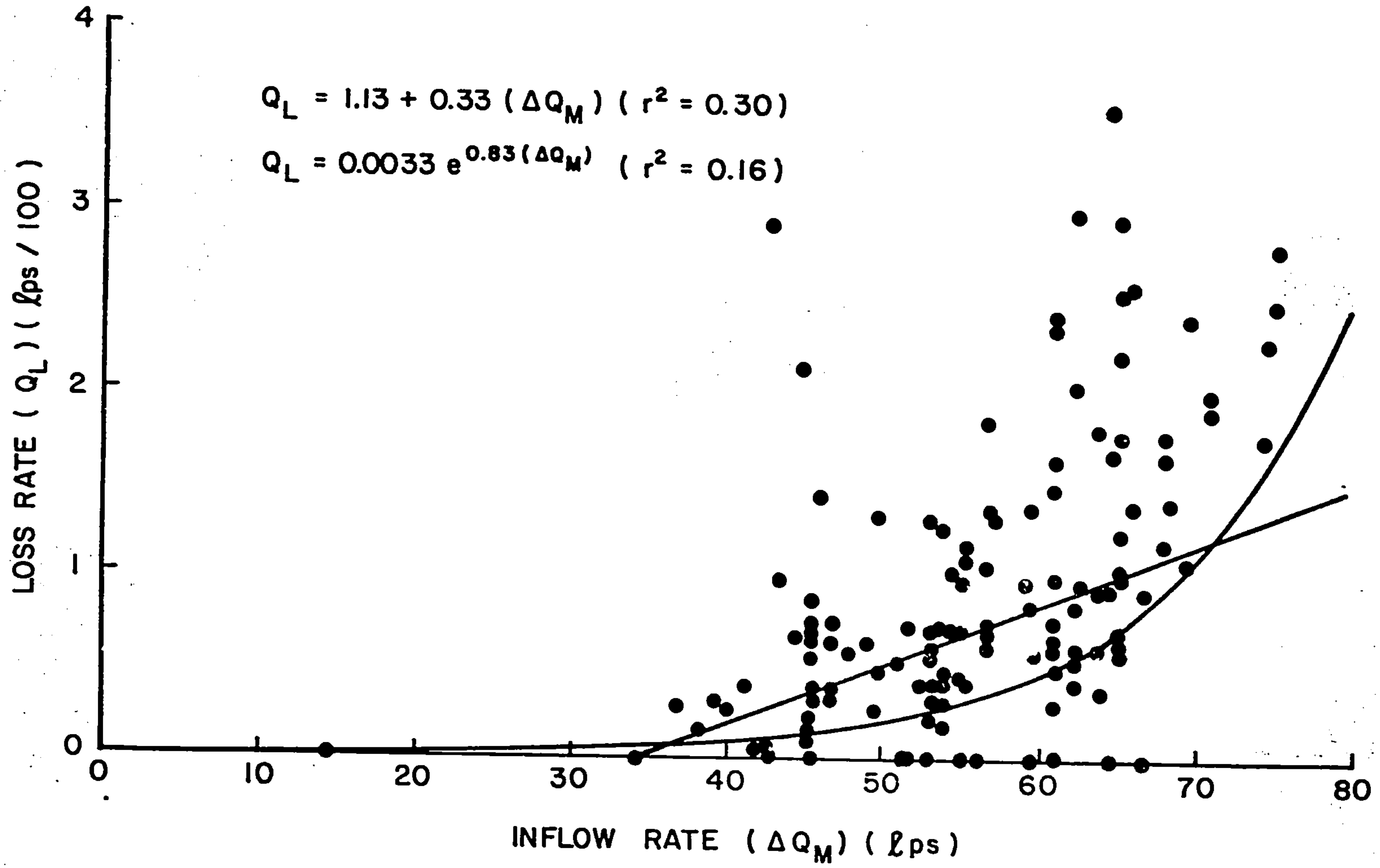


Figure 5. Steady state loss rate (Q_L) vs. inflow rate changes (ΔQ_M) for MP 6 watercourse including derived linear and exponential regression curves.

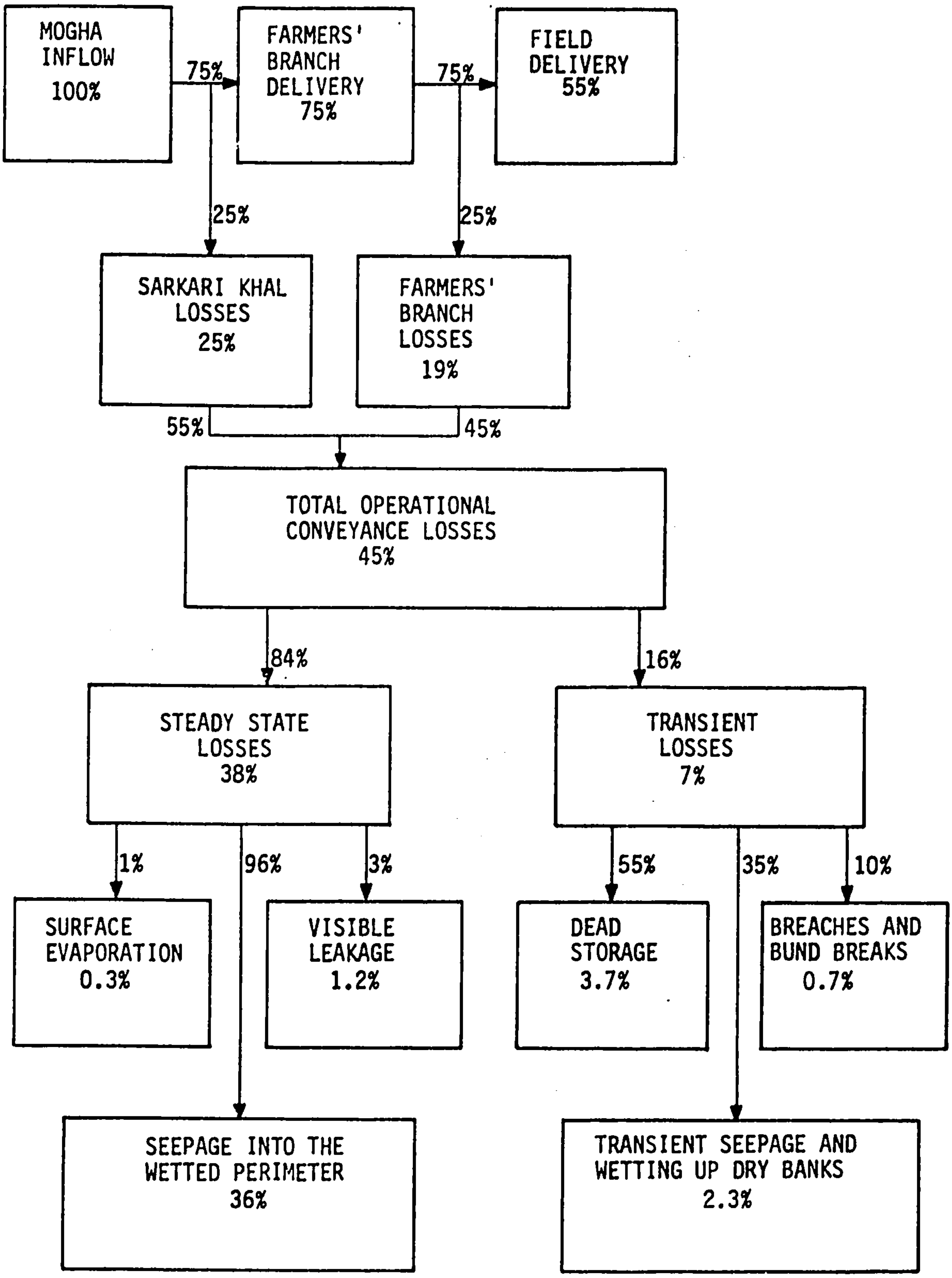


Figure 6. Flow diagram depicting the flow of water through and out of a watercourse conveyance system. Values are averages of the five measured watercourses.

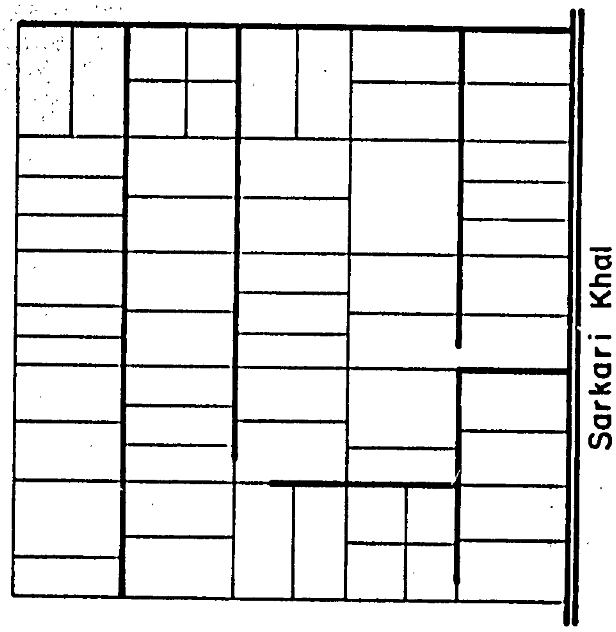


Figure 7. An example of present field and farmer's branch channel layout on a 10 hectare "square" of land showing 1300 m or 130 m/ha of channels.

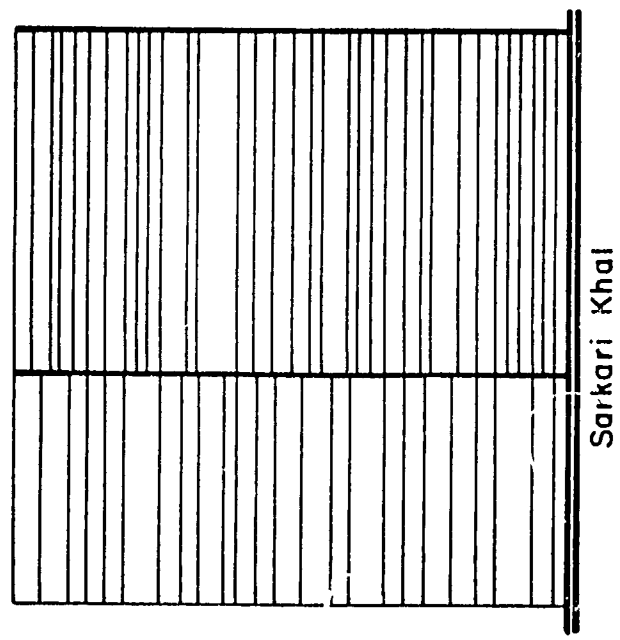


Figure 8. An example of field and farmer's branch channel layout after reorganization of fields into long narrow basins showing 640 m or 64 m/ha of channels.

system as requested by farmers would cause transient losses to increase drastically which would probably overshadow any application efficiency benefits derived from the change.

Half of the transient losses were dead storage. Dead storage losses can be eliminated by raising the channel bottom to the field level. However, saving the 4% dead storage losses would require more soil for channel construction, take more land out of production due to wider banks, lead to high losses in the event of a bank washout, and cause erosion problems at turnouts. Also, according to a ponding study of watercourse losses (Trout, 1979), elevated channels have higher seepage and leakage rates, which will overshadow the savings derived from eliminating dead storage. Lower dead storage loss can be attained by reducing the length of channels filled during each rotation. Dead storage loss will vary considerably with the average land slopes, and will not usually be a problem if channel slopes are greater than 0.001 m/m. In the Indus Basin, the slopes generally vary between 0.0002 and 0.001.

Short term bank or outlet washouts can be eliminated by building and maintaining stronger banks and using more dependable outlets. However, since this short term loss amounts to only about 1% of the inflow, the improvement costs required must be evaluated in terms of the low potential water savings.

Other channel conveyance systems cannot be assumed to have comparable transient losses. Although all systems will lose water in the process of filling empty channels, the total transient losses will depend on the length of channels filled and thus depend on the operation and layout of the system, on the channel maintenance, and on the local topography.

The steady state losses can be divided into four categories:

1. surface evaporation,
2. visible leakage,
3. infiltration into the wetted perimeter, and
4. excess seepage.

The surface evaporation was a very small percentage of the measured losses. Because the techniques to eliminate evaporation are costly, it will be one of the last types of loss to eliminate.

Visible leakage was not a large percentage of the total losses, but it is one of the easiest forms of wastage for the farmer to diagnose and is relatively inexpensive to control. Although individual action by a concerned farmer might not provide adequate benefits, a cooperative hole plugging activity would more than repay the effort in added water supply at the field. That little visible leakage was observed on three of the studied systems indicates that some farmer groups are aware of the benefits. Improved outlet structures would result in a reduction of visible leakage at outlets.

For three of the watercourses, the seepage rate into the wetted perimeter was significantly higher than the intake rates of the nearby soils, even though sediment layers, compaction, and algae growth would be expected to reduce the permeability of channel wetted perimeters much below the level of the parent soils.

This indicates that excess seepage is taking place and a potential exists to reduce seepage losses without using impermeable lining materials. Total reconstruction of channel banks on several Pakistan watercourse systems has shown that steady state seepage can be reduced by 50% in some earthen channels (Ashraf, et al., 1978). A special study indicated that, with proper soil compaction techniques, loss rates in earthen channels can be reduced even further. However, the life of such improvements is not yet known. It is suspected that the probable causes of the excess seepage rates--the insects, worms, snakes, and rodents--may quickly return to the desirable watercourse bank environment, and the loss rates may, after a few years, return to previous levels. To reduce seepage losses to yet lower levels, and more permanently, impermeable lining materials must be used.

The choice of water saving channel improvement techniques should be based on an economic analysis of the costs of the improvement vs. the benefits derived from the saved water. Perhaps the most useful information gained in an operational study is an indication of the amount of water which should be saved by various improvement techniques. For example, these results indicate that transient losses will be reduced proportionately with the reduction in the length of channels used in a rotation, eliminating dead storage can save about 4% of the water, plugging holes and stopping visible leakage can save 1% of the water, and earthen improvements can significantly reduce losses on some watercourses. They also indicate that even if all primary watercourse channels were lined and their losses were reduced to nearly 0, the 45% of the losses in the farmers' branches will still occur, and will in fact probably increase since loss rates increase with increasing flow rates, and flow rates will be higher from the efficient primary channels.

An economic analysis is complicated by the fact that, although costs are usually on a per unit channel length basis, the water savings are also dependent upon usage time (steady state losses) and number of times utilized (transient losses). This implies that different improvement techniques will be economically optimum on different sections of the conveyance system. The overall strategy will usually involve decreasing cost improvements (and thus decreasing water savings) as channels farther from the head or closer to the field are improved. Reuss (1979) has described a method to determine such a strategy.

Information collected in an operational study can provide the data necessary for such an economic analysis. On the five studied watercourses, the average primary channel section was full 36% of the time, while the average farmer's branch was utilized only during 2% of the rotation. Even though 45% of the total losses and 2/3 of the transient losses are in the branches, the cost to reduce them will be high because of the lengths involved.

Since benefits of primary channel improvements will be nearly proportional to usage time (all primary channels are generally filled once per rotation) the percentage of the primary channels which should be improved by a certain technique will vary greatly with the channel layout. Figures 9 and 10 show the variation of the primary channel usage on two of the studied watercourses, one with only one main channel and the other with several main branches. Assuming equal loss rates, a much higher percentage of the first system should be improved with high cost techniques than could economically be applied to the second system.

CONCLUSIONS

Although the operational conveyance loss measurement technique described requires considerable time and labor, selective study of representative channel systems will provide valuable information which can be gained by no other measurement technique. The results will indicate the extent of transient losses and allow a delineation of the total conveyance loss into several categories. Once the losses are better understood, techniques to increase the conveyance efficiencies can be more intelligently proposed.

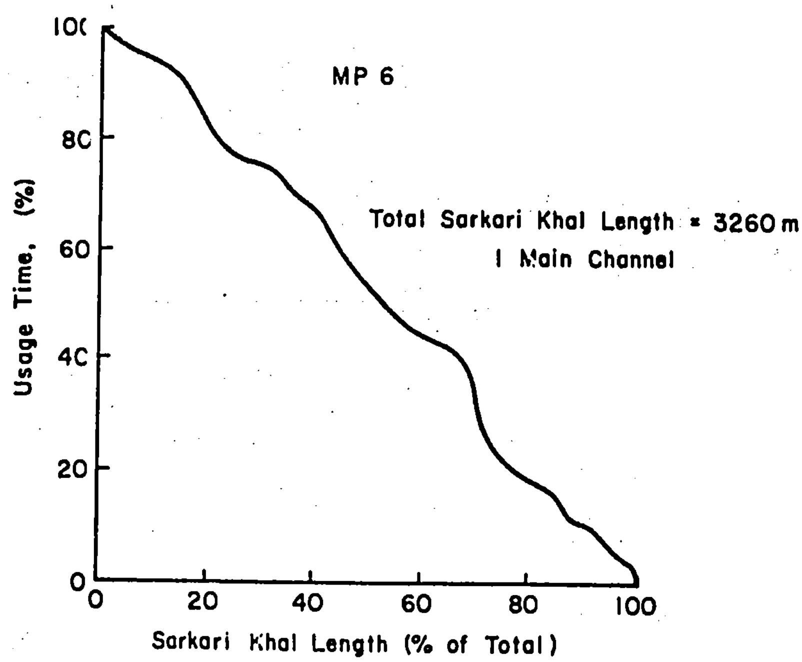


Figure 9. Normalized usage time vs. primary channel (sarkari khal) length for MP 6 watercourse.

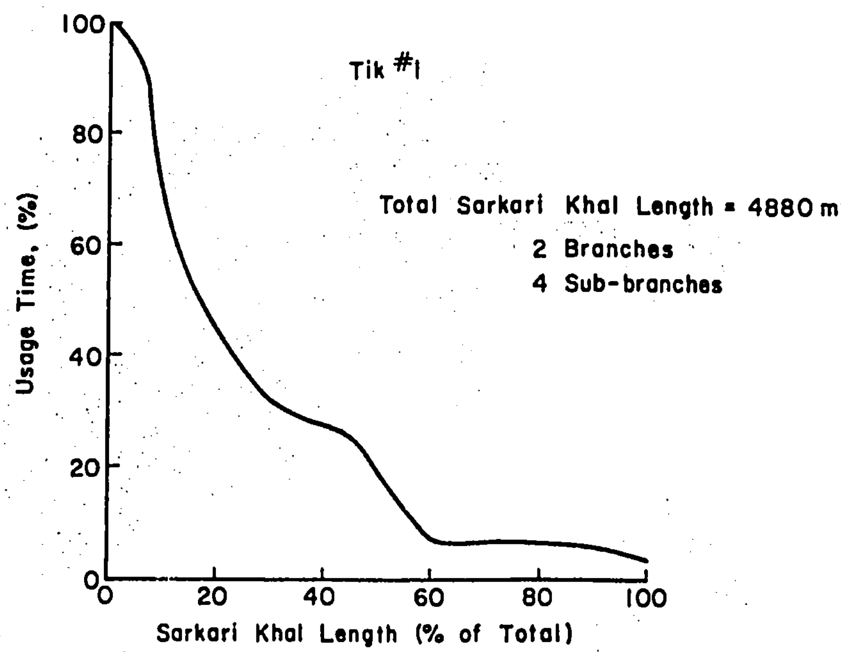


Figure 10. Normalized usage time vs. primary channel (sarkari khal) length for Tik #1 watercourse.

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APPENDIX 10

PROCEDURE FOR EVALUATION AND IMPROVEMENT OF IRRIGATION SYSTEMS

by

Gideon Peri, Gaylord V. Skogerboe, and David Karmeli[1]

INTRODUCTION

Poor water delivery and application efficiencies (ICID, 1978) may lead to some unfavorable effects resulting in lower yield per unit of area and per unit of water, less total area irrigated, and detrimental environmental effects, as well as lower returns from the irrigated crops. The need for the improvement of irrigation systems has been well established. The introduction of new technologies has been accelerated due to requirements for higher yields, as well as the need for reducing water applications and energy consumption. The evaluation of presently operating irrigation systems is conducted for the purpose of decision-making in relation to the level of required system improvement.

A comprehensive procedure for the evaluation and improvement of irrigation systems is suggested in Fig. 1. The procedure is based on the analysis of the performance of the system for an individual application, along with the irrigation management regime (intervals and depths of application), resulting in an analysis for the whole irrigation season.

GENERAL OVERVIEW

Analysis of System Performance for an Individual Application

The performance of the system for an individual application is evaluated by four performance parameters:

a. The irrigation pattern or the "Distribution Uniformity" - U_d;
b. The "Delivery Efficiency" - E_d;
c. The "Deep Percolation Efficiency" - E_p; and
d. The "Storage Efficiency" - E_s.

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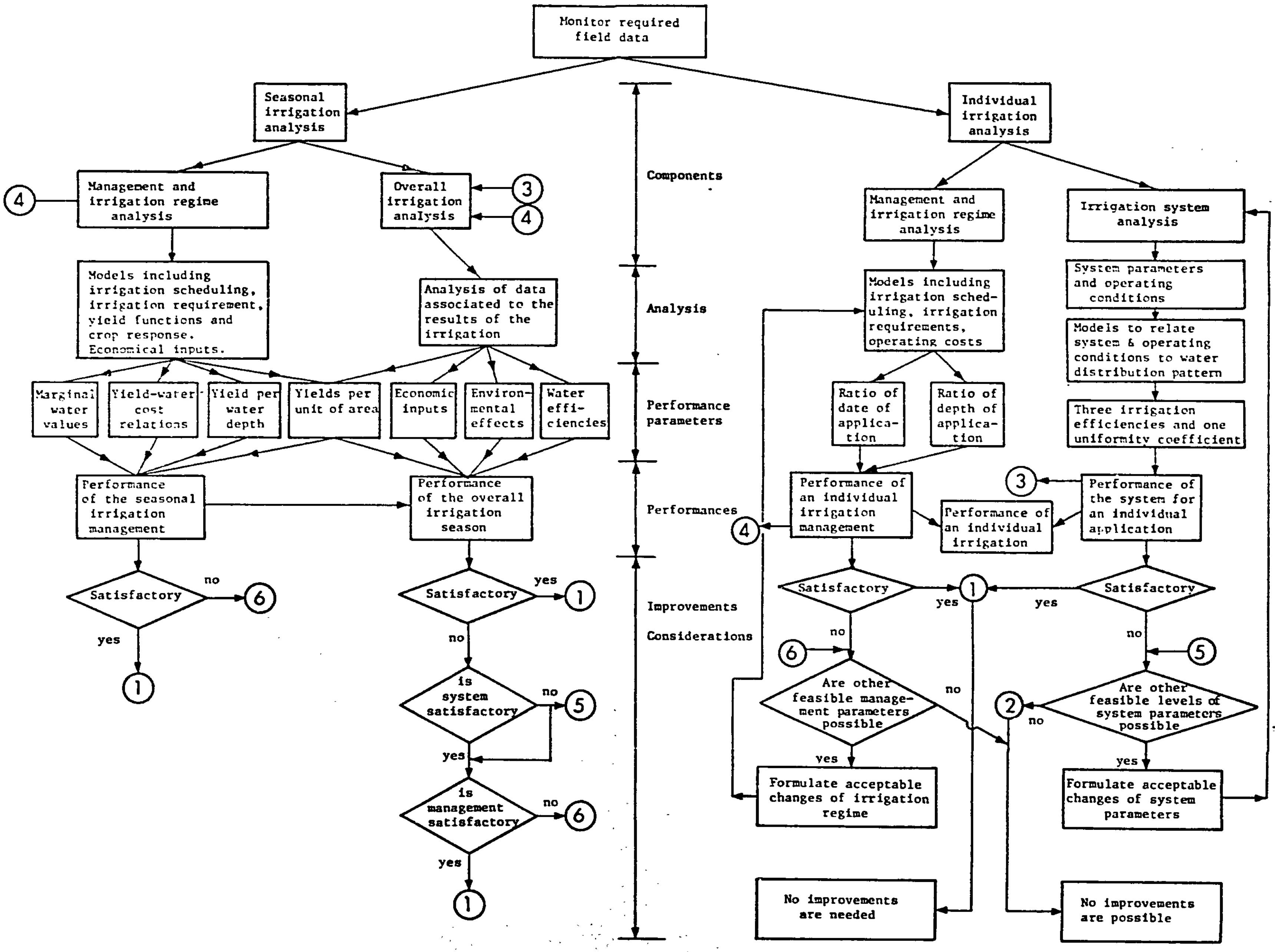


Fig. 1. Procedure for the evaluation and improvement of irrigation systems.

These four performance parameters are sufficient to define the performance of the system for an individual application.

Values for the four performance parameters are derived from the use of available models that utilize the present existing values of the system parameters (dimensions, pressures, flows, soil properties, slope, etc.) as well as feasible ranges of values for these system parameters. Each of the major irrigation methods (basins, borders, furrows, sprinkler and trickle) is analyzed by a specific model designed to evaluate the four different performance parameters in the study of a specific system.

The system evaluation and improvement is an iterative procedure where, following an initial establishment of levels of performance parameters other levels may be reached using the same models but with different levels of satisfaction, established by the farmer, design engineer, operator, planner, etc. Unsatisfactory levels of performance parameters require improvement of the irrigation system by changes in the system parameters.

Analysis of Performance of the Irrigation Management and Irrigation Regime

Analysis of performance of the irrigation management and irrigation regime is performed separately for an individual irrigation and for the overall seasonal irrigation. The performance of the seasonal irrigation management is evaluated by four performance parameters:

a. average yield expressions;
b. crop water use efficiency;
c. yield-water economic relationships; and
d. marginal water values.

The performance of an individual irrigation management is evaluated by the ratios between the recommended and actual depths of application and interval between irrigations.

Values of the performance parameters of the irrigation regime are derived from the use of available models which are basically independent of the irrigation system. These models utilize existing data of evapotranspiration, soil moisture stress and yield-water relationships.

Values for the management performance parameters of the seasonal and individual irrigations are obtained by utilizing existing values of the irrigation regime parameters (depths of application and intervals between irrigations), as well as from feasbile ranges of values of these irrigation regime parameters.

The irrigation regime evaluation and improvement is an iterative procedure, where following an initial establishment of levels of performance parameters, other levels may be reached, using the same models but with different values for the irrigation regime parameters.

For each study case, there will be different levels of satisfaction established by the farmer, design engineer, operator, planner, etc. Unsatisfactory levels of performance parameters require improvement of the irrigation system by changes in the irrigation regime parameters by the use of different values of the irrigation regime parameters.

Analysis of Results of an Overall Irrigation Season

The performance of the overall irrigation season is evaluated by four performance parameters:

a. Economic inputs;
b. Yield categories;
c. Water efficiencies; and
d. Environmental effects.

Values for the four performance parameters are derived from the use of available models utilizing values of the performance parameters of the irrigation regime. Consequently, the evaluation of the overall irrigation season is related to both the performance of an individual application and the overall irrigation regime. The overall irrigation season evaluation and improvement is an iterative procedure, where following an initial establishment of levels of performance parameters, other levels may be reached using the same models but different values for the system and/or irrigation regime parameters.

The major available models and the performance parameters for the evaluation of the irrigation management and irrigation regime are described by Peri and Skogerboe (1979) for the overall irrigation season and for the individual application, respectively, as well as the performance parameters of an overall irrigation season, while the individual application is described below.

EVALUATION OF THE INDIVIDUAL APPLICATION

Evaluation of performance of an individual application, is based on the water distribution profile after irrigation. Efficiencies and coefficients that describe the irrigation performance are derived directly from the water distribution profile. Based on these efficiencies, the irrigation performance is determined and classified into the appropriate performance categories and subsequently, the need for improvement and types of improvements are determined.

Water Distribution Profile After Irrigation

The water distribution profile after irrigation is expressed by one of three common methods.

a. Actual Water Distribution in the Field

The depth of water, y_i, is given for a set of points over the irrigated surface area. The set of points can be over the whole irrigated area (Fig. 2a), or along an axis representing the length or width of the irrigated field (Fig. 2b). The area or axis is usually divided into equal increments, although this is not necessary, and the chosen value of y_i is the average depth absorbed in that area. Graphical representation of the discrete water depths usually provides a continuous distribution of water depths. In either system, a maximum depth, y_{max}, and a minimum depth, y_{min}, may be identified. The mainadvantage of this representation is that the water depths are related to specific locations, and thus can also be related to the irrigation operating conditions (stream size, infiltration, spacing of sprinklers, pressures, soil variability, etc.).

b. Cumulative Frequency Distribution of Actual Water Depths and Areas

The actual depths of water are arranged as a cumulative distribution, where the abscissa is a fraction of the total area (Fig. 3). The cumulative frequency of actual depths of water can be represented in one of two ways:

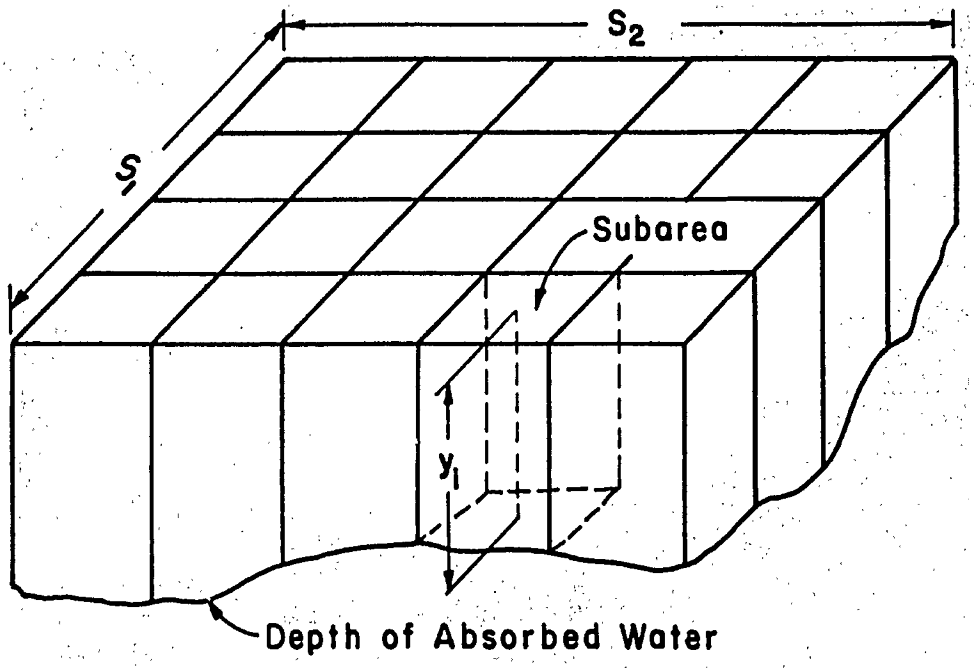
(1) "less depths (Fig. 3a) for which p fraction of the area received a depth of water of y_p or less and a k - p fraction of the area received a depth ranging between y_p and y_k.

(2) "greater" depths (Fig. 3b) for which p fraction of the area received a depth of water of y_p or greater and p - k fraction of the area received a depth ranging between y_k and y_p.

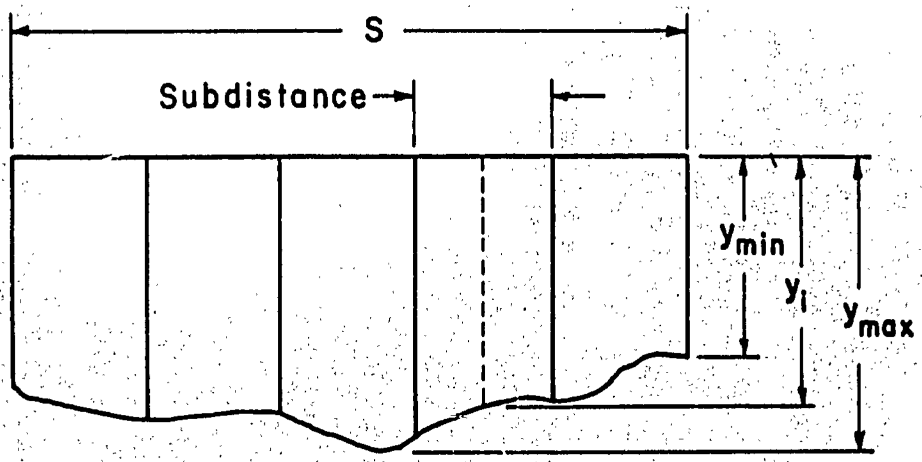
c. Cumulative Frequency Distribution of Nondimensional Water Depths

Each water depth, y_i, is transformed into a nondimensional water depth, $H_i (L\ L^{-1})$.

$$H_i = \frac{y_i}{\bar{y}} \qquad (1)$$

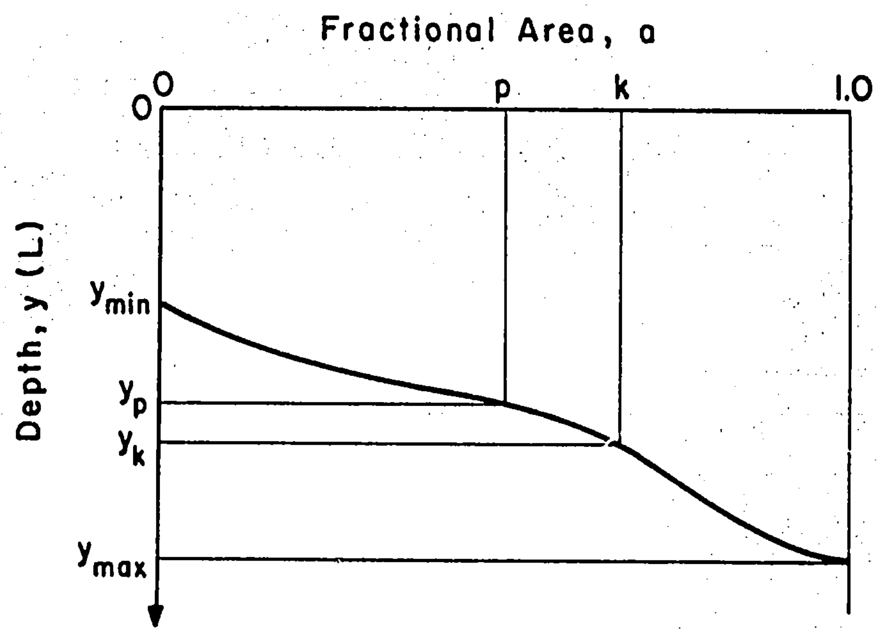


(a) Depth of Absorbed Water Over an Irrigated Area

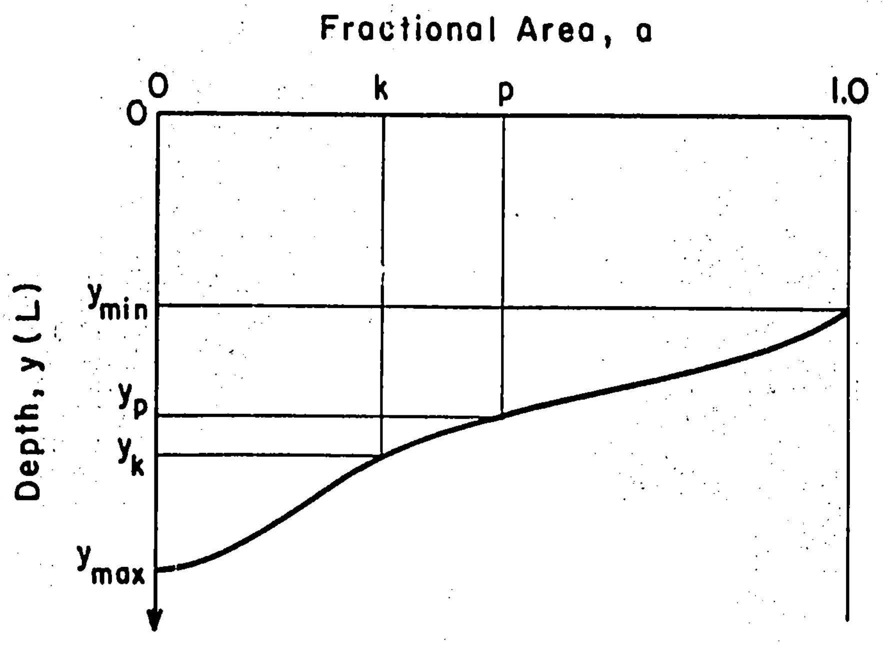


(b) Depth of Absorbed Water Along an Axis

Fig. 2. Actual field water distribution.



(a) "Less" Depth Frequency Distribution



(b) "Greater" Depth Frequency Distribution

Fig. 3. Cumulative frequency distribution of actual water depths.

where y_i is the actual water depth (L), and $\bar{y}$ is the average water depth (L). The average water depth is

$$\bar{y} = \frac{1}{A} \sum_{i=1}^{n} A_i y_i, \qquad (2)$$

where n is the number of water depth observations, A_i is the field area (L^2) associated with y_i and A is the total field area (L^2).

The field area is also nondimensionalized by dividing by the total field area. That is,

$$a_i = \frac{\sum_{j=1}^{i} A_j}{A}, \qquad (3)$$

where a_i is the dimensionless area ($L^2\ L^{-2}$) equal to the sum of all dimensional areas, A_j (L^2) up to and including $A_i(L^2)$. It is usual to relate a_i's and H_i's in a "greater" frequency distribution (Fig. 4). This type of representation of depths and areas will be referred to as a Water Distribution Profile (WDP).

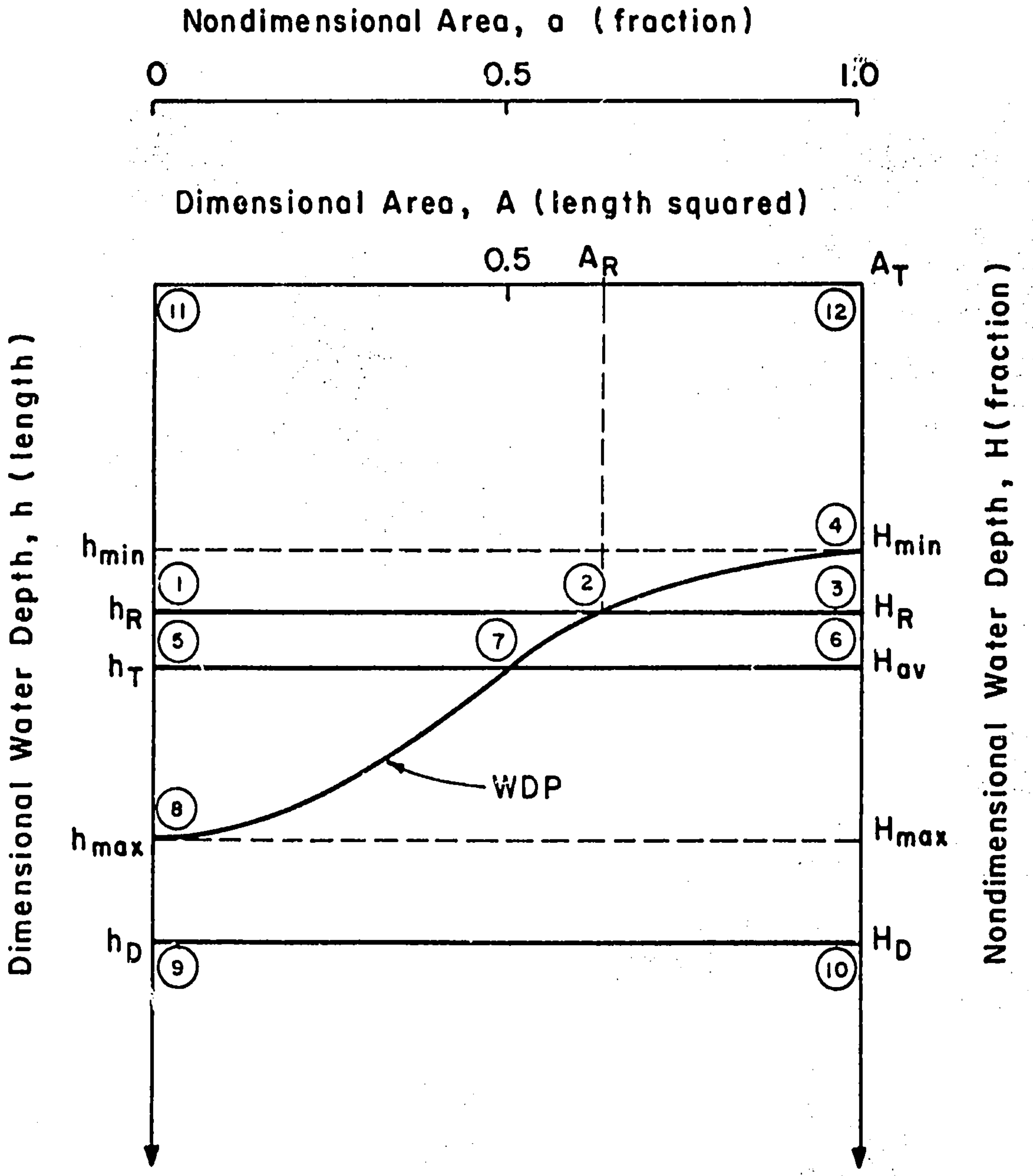
Parameters Related to the Water Distribution Profile

Each water distribution profile, no matter what its method of representation, can be described by a set of parameters. These parameters can be defined in terms of water volumes or in terms of water depths. These depths may be dimensional or nondimensional. The system of symbols used in this work are described below.

a. Scheme for Symbols

The scheme for designating water quantities and depths is as follows:

(1) The symbol A_T (L^2) is reserved for the area of the field;
(2) Actual infiltrated depths, at points in a field, are designated by the letter y, with or without a subscript, as described below:
(3) Volumes of water are designated with capital letters (R, T, etc.);
(4) Derived dimensional depths, determined by dividing a volume by the field area, are given the letter h, with or without a subscript, as described below;



B = ②, ④, ③, ②

C = ⑦, ②, ④, ⑥, ⑦

D = ⑨, ⑪, ⑫, ⑩, ⑨

E = ①, ⑧, ⑦, ②, ①

R = ①, ⑪, ⑫, ③, ①

F = ⑤, ⑧, ⑦, ⑤

T = ⑧, ⑪, ⑫, ④, ⑧ = ⑤, ⑪, ⑫, ⑥, ⑤

W = ⑧, ⑨, ⑩, ④, ②, ⑦, ⑧

$T = F + R - B$

$T = D - W$

$H_T = y = H_F + H_R - H_B$

$H_T = H_D - H_W$

Fig. 4. Definition sketch for symbo's.

(5) Dimensionless depths, determined by dividing the dimensional depth by the mean depth ($\bar{y}$) are identified by the letter H, with or without a subscript, as described below (these dimensionless depths depths may be derived from actual infiltrated depths (such as y's), or from volumes which have been converted to depths, such as h's).

b. Symbols Related to Volumes (dimension of L^3) (Refer to Fig. 4).

B = volume of deficient water after an irrigation, measured from the required depth, h_R.
C = volume of deficit (or excess) water after an irrigation, in relation to the mean depth applied. (Note that C = B when R = T.)
D = volume of water delivered to the irrigated area, including field runoff, evaporation and wind losses.
E = volume of water which infiltration beyond the required depth, h_R.
F = volume of water which infiltrated beyond the average depth, $\bar{y}$.
R = volume of available root zone water storage at the time of irrigation (i.e., the requirement).
T = volume of water absorbed in the irrigated area.
W = volume of water which was delivered to the irrigated area but was not absorbed by it.

c. Symbols Related to Derived Dimensional Depths

h_B = volume of deficient water after an irrigation, divided by the area irrigated = B/A_T.
h_C = volume of deficient water after an irrigation measured from the mean depth, $\bar{y}$, divided by the area irrigated = C/A_T.
h_D = volume of water delivered to the irrigated area, divided by the area irrigated = D/A_T.
h_E = volume of water that infiltrated beyond the required depth, h_R, divided by the irrigated area = E/A_T.
h_F = volume of water that infiltrated beyond the average depth, $\bar{y}$, divided by the irrigated area = F/A_T.
h_R = volume of available root zone water storage at the time of irrigation, divided by the area irrigated = R/A_T.
h_T = volume of water absorbed in the irrigated area, divided by the area irrigated = $T/A_T = \bar{y}$.
h_W = volume of water that was delivered to the irrigated area but was not absorbed by it, divided by the irrigated area = W/A_T.

d. Symbols Related to Nondimensional Depths

H_{av} = mean infiltrated depth divided by the mean infiltrated depth = 1.

H_B = $h_B/\bar{y}$

H_C = $h_C/\bar{y}$

H_E = $h_E/\bar{y}$

H_F = $h_F/\bar{y}$

H_{max} = maximum depth infiltrated divided by the mean depth infiltrated = $y_{max}/\bar{y}$.

H_{min} = minimum depth divided by the mean depth (i.e., the available root zone water storage divided by the product of the mean depth infiltrated and the area irrigated) = $h_R/\bar{y}$.

H_T = $h_T/\bar{y}$ = 1 (= H_{av}).

e. Symbols Related to Infiltrated Depths

$\bar{y}$ = average depth infiltrated.

y_{max} = maximum depth infiltrated.

y_{min} = minimum depth infiltrated.

The nondimensional water distribution profile (WDP) has some features that should be noted. First, there is a minimem value of H, H_{min}, and a maximum value, H_{max}, corresponding to $\bar{y}$ which is always numerically equal to 1. Finally, there is a value, H_R, that corresponds to the quantity of available root zone water storage at the time of irrigation. These values are shown on Fig. 4. The area below the water distribution profile (WDP) and above H_{av}, and the area below H_{av} and above the WDP are, by the definition of the mean, equal. They are, respectively, $H_F[=F/(A_T\bar{y})]$ and H_C $[=C/(A_T\bar{y})]$. The values H_B and H_E are, respectively, the areas below the WDP and above H_R, and the area below H_R and above the WDP. They are equivalent, respectively to $B/(A_T\bar{y})$ and $E/(A_T\bar{y})$. These are equal if and only if $H_R = H_{av}$.

A water distribution profile can also be plotted in terms of dimensional depths and areas, similar to that of Fig. 3. The water volumes that are derived from the dimensional water distribution profile are as follows:

$$T = \int_0^{A_T} y \, d\alpha, \tag{4}$$

where α is a dummy variable.

$$B = h_R \, (A_T - A_R) - \int_{A_R}^{A_T} y \, d\alpha, \tag{5}$$

where h_R is the average requirement (i.e., R/A_T) and A_R is the area of the field that receives the requirement or more.

$$E = \int_{o}^{A_R} y \, d\alpha - A_R h_R \qquad (6)$$

The above relationships and the dimensional water distribution profile both indicate that the following holds,

$$T - E = R - B \qquad (7)$$

Efficiencies Describing Irrigation Performance

The efficiency and distribution of an individual irrigation can be described through the measurement of four independent quantities. Three efficiencies and one distribution parameter will be defined in terms of these four quantities.

a. Storage Efficiency, E_s

This parameter is the fraction of the available root zone water storage (at the time of irrigation) that is filled by the irrigation.

$$E_s = \frac{R - B}{R} = 1 - \frac{B}{R} = 1 - \frac{h_B}{h_R} = 1 - \frac{H_B}{H_R} \qquad (8)$$

where R is the available root zone water storage (L^3) at the time of irrigation, and B is the available root zone water storage (L^3) after the irrigation has occurred. This is a measure of the adequacy of the irrigation.

b. Deep Percolation Efficiency, E_p

This parameter is the fraction of the total water absorbed in the irrigated area which contributes to filling the available root zone water storage (at the time of irrigation). It is a measure of the water which is lost to deep percolation.

$$E_p = \frac{R - B}{T} = \frac{h_R - h_B}{h_T} = H_R - H_B \qquad (9)$$

where T is the total quantity of water (L^3) applied to the field that infiltrates into the soil.

c. Delivery Efficiency, E_d

This parameter is the fraction of the water delivered to the irrigated area which is absorbed by the soil through infiltration. It is a measure of the water that is lost to factors other than deep percolation, i.e., the losses to runoff (even if collected by a tail-water reuse system), wind drift, evaporation, etc.

$$E_d = \frac{D - W}{D} = \frac{T}{W} = \frac{h_T}{h_D} = \frac{H_T}{H_D} \tag{10}$$

where W is all water lost (L^3) during an irrigation except that due to deep percolation, and D is the total quantity of water (L^3) delivered to the field.

d. Distribution Uniformity, U_d

This parameter is the fraction of the total water absorbed in the irrigated area that contributes toward filling the root zone or is lost to deep percolation. Although it is not immediately obvious, it will be shown later that this is a measure of the distribution of water over the field by the irrigation, and so this term will be called the distribution uniformity, U_d.

$$U_d = \frac{T - C}{T} = 1 - \frac{C}{T} = 1 - \frac{h_C}{h_T} = 1 - \frac{H_C}{H_T} \tag{11}$$

where C is the volume of deficit (or excess) of infiltrated water after an irrigation, in relation to the mean depth applied. In equation form,

$$C = \frac{A_T}{2n} \sum_{i=1}^{n} |y_i - \bar{y}|, \tag{12}$$

where y_i is the depth of absorbed water representative of one n-th of the irrigated field and $\bar{y}$ is the mean of the n absorbed depths in the field. A_T is the total irrigated area.

A more common distribution measure is Christiansen's (1942) uniformity coefficient, U_{cc} which is often expressed as

$$U_{cc} = 1 - \frac{\sum_{i=1}^{n} |y_i - \bar{y}|}{n\,\bar{y}} \tag{13}$$

This is equivalent to

$$U_{cc} = \frac{T - 2C}{T} \tag{14}$$

so

$$U_d = \frac{1 + U_{cc}}{2} \tag{15}$$

An examination of Eqs. 8 through 15 indicates that a total of five quantities (R, T, D, B, and C) were used to define the four parameters. However, since C is a special case of B, mathematically four quantities are sufficient to define the four parameters.

Analysis of Irrigation Performance Measures

The performance of an irrigation is determined by simultaneous analysis of the four quantities defined in Eqs. 8 through 15. Some typical cases that emphasize the need for a simultaneous analysis are the following:

a. Given a water distribution with $h_R \geq h_{max}$ (Fig. 5a). In this case, $E_p = 1$ because no deep percolation can exist. However, $E_s < 1$ which means that an inadequate irrigation has been applied. If the inadequacy is excessive, then the irrigation is not satisfactory.

b. Given a water distribution with $h_R \leq h_{min}$ (Fig. 5b). In this case, $E_s = 1$ because the entire requirement has been met. However, $E_p < 1$ because deep percolation occurs. If this is excessive, the irrigation is not satisfactory.

c. Given a water distribution with $h_{min} < h_R < h_{max}$ (Fig. 5c). In this case, E_p and E_s are both less than 1, but they may each be satisfactory. In such a case, both the level of adequacy and the deep percolation are acceptable.

The above examples can be extended to include an analysis of the distribution uniformity, U_d, and the delivery efficiency, E_d.

The above discussion suggests a special case in which R = T, which means that the average requirement is equal to the average application. In such a case B = C, and so

$$E_p = E_s = U_d \quad (R = T) \tag{16}$$

The above result can be generalized It is noted from Eqs. 8 and 9 that for a given irrigation (that is, one having a specific distribution of y values) U_d and E_d take

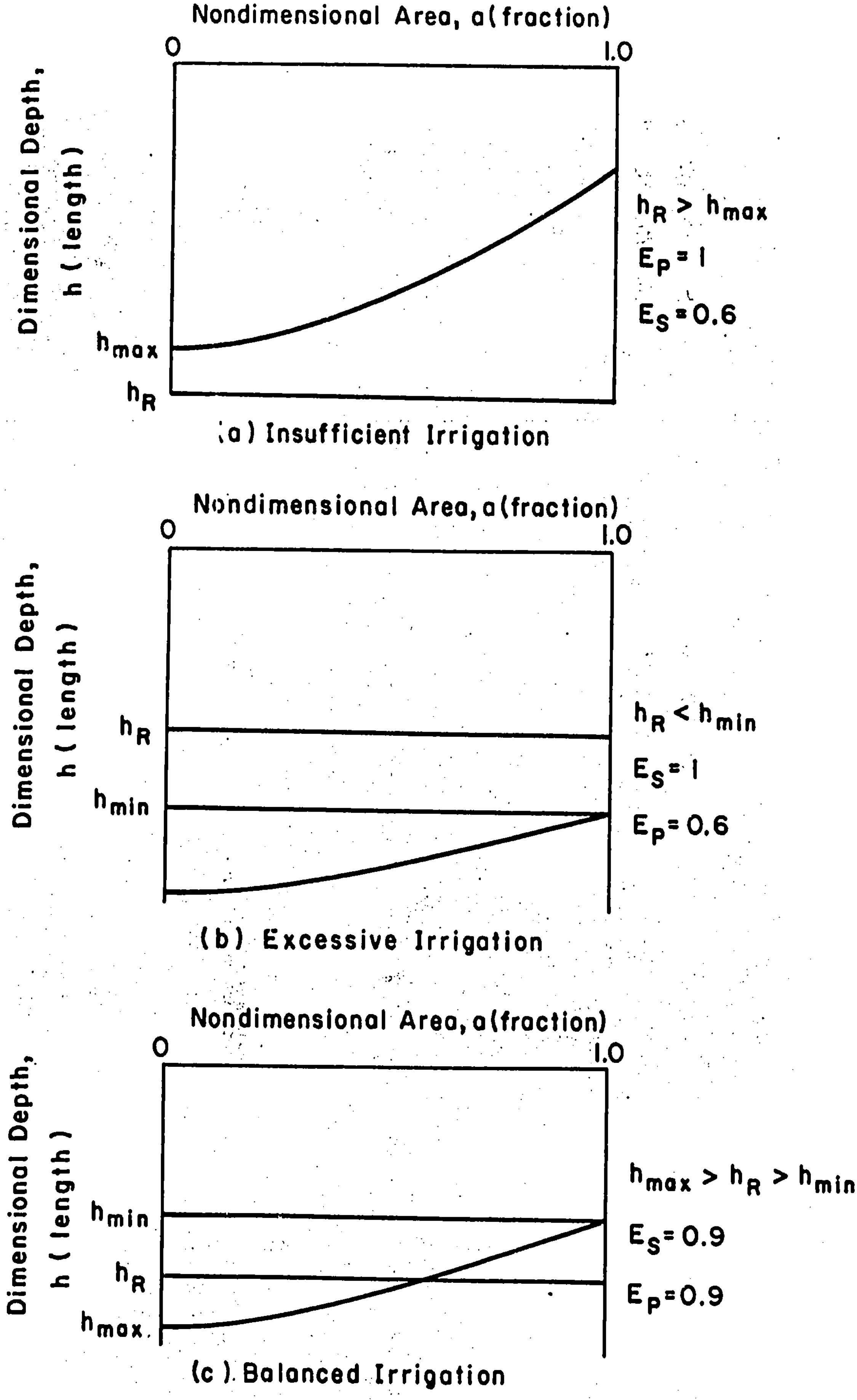


Fig. 5. Three possible water distribution profiles.

on specific values, and both E_s and E_p can be defined in terms of the dimensionless requirement (i.e., H_R). That is, E_p and E_s are dependent also on the required depth. Extending the example given in Fig. 5, E_s and E_p can be described as functions of the required depth. An example of this is shown in Fig. 6. The specific case plotted is for a normal distribution with $U_d = 0.9$ ($U_{cc} = 0.8$). Although the values of H theoretically range from $-\infty$ to $+\infty$, they have been arbitrarily cut off at 0.225 (H_{min}), corresponding to $E_s = 0.999$ and 1.775 (H_{max}), corresponding to $E_p = 1.000$.

Expressing E_p and E_s as a function of H_R (Fig. 6) enables further analysis of the irrigation performance as follows:

a. For a given water distribution profile, analysis of cases such as those given in Fig. 5 can be conducted.

b. For a given water distribution profile, both E_p and E_s can be determined simultaneously for any required depth of application, H_R.

c. For a given water distribution profile, the range of H_R can be determined so that a required combination of E_p and E_s is satisfied (for example, the range of H_R so that E_a and E_s will be greater than 0.85).

d. For a given water distribution profile, the effect of deviations in H_R, on the irrigation performance, can be determined.

e. If the given water distribution cannot be changed easily (due to stream sizes, dimensions, etc.) then the depth of application can be determined so that the irrigation performance is satisfactory. The interval between irrigations is then determined according to the depth of application, and the known daily crop requirement.

Acceptable Levels of Performance Parameters

The question arises as to what value of H_R (or h_R) is acceptable for a given irrigation. In Fig. 6, a minimum allowable value of E_s and E_p of 0.65 has been shown, and if this were accepted, the values of H_R could range from 0.66 to 1.56. This means that the average application would be between 0.66 and 1.56 times the requirement. Such a choice is entirely arbitrary, and a more comprehensive treatment of this would consider an objective function, Q, which included the three efficiencies and the distribution parameter, each with an associated weighting factor. Thus,

$$Q = C_1E_s + C_2E_p + C_3E_d + C_4U_d. \qquad (17)$$

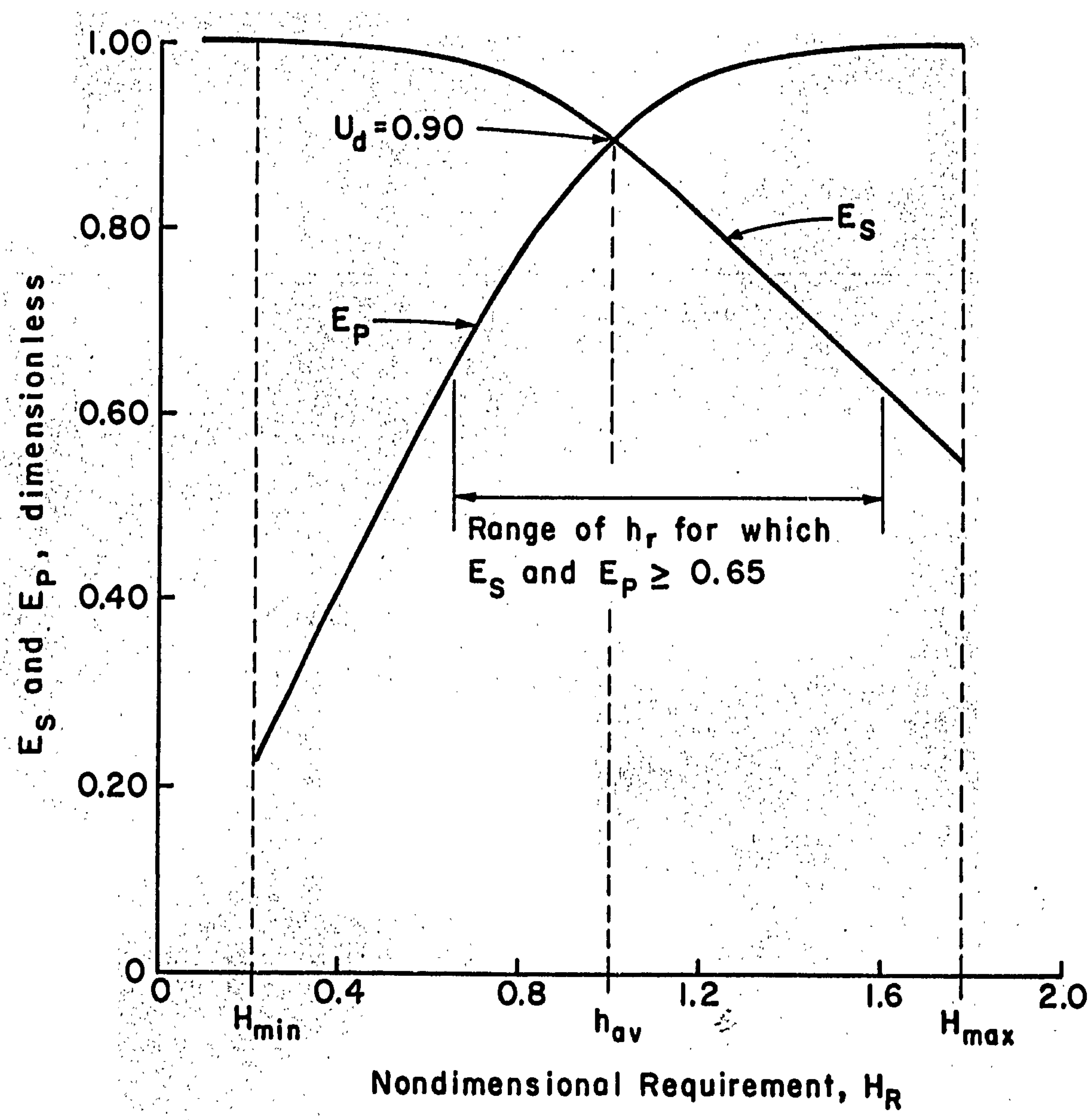


Fig. 6. Water storage efficiency (E_s) and deep percolation efficiency (E_p) as a function of H_R for a nearly normal distribution with U_d = 0.9 (U_{cc} = 0.8).

The C_i's are weighting factors giving the relative importance of the four performance parameters. The coefficients C_1 and C_4 are directly related to yield and water quantity. The coefficient C_2 is related to deep percolation and its cost (leaching of nutrients, waste of water and contribution to ground water problems). The coefficient C_3 is related to the cost of water that is delivered, but does not arrive on the field, or runs off the field. Unfortunately, specific values of C_i's are unknown in general, and although they may be set for specific crops, even this has not yet been done. Nevertheless, current knowledge of irrigation may suggest general ranges differing between the various sets of conditions. Three ranges of each have been listed--excellent, satisfactory and unsatisfactory. From this, six categories of irrigation performance can be developed. These are independent of the delivery efficiency, and apply only to absorbed water.

a. Category I.

The parameters E_s, E_p, and U_d are in the excellent range. No improvement in water distribution or depth of application is required.

b. Category II.

The efficiencies E_s and E_p are in the excellent range, but the water distribution is out of this range. The implication is that the water distribution should be improved for the same level of average application.

c. Category III.

The parameters E_p and U_d are in the excellent range, but the parameter E_s is less than excellent. This implies that the required amount of water, on the average, has not been absorbed by the soil. To meet the requirement, the average depth of application must be increased.

d. Category IV.

The parameters E_s and U_d are in the excellent range and the parameter E_p is out of this range. This implies that the distribution is good, and that the requirement has been absorbed by the soil. However, an excess amount of water has been absorbed. The total water applied should be reduced.

e. Category V.

The parameter U_d is not in the excellent range, and the parameters E_s and/or E_p are not in the excellent range, and $E_s < E_p$. Improved irrigation performance requires an improvement in distribution, and since E_s is deficient, then additional water must be applied in conjunction with the improved distribution.

f. Category VI.

The parameter U_d is not in the excellent range, and the parameters E_s and/or E_p are not in the excellent range, and $E_s > E_p$. Improved performance requires that the distribution be improved, and that the total application be decreased.

The delivery efficiency, E_d, is then associated with each of the categories, to provide an additional level of performance.

Fig. 7 summarizes the six categories, showing the relationships between the performance parameters, and the changes required to improve the irrigation, for each category.

SUMMARY AND CONCLUSIONS

The performance of an irrigation system can be fully described in terms of four parameters--the fraction of the absorbed water that is stored in the root zone, the fraction of the requirement that is met, the fraction of the delivered water that is absorbed, and the distribution of the water over the field. Most of the commonly used terms can be derived from these four parameters. If limits of acceptability for these parameters can be established, then the analysis of an irrigation system can be conducted to evaluate the irrigation performance and to determine how the irrigation can be improved (i.e., improve distribution, reduce or increase total application).

The steps required to evaluate the performance of an individual application are:

a. Determine the water depths applied to the irrigated area and represent the water distribution profile in one of the three methods as described in Figs. 2, 3 and 4.

b. Determine the total amount of water that was delivered to the irrigated area, D, and the total amount of water absorbed by the irrigated area, T. This also provides the quantity of water lost to the outside of the field, W.

c. For a given required depth of application, h_R, and using the water distribution profile, calculate the deficiency, h_B, and then (with the already known T, D, R, B) calculate the four efficiencies E_p, E_s, E_d, and U_d (Eqs. 8-15).

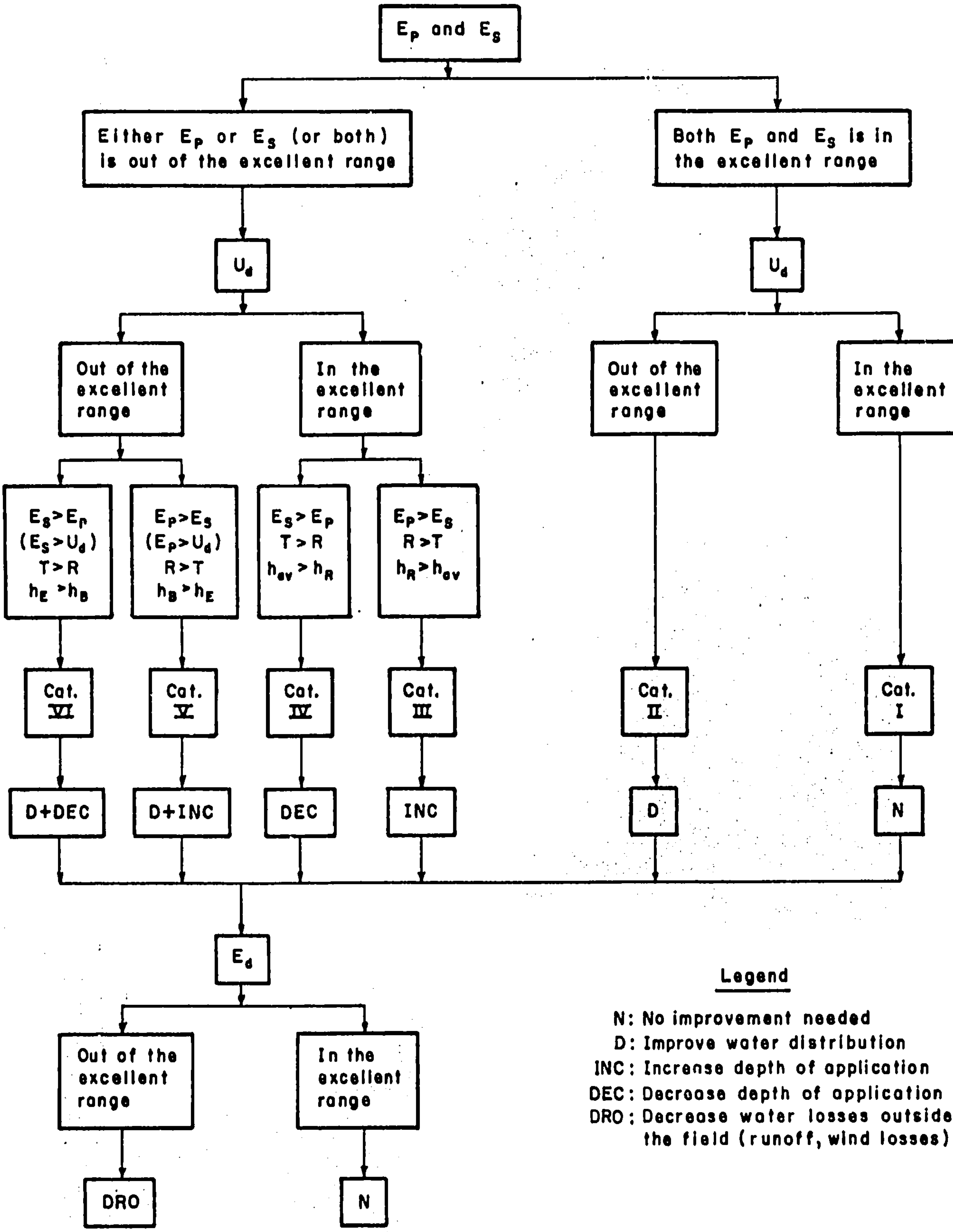


Fig. 7. Categories of irrigation performance for individual application.

d. For various values of the required depth, h_R, calculate the deficiency, h_B, and the resulting E_p and E_s. Represent E_p and E_s as a function of h_R (Fig. 6). The effect of deviations in the required depth of application, on the irrigation performance, can be determined.

e. According to the levels of efficiencies, determine the irrigation category and the required improvements from Fig. 7.

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APPENDIX 11

CONSEQUENCES OF AND FARMERS' REACTIONS TO INDUS BASIN WATER MANAGEMENT CONSTRAINTS[1]

by

A. C. Early[2], D. M. Freeman[3] and M. K. Lowdermilk[4]

INTRODUCTION

BACKGROUND

The Indus Basin Irrigation System of Pakistan represents one of the great agricultural resources of the world. The integrated system serves more than 12 million hectares and has fertile alluvial soils, a climate favorable to year-round cropping and a large farm population capable of intensive cultivation. With these potentially productive resources in place, the system however has many constraints that prevent the potential from being achieved. Despite the irrigation infrastructure, a maldistribution of supply exists: some areas have water deficiencies, others nearby have large water excesses and large areas of the system remain without water for up to half of the year as non-perennial command areas. In the past 15 to 18 years the farmers of Pakistan have recognized the value of water and have installed approximately 120,000 private, small discharge tubewells with capacity of 10 to 30 liters per second.

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[1]Paper presented at the American Society of Agricultural Engineers Joint Meeting with the Canadian Society of Agricultural Engineers, June 24-27, 1979, at the University of Manitoba, Winnipeg, Manitoba, Canada.

[2]Associate Agricultural Engineer, Irrigation Water Management Department, The International Rice Research Institute, Los Banos, Laguna, Philippines, formerly Agricultural Engineer, Water Management Research Project in Pakistan under USAID Contracts AID/ta-c-1100 and AID/ta-c-1411. All opinions are those of the authors and not necessarily those of the funding agency, the United States Government, Colorado State University, the Government of Pakistan or the International Rice Research Institute.

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[4]Director of International Education, Colorado State University, Fort Collins.

During this same period the government has undertaken the Salinity Control and Reclamation Projects (SCARP) with the intention of lowering the water table with a large number of large tubewells widely spaced across the pilot areas. The public tubewells number appropriately 8,000 currently in operation and have capacities that range from 90 to 140 liters per second serving as an important secondary water source. The emphasis in these developments along with the later stages of the Indus Basin Replacement Project have been the augmentation of supply or the development of new supplies.

Two quotations from a recent IBRD (World Bank, 1976) document are worth reporting here since they effectively summarize the findings of this report.[5]

> The agricultural situation in Pakistan has become increasingly grim over the past five years. The 1960's were exceptionally good years--annual growth in agricultural production averaged 5.65 percent, well above growth in population, and per capita production steadily improved. Since 1970, the average annual rate of growth in population at 3.0 to 3.5% has been much above the 0.45% annual rate of growth in agricultural production. Agriculture's poor performance in the 1970's cannot be explained solely in terms of adverse weather....
>
> Essentially nothing has been done to improve the efficiency of irrigated agriculture in the last decade--the deficit in agricultural production in Pakistan can be related to unreliable irrigation supplies, inefficient water management, negligible water management extension services and persistent use of traditional irrigation and farm practices unsuited to modern agriculture. These constraints cannot be overcome by individual farmers or groups of farmers unaided. Until decisive action is taken by Government, irrigated agriculture will remain inefficient whatever investment in major works. Given these difficulties, it is not surprising that individual farmers are reluctant to invest in other material agricultural inputs necessary for acceptable yields because the basic input, water, is unreliable.

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[5] World Bank, 1976. Pakistan Special Agriculture Sector Review, Foreword.

The research undertaken by the Colorado State University Field Team in Pakistan (of which this work is an example) has attempted to look at the water use end of the system rather than the water source. This water use subsystem is the on-farm component of water management and assumes the primary and secondary subsystems at the given level of management. The hypothesis behind this approach is that the current water supply could be used more efficiently at the tertiary level of the system where the effect of a new water supply could have the greatest impact on food and fiber production. The complementary inputs of good quality seed, fertilizer, improved technologies, market outlets and production facilitating inputs as credit production incentives, and extension information are all closely tied to the effectiveness of land and water utilization. The village social setting, the interrelations between farmers and the institutional services that they receive from the government agencies provide the background for production that determines the acceptance of new technology and the speed with which it is delivered to the end user.

The basic objectives of the survey can be stated in the following question format:

1. What are the significant farm level constraints confronting farmers in their tertiary level irrigation systems which are presently responsible for the low crop yields?

2. What are the significant consequences of the farm level water management constraints and what are the farmers' responses to the constraints as they attempt to feed and clothe their families?

3. What are the significant policy measures that the set of constraints and the resultant consequences from the current state of the farm water management situation would indicate for government action program?

The answers to questions 1 and 3 are provided in Early, et al., 1978a and 1978b. Question number 2 is the subject of this report.

METHODOLOGY

Farm water management research draws attention to the entire range of factors that influence the human, land, crop and water productivity in agriculture. The factors that constrain food and fiber production are then by definition a complex set of interrelationships receiving the attention of scientists of many disciplines. Investigators in identification of the constraints to food and fiber production and the consequences of the current level of constraints on the system must recognize that the task requires innovative identification techniques that combine the perspectives and strengths of several disciplines. The identification technique involved four major components, interviews, mapping, measurements, and system analysis and was developed and tested through a comprehensive study of one watercourse near Lahore (Lowdermilk, et al., 1975). The components were integrated into a survey conducted by a large team of sociologists, agronomists and engineers on selected villages (Figure 1) across the irrigated districts of Punjab and Sind of Pakistan in 1975 and 1976. The survey was conducted in 40 watercourse subsystems in 16 villages with approximately one to three weeks of concentrated effort in each village. The detailed methodology of the survey was developed and a printed handbook was designed to train the field observers (Early, et al., 1976). Data quality and management were major concerns. Extraordinary efforts were used to maintain quality of the survey data starting with the selection of highly motivated personnel, continuing with a 20% reliability re-interview on selected questionnaire items and including the initial calculation of the preliminary results of measurements in the field. The concern for quality continued throughout the analysis, coding, programming and reporting.

Six levels of analysis were possible within the design of the survey. These include the agroclimatic zone, the cropping region, the village, the watercourse command, the farm and the field unit. Eight strata are also available for categorization and further description of the data. These are the farm size, the tenure status, water supply duration on an annual basis, the supplemental water supply situation, the position of the farm on the watercourse, the watercourse on the secondary canal, the main canal in the Indus System, the general soil textural class, the village caste (tribal) composition, and the ancestral origin of the farmers (Early, et al., 1978b). The levels and strata for analysis included here are primarily the village, the watercourse command, the farm, the water supply situation and the position of the farm on the watercourse.

FARM WATER MANAGEMENT CONSTRAINTS SUMMARIZED

The tentative answers to the question, "What farm level constraints confront farmers and are responsible for the current low productivity?" are provided in the following sections (Early, et al., 1978a).

LEGEND
Contour of mean Annual Evaporation
Minus mean Annual Rainfall (centimeters
of moisture deficit) —

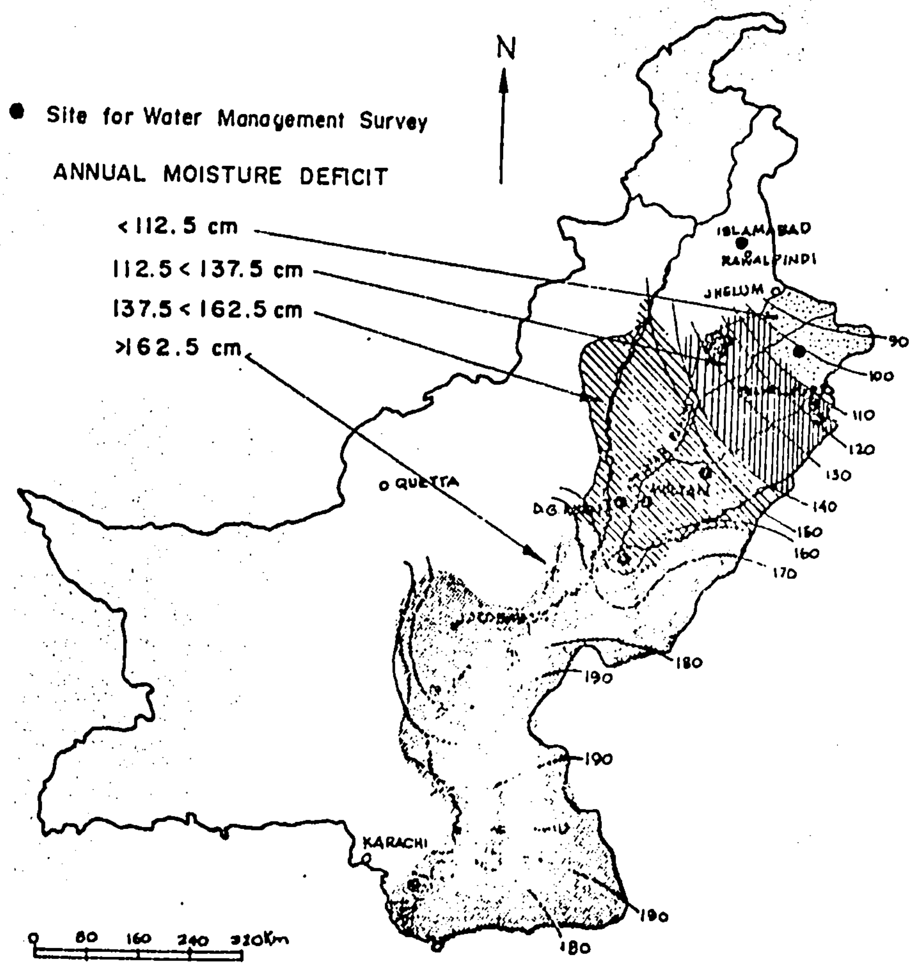


Fig. 1. Climatic regions in irrigated portions of Punjab and Sind provinces of Pakistan, Based on Annual Moisture Deficit.

Farm Level Irrigation Constraints

The farms are comprised of multiple parcels, small in size and widely spaced, thus requiring much travel time for management of the crop produciton. Fields are small primarily because of the unlevelness and the resulting difficulty in irrigation. The very large number of small fields then requires an excessive number of field delivery ditches, thereby removing land from its most productive use. Water availability is largely determined by watercourse conveyance losses and depends on the distance from the watercourse turnout (mogha) to the field turnout (nacca). An uneven supplemental water availability is concentrated in only a few watercourse command areas and is available mainly to farmers in the large farm size category. Uncertainty of regular water deliveries causes water in some crop root zones to be excessively and frequently depleted between irrigations. In other cases, water is applied to crops whose root zone reservoir is not depleted or has very little depletion, possibly as a hedge against uncertain future supplies. In some watercourse commands the mean irrigation interval extends to more than a month. Eighty-nine percent of all fields measured do not meet the precision land leveling field standard of 0.05 meter range within the field. Incomplete irrigations account for more than 60% of the evaluations and less than 60% of the root zone soil moisture reservoir is replenished for those which are partially irrigated. Watercourse command areas frequently are too high or contain significant areas which are not served by gravity, thus requiring water lifts or pumps at a marked increase in the cost of production. The survey of watercourse profiles indicates that a majority of watercourses have serious siltation problems leading to a lower hydraulic gradient and less water available at the farm level.

Agronomic and Economic Constraints

The availability of fertilizer is biased toward the largest farmers. Improved seed and pesticides are far less available to farmers than is fertilizer. Production credit availability increases with the size of the landholdings and is not available to 73% of small farmers. The rates of fertilizer use average less than one-third of the recommended rates for each crop. Improved bullock animal powered technologies are seldom used and the fossil-fueled tractors, threshers and tubewells are infrequently used although increasing with time. The trial and adoption rates of the modern wheat and rice varieties decrease in a regular progression as the farm size decreases. The trial and adoption rates of the improved practices requisite to the modern varieties are much less than for the traditional varieties and the trend of decline with farm size is repeated.

Knowledge and Information Constraints

Farmers' reported primary reason for cultivation of rice, wheat, fodder, and sugarcane is for home use, whereas the production of cotton is a market decision. Water availability is the most important determinant of the cotton cropping decision for 24% of the farmers. Farmers' decisions to irrigate a crop is based on the appearance of the crop rather than the recommended subsoil moisture observations. Most farmers stop irrigating a field when the surface is fully covered or when all the high spots are covered rather than when the recommended 3/4 or 5/6 of area is covered. Farmers lack precision in knowledge and tend to underestimate the amount of water they apply, but their depth estimates do increase with an increase in the annual moisture deficit or annual water requirements for the location across the agroclimatic zones. Farmers generally do not know the depth to which their crop roots penetrate and extension workers tested were equally uninformed. Farmers generally believe more frequent irrigations would be better for their crops than the number currently used, but without realization of the losses incurred due to more water applied and nutrients leached. Farmers are generally aware that the first irrigation applied at three weeks after wheat emergence is the most critical for wheat production, but are not aware of the water savings that can be achieved later in the season, especially when water is most scarce in the annual hydrological cycle. Farmers are generally aware of the cotton irrigation requirements except at the full boll stage, when irrigation should be ceased. Most irrigation applications are less than 6.25 centimeters depth, considerably less than the farmers' estimates of the amount of water applied. Farmers are aware of watercourse losses, with dead storage, leaks and spills, low gradients, due to silt deposits, water use by phreatophytes and percolation accounting for 95% of all responses. Farmers generally do not recognize the need for land leveling; 50% of the farmers reported that some of their fields were not sufficiently level for good irrigations, whereas almost 90% of the fields measured in the 40 watercourse command areas would to meet the precision leveling criterion of 0.05 meter tolerance. Farmers with small holdings and categorized as tenants-cum-owners often exhibit positive irrigation behavior, whereas large farmers leave the work to tenants, who do not serve the best interest of the owner in the performance of the irrigation. Improved management practices for wheat production were known to more than one-third of the farmers questioned for the seed rate, seeding method, nitrogen split dosage, and phosphorus rate. Farmers owning large farms have better knowledge of the requirements than the small farmers. Generally most farmers do not know their extension agent or even the location of his office. If these matters are known to the farmers, most did not have any contact with the extension agent in the last three months prior to the interview. Virtually all farmers know the canal fee collector and where his office is located, due to the fact that he has concessions to make for favors received from the farmers. Farmers rarely learn of canal closures prior to their being put into effect. Farmers take an active interest in farm radio broadcasts and depend upon this medium for much of their agricultural information. Farmers perceive water availability to be their greatest farm problem. This justifies their tendency to purchase water illegally, install tubewells when possible, and steal other farmers' irrigation turns when absolutely necessary to prevent crop failure.

Institutional and Organizational Constraints

As a result of the brotherhood kinship structure that tends to divide each village, farmers lack incentives to organize for the collective good of the village or of the watercourse members especially when the other brotherhood is perceived to also receive benefits. Farmer organizations perhaps require some legal status in order to contract for services with private contractors and with government agencies and to sanction nonparticipants in collective actions for the benefit of the entire group. Farmers generally receive minimal institutional services from government agencies in agriculture and water management matters. Most conflicts in the villages are over water and 35% of all reported social conflicts are related specifically to water theft. Most water related problems are resolved within the brotherhood, with the courts second, the police third and the irrigation department last in frequency of water conflict resolution. Wealth, farm size and power-influence ratings are closely linked to each other and are important considerations for farm water management improvement programs.

Recognition of Basic Problems

The amount of flow available to farmers is a major constraint to productivity. The flow available is a function (Figure 2) of the position of the farm on the watercourse command. This means the flow at the mogha tertiary turnout and the flow at the nacca farm turnout are both influenced by the place on the watercourse where water is

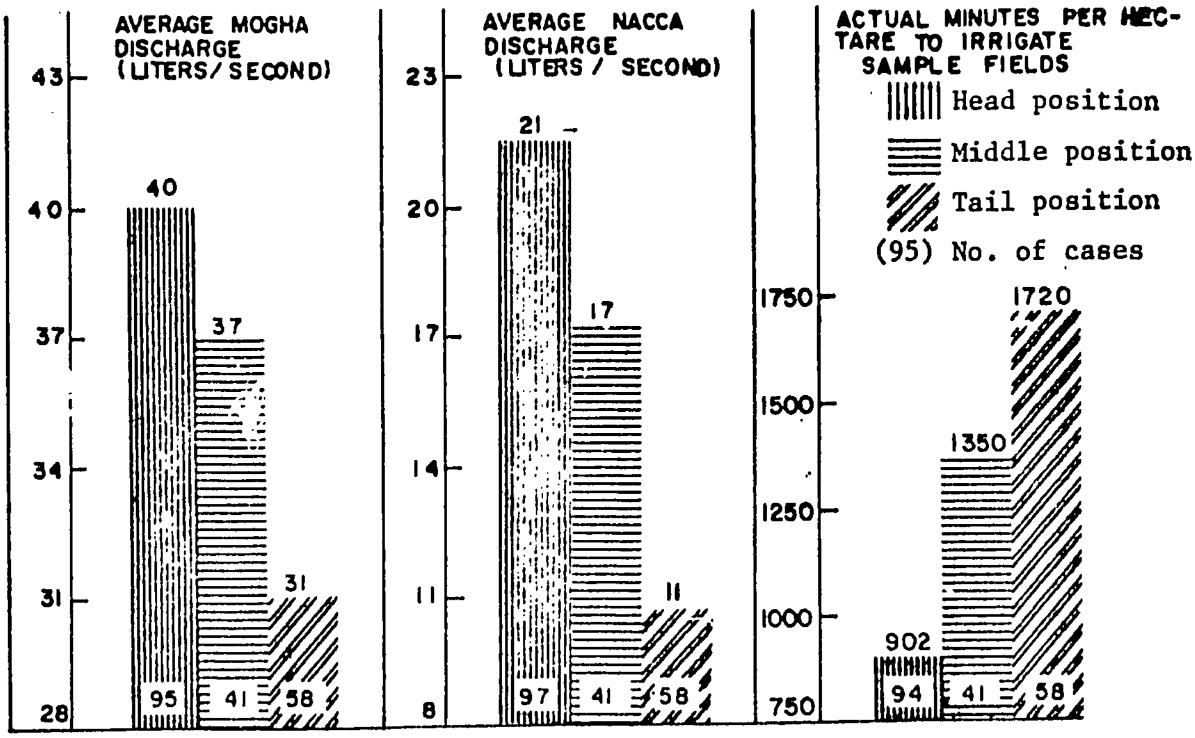


Fig. 2. Water availability measures for irrigation evaluations stratified by head, middle, and tail of watercourses.

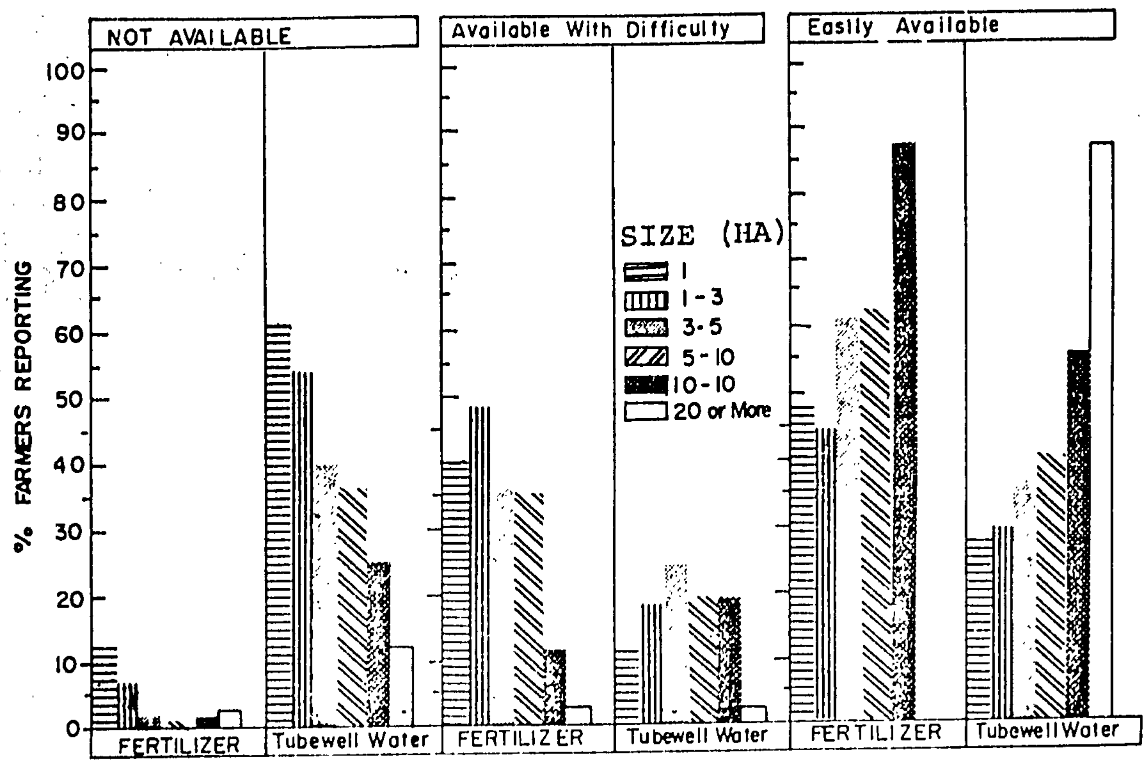


Fig. 3. Percentage of sample farmers reporting availability of fertilizer and tubewell water by farm size. (hectares)

delivered. The tertiary turnout flow is affected by the very low gradients of watercourse channels, often due to an intensive siltation problem and resulting in successively more tertiary turnout (mogha) submergence with increasing delivery distance. The field turnout (nacca) flow is of course limited also by the extent of watercourse conveyance losses. The tertiary turnout flow and field turnout flow available to head farmers on the watercourse system are 40 liters/second and 21 liters/second while the respective flows available to tail farmers are 31 and 11 liters/second. The mogha flow is decreased by 23% from head to tail and the nacca flow by 66%. These facts affect the farmer in two ways. First, it takes longer to irrigate a hectare of land at the tail for as standard depth of application versus the head (1,720 minutes at tail versus 902 minutes at the head). Secondly, it tends to force farmers at the tail of a system to discontinue irrigation before the soil moisture deficiency in the root zone reservoir is refilled. This is referred to as underirrigation and the adequacy of that irrigation is merely the ratio of water applied to the water needed as soil moisture deficiency.

Farmers are greatly constrained by the availability of inputs obtained in the market place, especially for fertilizer and tubewell water purchased from other farmers (Figure 3). The acquisition of fertilizer and water correspond to the farmer's economic status which in turn is closely linked to the farm size.

Farmers generally recognize their major farm problems. When asked, 73% of respondents stated water was their major farm problem, 9% said fertilizer and seed, 8% indicated machinery and spare parts, and 3% and 2% responded with lack of land and credit (Figure 4). When further queried about their water problem, 60% stated a perceived insufficient mogha tertiary outlet discharge, 12% and 10% indicated excessive watercourse losses and dead storage, and 7% responded for lack of sufficient fuel or electricity for tubewells and canal closure and public tubewell stoppages (Figure 5).

Irrigation Performance

The irrigation performance of the tertiary irrigation system has three aspects. First is the delivery or conveyance efficiency of the watercourse main and farm branch ditches between the source mogha and field nacca. Second is the application efficiency to the root zone of the crop irrigated as the ratio of water required to fill the soil moisture deficiency to the amount of water applied to the

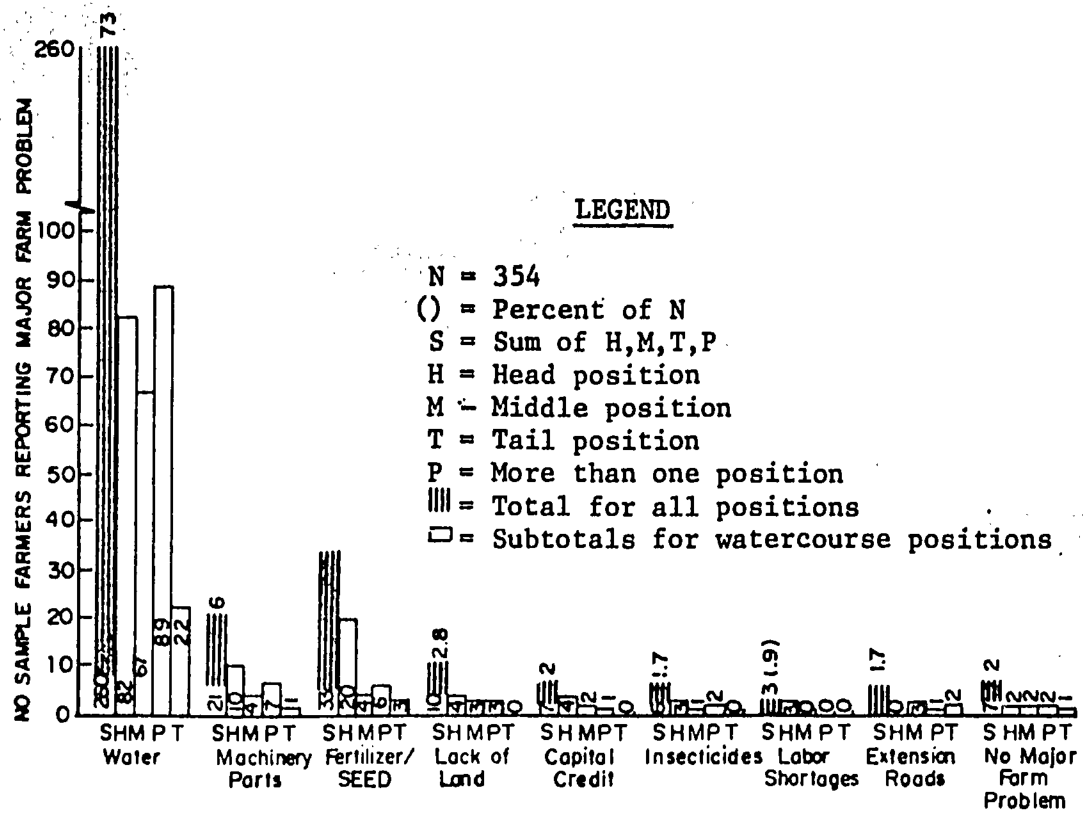


Fig. 4. Sample farmer perception of major current farm problem by position of landholding of watercourse.

Sample farmer perception of major problem with water

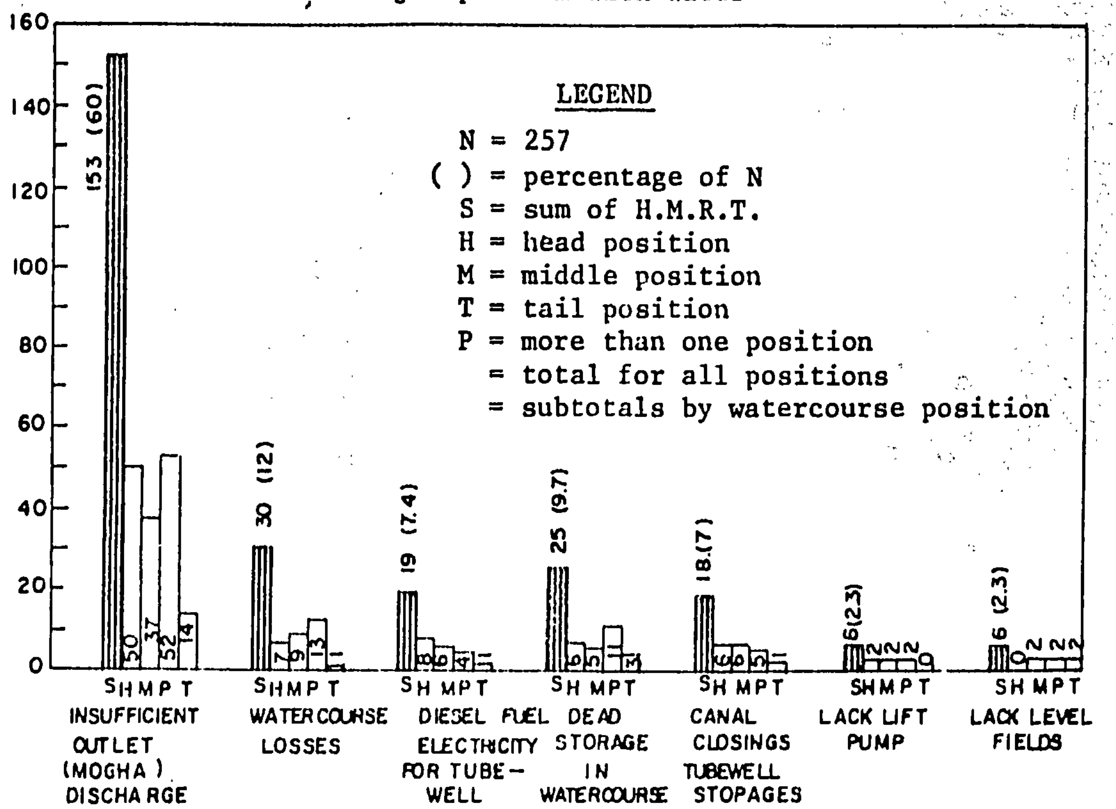


Fig. 5 . Farmers reporting specific water probl:m.

field. Third is the overall farm level efficiency expressed as the product of the delivery and application efficiencies.

The irrigation delivery efficiency (E_d) results indicate a wide dispersion of values (Figure 6), ranging from 0 to 100% categories. The data appears to have a normal distribution. The median category of delivery efficiency is 56-60% and mean 54%. In terms of position on the watercourse command area, the head, middle and tail have 61%, 51% and 42% E_d, respectively (Figure 7), a marked reduction of water supply with distance from the source. The mean percent loss rate per 300 meters distance for all positions is 28%, while head, middle and tail positions have 39%, 21% ad 13%, respectively.

In terms of the water supply situation perennial and nonperennial water supply commands have the s .e deliver efficiency (Table 1). Private water deliveries are more efficient than other types of water supplies, perhaps due to the added cost of water that must be pumped. In terms of the size of water supply at the mogha tertiary turnout, the smaller discharge available the higher are the mean and median delivery efficiencies, related of course primarily to channel capacity, condition for conveyance and freeboard available. The larger categories above 75 liters per second tend to be those served by public tubewells, the majority of which were never redesigned for the much larger discharges available.

For the sample of watercourses in 16 villages observed, the head versus tail disparity is marked (Figure 8). In village 103 watercourse losses were difficult to obtain because all water was lifted by animal driven jallars before use and the flows measured were in the range of 1 to 3 liters per second. In village 106 a pilot watercourse lining program provided improved delivery efficiencies from head to tail of the watercourse.

In general the highest watercourse delivery efficiencies were observed at locations where the farmers provided extraordinary effort in cleaning watercourses (101), where pilot watercourse lining programs had been completed (105), and where a very large number of private tubewells were used (110). The lowest occurred where public tubewells dumped into unlined channels (109 and 111) and excessive allocations plus farmer intervention to obtain extra supplies were most marked (116) and excessive waterlogging of the tail region was the major observable result. The coarser soil textural classes had the lower average delivery efficiencies but the difference was not significant.

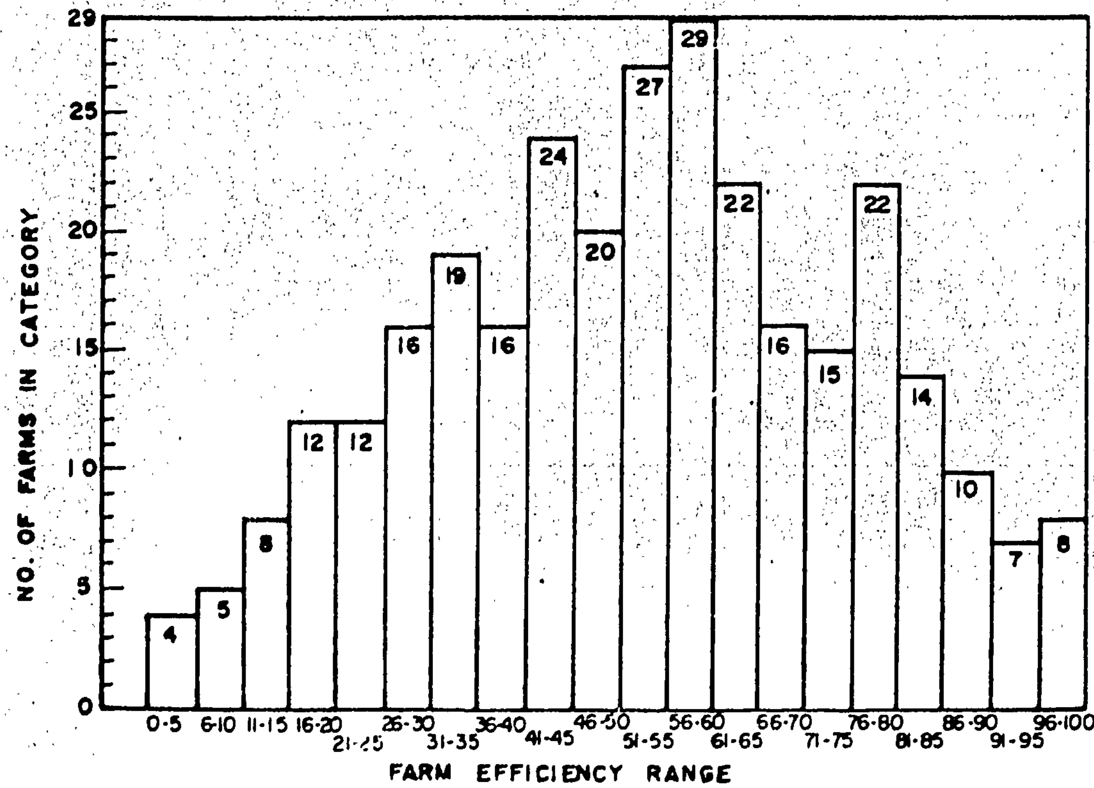


Fig. 6. Sample distribution of weighted mean farm delivery efficiency. Total cases = 306 farms.

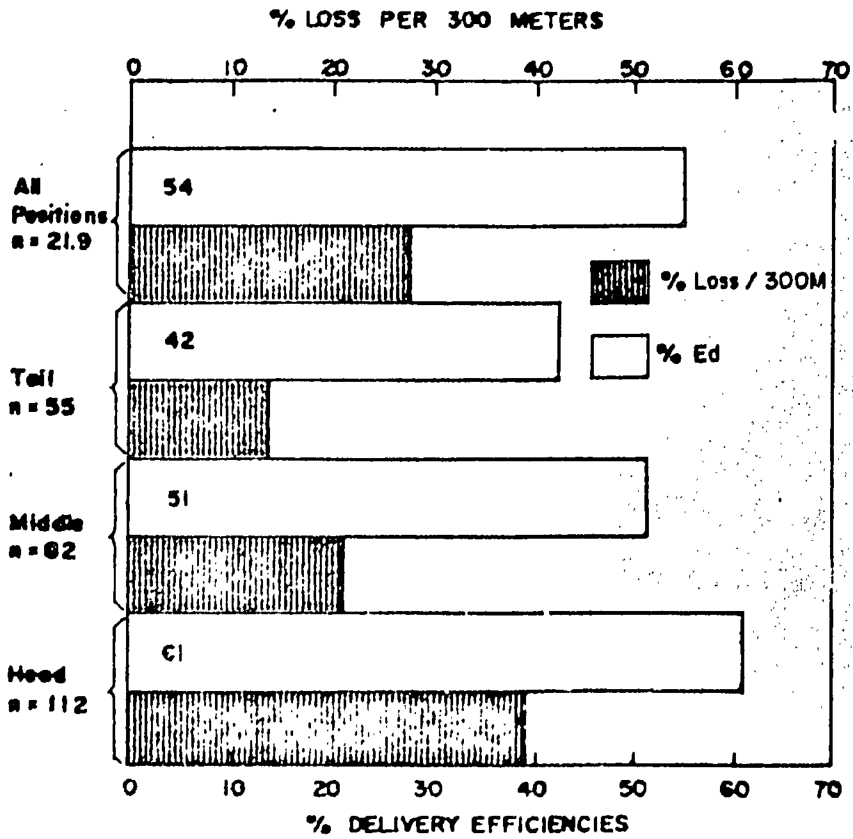


Fig. 7. Farm delivery efficiencies (E_d) and loss per 300 meters shown in percentages by adjusting position on watercourse.

Table 1. Mean, Median and Range of Delivery Efficiencies (E_d) by Water Supply Situation.

Water supply situations	No. of farms	Delivery efficiencies (%) Mean	Median	Range
A. Type command				
Perennial	198	52	53	0-100
Nonperennial	95	53	53	10-100
B. Tubewell supplemented				
None	157	51	51	0-100
Private	111	58	57	2-100
Public	22	47	50	11-84
Private + public	15	50	51	12-85
C. Mogha Q (liters/sec)				
up to 28.3	124	56	57	0-100
28.4 - 47.9	53	57	61	10-87
50.0 - 56.6	46	47	47	11-92
56.7 - 73.3	44	53	54	2-91
73.4 - 85.0	11	54	49	11-100
85.0 and over	6	46	44	7-43

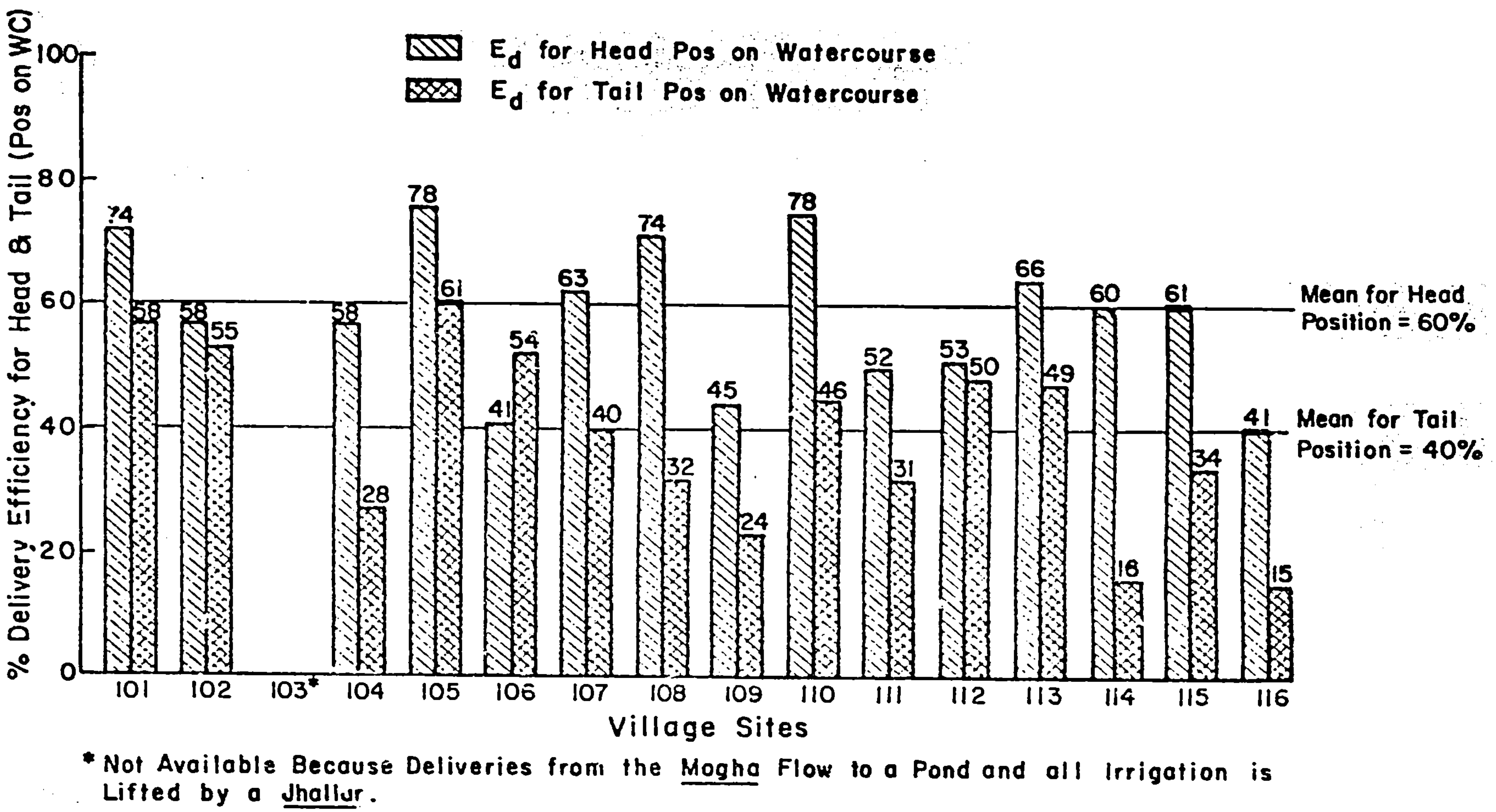


Figure 8. Mean delivery efficiencies for head and tail farms on watercourse.

The results of 559 application efficiency measurements indicate a high mean application efficiency of approximately 80%. This is however influenced markedly by the 41% occurrence of under-irrigation (Figure 9). The under-irrigation in the high evaporative demand-low rainfall arid climate of Pakistan tends to contribute to the increased salt accumulation at or near the soil surface, an irrigation performance factor which tends to affect the yield performance. When the under-irrigations ($E_a \geq 100\%$) are removed the application efficiency mean approaches 55% (Figure 10), and the tabulated with and without under-irrigations shows marked differences in villages (104, 107, 112, 114 and 115), with general water deficiency. Under-irrigation was almost nonexistent in public tubewell supplemented watercourses (105, 106, 108 and 109) as low application efficiencies and over-irrigation were the rule. In village 110 the major crop evaluated was rice irrigation, which has a vastly different moisture regime and for which the application efficiency concept is inappropriate.

With respect to water supply situation, private tubewells have a mean application efficiency of 81% versus 48% for public tubewell supplemented watercourses (Table 2), indicating greater care for private versus public resources. However, as the density of private tubewells increases on a command area the application efficiency tends to decrease. As a group, the perennial watercourse command areas tend to have lower application efficiencies than do the nonperennial areas. The inflation of application efficiency values by under-irrigations is demonstrated by water supply, farm size, tenure status and type of crop irrigated (Tables 2, 3, and 4). As farm size increases the application of water receives less careful management. For all irrigations the mean for farms under 10 hectares is 80% while that for larger farms is 61%. With under-irrigations removed, the mean for farms less than 10 hectares size is 56% while that for the larger farms is 36%. Farm tenure status does not appear to greatly influence irrigation application efficiency (Table 3). When the crops are compared (Table 4) sugarcane is most frequently over-irrigated (67%) whereas wheat and polyculture (intercropping) both experience a high (66%) frequency of under-irrigation. The land preparation application is frequently (60%) over-irrigated as are the fodder crops (58%).

The two months of August and September appear to have the lowest application efficiencies (32% and 13%), primarily because the irrigation system has no cutback alternatives to allow for effective use of rainfall. Considerable amounts of rainfall occurred during these months of the survey and farmers were observed using most of their irrigation turns

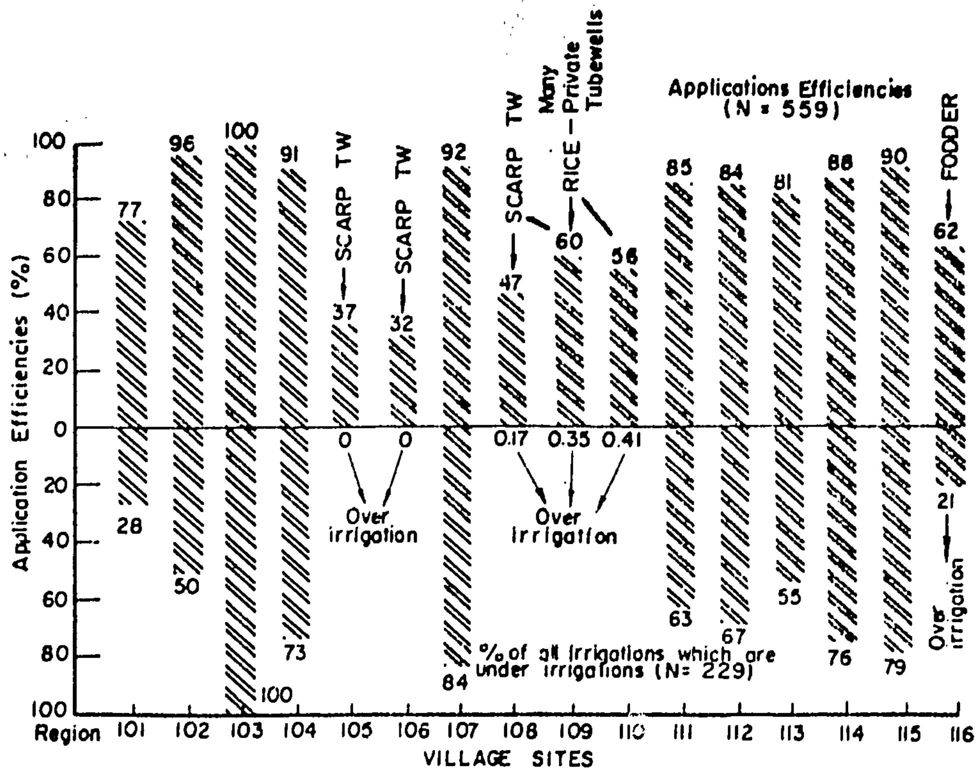


Fig. 9 . Application efficiencies by village sites and percent of total irrigations which are under-irrigation.

Using actual measured field application efficiency (Ea)
Using measured field application efficiency with 229 under irrigations removed (Ea)

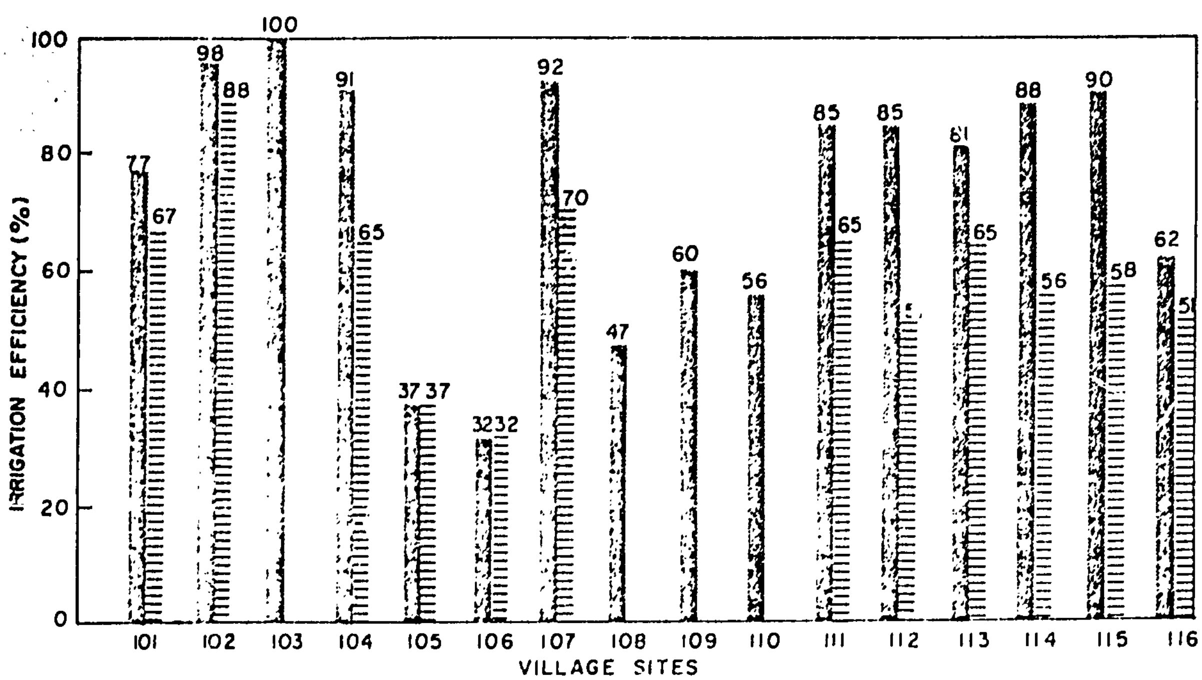


Fig. 10. Actual and adjusted mean irrigation efficiencies by village sites.

Table 2 . Field Application Efficiency Percentages (Ea) by Supplemental Water Supply Situation

Supplemental water supply situation	Farm Ea including under-irrigations(%) No. Farms	Mean	Median	Farm Ea excluding under-irrigations(%) No. Farms	Mean	Median
1) Type of tubewell supplement						
None	157	83	100	71	57	61
Private	115	81	100	58	59	61
Public	22	48	50	17	38	36
Public & private	5	75	86	9	56	63
2) Farmers' reports of tubewater availability						
Not available	134	81	95	68	57	60
W/ difficulty	44	80	100	20	53	57
Easily available	97	75	99	52	53	54
3) Farmers' reports of use of tubewell water						
None used	185	82	100	89	58	63
Purchases water	81	74	88	45	52	51
Owns tubewell	32	80	100	16	55	55
4) Density of tubewell* (Private tubewell equivalent)						
None	158	88	100	72	58	62
1-2	52	85	100	22	62	67
3-6	22	78	100	12	57	59
7+	77	68	77	49	49	51
5) Water supply duration			S.D.			S.D.
Perennial	202	76	30	115	55	27
Nonperennial	95	86	27	34	56	30
6) Type of warabundi						
Pucca	175	79	28	96	59	27
Kucha	117	80	31	48	47	30

*Tubewell density is obtained by counting public tubewells with discharge rates of 1.8 cusecs as equivalent to 3 private tubewells and public tubewells with discharges of 1.2 cusecs (usually serving two command areas) as equivalent to 2 private tubewells. These added to the actual number of private tubewells provides the density.

Table 3. Field Application Efficiency Percentages by Farm Size and Tenure Classes.

Farm Size and Tenure classes	Farm Ea including under-irrigations(%) No. Farms	Mean	Median	Farm Ea excluding under-irrigations(%) No. Farms	Mean	Median
1. <u>Total Hectares Cultivated</u>						
under 1 ha.	66	83**	100	29	57	59
1 - 3	73	80**	100	32	51	58
3 - 5	77	78**	99	38	56	56
5 - 10	75	81**	97	42	60	67
10- 20	14	69	68	11	50	59
20 and over	4	47	26	3	26	17
2. <u>Tenure Classes</u>						
Owner operators	208	80	100	104	55	59
Owner-cum tenants	43	77	99	20	52	55
Tenants	58	79	94	31	58	61

* Percentage figures in the table refer to irrigation application efficiencies (Ea).

** The weighted mean for this group is 80 percent.

Table 4. Field Application Efficiency (Ea) Percentages by Type of Irrigation.

Type of irrigation	Farm Ea including under-irrigations (%) No. farms	Mean	Median	Farm Ea excluding under-irrigations (%) No. farms	Mean	Median
Pre-irrigation	52	74	85	32	57	58
Sugarcane	24	68	72	16	44	49
Cotton	5	47	36	3	12	9
Fodder Crops	78	80	94	42	60	65
Wheat	67	88	100	23	64	63
Other crops	7	71	98	3	63	89
Polyculture	12	90	100	4	63	59

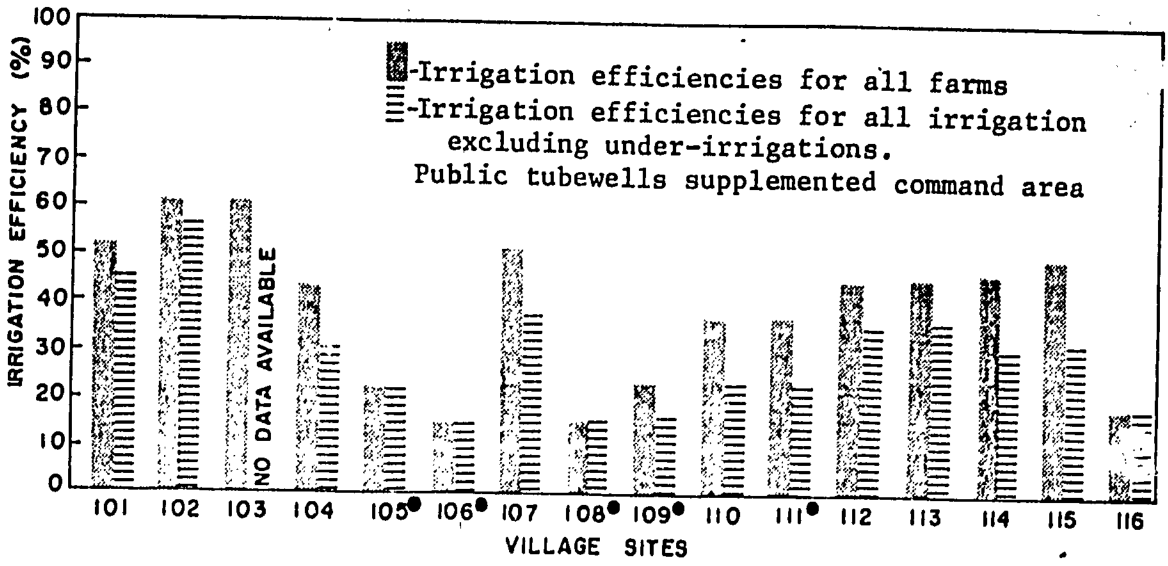


Fig. 11. Farm irrigation efficiency means by villages.

dumping water, even on neighbors' fields. The difference in application efficiency expected for daytime versus nighttime irrigations was not as expected. Daytime applications were slightly less efficient than nighttime applications, but not significantly different.

If the inverse of application efficiency is used as a measure of the adequacy of a given irrigation, then over-irrigation is represented by a value greater than 100% and under-irrigation is expressed as a value less than 100%. The villages with the excess adequacy are by and large the public tubewell supplemented watercourses and those villages with the greatest manifestations of extra-legal water procurement. The public tubewell adequacy mean is 212% while the remainder have an adequacy of 110%.

The overall farm irrigation efficiency observed for village sites is inflated by the occurrence of under-irrigations (Figure 11). The lowest efficiency values remain unchanged for the public tubewell supplemented watercourses and those with extra-legal supplies. Most other village means are adjusted downward by 5 to 18% with the deletion of the 41% of ≥100% application efficiencies due to incomplete irrigation. When considering the position within a village as head versus tail (Figure 12), a difference of 15 to 20% efficiency is evident. The two exceptions are a lined public tubewell watercourse (105) and a watercourse in Sind with an excessive number of under-irrigations (112).

The type of water supply appears to have a minor influence on the farm irrigation efficiency observed (Table 5). The means weighted by the number of evaluations conducted in each village indicate 41% for perennial and 44% for nonperennial commands. Public tubewell commands have 20% farm efficiency, and as the density of private tubewell equivalents increases the irrigation performance percentage tends to decrease.

Farm and Watercourse Layout

The summary statistics (Table 6) for the watercourses and watercourse command areas in the 16 villages observed indicate a large variation in the number of parcels per farm, in size of command areas, in total length of watercourses installed, in watercourse length per hectare (irrigation channel density), number of earthen nacca turnout cuts to fields per hectare in number of bunded units per hectare and amount of barren per village. The 40 watercourses have a total gross command area of 5318 hectares or 133 hectares per watercourse, a total length of field channels of 599 kilometers or 15 kilometers per watercourse, and means of 113 meters of channel per hectare, 5.8 nacca field turnout cuts per hectare and 5.1 individual bunded units per hectare. The barren area totals 947 hectares or 27 hectares per command area.

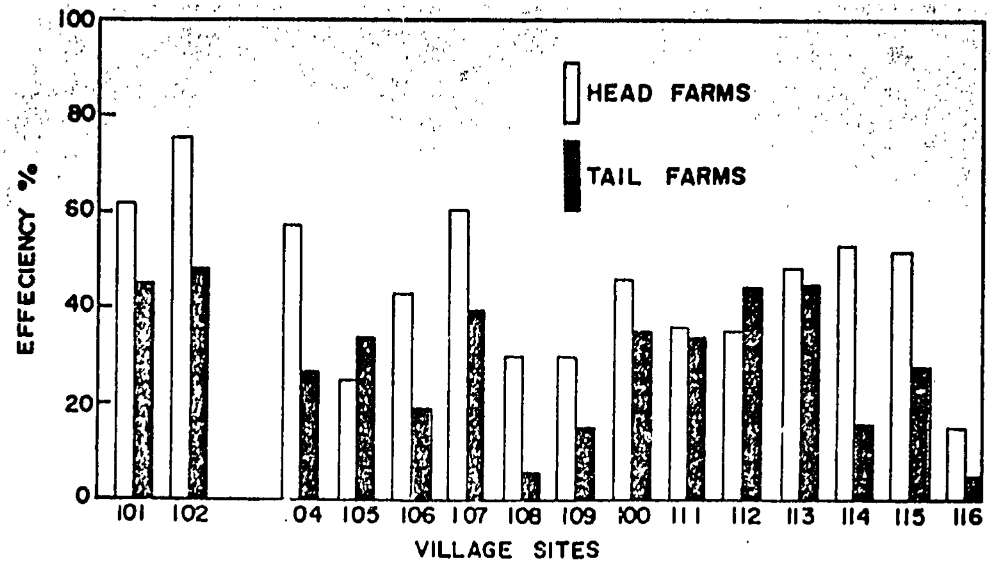


Fig.12 . Irrigation efficiencies for head and tail farms by village sites.

Table 5. Farm Irrigation Efficiency Percentages by Command Type and Tubewell Water Supply Situation.

Type of Command and Supplemental Water Supply Situation	No. Cases	Weighted Farm Irrigation Efficiency (%) Mean	Median
Perennial			
101-2WC	14	52	52
102-1WC	6	62	51
103-1WC	2	61	61
104-3WC	25	44	45
106-1WC*	6	15	10
107-3WC	27	52	47
109-2WC*	12	23	24
110-3WC	27	37	40
112-3WC	33	45	46
113-3WC	25	45	45
116-4WC	21	18	14
Perennial Totals	198	41	40
Nonperennial			
105-1WC*	5	22	25
108-1WC*	4	16	6
111-2WC*	24	37	35
114-4WC	35	47	51
115-6WC	38	50	48
Nonperennial totals	106	44	44
Type of tubewell supplements			
None	157	42	45
Private	110	47	47
Public	22	20	20
Public & Private	15	34	34
Density of Tubewells (Private Tubewell Equivalents)			
None	158	42	45
1-2	49	47	48
3-6	22	45	45
7 and above	75	37	36

*Denotes public tubewell supplemented canal command.

Table 6 . Village Level Summary Watercourse Characteristics

Village	Number of water-courses (WC)	Number of farms	Number of separate parcels	Actual gross command area (AGCA) (hectares)	Total water-course length (km)	Meters Water-course length per ha.	Number of field nakka cuts per ha.	Number of of field bunded units per ha	Total barren area (has.)	Total area (has)
101	2 wc	15	205	364	44.29	121.7	7.1	10.8	40	404
102	1 wc	9	34	217	21.77	100.3	7.9	4.5	4	221
103	1 wc	16	27	52	7.21	138.7	8.4	11.9	1	53
104	3 wc	36	48	187	15.39	82.3	4.2	3.4	35	222
105	1 wc	8	54	230	24.94	108.5	4.4	4.2	26	256
106	1 wc	12	110	208	26.15	125.7	6.8	5.0	9	217
107	3 wc	55	588	697	146.72	210.5	8.2	7.2	42	739
108	1 wc	9	35	209	19.55	93.6	5.6	4.4	5	214
109	2 wc	14	71	271	38.21	141.0	9.4	4.7	1	272
110	3 wc	27	157	363	35.15	96.8	6.6	5.3	2	365
111	2 wc	24	25	231	26.33	114.0	6.2	4.4	52	283
112	3 wc	34	64	796	41.75	52.5	2.4	1.9	342	1138
113	3 wc	26	52	463	51.92	112.1	3.7	3.1	176	639
114	4 wc	39	71	415	37.08	89.4	5.6	5.6	44	459
115	6 wc	39	67	281	33.20	118.2	6.3	6.2	35	316
116	4 wc	26	22	334	29.77	89.1	5.8	5.1	133	467
Totals				5318	599.43				947	6265
Means (weighted)						112.7	5.8	5.1		

Examples of the layout of village systems indicate a high intensity of small farm units (Figure 13) and a high irrigation channel density (Figure 14). Both size of fields and channel density are factors that influence the amount of land available for production. A high intensity of small field sizes is indicative of unleveled fields and the farmers' attempt to reduce water applications by bunding smaller areas. The bunds are land surface which do not contribute to production but which contribute to evapotranspiration. When field sizes are small and farms are highly fragmented, the tendency is for farmers to install a greater density of irrigation channels to serve all fields. This tendency also contributes to less land for production but more nonbeneficial consumptive use of water. When the intensity of field nacca turnouts is high, a greater opportunity for watercourse conveyance leaks occur reducing the supply of water available for beneficial use. A large number of naccas per hectare parallels the number of bunded units per hectare, but in those cases when more than one nacca is found per bunded unit it can also be taken as indicative of the lack of field levelness necessitating more inlets.

Cropping Intensity

Cropping intenstiy on Pakistan's watercourses is affected by water supply, seasonal characteristics and local agroclimatic adaptations. Within watercourses the head versus tail water supply difference constrains the resultant cropping intensity.

For perennial canal commands the head farms have a 10% greater cropping intensity than tail farms (Table 7). For nonperennial commands the difference is 9%. When public tubewells are considered the difference between head and tail cropping intensity is 25% on perennial commands and 8% on nonperennial with tail greater than head for the latter case. A general pattern exists for increasing cropping intensity in response to increasing tubewell density both private and public (165% and 176%) for perennial commands as compared to nonperennial--private and public tubewell commands (124% and 141%). Nonperennial commands in the sample did not have a high density of private tubewells and the 124% cropping intensity was for a command with only 1 tubewell owned privately.

Rabi (cool) season cropping intensity on perennial commands ranged from 75% for medium density tubewell supplements to 89% for public tubewell supplements (Table 8). The range for nonperennial commands (without canal supplies in

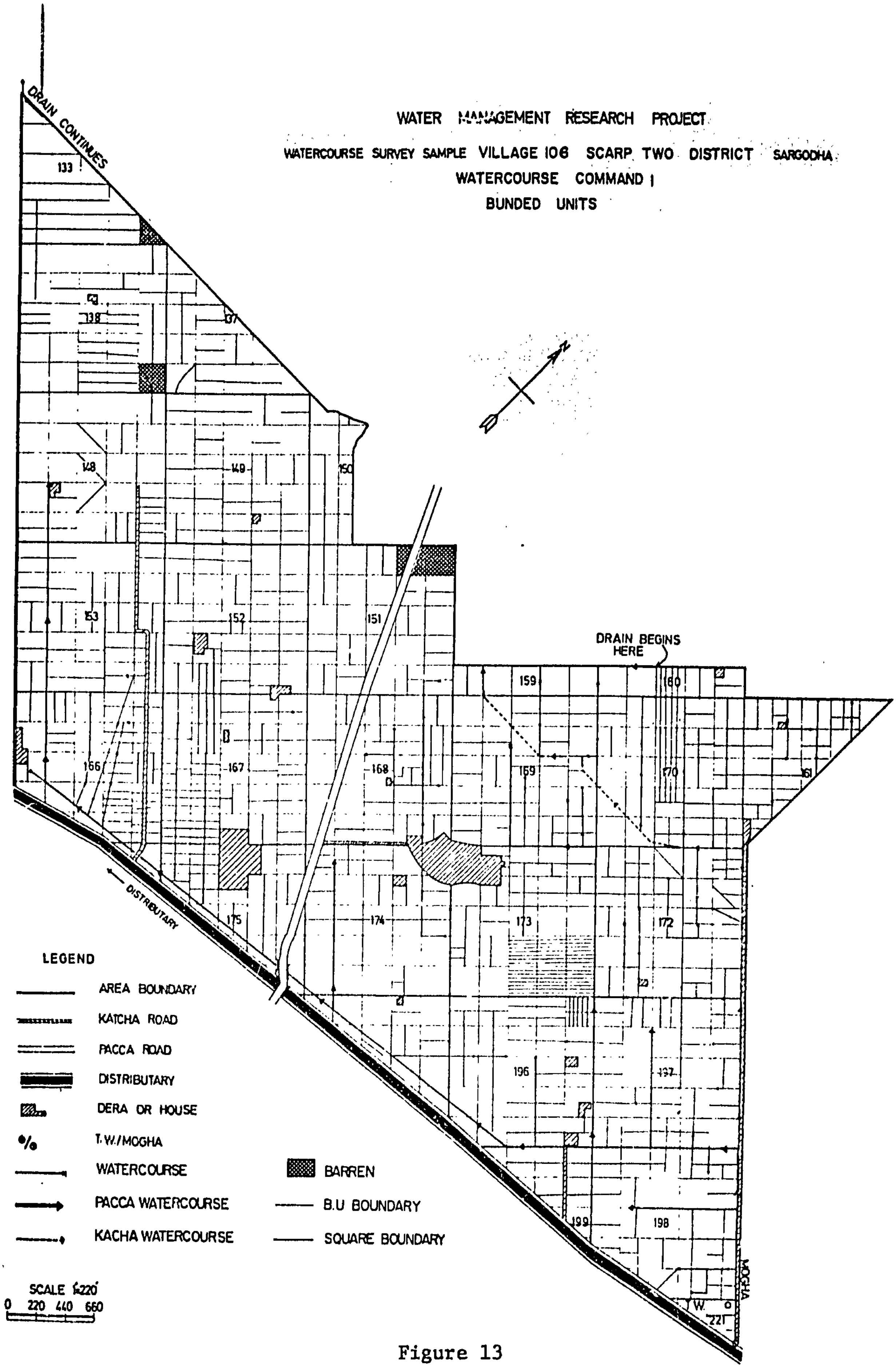
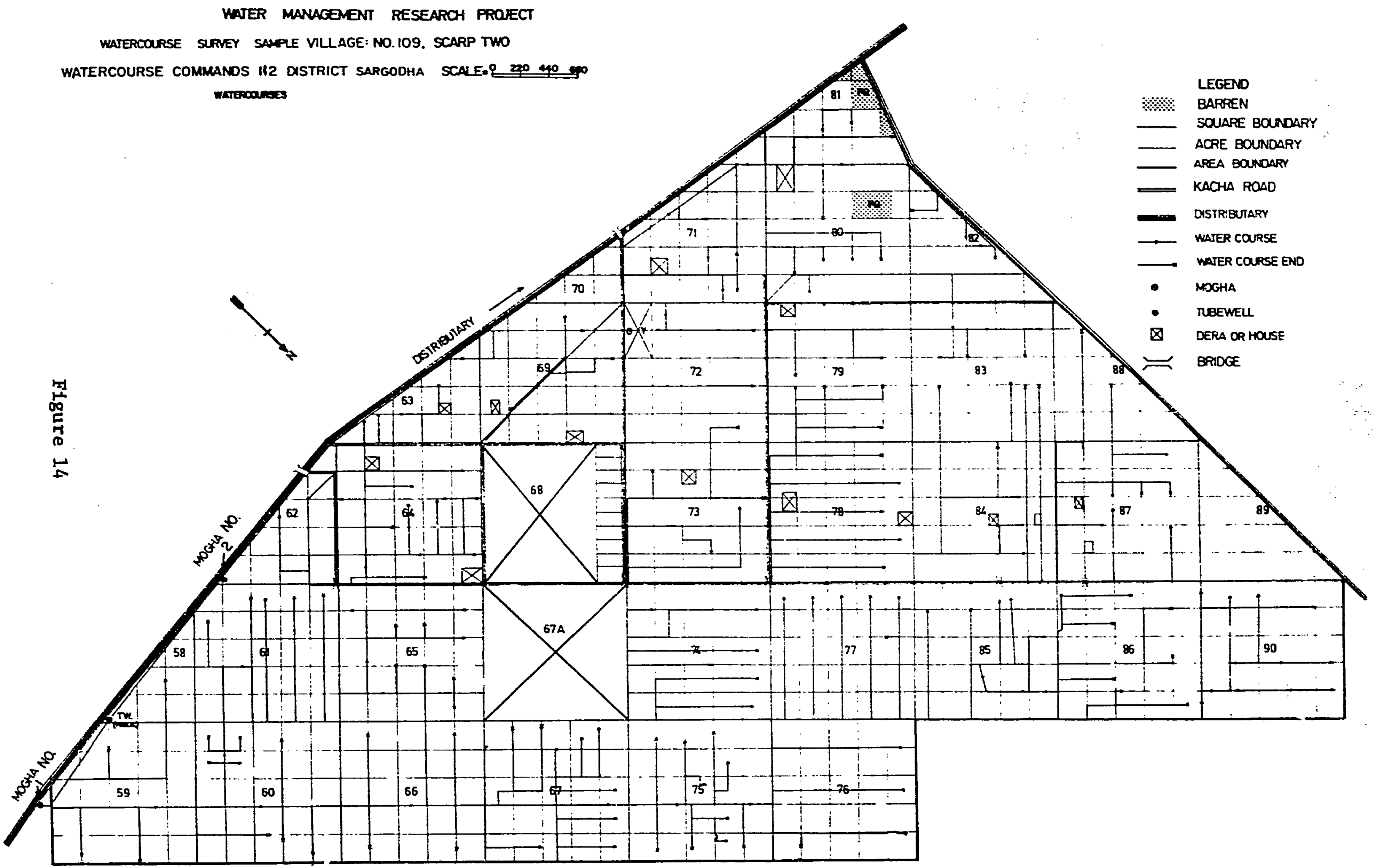

WATER MANAGEMENT RESEARCH PROJECT
WATERCOURSE SURVEY SAMPLE VILLAGE 106 SCARP TWO DISTRICT SARGODHA
WATERCOURSE COMMAND I
BUNDED UNITS
DRAIN CONTINUES
DRAIN BEGINS HERE
DISTRIBUTARY
MOGHA
LEGEND
AREA BOUNDARY
KATCHA ROAD
PACCA ROAD
DISTRIBUTARY
DERA OR HOUSE
T.W./MOGHA
WATERCOURSE
PACCA WATERCOURSE
KACHA WATERCOURSE
BARREN
B.U BOUNDARY
SQUARE BOUNDARY
SCALE 1"=220'
0 220 440 660

Figure 13


WATER MANAGEMENT RESEARCH PROJECT
WATERCOURSE SURVEY SAMPLE VILLAGE: NO. 109, SCARP TWO
WATERCOURSE COMMANDS 112 DISTRICT SARGODHA SCALE= 0 220 440 880
WATERCOURSES
LEGEND
BARREN
SQUARE BOUNDARY
ACRE BOUNDARY
AREA BOUNDARY
KACHA ROAD
DISTRIBUTARY
WATER COURSE
WATER COURSE END
MOGHA
TUBEWELL
DERA OR HOUSE
BRIDGE
DISTRIBUTARY
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MOGHA NO. 1
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Figure 14

Table 7. Cropping Intensity for Head and Tail of Water-course by Water Supply Situation

Type watercourse & tubewell supplements to canal supplies	No. farms	Tail farm (%)	No. of farms	Head farms (%)	Difference between tail & head farms
		Cropping Intensity Percentages			
1. Perennial commands					
a. No tubewells	32	146	36	151	- 5
b. Public TW only	7	151	10	176	-25
c. Private TW only					
1. Low density	10	127	15	145	18
2. Medium density	12	142	11	150	- 8
3. High density	12	154	14	165	-11
Perennial Total Weighted	73	145	86	155	-10
2. Nonperennial commands					
a. No tubewells	15	118	14	130	-12
b. Public TW only	7	149	16	141	+ 8
c. Both public & private	2	88	2	107	-19
d. Private TW only					
1. Low density	10	118	7	124	- 6
Nonperennial Totals Weighted	34	123	39	132	- 9
3. Totals	107	138	125	148	-10

Table 8 . Seasonal Cropping Intensity with respect to Type of Canal Water Supply Supplements.

Watercourse command area tubewell supplements	Cropping Intensity (%)					
	Farms reporting	Rabi season	Farms reporting	Kharif season	Farms reporting	Rabi & Kharif seasons
Perennial commands						
1. No tubewells**	101	82	96	61	70	143
2. Only public tubewells	33	89	33	72	33	160
3. Private tubewells						
a. Less than three	30	86	31	61	30	146
b. Three to six	33	75	33	73	33	148
c. Seven or more	45	79	46	78	45	157
4. Both private and public	4*	83	4	63	4*	146
Nonperennial commands						
1. No tubewells	49	71	48	61	48	131
2. Only public tubewells	0		0		0	
3. Private tubewells						
a. Less than three	54	74		54		127
4. Both private and public	16*	78	16	56	16	133
Non commanded area						
Private tubewells						
a. Seven or more	16	77	16	88	16	165

**Four watercourses in village 116 are removed from this analysis due to excess canal water supplies and waterlogging. Total intensity is 165 for site 116.

*Farms located on watercourse commands with public tubewell supplements and up to two private tubewells for canal supplements.

cool season) was 71% for no tubewell supplements to 78% for the case with both public and private tubewells present. Kharif (hot) season cropping intensity range was 61% for no tubewell supplements to 78% for high density private tubewell supplements on perennial commands and 54% for low density private supplements to 61% for no tubewell supplements. One command area whose canal supply was cut off by a large landlord and served by 7 tubewells had the highest annual cropping intensity of 165%. The second highest category was the public tubewell supplemented watercourse in a perennial command area (160%) followed by high density private tubewell supplemented watercourses also in a perennial command area (160%) followed by high density private tubewell supplemented watercourses also in a perennial command area (157%). The lowest cropping intensities were found in the nonperennial commands and ranged from 127 to 133%.

The distribution of water supply supplements influences the distribution of crops (Table 9). Where public tubewell water is available, farmers tend to grow more sugarcane and fodder, crops that farmers know require more water per annum because of cropping duration and which farmers tend to irrigate more frequently (Table 4). In perennial commands the percentage of area in sugarcane and fodder are 36 and 37% respectively, whereas in nonperennial commands the totals are 16% and 30%. In the presence of both public and private tubewells, the sum of the intensity for the two crops is 64% for perennial and 73% for nonperennial commands. The patterns for wheat, rice and cotton are not consistent.

Contrary to expectations relative to water supply and modest monsoon rainfall contribution, the Rabi (cool) season cropping intensity is greater in both perennial and nonperennial commands by 15% perhaps in response to the lower evaporative demand in the cool season. In perennial commands the highest rabi season intensity occurs for farmers who responded that tubewell water was unavailable for trade or purchase and for nonperennial the highest is for farmers who say that tubewell supplements are only available with difficulty. On perennial commands, 17% of rotations observed include fallow, while 38% were included for nonperennial commands. On commands with a high private tubewell density rotations recorded did not contain fallow.

Crop Yields

Crop yields are generally responsive to the water supply and location parameters. Farmers were questioned in depth about wheat, rice and cotton yields, all crops commonly grown across the Sind and Punjab. The data were tabulated in relation to the agroclimatic zone reflecting annual

Table 9 . Percentages of Area Cultivated in Major Crop with respect to the Tubewell Water Supplements.

Tubewell (TW) supplements)	No. of farms	Percentage of cultivated area in				
		wheat	rice	cotton	sugarcane	rabi + kharif fodder
		Perennial watercourse commands				
No tubewells	101	43	8	11	25	44
Public TW only	33	23	10	9	36	37
Public & private TWs	4	49	2	25	38	26
Under 3 private TWs	54	49	6	10	28	47
3-6 private tubewells	33	51	9	36	20	24
7 or more private TWs	45	53	9	35	15	31
Overall	270	44	8	18	25	39
		Nonperennial watercourse commands				
No tubewells	48	45	1	24	5	35
Public TW only	32	39	9	6	16	30
Public + private TWs	9	23	6	9	29	45
Under 3 private TWs	54	39	6	11	14	32
Overall	143	40	5	14	12	33

evaporative deficit and general cropping rotation found in the region (Table 10). Mean wheat yield ranged from 0.81 to 2.61 tons/hectare with the highest average obtained in the medium to low deficit wheat growing areas. For rice the range of reported mean yields was 0.91 to 2.25 tons/hectare with the highest mean 1.80 tons/hectare obtained for the low to medium evaporative deficit agroclimatic area. Mean yields were highest for the medium to high deficit area where the value obtained was 0.81 tons/hectare.

With respect to water supply situation wheat yields were highest under perennial canal irrigation, where private tubewells are available for supplements and highest when a farmer owns his tubewell (Table 11). For rice production the highest yield was obtained on commands with the highest tubewell density and for farmers reporting tubewell water easily available or owned by the farmer. For cotton the same pattern exists as for the rice crop. When comparing water supplements only, the incremental yields for wheat, rice and cotton for tubewell ownership is 0.56, 0.83 and 0.50 tons/hectare respectively (Table 12). The increment of wheat yield for private tubewell water purchase versus public tubewell water available is 0.19 tons/hectare, the rice yields by 0.99 tons/hectare and the cotton yields by 0.63 tons per hectare (Table 13).

Crop yields in Pakistan are low when compared to other countries (Figure 15). The yields observed in the survey were larger for wheat, but smaller for rice and cotton from those recently published from government statistics. Both suffer from being indirectly obtained, not from crop cutting procedures in the field.

Demonstration plot yields can be used to indicate potentially attainable yields for commonly grown modern varieties (Table 14). The mean yield for traditional treatment under farmer management is 2.27 tons/hectare and for improved treatment including seed rate, fertilization and irrigation, the yield was 4.26 tons/hectare. This provided an increment of nearly 2 tons per hectare for improved practices, an indication of attainable potential for the main food crop of Pakistan (Lowdermilk, et al., 1975).

FARMER RESPONSES TO CONSTRAINTS

Farmers have numerous legal and extra-legal responses to their water management constraints generally aimed at increasing their water supply. Farmers generally attempt to increase the area cultivated above the authorized command

Table 10. Mean wheat, rice and cotton yields by agro-climatic regions.

Agro-climatic* region showing dominant crops and estimated atmospheric evaporative annual deficit (inches)	Average reported yields					
	No. farms reporting	Wheat tons/ hectare	No. farms reporting	Rice tons/ hectare	No. farms reporting	Cotton tons/ hectare
Low deficit < 112.5 cm						
Rice-wheat	27	1.48	26	2.23	0	-
Rice-fodder-wheat	32	1.30	26	1.30	2	0.28
Fodder-wheat	15	1.67	2	0.93	6	0.46
Low deficit weighted means	74	1.48	54	1.76	8	0.46
Medium-low deficit 112.5-137.5 cm						
Sugarcane-wheat	15	2.50	3	2.32	2	0.65
Mixed crops	39	1.86	13	1.76	13	0.65
Medium-low deficit weighted means	54	2.04	16	1.86	15	0.65
Medium-high deficit 137.5-162.5 cm						
Cotton-wheat	91	2.04	5	0.93	85	0.93
Mixed crops	24	1.30	13	1.48	8	0.37
Medium-high deficit weighted means	115	1.86	18	1.30	93	0.83
High deficit > 162.5 cm						
Rice-fodder	11	0.83	25	1.21	0	-
Cotton-wheat	29	1.76	0	-	27	0.65
Rice-wheat	27	1.67	8	1.30	9	1.02
Sugarcane-wheat	24	2.69	2	1.86	7	0.56
High deficit weighted means	91	1.86	35	1.30	43	0.74
Total weighted means	334	1.76	123	1.58	159	0.83
Overall range by sites		0.83-2.69		0.93-2.32		0.28-1.02
Overall range by climatic zone & variation		1.48-2.04 37%		0.93-2.32 150%		0.46-0.93 100%

Table 11. Mean Yields of Wheat, Rice and Cotton for Selected Water Supply Situations.

Water supply situation	Average reported yields					
	No. farms report-ing	Wheat tons/ hectare	No. farms report-ing	Rice tons/ hectare	No. farms report-ing	Cotton tons/ hectare
Type watercourse command						
Perennial	242	1.95	88	1.67	112	0.93
Nonperennial	80	1.48	23	1.21	48	0.65
Noncommanded*	7	1.76	7	2.50	0	-
Command totals (weighted)	329		118		160	
Actual tubewell supplements						
None	139	1.67	62	1.30	69	0.65
Public tubewells	33	1.86	13	1.76	12	0.74
Private tubewells	146	1.95	42	1.95	72	1.02
Both public & private	16	1.21	6	1.39	7	0.46
	334		123		160	
Farmers' reports of availability and use of tubewells						
Not available	126	1.67	58	1.39	55	0.65
Available with difficulty	57	1.95	13	1.58	36	0.83
Easily available	122	1.95	37	1.95	56	1.02
	305		108		147	
No use	170	1.67	75	1.30	75	0.65
Hired tubewell	113	1.95	35	1.95	54	0.93
Owns tubewell	42	2.23	9	2.13	27	1.21
	325		119		156	

* For the rice-wheat rotation in village command 110-3 of Gujranwala District, 7 private tubewells serve about 119 cultivated acres.

Table 12 . Average yields of wheat, rice, and cotton per acre and water supply situation.

Type Water Supply Situation	No. farms	Wheat Yield t/ha	No. farms	Rice Yield t/ha	No. farms	Cotton Yield t/ha
1. Only canal supplies	139	1.67	62	1.30	69	0.65
2. Canal plus public tubewell supplies	33	1.86	13	1.76	12	0.74
3. Canal plus purchase of private tube-well supplies	113	1.95	35	1.95	54	0.93
4. Canal plus ownership of private tubewell	42	2.23	9	2.13	27	1.21

Table 13. Mean Wheat, Rice and Cotton Yields with Respect to Number of Private Tubewells on Watercourse Commands (excludes public tubewell commands).

Number of private tube-wells for canal supplements	Average reported yields					
	No. of farms	Wheat tons/ hectare	No. of farms	Rice tons/ hectare	No. of farms	Cotton tons/ hectare
None	112	1.76	49	1.30	81	0.56
Less than three (Low)	68	1.58	22	1.39	25	0.65
Three to six (Medium)	31	2.32)	7	2.69)	22	1.11)
		) 2.13*		)2.32*		)1.21*
Seven or more (High)	57	2.04)	19	2.13)	31	1.21)
Totals weighted means	268	1.86	97	1.58	159	0.74

* Weighted mean yields/acres for private tubewells supplemented commands with three or more private tubewells.

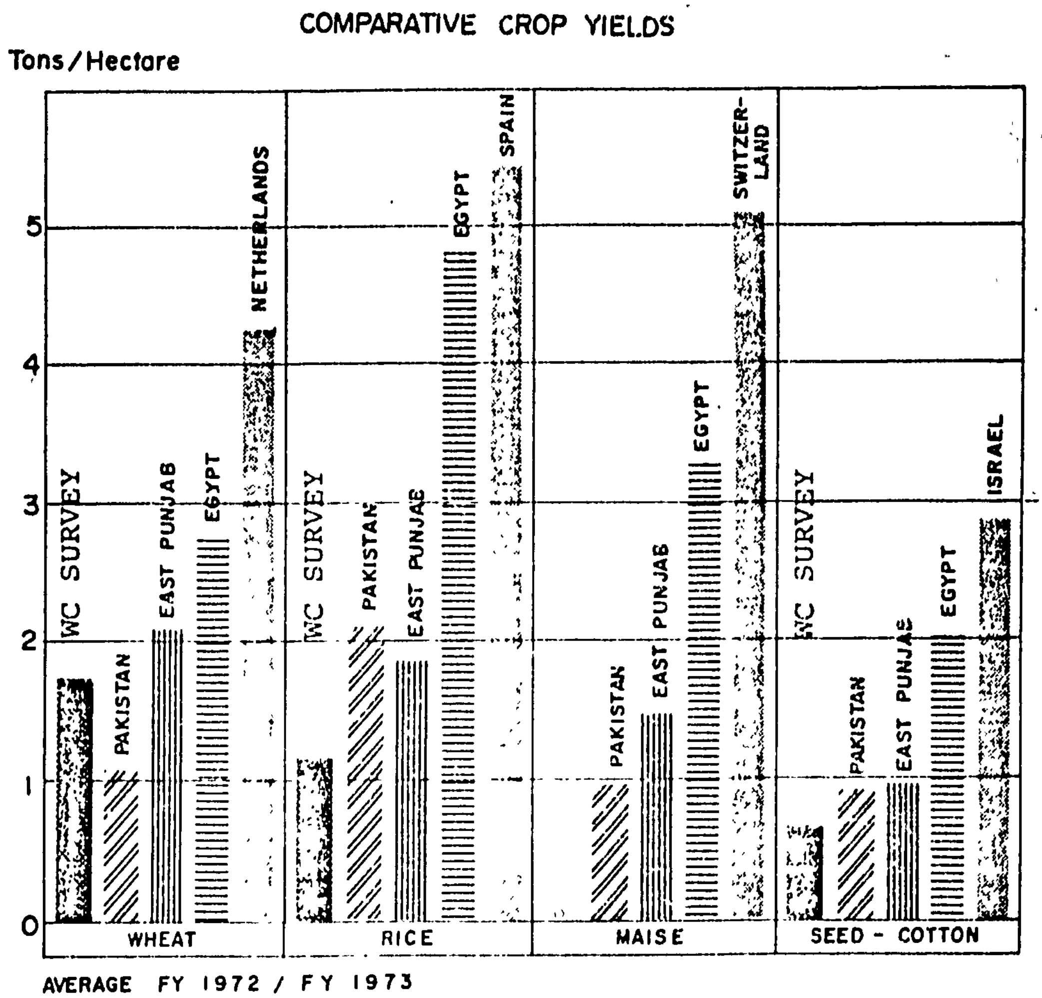

Fig. 15. Watercourse survey yields reported by farmers compared to official statistics for several nations.

Table 14. Demostration wheat yields using traditional and improved practices in tons/hectare (Lowdermilk, Clyma, Early (1975), p. 73).

Variety of Wheat	Traditional treatment	Improved treatment	Increased due to improved package of practices
Chenab 70	2.45	4.62	2.17
Chenab 70	3.14	5.79	2.65
Chenab 70	2.09	4.07	1.98
SA - 42	1.88	3.43	1.55
SA - 42	1.77	3.39	1.62
Mean	2.27	4.26	1.99

area set by the irrigation authorities to increase income. The number of minutes in a week divided by the area authorized provides the authorized warabundi time in minutes/hectare for weekly irrigation amount. Because the actual area increases the denominator, the quotient declines (Table 15). Thus, the time that water is available is less due to farmers' actions. Each command area includes some barren lands, which the faremrs tend to level gradually and ultimately bring under cultivation. This also shows up as the difference between actual and authorized discharge factors in liters/second/hectare (Table 16).

Farmers also add to their water supply by adding tubewell supplements (Table 16). The actual potential discharge factor tabulated includes all private tubewells at an average rate of 15 liters per second (which is a conservative estimate) and public tubewells at the mean measured rates during the survey. The gross potential discharge factor also includes those cases where farmers have taken extra turnouts to supplement their supplies, occurring in 10% of the sampled watercourses, 2 perennial and 2 nonperennial.

Farmers in some cases have been able to extract enlargements to their ungated tertiary turnouts from irrigation officials in return for payments. In those cases where actual mogha discharge is larger than authorized (positive values), the 14 perennial and 4 nonperennial cases are examples (Table 17). For the other 10 perennial and 8 nonperennial watercourses which have lost water supply, the fact that the widening of mogha turnouts is a zero sum game is all too evident. For all of those that gain water supply in this extra legal fashion, some others must lose.

In terms of increasing their water supply, buying tubewell water, buying canal water, trading partial or entire irrigation turns, and theft are methods that farmers practice. Of farmers who do not own tubewells 35% report renting tubewell water at some time each season and 2% borrow tubewell water informally (Table 18). Nearly 22% of farmers report buying canal water from other farmers, with owner operators and majority group engaging in this practice (Table 19). In terms of partial irrigation turn trading, nearly 68% of farmers report this practice (Table 20), with 80% of traders (53.7% of the total) occurring in the 1 to 10 hectare farm size category. Thirty-three percent of all farmers report trading entire irrigation turns with majority (82%) of full-turn traders also occurring in the 1 to 10 hectare category (Table 21). Forty percent of sample farmers experienced water theft in the past year (Table 22). One to five times was experienced by 20% of farmers and more than five times also by 20%. Seventy-five percent of the thefts are experienced by the 1 to 10 hectare farm size.

Table 15 . Actual versus authorized warabundi time.

Watercourse	Actual average warabundi time (min/has)	Authorized average warabundi time (min/has)	Watercourse	Actual average warabundi time (min/has)	Authorized average warabundi time (min/has)
Perennial			Nonperennial		
101-1	57	74	105-1*	49	50
101-2+	68	57	108-1*	49	50
102-1++	47	47	111-1*	113	82
103-1+	195	226	111-2	113	69
104-1+	154	159	114-1	149	131
104-2+	146	151	114-2	79	79
104-3	556	432	114-3	100x	131
106-1*	51	45	114-4	133	117
107-1++	36	40	115-1	216	203
107-2++	39	47	115-2	471.7	439
107-3++	85	72	115-3+	357	131
109-1*	72	64	115-4	287	196
109-2*	77	64	115-5+	258	203
110-1++	70	52	115-6	135	146
110-2++	60	84	$\bar{X}$ =	166	135
112-1	31x	55	SD =	118	95
112-2	362	181	Noncommanded (no canal water)		
112-3	98	92	110-3++		no mogha
113-1	162	109			
113-2	100	67			
113-3	81	62			
116-1	338	146			
116-2	234	114			
116-3	92	102			
116-4	481	236			
$\bar{X}$ =	129	101			
SD =	111	72			

*Public tubewells
+Private tubewells
++Heavy density of private tubewells

Table 16 . Distribution of discharge factor values (liters/second/hectare) by watercourses.

Watercourse	Authorized discharge factor	Actual discharge factor	Actual potential discharge factor	Gross potential discharge factor
Perennial				
101-1	0.20	0.37	0.37	0.37
101-2+	0.23	0.42	0.64	0.64
102-1++	0.23	0.16	0.64	0.64
103-1+	0.31	0.16	0.49	0.49
104-1+	0.33	0.85	0.85	0.85
104-2+	0.21	0.36	0.61	1.43
104-3	0.31	0.44	0.44	0.44
106-1*	0.24	0.31	0.50	0.50
107-1++	0.23	0.16	0.98	0.98
107-2++	0.23	0.24	0.77	0.77
107-3++	0.23	0.25	0.97	0.97
109-1*	0.20	0.23	0.45	0.45
109-2*	0.20	0.38	0.59	0.59
110-1++	0.32	0.14	2.15	2.15
110-2++	0.32	0.26	1.16	1.16
112-1	-	0.23	0.23	0.23
112-2	0.19	0.42	0.42	0.42
112-3	0.20	0.47	0.47	0.47
113-1	0.23	0.26	0.26	0.26
113-2	0.27	0.49	0.49	0.49
113-3	0.23	0.32	0.32	0.32
116-1	1.03	0.80	0.80	0.80
116-2	0.67	0.32	0.32	0.32
116-3	0.31	0.14	0.14	2.32
116-4	0.33	0.62	0.62	0.62
$\bar{X}$ =	0.27	0.34	0.75	0.83
SD =	0.10	0.19	0.57	0.61

*Public tubewells
+Private tubewells
++Heavy density of private tubewells

- missing data

Watercourse	Authorized discharge factor	Actual discharge factor	Actual potential discharge factor	Gross potential discharge factor
Nonperennial				
105-1*	0.30	0.28	0.53	0.53
108-1*	0.41	0.40	0.81	0.81
111-1*	0.54	-	0.54	0.54
111-2*	0.36	-	0.54	0.54
114-1	0.39	0.28	0.78	0.78
114-2	0.39	0.25	0.25	0.25
114-3	0.39	0.28	0.28	0.28
114-4	0.39	0.34	0.34	0.34
115-1	0.42	0.50	0.50	0.50
115-2	0.43	0.64	0.64	0.64
115-3+	0.43	0.74	1.34	1.34
115-4	0.47	1.03	1.03	1.03
115-5+	0.41	0.55	1.42	2.14
115-6	0.42	0.30	0.53	0.91
$\bar{X}$ =	0.41	0.44	0.64	0.70
SD =	0.06	0.23	0.35	0.46
Noncommanded				
110-3++	no mogha	no mogha	2.83	2.83

Single correlation between authorized and actual discharge factors (Pearson's r)	N
Overall	.29(330)
Perennial	.08(235)
Nonperennial	.70(95)
Public TW	.54(93)
Private TW	.54(152)
Heavy Density	-.06(79)

Simple correlation between authorized and actual discharge factors (Pearson's r)	N
Overall	.039(389)
Perennial	.032(270)
Nonperennial	.120(119)
Public TW	.356(67)
Private TW	.462(152)
Heavy Density	.790(79)

Table 17. Actual Versus Authorized Mogha Discharge (liters/second) by Watercourses.

Watercourse	Actual mean mogha discharge	Authorized mean mogha discharge	Actual minus Authorized Difference
Perennial			
101-1	64.3	27.2	37.1
101-2+	61.7	40.5	21.2
102-1++	34.3	49.8	-15.5
103-1+	8.5	13.9	-5.4
104-1	55.8	21.0	34.8
104-2	24.9	14.2	10.7
104-3	7.9	7.4	0.5
106-1*	61.5	53.0	8.5
107-1++	52.4	60.9	-8.5
107-2++	60.3	49.8	10.5
107-3++	29.5	33.1	-3.6
109-1*	32.3	31.4	0.9
109-2*	49.3	32.0	17.3
110-1++	19.8	60.6	-40.8
110-2++	43.6	38.2	5.4
112-1	75.3	-	-
112-2	11.6	10.8	0.8
112-3	48.1	21.8	26.3
113-1	16.1	21.5	-5.4
113-2	49.8	40.5	9.3
113-3	39.9	38.5	1.4
116-1	23.8	70.8	-47.0
116-2	27.8	58.9	-31.1
116-3	15.3	30.9	-15.6
116-4	13.0	14.2	-1.2
X =	39.4	36.8	
SD =	19.8	18.1	

Watercourse	Actual mean mogha discharge	Authorized mean mogha discharge	Actual minus Authorized Difference
Nonperennial			
105-1*	56.4	62.0	-5.6
108-1*	81.0	85.0	-4.0
111-1*	-	66.8	-
111-2*	-	53.8	-
114-1	18.7	30.0	-11.3
114-2	31.4	49.0	-17.6
114-3	27.8	30.0	-2.2
114-4	25.8	33.7	-7.9
115-1	23.5	21.0	2.5
115-2	13.6	9.9	3.7
115-3+	21.0	27.5	-6.5
115-4	36.0	21.8	14.2
115-5+	21.5	20.1	1.4
115-6	22.4	28.9	-6.5
X =	32.6	41.6	
SD =	19.0	21.2	
110-3++	No mogha	- noncommanded	

Correlation between actual and authorized mogha discharges, Pearson's r	
Overall	.52(339)
Perennial	.34(244)
Nonperennial	.93(95)
Public TW*	.92(43)
Private TW+	.79(152)
Heavy Density++	.36(79)

*Public tubewells on watercourse
-missing data

+Private tubewells on watercourse
++Six or more private tubewells on watercourse

Table 18. Utilization of private tubewells by farmers not owning tubewells.

Type of use	Number	Percent
No use	212	63.1
Borrow tubewell water informally	6	1.8
Rent tubewell water	118	35.1
Total	336	100.0

Table 19. Buying canal water by tenure status.

N = 314
( ) = %

Does farmer buy canal water from other farmers	Owner/ operator	Owner cum tenant	Contractor	Pure share tenant
No	(51.3)	(9.9)	(.3)	(16.9)
Yes	(15.9)	(4.1)	(.3)	(1.3)

Table 20. Trading of partial irrigation turns (last kharif and rabi season) by farm size.

N = 352
( )= %

Times traded partial turns	Farm size (hectares)					
	<1	1-3	3-5	5-10	10-20	>20
None	(11.4)	(8.5)	(6.8)	(5.1)	(.6)	(0)
1-2	(1.4)	(2.0)	(1.4)	(1.7)	(.3)	(0)
3-5	(1.4)	(4.0)	(3.7)	(3.1)	(.9)	(.6)
6-10	(1.7)	(4.3)	(5.1)	(5.4)	(1.1)	(.3)
11-15	(1.4)	(1.4)	(2.3)	(1.7)	(0)	(.6)
16+	(1.7)	(5.7)	(5.4)	(6.3)	(2.0)	(.9)

Table 21. Trading of full irrigation turns during last kharif and rabi seasons by farm size.

N = 335
( ) = %

Time traded full turns	Farm size (acres) <1	1-3	3-5	5-10	10-20	>20
None	(15.2)	(17.3)	(16.7)	(12.8)	(3.0)	(1.5)
1-2	(.9)	(.6)	(.3)	(1.5)	(.6)	(0)
3-5	(.3)	(1.5)	(2.7)	(2.4)	(0)	(0)
6-10	(.6)	(.9)	(2.4)	(3.6)	(.6)	(0)
11-15	(.3)	(.6)	(1.8)	(.6)	(0)	(0.3)
16+	(.9)	(4.5)	(1.2)	(3.0)	(.9)	(0.6)

Table 22. Frequency of water theft experienced in past year by sample farmers in relation to farm size category.

( ) = % of total

Frequency of water theft experienced in past year	Farmer size of holdings (hectares) <1	1-3	3-5	5-10	10-20	>20	Row totals
None	(11.1)	(15.1)	(17.2)	(11.7)	(4)	(.6)	(60)
1-5	(2.8)	(6.8)	(4.6)	(4)	(.6)	(.9)	(20)
6-10	(2.5)	(1.2)	(1.8)	(3.4)	(0)	(.6)	(9)
11+	(1.2)	(1.8)	(3.4)	(3.7)	(.6)	(.3)	(11)
Column totals	(18)	(25)	(27)	(23)	(5)	(2)	(100)

N = 325
X^2 = 33.72
d.f= 15
p.= <.005
c = .31

Four situations were posed to farmers framed as problems with lower irrigation authorities in matters related to water supply and irrigation fees (Table 23). If one wants the irrigation fee reduced 68% would use bribery to get it. If the rate of bribe is escalated, 59% report using bribery to get it reduced. If a reduction in the discharge capacity of the mogha is threatened, 71% would use bribery to counter the attempt. If the water rate were incorrectly entered too high, 60% would use bribery to get it reduced. In the above cases only 8, 11, 7 and 24% of farmers respectively would use legal means of achieving those ends. In sum, 2/3 of farmers report trading partial irrigation turns, 1/3 full turns, 1/5 buying or selling canal water, 1/16 and 1/20 buying water allotted roads and schools and 1/7 trading canal water for tubewell water (Table 24). All of these practices are expressly forbidden by the Canal and Drainage Act, but frequently practiced if the sample is representative of Punjab and Sind farmers.

As a hypothetical question to determine farmers' response to water supply availability, the same was asked, how much they would expand crop production of 4 major crops if their water supply was doubled (Table 25). On public tubewell supplemented perennial watercourses none of the farmers would respond with 50% or greater increase of crops, where the farm irrigation efficiency is already a low 23%. For the nonperennial public tubewell commands the increase was 20, 55, 45 and 55% of farmers who would increase the respective crop area of wheat, cotton, rice and sugarcane by 50% or more. For those farmers owning private tubewells on perennial commands none would increase any one crop area by 50% or more. For those private tubewell owners on nonperennial commands 50, 20, 35 and 35% would increase by 50% or more. The mean response would be greater for perennial and nonperennial commands without tubewell supplements averaging 36% per crop for perennial and 54% per crop for nonperennial commands. The mean response for farmers at head of perennial commands was 8.5% per crop and 24.3% for nonperennial. For the tail farmers questioned, the mean response was 24% per crop in perennial and 36% per crop in nonperennial. These results indicate that the deprived tail end farmers wish to increase their water supply and would markedly increase their cropping intensity in response to a water supply doubling.

SUMMARY AND CONCLUSIONS

An interdisciplinary problem identification field survey in irrigated districts of Pakistan provided insights into the four major categories of water management constraints

Table 23. Farmers' Modes of Resolving "Problems" with Lower Level Irrigation Authorities by Farm Size

		Land Holding size (Hectares) ( ) = %						
If one wants reduction of abiana assessment		<1.00	1-3	3-5	5-10	10-20	>2	Total
x_2 = 15.63	Do nothing	(6.1)	(6.5)	(5.5)	(4.9)	(1)	(.3)	(24)
p = .33 N.S.	Use legal							
c = .21	means	(1.6)	(1.6)	(1.6)	(1.9)	(1.3)		(8)
N = 309	Use bribery	(8.7)	(16.5)	(20.4)	(16.5)	(3.2)	(2.3)	(68)
If patwari requests one to increase one's fasalana								
x_2 = 19.32	Do nothing	(8.1)	(7.2)	(5.9)	(7.8)	(.9)	(1.3)	(30)
p = .15 N.S.	Use legal							
c = .24	means	(1.2)	(3.7)	(3.1)	(1.2)	(.6)	(.3)	(11)
N = 320	Use bribery	(7.8)	(13.4)	(18.1)	(15)	(3.1)	(2.1)	(59)
If overseer threatens reduction in mogha size								
x_2 = 30.73	Do nothing	(7.1)	(6.1)	(3.5)	(5.2)			(22)
p = .006	Use legal							
c = .30	means	(1)	(2.3)	(2.9)	(.6)	(.3)	(.3)	(7)
N = 310	Use bribery	(8.4)	(16.1)	(21.3)	(19.4)	(5.2)	(2.3)	(71)
If patwari incorrectly records water rate								
x_2 = 46.71	Do nothing	(5.9)	(3.2)	(2.4)	(3.2)	(.9)		(16)
p = .001	Use legal							
c = .35	means	(3.8)	(6.5)	(5.6)	(3.5)	(2.0)	(2.1)	(24)
N = 339	Use bribery	(8.0)	(16.5)	(18)	(15.9)	(1.8)	(.3)	(60)

Table 24. Summary of farmers' reports of extra legal canal water transactions.

Type of extra legal transactions	Number reporting	Percentage reporting Yes	Percentage reporting No
1. Trading partial turns of canal water	352	67.6	32.4
2. Trading full turns of canal water	335	33.4	66.6
3. Buying or selling canal water with other farmers	314	21.7	78.3
4. Buying water allotted by canal department for village roads	305	6.6	93.4
5. Buying water allotted by canal department for village school	305	5.2	94.8
6. Trading canal water for tubewell water	309	13.9	86.1

Table 25 . Summary information related to economic dualism among and within command areas (CA).

Selected types of farms	No. of cases	Crop yields (maunds/acre) Wheat	Rice	Cotton	Percentage in CA in Wheat	Rice	% of CA in crop	Percentage of farmers who estimate 50% or more increases in crops given a doubling of irri. supplies Wheat	Cotton	Rice	Sugar-cane	Weighted Mean Irrigation efficiency %
Tubewell supplements								P = perennial (NP) = nonperennial				
Public TW[1]	33	1.86	1.76	0.74	37	10	160	P 0 (NP20)	P 0 (NP55)	P 0 (NP45)	P 0 (NP52)	23
Owns private TW[2]	42	2.23	2.13	1.21	48	8	151	P 0 (NP50)	P 0 (NP20)	P 0 (NP35)	P 0 (NP35)	44
No tubewell	139	1.67	1.39	0.65	43	6	140	P 45 (NP68)	P 35 (P55)	P 35 (NP45)	P 30 (P50)	42
Farm location on command area												
Head	49	1.86	1.58	0.65				P10 (NP57)	P 9 (NP47)	P11 (NP45	P 4 (NP47)	47
Tail	64	1.67	1.39	0.56				P 28 (NP36)	P22 (NP36)	P24 (NP36)	P23 (NP36)	32
Type command												
Perennial	242	1.95	1.67	0.93	44	16	150	21	14	16	19	39
Nonperennial	80	1.48	1.21	0.65	43	3	130	48	38	53	38	45

1/ Only public tubewell commands are taken where there are no private tubewells.
2/ Only owners of tubewells are used here. Farmers who purchase tubewell water are excluded.

experienced by farmers and the resultant consequences of those constraints. The physical and irrigation constraints emphasized water supply, farm location, field levelness, and watercourse conveyance condition. 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 constraints 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. The consequences are irrigation performance, system layout and utilization, land use, crop yields and economic returns to production. The irrigation performance observed through field efficiency measurements indicated that conveyance efficiencies in the tertiary subsystem averaged 54%, that 41% of all irrigations were incomplete, that application efficiencies without under-irrigations averaged 55%, leaving an overall farm level efficiency of approximately 30%. The farm layout, irrigation layout and utilization consequences showed that the farm parcels were widely spaced, field sizes were small and ditch densities were high in response to nonlevel fields. Considerable areas were occupied by field ditches and bunds and represented nonproductive use of land. The land use consequence indicated that the cropping pattern and intensity were generally responsive to the water supply situation, with commands having a high availability of supplemental tubewell water having the highest cropping intensity. The head versus tail water supply constraint greatly influenced the land use observed. The crop yields obtained from the system indicated generally poor yields obtained, with mean wheat yields ranging from 0.81 to 2.61 tons/hectare, rice yields ranging from 0.91 to 2.25 tons/hectare and cotton yields ranging from 0.28 to 1.02 tons/hectare. Crop yields obtained were directly correlated with the water supply available and with the position on the tertiary watercourse system. Yields are generally comparable to those recorded for irrigated conditions in other developing nations but remained far below the potential. The farmers' reactions to the farm water management constraints were largely through individual initiatives to increase the water supply, legally by installing wells or buying and selling tubewell water. Extra legal means included obtaining enlargements to the tertiary outlet although the relatively fixed total canal water supply makes this a zero sum game, with losers occurring for every group or individual who gains from this activity. Farmers generally participate in extra legal activities to increase their water supply or flexibility in water supply such as trading turns and tubewell water for canal water. Water theft is common, and bribery is the major method used by farmers to cope with the lower level irrigation officials. Farmers tend to increase the area under cultivation on the watercourse command above the officially sanctioned levels thus causing a reduced irrigation time available per hectare and reduced discharge factors in liters per second per hectare. Farmers with sufficient to excessive water supplies would not respond to an increased water supply with increased area of selected crops, but those farmers without tubewell supplements would markedly increase cropped areas with a doubling of water supply. A potential for improvement exists through joint activities of farmers on watercourses to improve the delivery capability of the system, hence increasing the quantity and reliability of the water supply, and to level their land to increase field size, reduce irrigation depth per application, and reduce the land utilized for delivery ditches, thus enhancing the production potential.

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APPENDIX 12

FARM RESOURCE PRODUCTIVITIES, ALLOCATIVE EFFICIENCIES AND DEVELOPMENT POLICY IN THE INDUS BASIN, PAKISTAN

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The major challenges facing Pakistan's economy, problems shared with many other developing countries, are to provide enough food for a rapidly growing population, and to absorb the expanding labor force into productive employment. Although more than half of the labor force is engaged in direct agricultural production and significant gains in food output have been achieved in the past 10 to 15 years, Pakistan continues to experience difficulty in increasing food production at a rate to match demand growth. Government policies to increase domestic food output have included emphasis on increasing use of conventional resources such as irrigation water and fertilizer, and on adoption of new technologies such as improved crop varieties, pesticides and mechanization of farm power sources.

With possibilities for increasing the quantity of arable land being relatively limited, Pakistan must look to methods which increase productivity per acre, rather than emphasizing labor productivity as has been the case in the developed economies. The effects on food production and employment of policies which attempt to increase irrigation water supply and encourage farm mechanization are the focus of this study.

A production function analysis was performed on farm survey data obtained in the Indus Basin, Pakistan, for 1972-73 crop year. The sampling procedure and specification of variables explicity consider irrigation water and farm power inputs. The derived marginal productivities and estimates of social opportunity costs of resources are employed to examine efficiency of resource allocation on several types of farms. Tentative implications for agricultural development policy are indicated.

Most of Pakistan's agricultural production is carried out in the Indus Basin, and is based on irrigation from the world's largest irrigation network. The elaborate canal network consists of some 38,000 miles of canals and a series of barrages and canal headworks which control the diversion of river flows into the canals. The average annual river diversions are about 85 million acre feet, out of the about 142 million acre feet average annual flow in the Indus System.

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Although practically all farms in the Indus Basin have irrigation water supplies, the quantity of water available per acre is subject to wide variation. Both the seasonal distribution and total water supplies vary among watercourses and within watercourses. Some watercourses are inadequately supplied, and within watercourses, those nearest the diversion point tend to be more adequately supplied than those closer to the end (Johnson, et al., 1977).

Recent government policy has emphasized both surface and goundwater development. However, further possibilities for surface water development appear to be relatively limited.

Nearly all of the Indus Basin plains are underlain by an extensive groundwater aquifer. The gross area of the aquifer is of the order of 63,000 square miles, with a depth exceeding 1,000 feet in most areas (Chaudhry, 1973). The surface water supplies have been augmented by both private and public tubewells to tap groundwater supplies. Salinity in groundwater is a problem in some of the area, but can usually be dealt with by diluting with canal water.

Tractor imports have been encouraged by favorable rates for foreign exchange used for tractor purchases up to 1972, duties and sales taxes lower than for other machinery and low interest rates on loans. The stress on farm mechanization has been challenged in recent years. Proponents of mechanization pointed to the expected gains in output from improved tillage, more effective timing of field operations (particularly as it facilitates growing more crops per year) and the release of land otherwise used for producing fodder for work animals. Critics of the program have expressed doubt that really significant increases in crop production would be obtained and note the adverse employment impacts of mechanization in an already labor surplus economy, and the drain on scarce foreign exchange reserves. See Gotsch (1973) for a review of farm mechanization issues in Pakistan.

Resource productivity estimates from cross sectional farm surveys provide a useful technique for diagnosing the efficiency of existing resource allocation and to aid in formulating national and regional resource development policies. Heady and Dillon (1961) summarized numerous such studies from the U.S. and elsewhere in the world. A partial listing of more recent applications of this approach includes Hopper (1965), Welsch (1965), Sahota (1968), Saini (1968), and Singh (1973).

Data Sources and Production Function Estimates

The Sargodha Division of Punjab Province, one of the most important agricultural areas in Pakistan, was chosen for study. The Division encompasses about 11 million acres and its population exceeds nine million. About one-sixth of Pakistan's cropped area is found in the Division. The region is reasonably representative of the Indus Basin, producing a number of irrigated crops including wheat, rice, maize, cotton, sugar cane, tobacco, vegetables and various fodder crops.

A questionnaire was formulated to obtain farm production and input data relevant to farming conditions in Pakistan (see Khan (1975) for details). The questionnaire was administered to a sample of farmers in Sargodha Division in 1973 regarding the 1972-73 crop year. Data collection took place well after the introduction of high-yielding varieties, and the analysis is thought to reflect recent productivity conditions. Interviews were conducted by trained agricultural specialists employed by the Punjab Department of Agriculture in the area. The sample was divided into four categories representing different combinations and sources of irrigation water and farm power: (1) Farms with canal water and bullock power; (2) Farms with canal water and tractor power; (3) Farms with canal and tubewell water and bullock power; and (4) Farms with canal and tubewell water and tractor power. (Category 1 is representative of the great majority of Indus Basin farmers, who obtain water from the extensive canal system and rely on animal power to supplement human labor inputs. Relatively few tractors are found, and these are on the larger farms. Supplementary water supplies from tubewells are relatively more common, but not yet typical.) Farmers with tubewells and/or tractors were selected randomly from lists maintained by the Punjab Department of Agriculture. Farmers interviewed in Category 1 were chosen randomly from among those without tubewells or tractors in villages where a Category 4 farmer had been successfully interviewed, such that one was interviewed for each completed Category 4 questionnaire. Two hundred twenty-two usable questionnaires were obtained for analysis.

Detailed information was obtained on crop production and sales and resource use in the categories of land, labor, irrigation water, power (bullocks and/or tractors) and cash purchases (seed, fertilizer and pesticides). For labor, total hours actually worked by the family and by permanent and temporary hired workers was obtained. The estimate of irrigation water used relied on farmers' recollections of water distribution during the year. For each crop were recorded acreage, depth of water applied and time taken for pre-irrigation and each subsequent irrigations as well as the time intervals between irrigations. Each respondent was asked cross-check questions about the nature of his water supply, the system of water supply rotation, duration of turn, intervals between turns, and area irrigated in each turn. Where supplemental tubewell water was available, pump capacity and hours used were obtained. For tractors and attached implements, cost of fuel, lubricants and repair were added to the annualized capital investment to arrive at a total annual cost for these types of capital services. Similarly for animal power, the cost of variable items (fodder, concentrates, medicines, implement repairs, etc.) were added to annualized cost of ownership to determine total annual cost of bullocks and implements.

Sample size and selected data on production and resource use by category are shown in Table 1.

The power function, usually called the Cobb-Douglas function, is the most widely used form for fitting agricultural production data, because of its convenience in computation, simplicity in interpreting production elasticities and because estimation involves fewer degrees of freedom than other forms which allow increasing or decreasing returns to scale (see Heady and Dillon (1961)).

The survey data were fitted to a Cobb-Douglas function taking the following form:

$$Y = aL^{b_1} W^{b_2} B^{b_3} T^{b_4} C^{b_5}$$

where

Y = gross farm income (Rs. per acre)
L = labor input (man-equivalent hours per acre)
W = water input (inches/acre)
B = annual cost of bullocks and implements (Rs. per acre)
T = annual cost of tractor and attached implements (Rs. per acre)
C = cash expenses (fertilizer, seed, plant protection, land and other taxes) in Rs. per acre
$b_1 \ldots b_5$ = production elasticity of respective inputs

The initial formulation included crop land as an independent variable. However, high intercorrelation between land and other independent variables was observed. Since the problem focuses on resource productivity per unit land, all the other variables were expressed in per acre terms.

Standard least squares regression procedures were employed, with the regression equation expressed as a function linear in logarithms. The results of the regression analysis are presented in Table 2. The coefficient of determination (R^2) and tests of significance on the regression coefficients show a relatively good fit.

On the whole, irrigation water and cash inputs were found to have an important influence in gross income per acre, as the b_2 and b_5 coefficients were large and significantly greater than zero on all categories of farms. The labor coefficient (b_1) was significantly greater than zero except on Category 2

Table 1. Sample Means of Selected Characteristics of Farms in Survey, Sargodha Division, Pakistan, 1973.

Type of Farms	Category 1	2	3	4
Source of Irrigation Water	Canal	Canal	Canal and Tubewell	Canal and Tubewell
Main Source of Farm Power	Bullock	Tractor	Bullock	Tractor
Number of Observations	60	54	54	54
Average Size (acres)	26.92	48.63	43.62	76.49
Cropping Intensity	110.75	112.75	130.93	122.17
Labor Use/Cultivated Acre (man hours)	504.56	281.48	508.70	296.64
Bullock Cost/Cultivated Acre (Rs.)	164.24	60.52	162.89	45.13
Tractor Cost/Cultivated Acre (Rs.)		204.52		150.68
Water Use/Cultivated Acre (acre inches)	21.15	22.85	26.38	24.37
Cash Cost/Cultivated Acre (Rs.)	133.40	154.34	151.02	134.90
Net Income/Cultivated Acre (Rs.)	234.71	217.72	341.87	294.27

Table 2. Regression Results Relating Gross Income Per Acre to Selected Factor Inputs Per Acre from a Sample of Farms in Sargodha Division, Pakistan[a,b]

Type of Farms	Category 1	2	3	4
Source of Irrigation Water	Canal	Canal	Canal and Tubewell	Canal and Tubewell
Main Source of Farm Power	Bullock	Tractor	Bullock	Tractor
Number of Observations	60	54	54	54
Constant (a)	19.01	21.03	7.23	8.34
Labor (man hours)	0.100 (1.584)*	0.028 (0.330)	0.268 (2.359)**	0.172 (1.584)*
Water (acre inches)	0.514 (7.568)***	0.639 (4.879)***	0.543 (4.907)***	0.381 (2.954)***
Bullocks and Implements (Rs.)	0.043 (0.571)	0.019 (0.655)	0.099 (0.861)	0.098 (1.868)**
Tractor and Allied Implements (Rs.)	-	0.040 (1.058)	-	0.106 (1.665)*
Cash (Rs.)	0.313 (4.671)***	0.279 (2.526)***	0.210 (2.437)**	0.347 (3.133)***
Coefficient of Multiple Determination (R^2)	0.859	0.778	0.867	0.729

[a] Regression coefficients are the production elasticities (Cobb-Douglas function expressed in logarithmic form).

[b] t ratios in parenthesis.

*Coefficients significantly greater than zero (one-tailed test) at 0.10 level of probability.

**Coefficients significantly greater than zero (one-tailed test) at 0.05 level of probability.

***Coefficients significantly greater than zero (one-tailed test) at 0.01 level of probability.

farms (mechanized farms lacking supplemental water). Expenditure on bullocks and tractors were found to be significant only on Category 4 (but only at the 10 percent probability level for tractors).

Allocative Efficiency of Resource Use

The ratio of the marginal value product (MVP) of a resource to its opportunity cost gives a measure of the efficiency of resource allocation prevailing on the average throughout the population of farms studied. If this ratio is greater (less) than one, too little (too much) of the particular input is being used under the existing price conditions, given the level at which other resources are being utilized.

For any input, X_i, the marginal value product can be derived from a Cobb-Douglas function as:

$$MVP_{X_i} = \frac{\partial \hat{Y}}{\partial X_i} = b_i \frac{\hat{Y}}{X_i}$$

The opportunity costs of the various inputs were estimated as follows:

Labor: The average daily wage for hired labor was found to be about Rs. 3 in the study areas, which comes to Rs. 0.37 per hour assuming an average eight-hour working day. The total labor used on the farm consisted of family and hired labor. The family labor included women and children, who would have very limited prospects of off-farm employment. Although there are seasonal peaks around crop harvest when labor becomes scarce, the general situation is one of abundance of labor. Under such circumstances the social opportunity cost of labor in general would be less than the hired labor wage. There is no exact a priori information available on the social opportunity cost of labor. Therefore, it has been assumed that the social opportunity cost of labor was 2/3 of the average wage of hired labor, Rs. 0.25 per hour.

Water: Canal water is not priced by market forces to the extent of the other resources. This is because of several factors such as inflexibility of the timing of water supply, physical limitations of the distribution system and institutional impediments to the sale of irrigation water among users. Sale of tubewell water, however, is a common practice. Reducing losses in conveyance channels can increase the effective supply in many locations, although the cost varies widely depending upon local conditions (Johnson, et al., 1977). Pumping ground water to supplement the canal water is the most generally available means of increasing irrigation water supply in the Indus Basin. We estimated the average cost of pumping ground water to be Rs. 5.25 per acre inch and this figure is assumed here to be the opportunity cost of water.

Cash Expenses: Returns on cash expenses should equal Rs. 1 for each Rs. 1 spent, plus interest on the money. The Government provided credit to farmers at an interest rate of 8 percent per annum at the time of the survey, which we judge to be less than the social opportunity cost of capital. Therefore, the opportunity cost of cash expenses is set at Rs. 1.10.

As with cash expenses, the opportunity cost of expenditures on bullocks, tractors and implements is set at Rs. 1.10.

The computations of marginal value products and ratio of MVP to opportunity costs are given in Table 3. All MVP's are calculated at the geometric mean of the observations. The difference between the estimated marginal value productivities and the respective opportunity costs were tested for statistical significance by a t-test procedure (Heady and Dillon, p. 231). The t-ratios and test results are shown in Table 3 in the conventional notation.

Discussion of Results and Policy Implications

From the analysis in Table 3 can be drawn the following inferences.

The Category 1 sample (unmechanized farm without supplemental water sources) is presumed to be representative of the typical farming system in the region. This group exhibits a rather serious misallocation of resources. Irrigation water and cash expenditures are underallocated, while bullock power is, relative to land, in excess supply. Labor appears to be used in somewhat excessive quantity, although the difference is not statistically significant. In contrast, however, the other categories, representative of larger, more capitalized and technologically advanced operations, exhibit no pervasive evidence of misallocation, (although water is inadequate on all these categories). One might speculate that these latter types of farms have largely come to terms with the new technological opportunities.

Irrigation water is seen to be the resource with the largest social rate of economic return, and has a favorable influence on labor utilization and productivity. In contrast, mechanization yields a low rate of return and is detrimental to employment. We conclude with a more detailed analysis of the policy implications.

Mechanization Policy - Subsidies to tractor and implement purchases were granted in the expectation that improved timing and effectiveness of field operations and reduced need for

Table 3. Marginal Value Products, Opportunity Costs and Allocative Efficiency of Selected Inputs from a Sample of Farms in Sargodha Division, Pakistan.

Type of Farms			Inputs	Unit of Measurement	Marginal Value Product	Opportunity Cost	t - ratio[a]	Ratio of MVP to Opportunity Cost
	Source of Irrigation Water	Main Source of Farm Power						
1	Canal	Bullock	Labor	Hour	0.19	0.24	-0.41	0.79
			Water	Acre Inch	23.38	5.25	5.87***	4.45
			Bullock	Rs. 1.0	0.25	1.10	-2.04**	0.23
			Cash	Rs. 1.0	2.43	1.10	3.09***	2.21
2	Canal	Tractor	Labor	Hour	0.10	0.24	-0.48	0.42
			Water	Acre Inch	27.05	5.25	3.93***	5.15
			Bullock	Rs. 1.0	0.42	1.10	-1.10	0.38
			Tractor	Rs. 1.0	0.23	1.10	-4.14***	0.21
			Cash	Rs. 1.0	1.82	1.10	1.00	1.65
3	Canal and Tubewell	Bullock	Labor	Hour	0.56	0.24	1.33	2.30
			Water	Acre Inch	21.67	5.25	3.71***	4.13
			Bullock	Rs. 1.0	0.65	1.10	-0.59	0.59
			Cash	Rs. 1.0	1.58	1.10	0.74	1.44
4	Canal and Tubewell	Tractor	Labor	Hour	0.56	0.24	0.89	2.33
			Water	Acre Inch	14.79	5.25	1.58	2.82
			Bullock	Rs. 1.0	2.65	1.10	1.09	2.40
			Tractor	Rs. 1.0	0.78	1.10	-0.65	0.70
			Cash	Rs. 1.0	2.57	1.10	1.79*	2.30

[a]Marginal Value Product significantly different from opportunity cost (two-tailed test):

*at 0.10 level of probability.

**at 0.05 level of probability.

***at 0.01 level of probability.

animal fodder would increase farm production. The results reported here do not confirm that expectation and support the prescriptions of Gotsch and others who suggest that mechanization programs should be given lower priority or should take other forms.

The marginal value productivity of the tractor input was insufficient to justify the expenditure on each of the relevant farm classes. This finding can be attributed to several causes. About half the tractor owners in the survey were found to be maintaining one or more bullock pairs to hedge against tractor breakdown, and therefore had to devote resources to forage production. Also, only 24 percent of tractor owners interviewed owned more than one attached implement, so tractors are not being used to full potential. It was also observed that the typical mechanized farm had insufficient acreage to fully utilize the 35 to 45 horsepower units which are typically imported. Average annual use was only 650 and 750 hours in the two cases, so the hourly cost of tractors tends to be rather high for the work accomplished. (Farmers' motivation for mechanization will likely extend beyond pure economic considerations. In particular, the possibility of further land redistribution programs encourages many landowners to directly till as much of their land as possible so as to reduce the risk of losing part of it because the owner is not himself the operator.)

The measurements also show a marked effect of mechanization on labor utilization and productivity. Table 1 showed the effect of mechanization on the hours worked per acre. In Table 3, it is seen that the marginal value product of labor in farm type 2 is lowered by the availability of tractor power when compared to the MVP in Category 1. However, in the presence of supplemental irrigation water (Category 4), MVP of labor was not affected by mechanization when compared with Category 3.

We computed from the production functions the marginal rate of technical substitution of tractors for labor (the reduction in labor associated with a unit increase in tractor input, given a constant rate of output). Expressed in hourly terms, the estimates imply that on Category 2 farms, one hour of tractor replaces 26.4 hours of labor. On Category 4 farms (those with supplemental water), the substitution was considerably less, but nevertheless substantial, at 16.8 labor hours lost per hour of tractor. On the average, each tractor displaces about six full-time workers.

These findings suggest that mechanization contributes relatively little to agricultural output, representing mainly a substitution of capital for labor. In an economy where land is relatively scarce and labor is abundant, policies which subsidize mechanization are counterproductive. Our analysis adds to the growing body of evidence that in situations like Pakistan's, where foreign exchange for tractors, implements and fuel is scarce and where urban employment opportunities are not keeping up with labor force growth, policies which encourage mechanization with large tractors have limited economic rationale.

Alternatives relating to farm power sources which warrant more attention include improving the efficiency of animal power by better design on harnesses and implements, emphasizing smaller mechanical power units, including hand tillers, and setting up cooperative or market mechanisms for increasing the annual use of tractors.

Policy Regarding Irrigation Water Supplies - The most significant finding of the analysis relates to the high potential private and social returns to improved supplies of irrigation water. The elasticity coefficients for water and the marginal returns to the resource are so high as to indicate that much larger quantities could be profitably used. In so doing, the returns to other inputs would also rise, and thus justify using more of them as well.

Labor productivity and allocative efficiency appear to be influenced by supplemental water availability, as well as by size of farm. (See also Table 1 for employment per acre on farms with and without tubewells.) Excess labor is indicated, relative to opportunity costs, on farms lacking tubewells, while the opposite occurs in the presence of supplementary water. This illustrates the degree to which additional water is employment-generating, as compared to the labor replacing effect of capital invested in mechanization.

It appears that the effects of water on production can be traced to both increasing the supply per crop and to the timing of its availability. It is likely that the availability of supplemental ground water permits irrigation during periods when canal deliveries are relatively restricted, which in turn facilitates double cropping and growing high-valued crops in situations where it would otherwise be infeasible. The survey data exhibit a high correlation between water applied and cropping intensity (average crops harvested per acre per year) suggesting that the most fruitful path to increased food production is in using more water and plentiful labor to obtain more crops per year. The linear programming models reported by Khan show that multiple cropping has not been exploited by Pakistani farmers to nearly its full potential.

Recent Government policy has encouraged both surface and ground water development. However, further surface water development possibilities appear to be relatively limited. Chaudhry (1973) concludes that by optimal conjunctive use management of the hydrologic system in the Indus Basin, the available water resources can be used more efficiently and at a lesser cost; the ground water aquifer can serve as a functional reservoir and a recycling facility considerably increasing the usable water supplies. A high proportion (over 80 percent) of the land in the study area lies over ground water which is suitable for irrigation. Thus a concerted effort to increase the effective supply of irrigation water through tapping ground water resources deserves immediate attention.

Improving the efficiency of on-farm water use and for reducing the delivery losses in existing canal systems is an important additional avenue. Easter (1977) and Johnson, et al. (1977) show for differing situations in South Asia that such techniques are available and economically feasible, but their adoption requires an imaginative and determined extension education program. (Each of these approaches--ground water use and improvement in conveyance and application efficiency--carry with them unmeasured external economies in the form of reduced waterlogging and salinization on down-slope farms. To this extent, the net social benefits as measured here are underestimated.)

In summary, our findings indicate that programs to make more irrigation water available to farmers, particularly outside the normal summer cropping season so as to facilitate more harvests per year, would have extremely high rates of return. Desirable effects on food production, employment and the value productivity of labor would also be expected. Emphasis on water supply, together with already operating input supply and credit policies to encourage use of fertilizers, improved crop varieties and plant protection chemicals have much more desirable consequences than incentives toward tractor mechanization.

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APPENDIX 13

PROBLEMS OF FARMER ORGANIZATION IN AN "APPROPRIATE TECHNOLOGY" PROJECT: LESSONS FROM THE WATERCOURSE IMPROVEMENT PROJECT IN PAKISTAN[1/]

DOUGLAS J. MERREY[2/]

1. INTRODUCTION

The Indus River Basin contains the largest integrated irrigation system in the world. Using a series of dams, barrages, major and minor canals, and tertiary watercourses, the system irrigates about fourteen million hectares of land. Much of this land is double-cropped, especially in the province of Punjab, Pakistan. With its favorable climate, good soils, and adequate water supply, this region ought to be one of the most productive in the world. However, for many reasons, the system is operating far below its potential level of productivity. As a result, Pakistan is one of the poorest countries in the world; and it will remain so until the "Indus Food Machine" (Johnson, Early, and Lowdermilk, 1977) begins to achieve its potential.

During the early 1970's, a team of Colorado State University water management specialists, under a contract with the United States Agency for International Development, began applied research on local level water management. This research was done in very close cooperation with various Pakistani research organizations, including the Mona Experimental Research Project (part of the massive Water and Power Development Authority), and Agriculture University at Faisalabad, Punjab Province.

Among their many important findings, these researchers discovered that about half of the water entering the watercourses from the canals is lost before it gets to the fields. This finding is contrary to previous World Bank and other organizations' assumptions that only ten to twenty percent of this water is lost (Kemper, Clyma and Ashraf, 1975). Further research has confirmed these high

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water losses (Clyma, Ali, and Ashraf, 1975). As a result the Pakistan Government, in cooperation with USAID, launched a Pilot On-Farm Water Management (OFWM) Project. Utilizing methods of watercourse reconstruction developed by CSU and its collaborators, this project aims to improve 1500 watercourses over a five-year period, in order to test the benefits of this new technology.

This program would appear to be a classic "appropriate technology" (Schumacher, 1973) project: it was developed by working with local farmers during the research phase; it is low-cost, compatible with local skills, labor-intensive, utilizes local materials, contributes to developing local industry (fabrication of control structures), is ecologically sound, and involves collective self-help. Farmers have responded enthusiastically to the program, and there is more demand than can be fulfilled. Because of the funding agency's requirement, only watercourses shared mostly by small farmers having holdings of less than ten hectares are being improved.

However, a major problem has developed as the project has expanded, namely the poor maintenance of the improved watercourses. Maintenance is the responsibility of the farmers on the watercourses. The OFWM team includes an extension specialist whose primary duty is to "motivate" the farmers to carry out regular cleaning and maintenance. However, recent research has shown that the watercourses continue to be poorly maintained. The thesis of this paper is that this poor maintenance is not because of a lack of motivation or knowledge but is the result of inadequate organization of farmers for maintaining their watercourses.

In this paper, I first briefly describe the Indus irrigation system; then I discuss the research and development, and pilot project, phases of the watercourse improvement program. This is followed by a discussion of recent research on the organizational problems of improving and maintaining the watercourses. Finally, the implications of this project for the introduction of other "appropriate technologies" are considered.

2. THE IRRIGATION SYSTEM

More than 142 million acre feet (MAF) of water is estimated to be available in the Indus River system annually. Of this about 92 MAF are diverted into the canal system of Punjab and Sind. About 30 MAF is lost in the main canal and distributary system before it reaches the watercourse, but about an equal amount is added by public and private tubewells (Johnson, Early, and Lowdermilk, 1977).

There are about 80,000 watercourses in the Indus Basin. Although these vary considerably in size and condition, the average watercourse is three to four thousand meters long, and irrigates 150 to 200 hectares; the number of farmers may vary from about ten to over one hundred. Pakistan's irrigation system is a continuous flow system, and the outlet (mogha) from the distributary to the watercourse is a fixed size to allow a fixed volume of water to flow. This volume is set by the Irrigation Department based on the amount of land irrigated, and varies from canal to canal. The water is normally distributed according to a fixed turn (warabundi) system in which each farmer uses water for a period proportional to the size of his landholding. This period comes at exactly the same time each week.

The Irrigation Department is directly responsible for the system up to the mogha. The farmers themselves are responsible for the maintenance of their watercourses, and in the beginning even set their own warabundis. Using its residual powers under the Canal and Drainage Act (see Jahania, 1973), the Irrigation Department can set the warabundi on request of the farmers; most watercourses in Punjab now have such a fixed warabundi. In theory the Irrigation Department can also enforce standards of maintenance, but in practice it has rarely done so, and its actual authority today is so weak that the Department prefers to avoid this question.

In any one week no farmer gets sufficient water to irrigate all of his land. Therefore, he must decide each week which fields have priority. Originally, the system was designed to irrigate half or less of the commandable area per growing season; but today in Punjab most land is in fact double cropped, with the major crops being cotton, rice, sugar cane, various fodders, and vegetables in the summer (kharif) season, and wheat, fodder crops, and vegetables in the winter (rabi) season. The level basin system is the most widely used irrigation method (Corey and Clyma, 1975). In practice, this means land is subdivided into basins of one decare or less and flooded for irrigation. This minute fragmentation, compounded with the fragmented holdings of farmers, and the difficulties of precisely leveling the land using the crude equipment available, further reduces the efficiency of an already inefficient system.[3/]

3/Corey and Clyma (1975); Johnson, Early, and Lowdermilk (1977); and Lowdermilk, Freeman, and Early (1978) for more complete discussions of the system at the local level. For an overview of the history and technical problems of the system, Michel (1967) is comprehensive.

3. WATERCOURSE IMPROVEMENT: THE RESEARCH AND DEVELOPMENT PHASE

Colorado State University's researchers and their Pakistani collaborators initiated research on local level water management practices in the early 1970's. Their early reports discuss various problems of local level water management, including lack of level fields, the imprecision of the amounts of irrigation water applied to crops, the need to improve cultivation practices, and the uncertainty of the supply of irrigation water from the point of view of the farmer (Corey and Clyma, 1975). However, one of their earliest research activities was measuring the efficiency of watercourses. They discovered that contrary to previous assumptions, a substantial portion of the water entering the mogha is lost before reaching the fields. Most of this loss is a result of the poor maintenance of the watercourses: the banks are thin, porous, and full of rat holes, and therefore leak badly; and the channels are clogged with vegetation and silt, reducing water flow and causing overtopping. CSU and other organizations continued to survey watercourses to find out how general these water losses are; although there is considerable variation by area and among watercourses in the same area, it was discovered that an average of forty to fifty percent of the water entering the watercourses is lost (Clyma, Ali, and Ashraf, 1975; Lowdermilk, Freeman, and Early, 1978). If this average is multiplied by all of the 80,000 watercourses in Pakistan, the potential losses are staggering to say the least.

While this research continued, CSU and its collaborators at the Mona Reclamation Experimental Project began working with farmers to develop solutions to the problems of high water losses. Many different techniques and designs were tried, including various types of cement, and soil cement block, lining; but at the time the costs of these solutions appeared prohibitive. The researchers then tried methods of rebuilding and compacting earthen banks to proper engineering design and levels, and developed low-cost cement control structures which could be easily fabricated by local manufacturers, and installed by village masons. Using this technology, losses can be reduced by fifty percent or more, at a very high benefit-cost ratio (Eckert, Dimick, and Clyma, 1975).

Based on their experience in Pakistan, CSU researchers have formalized the research-development process for improving on-farm water management technology (Clyma, Lowdermilk, and Corey, 1977). They analyze this process into four phases. The first two are "Priority Problem Identification" and "Search for Problem Solution". These two stages of the watercourse development project are described above: identifying the problem of water losses, and working with farmers, searching for a solution.

The third phase in their scheme is "Assessment of Solutions" In this phase they emphasize working closely with farmers to develop and test solutions that will be appropriate to the situation. They emphasize the necessity of examining the compatibility of the new technology with existing values and past experience; "*farmer acceptance* is the most important criterion for technological assessment" (ibid.:44; their italics). The final phase is "Program Implementation"; in this stage, appropriate institutional arrangements and provision for training are necessary; this phase should begin on a pilot basis, and as experience is gained, converted to a full-scale program.

In the case of the watercourse improvement program, the last phase, a pilot project, was begun before the third phase had been completed. The Government of Pakistan and USAID were apparently impressed with the results of the research, and the possibilities of a water management program. Farmers who had been involved in the first few reconstructed watercourses were also very enthusiastic. Their water supply had increased dramatically, and on the first watercourse completed there were several farmers who were effective in helping the Pakistani collaborating agency sell the program. Therefore the On-Farm Water Management Pilot Project was launched in three provinces in 1976-77.

4. THE PILOT PROJECT PHASE

Institutionally, the On-Farm Water Management Pilot Project is organized as a separate directorate within the provincial Agricultural Departments of three provinces: Sind, Northwest Frontier Province, and Punjab. In Sind and the NWFP the project has faced various administrative delays. Another problem is that the project was designed based largely on Punjab research results; but some components of the project as designed are apparently inappropriate for conditions in these other provinces. The program in Punjab, especially the watercourse reconstruction portion, has made a lot of progress. As of the end of June, 1979, about 200 watercourses had been improved in Punjab.

The work of watercourse improvement, precision land leveling, and water management extension is carried out by field teams, generally based at the Tehsil (sub-district) headquarters. Until reorganized recently, each team included a Water Management Specialist who is the team leader, one watercourse engineer, one extension man, and several land development officers in charge of land leveling. (The distinction between the land development and watercourse engineers was recently eliminated). The number of Area Teams has been expanding in a phased manner as more persons are trained in the various on-farm water management skills. Each team has quotas--a certain number of watercourses improved and acres precision leveled--to fulfill, and the Pakistan-USAID contract sets goals. The Pakistan Government is reimbursed at a fixed rate for work completed.

Generally, the watercourse engineer meets with farmers to discuss reconstruction of their watercourse. If they agree they are asked to remove all the trees from their watercourse. When this is done, the engineer carries out a survey and develops a design for the watercourse. The farmers must form an executive committee through which the engineer works, and which is responsible for organizing the farmers' contributions to the project. The farmers must supply all the labor, including the mason for installing cement lining and control structures. The Government supplies all materials--cement, bricks, and pakka nakkas (the control structures). These structures are manufactured by small local private companies. Presently, up to ten percent of the length of the sanctioned watercourse may be lined with bricks and cement; usually sections passing through populated areas or sandy soil are lined.

After the watercourse is completed, the farmers are expected to maintain it. The extension officer on the Area Team is responsible for teaching the farmers to use their water more effectively, and to "motivate" the farmers to maintain the watercourses. However, poor watercourse maintenance has become a very serious problem. The newly rebuilt banks require regular maintenance to prevent deterioration; yet the frequency and quality of cleaning and maintenance at best remains at the previous inadequate level, and sometimes declines. The designers of the program envisioned the watercourse committee established for reconstruction would continue to operate for maintenance, but this has not happened: in a recent survey of improved watercourses it was discovered that none of the committees were still operating (Mirza and Merrey, 1979).

Many officials and bureaucrats explain the problem of poor maintenance by saying the small farmers are uneducated, not "progressive", and do not understand the benefits of maintenance. They suggest more extension effort to "motivate" them; there has even been recent discussion among officials of establishing a quota for extension workers of contacts with farmers to motivate them for maintenance; under this scheme USAID would reimburse the Pakistan Government for these contacts. Other officials suggest the solution is to eliminate the requirement to work with small farmers; big farmers, they argue, are more "progressive" and will maintain the watercourse better.

Some of the designers of the project recognized that improving the physical structure of the watercourses would not be sufficient; their organization would also have to be improved. The project therefore includes a requirement that research be carried out on setting up "Water Users Associations". However, while much lip service is paid to this idea, to date not one association has been established.

Preliminary research on the organizational problems of improved watercourses suggests that the assumption underlying the "extension" approach to maintenance, that "ignorance" is the problem, is incorrect. The real problem is inadequate organization for collective action. This research is discussed in the next section.

5. THE SOCIAL ORGANIZATION OF WATERCOURSES

During 1978 I collaborated in a study of the social organization of ten improved watercourses (Mirza and Merrey, 1979). This section is based mainly on the report on that research. We selected a total of ten watercourses, deliberately chosen to include several "problem" watercourses and several "model" watercourses. We also tried to choose watercourses for which a maximum period of time since improvement had elapsed (the range was four months to two years). The sample watercourses represented several different agronomic areas of Punjab, Pakistan. The purpose of the study was to identify those characteristics of rural society that both promote and inhibit effective cooperation on watercourse rehabilitation and maintenance.

Our field team members spent ten to fifteen days on each watercourse. They interviewed selected informants intensively as well as a random sample of farmers stratified by location on the watercourse (head, middle, tail). The formal questionnaire data were supplemented by detailed field diaries and observations of the condition of the watercourse. Mirza and Merrey (1979) provide a detailed discussion of the methods and results of the research. Here only a brief summary of the major conclusions is possible.

We discovered that both the ease and completeness of the actual reconstruction process, and the quality of maintenance after improvement on the sample watercourses, vary considerably and there are systematic relationships between the relative "success" of improvement, and maintenance quality; and also between these and certain sociological characteristics. Watercourses whose improvement was completed without significant delay or disruptive conflict are generally better maintained than those where the improvement process had been difficult. The better maintained watercourse tend to have all or most of the following characteristics:

1. A large percentage of farmers with land holdings in the 2.6 to 10 hectare (6.5 to 25 acre) range. We defined holdings in this range as "small but economically viable" in irrigated Punjab. Watercourses dominated by farmers

8. Membership of most of the shareholders in a single kinship group (biradari). Patterns of cooperation and conflict in Punjabi villages are generally based on kinship; single-biradari watercourses are generally better maintained than multi-biradari watercourses. The biradari ("brotherhood") is an agnatic kinship group within which marriages usually also take place, and is perhaps the most significant group in rural Punjab. Biradari members are expected to cooperate with each other, especially in situations of conflict with other biradaris; but even these groups often prove fragile (see Alavi, 1972; Merrey, 1979).

In reality the ideal characteristics listed above are not found very often in rural Punjab. None of the watercourses in our sample were well-maintained by any absolute standard; the point is that those which were comparatively better maintained share more of these characteristics than those which were in poor condition. On five of the ten watercourses studied, the reconstruction work had not even been completed, because of conflict among the shareholders or between the farmers and the OFWM engineers. Our study shows that the quality of improvement and maintenance are closely related to sociological characteristics of the watercourses; but it also shows that present forms of organization are not adequate to insure good maintenance of the system, even on relatively conflict-free watercourses.

One may go a step further and say that not only are present forms of organization inadequate to insure watercourse maintenance, but that various features of rural Pakistani society operate to generate competition and rivalry and discourage cooperation. There is constant rivalry and conflict among and even within biradaris, as people strive to prevent others from gaining, or appearing to gain, any advantage, or to pull down people who seem to be doing well. This conflict is generated by a value system which emphasizes acquiring honor and prestige by reducing others' honor, and by a social system marked by profound inequalities in economic and political power. Men are often willing to forgo opportunities for improving their water supply, for example, out of concern that their neighbor may benefit more than they. Projects requiring cooperation often fail because one or a few men would rather have no one benefit than to allow their "enemies" to receive some benefit. By its very nature, the benefits of watercourse improvement are distributed unequally--the farmer whose land is at the tail, for example, usually gets far less water per hectare before improvement, and also benefits proportionally more than the head farmer after improvement. These cultural and social impediments are not unique to Pakistan, of course; but they have proven major obstacles to the present watercourse improvement program.[4/]

4/See Merrey (1979) for a more detailed discussion, focused on the cultural impediments.

below this range seem to be very difficult to organize for cooperative programs, perhaps because they are less committed to farming. Larger farmers usually have servants and laborers do their share of watercourse work, so it is often done carelessly; and large farmers are also the ones who can most easily violate sanctions and who are involved in the most interpersonal conflict.

2. Relatively equal distribution of power and influence among farmers on a watercourse. "Power and influence" was measured by asking sample farmers to rate all the other farmers on the watercourse, and adding the scores. Where influence is more equally distributed, and one or a few farmers do not dominate, farmers seem to cooperate better on collective projects.

3. A large percentage of farmers being perceived by fellow shareholders as having some influence and power. On some watercourses, power and influence scores were uniformly low--no one commanded any respect. Cooperation on such watercourses was much less than on watercourses where the scores were higher across the board--that is, where most shareholders have at least some standing and respect.

4. Concentration of power and influence at the tail or tail and middle of the watercourse. Farmers at the tail of a watercourse usually receive the greatest benefits from improvement, and are thus more highly motivated. If these farmers have comparatively greater influence, they often insure maximum cooperation by others.

5. "Progressiveness" of the community, as measured by the percentage of farmers with a better than primary education, number of institutional services available in the community, and the percentage of farmers who listen to the radio. These three components together were used as a measure of community attitudes toward modernization and change.

6. Previous history of cooperation on community projects, and lack of serious recent conflict. Communities that had successfully cooperated on previous projects, such as school building, and which had not been divided by serious group conflict in recent years, cooperate more effectively on watercourse rehabilitation and maintenance.

7. A small number of shareholders on the watercourse. On the watercourses with the largest number of shareholders--even if they all belonged to one kinship group--getting the farmers to work together to rebuild and maintain their watercourse proved most difficult.

Even though legally the farmers are collectively responsible for the maintenance of their joint watercourse, no mechanism has been incorporated into the law to insure that the farmers would be able to fulfill their responsibility. There is no formal provision for organizing the farmers, or sanctioning "free riders" who do not do their share of watercourse cleaning. On most watercourses there have been informal mechanisms, where farmers agree to clean the watercourse several times a year, and farmers who do not do their share are subject to a nominal fine; but our research shows that even this fine is rarely enforced; the fine itself is insufficient to be effective; and there is no way to enforce it if relatively powerful farmers refuse to participate.

Inadequate watercourse maintenance is not the result of ignorance of the benefits of cleaning and maintenance. Discussions with many farmers have made it clear that they do see the benefit of a well maintained watercourse. In the OFWM Project areas the demand for watercourse improvement is substantial. Farmers know that water is the major constraint on production, and they know they can improve their water supply by rehabilitation and maintenance of their watercourses. The major reason for the present poor condition of the watercourses in Punjab is their poor maintenance in the past; this poor maintenance is the result of inadequate organization to insure that maintenance tasks are carried out; and improvement of watercourses without also setting up some means to insure their maintenance is likely to be a very poor investment indeed.

6. CONCLUSION

In the early 1970's, Colorado State University scientists and their Pakistani collaborators identified a significant constraint to improving agricultural production in Pakistan, and developed what appeared to be a very appropriate technology to solve the problem. Using local materials and labor, and for a relatively low capital investment, they demonstrated that reconstruction of irrigation watercourses could potentially save millions of acre feet of water every year. This would both provide more water for irrigation, and reduce the problem of waterlogging and salinity plaguing the Pakistani irrigation system. Under the pilot On-Farm Water Management Project several hundred watercourses have been improved. However, recent research on some of the watercourses suggests they are not being well maintained. This poor maintenance is the result of inadequate and inappropriate organization of farmers on the watercourses.

The research briefly reported here was originally planned as preliminary to setting up experimental farmer organizations on the watercourses. It was expected that about a dozen "Water Users Associations" would be organized as part of the improvement process. These would be registered under existing law such as the Cooperative Act. The end product of this research was to be a series of recommendations for organizing legal associations of irrigators for improving the management of the irrigation system (see Mirza and Merrey, 1979). However, the recent cutoff of American aid to Pakistan, as well as various political developments in that country, have made it unlikely this research will be done in the near future. Research reported in Mirza and Merrey (1979) and Merrey (1979) raises doubts about the likelihood of success of such farmer organizations in the present social and political context.

There are a number of lessons to be learned from this project. One is that, with hindsight, it might have been better if there had been a social science component of the research from the beginning. The early CSU researchers were aware that organizing farmers for reconstruction and maintenance would be a problem, but a formal research project on farmer organization was initiated only after the pilot OFWM project had been launched. Another lesson, following from the first, is the crucial importance of social structural and cultural factors in the introduction of "appropriate technologies". Watercourse improvement is certainly technically appropriate, and farmers' enthusiasm might lead one to think socially and culturally appropriate, for the conditions of rural Pakistan. However, farmer "acceptance" alone is an insufficient criterion for designing technologies involving community cooperation. The type of watercourse improvement being introduced requires that farmers cooperate not only to carry out the reconstruction, but also to maintain the watercourse in the long run; but the cultural and social impediments to such cooperation under present conditions seem overwhelming. It is difficult to see how the present program can be successful in the long run.

Yet Pakistan's watercourses must be improved; if they are not the Indus Food Machine will never achieve its potential productivity. Both the Pakistan Government and various international donor agencies including the World Bank recognize this, and are planning large investments in watercourse reconstruction. There are two possible strategies for carrying out watercourse reconstruction: one is that the government take over the responsibility of improving and maintaining the watercourses, perhaps charging the farmers for the expense. This approach is being tried in India, and many Pakistan Government officials find it attractive. Under such an approach rapid progress in reconstructing watercourses would probably be achieved at the early stages. However, such an approach would entail either a major expansion of the existing Irrigation Department or creating yet another inefficient government bureaucracy; it would exacerbate the already serious shortage of trained engineers; and it would further reduce the farmers' sense of responsibility for their watercourses.

The other possible strategy, in my opinion more viable in the long run though difficult to achieve in the short term, is to encourage the establishment of legalized Watercourse Associations with substantial responsibilities, federated into larger units, and integrated into the management of the larger system. CSU has recommended such a strategy to the Pakistan Government (see Water Management Research Project Staff 1976; Reuss, Skogerboe, and Merrey 1979). The CSU suggestions involve establishing an association on each watercourse, with all shareholders as members. This association would be responsible for improving and maintaining its watercourse, and would have the legal power to obtain loans for financing improvements. Each watercourse association on a larger distributary would send a representative to a Distributary Association; and all these associations would be represented on a Canal Association for each major canal. The plan envisions giving these associations substantial responsibility for managing the canal system.

In order to be successful, it is now clear that this decentralized approach would have to be accompanied by various other social and economic reforms to facilitate the organization of farmers, so that they can work to improve their own irrigation system. Such reforms would have to include real land reforms to reduce economic inequalities, changes in inheritance laws to curb fragmentation of holdings, a more responsive banking and marketing system, and education of farmers, not only in improved agricultural and water management practices, but in how to operate in a new social order. Perhaps this is the most important lesson to be learned from this project: purely technological solutions to problems of development may often not be viable unless accompanied by substantial and effective social and economic reforms.

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APPENDIX 14

THE GREEN REVOLUTION IN PAKISTAN: WHOSE CORNUCOPIA?[1]

Max K. Lowdermilk[2]

The initial optimism about the high yielding varieties (HYVs) in the late 1960's and early 1970's as a solution to the world food problem is giving way to concerned pessimism. The technical literature is mixed in regard to the benefits received by different classes of farmers. The remaining optimists claim that since the indivisible nature of the new seed technology is neutral to scale all farmers benefited (Sen, 1971; Randhawa, 1974). The pessimists, however, find that the new seed not only benefited the larger farmers but also created a host of social problems including rural unemployment, off-farm migration, and political instability (Frankel, 1972). Few of these studies have provided empirical data to show who benefited and how. The Pakistan experience with the HYVs once hailed as a model for other countries provides a good case study to attempt to answer several crucial questions which include: In what specific ways were small farmers and tenants at a disadvantage in adopting the HYVs of wheat? To what degree were scarce resources and services skewed toward the large landlords? How well do small farmers and tenants perform in yields per hectare as compared with larger farmers?

Statement of the Problem and Approach of the Paper

Simply stated, the problem of this paper is to provide a descriptive account of the Pakistan experience with the HYVs program for wheat and to isolate how small farmers and tenants have been at a disadvantage in relationship to larger farmers. They HYV technology is unique in two respects. First, the new seed has all the positive attributes usually associated with rapid adoption such as relative advantage, congruence or compatability, simplicity, trialability or divisibility, and high visibility (Rogers et al., 1971). Secondly, the new seed technology require a set of associated practices for high yields. While there is an empirical basis for understanding the attributes of an innovation and adoption rates, few studies have examined the adoption of the individual practices which accompany the main innovation (Rogers and Shoemaker, 1971). Previous research has been mixed on the relationship of farm size or

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commercial scale farms and adoption of agricultural practices (Jones, 1965; Rogers and Shoemaker, 1971). The conventional view in sociology and economics has been that the larger the farm, the more efficient in terms of production. Another argument often used about divisible innovations, such as the new seed, is that since the technology can be tried and adopted in small increments without large initial cash outlays there are no major impediments to small farmer adoption (Probhat and Ashok, 1973). Though there are few studies to show the relationship between the adoption of the innovation and social system or contextual effects, there is general agreement that the social context which receives the innovation greatly affects adoption rates and distribution of benefits (Van den Ban, 1960; Qadir, 1966; Saxena, 1968; and Davis, 1968). Simple logic suggests that in a semi-feudal agricultural sector where there are scarce resources and services the larger farmers will capture them for their use (Gotsch, 1971). Therefore, there is a need for examination of the often used assumption that farmers who adopt the main innovation also adopt the package of practices that make the innovation beneficial.

The approach of the paper is, first, to examine the adoption behavior of several classes of farmers over time to determine who adopted what. Secondly, the focus is on institutional constraints and the availability of requisite inputs and services to farmers. Thirdly, the progress of all classes of farmers in terms of yields is examined with implications for policy. This will provide an opportunity to examine the growth with equity argument to determine if substantial increases in aggregate production required broad participation by all classes of farmers. Is, for example, growth with equity also economically efficient? (Grant, 1973)

Data Base

The data utilized for HYVs of wheat are from two comprehensive field surveys conducted in the Punjab of Pakistan in 1970 and 1976. All data are from irrigated farms in a province where by 1976 about 75 percent of the irrigated region had been sown to the HYVs (Dalrymple, 1978). The 1970 study by Lowdermilk included 350 farms and the 1976 study by Lowdermilk included 251 farms. A major limitation of the data is that they represent two different samples and cannot be compared statistically in some respects. Also in the 1976 study all farms of less than one hectare in size are excluded to correspond to the 1970 study. The 1970 data are from a nonproportional random sample stratified on farm size in 30 villages and the 1976 data are from a random sample of farmers in 12 villages. The studies, however, will provide valid insights about farm level problems to be examined. The data are usually presented in relationship to farm size and tenure classes for 1970 and 1976 to indicate differences in between several types of farms.

Farmers' Experience in Adoption of HYV Technology

This section will describe the environment in which the new technology was introduced and its initial rapid adoption. First, in terms of physical endowments, Pakistan not only has the world's largest contiguous irrigation system in the world but also from good to excellent alluvial soils and a climate suitable for year-round cropping. The Punjab Province which is the focus of this paper, for example, has almost 9 million hectares of irrigated land. Secondly, farmers in the Punjab had installed about 30,000 tubewells by 1965 for improved water control prior to the introduction of the HYVs of wheat (Lowdermilk, 1975). Thirdly, due to great dependence on food imports in the early 1960's the timing was right for the HYVs which offered higher yields (Lowdermilk, 1972). Fourthly, government policy in the middle 1960's favored increased incentives to farmers in the form of subsidies on inputs. Fifthly, there was little or no change in the semi-feudal agrarian structure of the Punjab which is characterized by 85 percent of the farmers with holdings of under 5 hectares owning 43 percent of all agricultural land and 5.2 percent of the farmers with holdings over 10 hectares owning 43 percent of the land. Of all holdings roughly 36.8 percent are cultivated by tenants and 24 percent by owner-cum-tenants and 42 percent by owner operators (Agricultural Census, 1972). In such an environment large landlords dominate politics and largely determine agricultural policy (Alam, 1974; and Alavi, 1971).

In summary, there was both a positive physical environmental and a negative institutional setting in which the HYVs were introduced (Hiroshima, 1978). The semi-feudalistic nature of the agrarian structure has remained essentially the same.

Historically the spread of the new wheat seed in Pakistan was similar to the spread of hybrid maize in the United States. In Pakistan between 1965 and 1971, area increased from 4,800 to 3 million hectares as compared to the United States where area of hybrid maize increased from 4,800 hectares in 1933 to 9.6 million hectares by 1939. As Ryan and Gross (1943) in their pioneer studies described the seed innovation, "This represents a farm trait that can almost unqualifiedly be termed a good economic farm practice."

Initial Adoption of HYV Seed Technology

In terms of positive characteristics of the new seed technology it meets the criteria which a number of researchers have found significantly related to rapid adoption. In comparison with local varieties, the HYVs had a definite relative advantage in yield and profitability even when cultivated under traditional practices (Lowdermilk, 1972). The relative advantage ranged from 50 to 100 percent higher yields for farmers who adopted. The new seed was compatible in terms of past experience with wheat cultivation and met a need of farmers for improved production. The seed technology is not complex in the sense that it is highly divisible and farmers can produce the seed on their own farms. The seed had high trialability in that farmers could introduce it incrementally. Finally, the innovation was highly observable and easy for farmers to communicate to other farmers. Given these positive attributes, 1970 data show that at every stage of the adoption process 70 percent or more of the sources of information used by farmers were of a local interpersonal type (Lowdermilk, 1972).

Table 1 provides data to indicate how rapid adoption took place between 1966 and 1970 for five farm size classes. Adoption is defined as a farm having 50 percent or more of total wheat area in the HYVs. These data show that small farmers were not at a great disadvantage in adopting the new seed at any time during the time periods indicated. The greatest differences between the very small and largest farmers are for the 1970-71 period which is 19 percent and in the 1976 study which is 16 percent. Though not shown in tabular form, of farmers who used only HYVs in 1970-71, 61 percent of the smallest farmers and 65 percent of the larger farmers had all of their wheat area in HYVs.

Table 1. Percentage of farmers adopting HYVs for 1970 and 1976 studies by farm size classes.

Year and study	Farm size classes (acres)				
	1-3 Ha (N=62) (1)	3-5 Ha (N=56) (2)	5-10 Ha (N=71) (3)	10-20 Ha (N=75) (4)	20>Ha (N=86) (5)
1970 study					
1966-67	5.2	5.4	1.4	2.6	2.3
1967-68	25.8	16.2	15.4	23.9	37.6
1968-69	59.1	60.9	67.8	69.1	78.5
1969-70	69.4	72.1	74.5	81.1	90.3
1970-71	74.2	78.9	84.5	89.3	93.5**
1976 study	84.0 (N=58)	81.0 (N=52)	98.0 (N=61)	100.0* (N=17)	100.0* (N=8)

*Farm size classes (4) and (5) significantly different from (1) and (2) at .07 level (1976 study).
**Farm size class (5) significantly different from (1) at .01 level (1970-71 study).

Table 2 provides data for an examination of how well three tenure classes did in adopting the HYV seed.

Table 2. Percentage of farmers adopting HYVs for 1970 and 1976 studies by tenure class.

Year and study	Tenants (N=63)(n)	Owner-cum-tenants (N=52)(2)	Owner/operators (N=235)(3)
1970 study			
1966-67	0.0	2.8	5.2
1967-68	16.0	26.1	21.9
1968-69	73.0	52.1	61.3
1969-70	83.8	58.0	75.7
1970-71	92.9**	71.4	77.6
1976 study	86.4	77.1	93.6*

*Tenure class (3) significantly different from (2) at .001 level (1976 study).
**Tenure class (1) significantly different from (2) and (3) at .001 level for 1970-71.

Data in Table 2 show that in terms of adoption of the new seed, tenants had adopted at a higher rate than other farmers in 1970-71 and adoption rates between tenants and owners were not significantly different in the 1976 study. Though not shown in tabular form. 59 percent of the tenants and 54 percent of the owner/operators by 1970-71 had their total area in the HYVs. Explanations for this difference offered at the time of the interviews with tenants were "higher yields than local varieties," "pressure from landlord to grow HYVs," and "lack of land for production of favored local varieties for home consumption."

The widespread adoption of the new seed created much optimism on the part of most observers and policy makers. By 1974, 55 percent of the total wheat acreage was in HYVs and all classes of farmers were participating. Total wheat production also had increased about 75 percent between 1960 to 1970 largely as a result of the new seed (Dalrymple, 1975). This progress led to conclusions such as the following by Nulty (1972)

> In common with many underdeveloped areas West Pakistan has a fair share of the institutional disabilities often cited as barriers to growth. . .
> The West Pakistan experience has shown that substantial results can be obtained with minimum stress on administrative, organizational, and research capacity by concentrating on what are likely the most difficult bottlenecks.

This optimism has since given way to pessimism since yields of the HYVs peaked in 1972 at less than a third of their potential of two tons per hectare under improved practices. As a result of rapid population pressures, Pakistan has continued to import wheat. Between 1970-71 and 1974-75 imports cost over $700 million and by 1978 given high world grain practices, imports costs $300 million or about one-fourth total foreign exchange earnings (Hyderabad Times, 1978).

Complexities of the New Technology

Research has shown that the simple seed innovation requires a complex of associated practices for improved yields. Under traditional practices the HYVs of wheat in Pakistan initially did out yield local varieties, but very quickly in terms of potential a low yield plateau was reached (see Lowdermilk, 1972). The assumption in Pakistan as in much adoption-diffusion research was that farmers who adopt a new technology also adopt those practices necessary to make it more beneficial (Rogers and Shoemaker, 1971). Wharton (1969) describes the complexities involved with the HYVs for farmers who want to obtain higher yields:

> Farmers must learn new farming skills and expertise of a higher order than was required in traditional methods of cultivation. The new agronomic requirements are quite different as regards planting dates and planting depths, fertilizer rates and timing, insecticides and fungicide applications, watering and many others.

Selected practices which must accompany the new seed for higher yields have been researched extensively in Pakistan and India (see Lowdermilk, 1972). Those associated practices examined in the two field surveys are shown in Table 3. Due to space limitations, the significant differences between farm size classes are denoted on the table by an asterisk. These data suggest that, by and large, farmers have continued to cultivate the new wheat under traditional practices. It is also evident that there is a significant relationship between farm size and the adoption of most of the associated practices.[3] Both the 1970 and the 1976 surveys indicate that the package of practices was only accepted by the larger farmers. It can be argued that the adoption of the seed technology alone is not complete adoption because there are a number of important associated practices or complimentary inputs which are necessary for increased yields. As Wharton (1969) suggested,

3/Associated practices include a steel plow for seedbed preparation, a small local seed drill for seed placement, and more fertilizer than local varieties, though low cost small farmers find capital or credit difficult to acquire. The importance of these associated practices for yields are documented by Lowdermilk (1972). For example, seed rate, seed placement, seedbed preparation, nitrogen, and extra water availability explained 87 percent of the variation in yields for the 1970-71 season.

Table 3. Percentage of HYV wheat farmers utilizing selected recommended practices and having correct knowledge about selected practices (1969-70 and 1975-76).

Recommended practices	1970 Survey N=324	1976 Survey N=200
A. Utilization		
Seedbed preparation	28*	30**
Sowing date range	NA	64
Sowing method	5*	24**
Seed rate	39*	55
Depth of seeding	NA	39*
Nitrogen fertilizer	7*	18*
Phosphorus fertilizer	7*	8*
Nitrogen application	41*	42
B. Knowledge of:		
Seedbed preparation	NA	40*
Sowing date range	70	60
Sowing method	NA	66
Seed rate	NA	63
Depth of seeding	44	37
Nitrogen fertilizer	NA	38
Phosphorus fertilizer	NA	52
Nitrogen application	60	42

** and * respectively denote significant differences of .01 to .05 level using chi square test in relationship to farm size, i.e. the larger the farm size, the greater use or knowledge of the recommended practice indicated.

some of these practices are different from the local practices. For example, deep plowing for seedbed preparation, placement of the seed at a critical depth of not more than 2.5 inches, higher seed rates and levels of fertilizer. While knowledge of an innovation and its actual use are two different dimensions, it is important to note that after about 10 years (1966-1976) that a relatively large percentage of farmers could not report the correct recommended practice when tested by interviewers. Note that in terms of knowledge of the practice there is only one, "seedbed preparation," which is significantly related to farm size.

When there is such a gap between recommended practices and their use, farmers cannot be described as inefficient. The major fault rests with the system which does not make inputs and services available to farmers. In low income nations especially it cannot be assumed that all farmers have equal access to essential inputs and services. As we have shown, when resources are in short supply the larger farmers with power and influence capture them for their use. As Whyte (1975) states cogently, much of the research which show that the small traditional farmer is "fatalistic, tradition bound, passive, and resistant to change" needs to be re-examined. Experience shows that either the recommendation was unsatisfactory under his farm conditions or he was unable to obtain the innovation or credit to acquire it. When small farmers are provided new production possibilities, they usually adopt them with success (see Lowdermilk, 1975).

Institutional Constraints and Small Farmers

Mellor (1967), Mosher (1957), and others have developed frameworks of institutional services needed for modernization of agriculture. These are described in nonconventional inputs which farmers cannot supply themselves. In brief, these include: 1) institutions to provide farmers incentives; 2) institutions which provide research findings; 3) institutions which provide farmers physical inputs; and 4) institutions which provide farmers information. These are only a few of the essential nonconventional inputs that are thought to be most essential. Each of these institutional inputs will be examined using the data available.

1. Institutions to Provide Farmers Incentives

Increasingly it is realized that if small farmers and tenants are not able to participate more fully in agricultural development both aggregate production and wider distribution of benefits will not be achieved. In many countries like Pakistan there is need for a reform of the traditional rural structure and the provision of protection for tenants and services for all classes of farmers if they are to participate more fully in the HYV programs.

The major force that operates to the detriment of small farmers and tenants in taking advantage of improved production possibilities is the feudal nature of the agricultural system. Alam (1974) in an examination of the economics of the landed interests describes the power of large landlords over small farmers and tenants in relationship to local and regional politics, influence over price policy and resources needed for improved production. Alam (1974) states that modernization of agriculture as it has taken place in Pakistan will accentuate the feudal power of the big landlords. Adequate institutional arrangements is an ideal condition rarely met satisfactorily anywhere. Influence over agricultural policy results from the large percentage of landlords in politics. For example, in the 1951 Punjab provincial elections, 80 percent were large landlords. This trend has continued and even in Bhutto's general election in December of 1970, 105 of 138 members elected were landlords (Alam, 1974 and Frankel, 1971).

There are several ways tenants and small farmers must depend directly or indirectly on large landlords. First, in terms of inputs which are often controlled or pre-empted by those with power. Secondly, large farmers who have purchased tubewells control a valuable water supply. Thirdly, large landlords have power to provide or withdraw credit from tenants and small farmers for whom they are the money lenders. Fourthly landlords have many extra legal means to evict tenants and pay less than the legal rate for harvest work. Frankel (1971) in his study of "The Politics of the Green Revolution" shows that the new technology while changing the norms of the crop sharing between tenant and landlord actually worked to the disadvantage of the tenants. Local custom established that seed, implements, bullocks, payment of land revenue and water revenue, were shared by both landlord and tenant. The crop was divided on a 50-50 basis as well as inputs and some landlords provided tenants with consumption loans. Given the new HYV technology and tubewells for supplemental water supplies to the canal supplies several changes have taken place. Now the tenant must purchase water from the landlord. Though the new share basis for the crop is 60 percent tenant and 40 percent landlord, in actual practice the old norm remains. The traditional one-twentieth of the harvest for cutting the grain is being replaced by a fixed amount of grain thereby favoring the landlord. In the 1970 survey (Lowdermilk, 1970) found that the median rate paid for winnowing grain was 1.4 kilos of grain per 64 kilos for landlords with 30 hectares or more of holdings as compared to 1.8 kilos of grain per 64 kilos for farmers with holdings under 3 hectares of land. Frankel (1971) found a ferment of unrest among the landless poor, tenants, and small farmers in the rural areas as a result of the disadvantage of small farmers and tenants to benefit more from the HYV of wheat and attributes Bhutto's rise to power to the strong support from the rural poor in the 1970 election. Though Bhutto implements a land reform in 1973 only 7,828 tenants received 24,414 acres of land or about 1.2 hectares each. All three land reforms to date have been used as a political tool with limited impact on the strong feudal base of rural society. None of these reforms have altered the position of tenants or improved institutional services for farmers. By and large benefits of the HYV technology have been in proportion to size of holding and the ownership of tubewells which provide water control.

2. Institutions Which Provide Research Findings.

When new technologies are introduced there is a need for a continuous flow of new production possibilities for farmers. While the biological research has been well organized with well trained personnel from CYMITT[4] in Mexico, there have been disruptions due to the breaking up of the one unit of Pakistan into four provinces and political dismissals or transfers.

4/CYMITT is the Mexican acronym for International Maize and Wheat Improvement Center, Mexico.

Nevertheless, researchers have produced 14 new HYVs since 1967. While biological research has progressed, there is a dire lack of economic and sociological research.

3. Institutions Which Make Available Physical Inputs

Since the inception of the HYVs fertilizer policies including price and means of distribution have changed many times. These shifts from heavy subsidies to lower subsidies and prices of grain have had an impact on farmers (World Bank, 1975). The crucial issue, however, is whether farmers are able to acquire credit for fertilizer and fertilizer when it is required. Table 4 provides data to show the degree of credit and fertilizer availability for both the 1969-70 and 1975-76 studies. As expected, small farmers were at a great disadvantage in acquisition of credit for fertilizer and fertilizer in comparison to larger farmers. Small farmers reported to interviewers that they would apply more fertilizer if they were in a position to obtain it. This suggests that small farmers though willing are unable to purchase the inputs needed to reap more benefits from the HYVs.

As suggested earlier a major input for the HYVs is irrigation water since the canal system supplies only about .19 hectare meters of water for the rabi or fall wheat season and farmers receive water on a weekly basis for only part of their irrigated acreage, they need supplementary supplies and more control over irrigations. Farmers who are able to purchase water from public or private tubewells are able to control irrigation better. Table 5 shows that both in the 1970-71 and 1975-76 studies the majority of farmers had problems of receiving supplements to the canal supplies. Again it is obvious that the larger the farm size the more control over water. Private tubewell farmers have the greatest control because they can irrigate on a demand basis. As will be shown later in the discussion on yields where there is water control wheat yields are significantly higher.

These data indicate that small farmers with under 5 hectares who make up 30 percent of all the farms in Pakistan and cultivate 35 percent of the total wheat area are facing problems of not only lack of water but also credit for fertilizer and fertilizer (Agricultural Census, 1972).

4. Information and Communication Services

As farmers begin to be introduced to new technology as the HYVs, there is an upsurge in their need for field level advice in decision making. Decisions are not only more complex but usually are frought with much more risk than outsiders realize.

Table 4. Percentages of farmers obtaining credit or capital for fertilizer and commercial fertilizer when needed for HYV of wheat (1969-70 and 1975-76).

Farm size (Ha)		Percentage of farmers obtaining credit or fertilizer when needed					
		No. farms	Credit for fertilizer (1969-70)	Fertilizer	No. farms	Credit for fertilizer (1975-76)	Fertilizer
1-3	I	51	24	23	58	22	39
3-5	II	51	33	14	52	38	51
5-10	III	65	35	25	61	48	63
10-20	IV	71	56	25	17	53	88
20>	V	86	71	61	8	100	100
All sizes		324	47	32	196	40	56

Differences in proportions by farm size classes:

1969-70:
*V over IV: significant .05 level.
*V over I,II,III: significant .01 level.
**V over I,II,III,IV: significant .01 level.

1975-76:
*V over I,II,III: significant .01 level.
*V over IV: significant .05 level.
**V over I,II: significant .01 level.
**V over II,IV: significant .05 level.

Table 5. Percentage of sample farms and availability of irrigation water supplemental to canal supply (1969-70 and 1975-76).

Farm size (Ha)		Availability of Supplemental Supplies								
		1969-70 Study				1975-76 Study				
		No.	Very difficult %	Easily %	Private tubewell	No.	None %	Difficult %	Easily %	Private tubewell
1-3	I	62	76	24	6	56	41	22	37	14
3-5	II	56	76	24	5	54	30	37***	33	18
5-10	III	71	63	37	13	57	23	21	56	13
10-20	IV	75	32	68	47	16	25	19	56	29
20	V	86	18*	83*	78*	8	12**	--	88**	50**
All sizes (weighted)		350	65	35	34	191	30	25	45	17

Difference in proportions by farm size classes:
*V over I, II, III, IV: significant at .01 level

**V over I, II, III, IV: significant at .05 level
***II over I, III: significant at .04 level

Lowdermilk (1972) and other observers (World Bank, 1976) evaluated the impact of extension services to farmers in Pakistan. The extension service has over 4,000 employees for over 3.7 million farms. The field assistant who is the direct contact with farmers usually covers an area of over 32 square kilometers on a bicycle and has about 1250 farms as his responsibility. He is only a high school graduate with two years of general agricultural training and has little effective supervision, technical support, and few incentives.

In the 1969-70 study of 324 growers of HYVs of wheat only about 10 percent of the farmers reported receiving any information from extension services at awareness, interest, evaluation, trial or adoption stages. Most of the information was received from other farmers. For example, at the trial and adoption stages in 1969-70 and 1975-76 respectively about 16 and 17 percent of the farmers reported using information or advice from extension personnel. As an attempt to estimate farmers' contacts with extension workers, farmers were asked to report contacts over a six-month period. Table 6 provides information about the low level of contacts. In both studies about 80 percent reported no contacts and as expected, the few contacts are with farmers with 25 or more acres. The median contacts was one to two in a six-month period for the fifty farmers who reported contacts. Though not shown in the table, 51 percent of the farmers in 1969-70 and 84 percent in the 1975-76 study could not report the name of the extension worker assigned to their area.

Small Farmer Yield Performance: Implications for a New HYV Strategy

Most adoption-diffusion studies have shown that the larger the farm size or degree of commercialization the earlier and greater the adoption of new technologies. This finding was in keeping with the conventional wisdom of economics that the small farm is inefficient and less productive than larger farms. Recent research has challenged this view and shows that two important factors such as nature of the technology and provision of services may operate to make the small farmer more efficient than large farmers (Rogers et al., 1971; Grant, 1973).

The HYV technology that is required to increase yields is labor intensive. The new varieties require more labor and care as seeding time, more fertilization, more irrigations, much more weeding, and labor at harvest. Tubewells, though an indivisible input, are actually labor intensive by providing extra water to irrigate more land area and by providing higher cropping intensities and more high quality crops which tend to require more labor (Mellor, 1967). Other types of mechanization such as small seed drills, spray machines, and improved plows can also be used in labor intensive agriculture as in Taiwan and Japan. Small farmers also usually provide more care to

Table 6. Percentage of farmers having some and no contacts with extension personnel (1969-70 and 1975-76).

Farm size (Ha)		Extension contacts with farmers in six months					
		1969-70 Study			1975-76 Study		
		No.	Some %	None %	No.	Some %	None %
1-3	I	62	11	89	70	14	86
3-5	II	56	16	84	68	13	87
5-10	III	71	21	79	64	30	70
10-20	IV	75	35	65**	17	41	59
20	V	75	64	36*	18	63	37***
All sizes		350	20	80	227	22	78

*Difference in V over all classes at .001 level.
**Difference in IV over I at .001 level.
***Difference in V over I at .001 level.

crops throughout the growing season in comparison with larger farmers such as careful irrigation and cultivation. When small farmers with their more intensive husbandry and labor have access to required inputs and credit, they are able to out produce larger farms (see Lowdermilk, 1975; and Grant, 1973).

HYV Wheat Yields by Farm Size and Water Control Situation

The purpose of this final section is to show the importance of water control for yields and also to compare the yield performance of various classes of farmers. Data in Table 7 shows the average HYV wheat yields by farm size and by supplemental water availability. Note the significant difference in yield between farmers who own tubewells and those who do not and between those who had "easy availability of tubewell water" and those who did not. Earlier we observed that the larger landlords own the majority of the tubewells but must sell water to other farmers as a business but timely supply of water is irregular.

In terms of farm size, for the year 1969-70 there are no significant differences in yield for the five farm size classes. In the 1975-76 survey there were no significant differences in yields between farm size group V and I and III at the .01 level and between V and II and IV at the .02 and .05 levels. Also note under B and C that there is a significant difference in yield between farms where supplemental irrigation supplies are "easily available" and farms where water is not available or "not easily available". Also yields for private tubewell farmers are significantly different from farmers without private tubewells.

As expected, owners and owner-cum tenants out produce tenants but not by a wide margin (Table 1 in Appendix). When one considers the disincentives for tenants such as payment of half of the costs of production plus sharing 40 to 50 percent of the output and the constant threat of eviction, the yield performance of tenants is surprisingly high. The analysis of variance test results show that there is only a significant difference at the .054 level between tenants and other farmers in yield performance. Though yields in 1975-76 are greater for large owner operators a case can be made that a small farm strategy would not only be more equitable but could be efficient economically.

Another measure for efficiency of grain produced per unit of fertilizer is the grain/fertilizer ratio.[5] This is obtained by taking the yield/ha in kilos and subtracting it from that

5/Grain fertilizer ratio is obtained by taking the yield obtained with no fertilizer (0-0-0) and subtracting this from total yield which gives increment to fertilizer. The incremental yield in kgs is then divided by the nutrient kgs of fertilizer to obtain the ratio.

Table 7. Average HYV wheat yields in tons/hectare by farm size and supplemental irrigation supply situation (1969-70 and 1975-76).

Type of farm	No. farms	1969-70 HYV survey yields (T./Ha.)	No. farms	1975-76 HYV survey yields (T./Ha.)	Difference (2-1) (T./Ha.)
A. Farm size (Ha.)					
I. 1-3	51	2.10	55	1.89	-.21
II. 3-5	51	1.94	49	1.93	-.01
III. 5-10	65	2.00	63	1.87	-.13
IV.10-20	71	2.14	17	2.04	-.10
V.20>	86	2.23	7	2.79	+.56
All sizes	324	2.04	191	1.94	-.10
B. Supplemental irrigation available					
None	31	2.10	53	1.71	-.39
Not easily	132	NA	44	1.86	--
Easily	171	2.47	83	2.19	+.28
C. Private tube well ownership					
Yes	118	2.70	88	2.29	-.41
No	206	2.10	157	1.87	-.23

1969-70:

A. Difference between V,IV,III, II,I - not significant.
B. Difference between Easily and None - significant at .05 level.
C. Difference between Yes and No: significant at .01.

1975-76:

A. Difference between V,I, III: significant at .01 level.
Difference between V and II: significant at .02 level.
Difference between V and IV: sig. at .05 level.
B. Difference between Easily and None: sig. at .01 level
Difference between Easily and Not Easily: significant at .05 level.
C. Difference between Yes and No: sig. at .02 level.

yield obtained with no fertilizer and dividing the remaining kg. of grain by nutrient fertilizer units applied. The yield with 0-0-0 fertilizer in 1972 (Lowdermilk, 1972) was 1833 kg/ha. Table 8 shows the actual ratios obtained by farm size classes.

Table 8. Grain/fertilizer ratio by farm size classes for 1970-71 and 1975-76 studies.

Farm size (ha)	Kilos per ha of wheat less 1833 kg obtained with 0-0-0 fertilizer					
	1970-71 study			1975-76 study		
	Grain increment	Fertilizer	Ratio	Grain increment	Fertilizer	Ratio
	k	kg		kg	kg	
1-3	+ 72	53	1.5:1	-118	76	* -:1
3-5	- 73	49	* -:1	- 82	76	* -:1
5-10	- 19	51	* -:1	-136	82	* -:1
10-20	+100	61	1.6:1	+ 18	97	.2:1
20	+190	95	2.0:1	+698	134	5.2:1
All sizes	+ 18	54	0.3:1	- 73	82	* -:1

*Denotes less than 1 kg of grain per kg of fertilizer after yield with zero fertilizer of 1833 kg/ha is removed.

These grain/fertilizer ratios indicate a major problem for all classes of farmers because optimum ratios for plots utilizing all improved practices range from 10 to 20 kg of grain to one kg of nutrient fertilizer units (Lowdermilk et al., 1978). Note that in the 1970-71 study the smallest farms had a ratio of 1:5 and the largest farms had only 2.0. Also it is obvious that many farms had a negative response since they applied only about half of the recommended rate of nitrogen (110-126 kg/ha) and almost no P_2O_5. By 1975-76 the natural phosphorus in the soil had been depleted, therefore, yields plateaued or decreased. Given these data it is probable that small farmers could improve their yields substantially if provided means to acquire inputs.

If the small farmers with holdings under 10 ha who constitute 89 percent of the farms and control 57 percent were able to apply an extra bag of nitrogen this would probably result in increased aggregate production to meet the current deficit of 1.5 to 2.0 metric tons of wheat (Khan, 1978). Pakistan must choose whether to stay with the "old trickle down theory" which has not worked except to create increased rural poverty and discontent or to choose a strategy that has broad-based participation and will increase aggregate production.

Given these results it is evident that smaller farmers with under 10 hectares in holdings have not been brought into the development strategy for agriculture in Pakistan. These farmers constitute 89 percent of the total farms and control about 57 percent of the farm land. Khan (1978) concludes that HYV technology is known and has been proven, but the major problems are institutional. Small and middle-size farmers have been virtually bypassed in terms of credit, availability of fertilizer, extension and other inputs. Given a new strategy which gives more focus to small farmers' needs and protection of tenants Pakistan could meet several objectives. First, with broader participation in the HYV program overall production will rise due to increase in yields. Secondly, levels of living for the majority of the population would improve. Thirdly, fewer people would likely migrate to the already overcrowded urban areas. Fourthly, unless small farmers and tenants are provided more facilities, rural unrest is expected to continue (Alam, 1974). Rural unrest has been on the increase in Pakistan since the 1970 Bhutto elections primarily due to increasing socio-economic dualism between the large landlords and small farmers and tenants.

Like many other countries, Pakistan has experimented with many types of programs to get agriculture moving such as introduction of HYV technology, private and public tubewell installation, many changes in price policy, and many changes between private and public distribution of fertilizer inputs. As described in this paper, the strategy used resulted in a situation where larger farmers were able to acquire requisite inputs while small farmers were at a disadvantage. Given the structure of rural society in Pakistan as well as in a number of low income countries, the "trickle down" theory has not worked (Grant, 1973; Owens and Shaw, 1974). The present agrarian structure in Pakistan will not change short of radical intervention by government or rural uprisings, however, if Pakistan desires to maintain political stability and to become self-sufficient in food grain, several short-run steps can be taken; these are: improved credit facilities for small farmers, protection against frequent unjust eviction of tenants, improved extension services, and more availability of fertilizer. Without these and related facilities for helping all farmers to learn about improved production possibilities, it is highly questionable whether farmers will either increase irrigation on the area in wheat or improve current yields. Until Pakistan places more emphasis on reducing the growing discontent in the rural areas and provides small farmers with more incentives both economic development and political stability will continue to be in grave jeopardy.

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APPENDIX I

Table 1. Analysis of variance: yield of HYV wheat by tenure class (1975-76).*

Source of variation	Sum of squares	DF	Mean squares	F	Signif of F
Among	506.326	2	253.163	2.963	.054
Residual	16065.496	188	85.455		
TOTAL	16571.822	190	87.220		

*Owner, owner-and tenant, tenant.

APPENDIX 15

Cancian's "UPPER MIDDLE CLASS CONSERVATISM" Thesis: A Replication from Pakistan[1]

R. Scott Frey, David M. Freeman
and Max K. Lowdermilk[2]

During the past 40 years a substantial body of research has accumulated which reports the existence of a direct and linear relationshipbetween socioeconomic status and the adoption of a variety of innovations (Rogers and Shoemaker, 1971:354-63). Despite the findings of this research, Cancian (1967; 1972:134-59; 1977a, 1977b) has formulated and provided empirical support for a different conception. In general, Cancian argues that the relationship is curvilinear. Specifically, he characterizes the relationship as one in which those of high middle economic rank have a lesser propensity to adopt innovations than their low middle rank counterparts in the early stages of the adoption process, while both innovate more than those of low rank and less than those of high rank.

Cancian's reformulation represents an attempt to construct "a general theory relating rank to risk" (Cancian, 1977b:Chapter 2:1). As such, rank is "conceptualized as the possession or control of resources and risk taking as the deployment of resources in situations of uncertainty" (Cancian, 1972:136). Operationally, economic rank is regarded as a specific case of rank and the adoption of agricultural innovations as a specific case of risk taking. Taken as a whole, the argument is predicated on three interrelated elements: (1) the "inhibiting effect of high rank," (2) the "facilitating effect of high rank," and (3) the "curvilinear effect".

1/This is a revised version of a paper presented at the 1978 Annual Meeting of the Rural Sociological Society in San Francisco. We would like to express our gratitude to Alan C. Early who played an instrumental role in the collection of the data. Thanks also to Frank Cancian for allowing us to quote from his unpublished manuscript "The Innovator's Situation: Upper Middle Class Conservatism in Agricultural Communities (1977b) and to an anonymous reviewer for several helpful suggestions. The data reported were gathered as part of a larger research effort focused on problems of irrigation and social organization supported by the Agency for International Development under contract AID/ta-c-1411.

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Cancian (1972:136) starts with two related notions: (1) persons "prefer high rank to low rank" and (2) "the possibility of achieving higher rank is often the motivation for risk taking". He then suggests that the adoption of an innovation in the early stages, when uncertainty is greatest, represents a substantial risk which is not equally shared by all members of a stratification system. More precisely, "the higher a person's rank the more likely it is that a random change will be downward rather than upward" (Cancian, 1972: 137). Consequently, "persons of higher rank will risk less than persons of lower rank" (Cancian, 1972:137); i.e., they will adopt less. This is referred to as the "inhibiting effect of high rank" and exists only in situations where the following five conditions are met (Cancian, 1972:137-8):

1. All risks (uncertain investments of resources) are perfectly divisible.
2. Knowledge is equally spread over all ranks.
3. The risk necessary to maintain present rank is equal, as a proportion of total resources, for persons of all ranks.
4. No individual can suffer total loss of resources from loss on a single risk.
5. No individual has so many more resources than the next lower relevant individual (or category of individuals) that he is completely protected from loss of rank.

However, since these conditions are seldom, if ever, met in real situations, adoption varies directly with rank - a condition described as the "facilitating effect of high rank".[3] Emphasizing the importance of the divisibility of innovations (Condition 1) and the equality of the distribution of knowledge across ranks (Condition 2), (Cancian argues that the absence of these conditions undercuts the capacity of the lower ranks to adopt. This is not to say that those of higher economic rank have a greater propensity to take risks it simply suggests that greater wealth and attendant knowledge provided the requisite opportunities for them to adopt.

Following Homan's (1961:336-58) reasoning that status and conformity are related in a curvilinear manner, Cancian further modifies the initial proposition (i.e., the "inhibiting effect of high rank") by arguing that it is only applicable in the context of the middle ranks. More specifically, he suggests the existence of a "curvilinear effect". This "curvilinear effect" is described as resulting from a set of factors which act to undercut adoption in the low rank and enhance it in the high rank - conditions

3/Cancian (1977b:Chapter 2:5) has come to refer to this factor as the "facilitating effect of wealth".

that do not impinge directly on the middle ranks.[4] Centering attention on the middle ranks, Cancian indicates that they are subject to the "inhibiting effect of high rank" in the early stages of adoption when uncertainty is greatest and to the "facilitating effect of high rank" when uncertainty is significantly reduced through widespread adoption. This reasoning forms the foundation on which the upper middle class conservatism thesis is based.

Cancian (1967; 1972) assesses the thesis -- as presented in eight specific hypotheses[5] - using data from studies conducted in Mexico, Japan and the United States. Operationalizing rank by dividing various economic rank variables into quartiles and operationalizing adoption by dividing the adoption variables into the first and second quartiles of adopters, Cancian presents support for the thesis with three separate data sets collected in Mexico. Utilizing the same procedures in a reanalysis of data from six studies - previously undertaken by others in Japan and the United States - Cancian finds that three of these six studies provide support for the thesis. Taken together, then, these findings lead to the conclusion that the thesis is empirically valid cross-culturally.

OBJECTIONS AND REFUTATIONS

The validity of Cancian's position has been challenged recently by a number of researchers. This challenge is predicated on three specific grounds: theoretical, methodological and empirical.

In a theoretical vein, Morrison (1973) has probably provided the best single critique of Cancian's argument, and

4/In effect, those of the low and high ranks face a unique set of conditions due to their positioning in the stratification system. In Cancian's (1977b:Chapter 2:7) own words: "There are essentially two arguments for why high ranking people are innovators: (1) they are secure in their positions and take 'flyers' out of what amounts to boredom (as contrasted with economic motivation) and (2) they realize their distinctiveness is based on leadership in economic techniques and take self-conscious risks in order to maintain this distinctiveness. The arguments for why low ranking people are not innovative are also essentially two: (1) they are so poor that any risk threatens total economic extinction and therefore they are unusually conservative... and (2) they refuse to compete in the economic system because past failures have made it seem like an inefficient way to seek rewards."

5/Due to limitations of space, we do not enumerate these eight hypotheses. We refer the interested reader to Cancian (1967:917-9 or 1972:144-8).

it bears repeating here. This critique, which has also been emphasized in various ways by others (Gartrell, et al., 1973:408-9; Morrison, et al., 1976:1086-9; Gartrell, 1977: 334-5), centers on the identification of factors which Cancian fails to fully explore in his argument. They include the following (Morrison, 1973:264):

1. The properties of the innovation, Cancian's sole concern (including real as well as perceived probabilities of producing desirable or undesirable outcomes).
2. The properties of the rank structure (shape, size of strata, and permeability of boundaries).
3. The properties (magnitude and content of information flow about innovation in the rank structure.

Methodologically, Cancian has been criticized on the grounds that his operationalization of risk and rank is invalid. For example, Morrison (1973:263) and others (Morrison, et al., 1976:1088-9; Gartrell, 1977:334-5) argue that the use of agricultural innovation as a measure of risk is of questionable validity. Such a view is based on the observation that many agricultural innovations represent attempts by government to decrease the risks associated with farming and thus do not necessarily represent substantial risks for farmers. Moreover, Gartrell, et al., (1973:400-2) point out that Cancian's use of quartiling procedures in the operationalization of the variables has the effect of biasing results in support of several hypotheses.[6] Likewise, Morrison, et al., (1976:1088) indicate that Cancian's operational depiction of rank on the basis of quartiles does not take into account "crucial features of stratification systems." Such a strategy, they argue and demonstrate empirically, "introduces biases tending to favor Cancian's basic notion" (Morrison, et al., 1976:1088). Taken together, the existing literature suggests that Cancian's operationalization of the variables is questionable and leads to a number of misleading conclusions.

As noted earlier, Cancian presents cross-cultural data which he claims support the thesis. However, Morrison (1973:264-5) argues that the thesis may not be applicable in the context of developed countries. This argument, which is also articulated by Gartrell, et al. (1973:408), is based on the observation that Cancian's data from Mexico confirm the thesis, while only three of the six studies conducted

6/They observe: "Assuming a normal distribution in the population characteristics and assuming an underlying linear scale for both variables, the distortion introduced by the measurement procedures defines the curve which is predicted in Cancian's hypotheses" (Gartrell, et al., 1973:401).

in developed countries report findings substantiating the thesis. Moreover, studies undertaken in India (Morrison, et al., 1976; Gartrell, 1977) and the United States (Gartrell, et al., 1973) report findings which refute the thesis. In sum, Cancian's findings and those of three subsequent studies indicate that the empirical validity of the thesis is, at best, suspect.

PURPOSE

Despite the criticism his work has engendered, Cancian defends the use of agricultural innovation as an indicator of risk (1977b:Chapter 5:2-3) and contends that the three refutations reported in the literature (Gartrell, et al., 1973; Morrison, et al., 1976; Gartrell, 1977) are inadequate attempts to operationalize the theory (Cancian, 1976:1091; 1977a:5; 1977b:Chapter 6:8-9).[7] However, in response to several methodological criticisms, Cancian has modified his procedures for assessing the thesis in two important ways. First, in response to Gartrell, et al.,'s (1973:400-2) suggestion that the confirmation of several of the hypotheses is a direct result of the quartiling procedures used, Cancian (1977a:5; 1977b:Chapter 2:10) has deleted all but two of the eight hypotheses. The remaining hypotheses are (Cancian, 1977b:Chapter 2:13):

1. In the early stages of the process of spread of an innovation (sic), individuals of low middle rank are more likely to adopt it than are individuals of high middle rank.
2. The adoption rate of high middle rank individuals in later stages of the adoption process minus their adoption rate in earlier stages of the adoption process will be greater than the adoption rate of individuals of low middle rank in the later stages of the adoption process minus their adoption rate in the earlier stages of the adoption process.

Second, in response to Morrison, et al.,'s (1976:1086-8) criticism that he fails to take into account the structure of stratification systems as they exist, Cancian (1977a:6-7; 1977b:Chapter 4:14) has adopted cutting points in the proportion of 30/30/20/20 in the operationalization of rank.

7/He bases this latter point on the argument that these researchers have aggregated data on diverse populations in their attempts to operationalize the theory and thus have not "approximated communities of reference." Since the theory "emphasizes the importance of relative position in a community ranking system" (Cancian, 1977b:Chapter 3:9), data for a population not meeting this criterion cannot be considered adequate for an assessment of the thesis. For a full exposition of the "community of reference" notion, see Cancian (1977b:Chapter 1:4-10, Chapter 3:9-12).

Utilizing these modifications in a reanalysis of the original data presented in support of the thesis and a reanalysis of new data from 11 studies conducted by others, Cancian (1977b:Chapter 6:16) reports that "both hypotheses are strongly supported". In effect, Cancian continues to maintain that the thesis is in general agreement with the existing cross-cultural research - his own and others. Given the finality of Cancian's claims and the critical response his work had received, we believe it would be appropriate to bring forth additional data on the relationship. The purpose here is to provide such an assessment by examining the empirical validity of the two hypotheses Cancian suggests as central to the theory. Employing previously unanalyzed data collected in Pakistan, we examine the relationship between economic rank and the adoption of agricultural innovations.

DATA, VARIABLES, AND METHODS OF ANALYSIS

Sample

The data reported here are taken from a larger study conducted by the Colorado State University Water Management Research Team in 1976 and were gathered through structured interviews with a sample of 387 farmers from 16 villages in the Sind and Punjab provinces of Pakistan.[8] Since Cancian (1976:1091; 1977a:5; 1977b:Chapter 1:4-10, Chapter 3:9-12) suggests that an adequate test of the thesis must be based on a sample that approximates a "community of reference," only Punjab cases with complete data on all relevant variables are considered in the present analysis. Eliminating cases on this basis, we present an analysis based on 173 cases representing 10 Punjab villages.[9] Clearly, such a procedure only allows for a crude approximation of a "community of reference." However, we make the assumption that such a bias does not seriously hamper our efforts at providing a general assessment of the two hypotheses.

Independent variables

Rank is operationally defined in terms of acres of land owned and acres of land cultivatable. Two four-point

8/The purpose of this larger study was to acertain those factors (physical, social, economic, etc.) which act to undercut the farmer's capacity to realize full crop production potentials. For a discussion of the purposive sampling procedures utilized and related methodological points, see Lowdermilk, et al., (1978:Volume VI:Appendix 1-A).

9/We do not present a separate analysis of the Sind data because the available sample of 75 cases is too small for a meaningful analysis.

rank scales were constructed for each variable (i.e., low, low middle, high middle, and high) by dividing the sample distribution along these variables into ranks on the basis of distinct proportionate breakdowns. First, a four-point rank scale was constructed for each variable in accordance with cutting points that divides the sample in the proportion of 25/25/25/25 (quartile).[10] Second, a sample breakdown with cutting points in the proportion of 30/30/20/20 (Cancian T-Distribution) was constructed for each variable in an effort to provide a scale more closely approximating stratification systems as they exist in the real world.[11] In effect, the current operationalization of rank directly parallels Cancian's (1977a; 1977b:Appendix A:1) most recent efforts in this area.

Dependent variable

The risk-taking measure is an index (range 0 to 36) based on the summation of the following weighted agricultural innovations: (1) level of nitrogen applied per acre, (2) level of phosphorus applied per acre, (3) split application of nitrogen, (4) use of proper sowing date in planting, (5) use of improved seeding method in planting, (6) use of proper seed depth in planting, (7) use of Chenab 70 wheat, and (8) use of S.A. 42 wheat.[12] Following procedures developed by Cancian (1977b:Appendix A:2). Stage 1 adopters (high risk takers) and Stage 2 adopters (low risk takers) were defined as the first and second quartiles of adopters,

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10/Due to the nature of the data, we were only able to approximate the 25/25/25/25 breakdown. For total acres of land owned, the sample was divided into ranks according to cutting points in the proportion of 23.1/27.2/27.2/22.5. Similar figures for acres of land cultivatable are 20.2/30.1/26.0/23.7.

11/The Cancian T-Distribution was approximated by dividing the sample on the basis of cutting points in the proportion of 29.5/32.9/19.7/17.9 for acres of land owned and 28.3/32.9/19.7/.9.1 for acres of land owned which are cultivatable. The terms quartile and T-Distribution are used by Cancian (1977b).

12/The range of numerical weights for each agricultural innovation are as follows: 1 = 0-8 (where 0 = does not use, 1 = 74 pounds or less, 2 = 75-99, 4 = 100-114, 8 = 115 pounds or more); 2 = 0-8 (where 0 = does not use, 1 = 24 pounds or less, 4 = 25-49, 8 = 50 or more pounds); 3 = 0-2 (where 0 = no, 2 = yes); 4 = 0-4 (where 0 = off by more than 5 days, 2 = within 5, 4 = correct date); 5 = 0-4 (where 0 = broadcast, 2 = hand sowing into furrow, 4 = local seed drill); 6 = 0-4 (where 0 = off by more than .5 inch, 2 = within .5, 4 = correct depth); 7 = 0-3 (where 0 = no, 3 = yes); 8 = 0-3 (where 0 = no, 3 = yes).

respectively. In other words, Stage 1 adopters are those having adoption scores which fall within the upper quartile of the distribution of all scores (i.e., scores between 22 and 36), while Stage 2 adapters are those with scores falling within the second quartile of the distribution of all scores (i.e., scores between 14 and 21).[13]

Method of analysis

As noted earlier, Cancian (1977b:Chapter 6:2) identifies two hypotheses as central to the theory. These hypotheses are:

H_1: $LM_1 > HM_1$ and

H_2: $HM_2 - HM_1 > LM_2 - LM_1$

where LM equals low middle rank, HM equals high middle rank, $_1$ equals Stage 1 of the adoption process or high risk and $_2$ equals Stage 2 of the adoption process or low risk. Utilizing the procedure of simple cross tabulation and standardizing the percentage rates for each rank to a base of 100 across stages,[14] we present a total of four tests for each hypothesis.

FINDINGS

Data on the relationship between rank and adoption are reported in Table 1. In order to simplify the presentation of the data, we have organized the findings according to the independent variables. In the following analysis two separate tests of each hypothesis are presented for each independent variable.

Area owned

Looking first at the quartile breakdown of rank, we observe that both Hypothesis 1 ($13.2 \not> 26.4$) and Hypothesis 2 ($6.2 \not> 10.1$) are refuted by the data. Likewise, findings for the Cancian T-Distribution breakdown of rank provide the basis for rejecting both Hypothesis 1 ($17.1 \not> 25.9$) and Hypothesis 2 ($-5.7 \not> 17.1$). These data clearly indicate that area owned, regardless of the particular form of the

13/As with the rank variable, we were only able to approximate quartiles. These approximations are 23.7 percent of the sample for Stage 1 and 23.1 percent of the sample for Stage 2.

14/Percentage scores were standardized in the effort to ensure the meaningful comparison of the present findings with those reported by Cancian (1977b). See Cancian (1967:922-3; 1972:151; 1977b:Appendix A:3) for a discussion of the procedure used in standardizing percentage scores.

Table 1. Standardized percentage rates of adoption by economic rank, rank structure, and stage of adoption (N = 173)

Rank structure and stage of adoption	Economic rank			
	Low	Low middle	High middle	High
	Area owned			
1. Quartile[a]				
Stage 1[b]	23.3[c] (9)[d]	13.2 (6)	26.1 (12)	37.1 (14)
Stage 2	27.3 (10)	23.3 (10)	32.6 (14)	16.8 (6)
State 2-1[e]	4.0	10.1	6.2	−20.3
2. Cancian F-Distribution[f]				
Stage 1	19.2 (10)	17.1 (10)	25.9 (9)	37.8 (12)
Stage 2	27.0 (12)	34.2 (17)	20.2 (6)	18.5 (5)
Stage 2-1	7.8	17.1	−5.7	−19.3
	Area cultivatable			
1. Quartile[g]				
Stage 1	23.3 (8)	9.8 (5)	24.8 (11)	42.2 (17)
Stage 2	22.1 (7)	27.6 (13)	34.3 (14)	16.1 (6)
Stage 2-1	−1.2	17.8	9.5	−26.1
2. Cancian F-Distribution[h]				
Stage 1	17.8 (9)	15.3 (9)	25.7 (9)	41.1 (14)
Stage 2	25.8 (11)	36.4 (18)	20.3 (6)	17.5 (5)
Stage 2-1	8.0	21.1	−5.1	−23.6

[a] Approximation of ranks in the proportion of 25/25/25/25. Actual cutting points in acreage are as follows: Low = 1–6; Low middle = 7–11; High middle = 12–19; High = 20–282

[b] Stage of adoption, with Stage 1 representing high risk takers and Stage 2 low risk takers.

[c] Percent of total number in rank category adopting and standardized to a base of 100 across stages. Percentage scores do not add to 100 in all cases due to rounding error

[d] Number of cases

[e] Difference in percentage rates between Stage 2 and Stage 1.

[f] Approximation of ranks in the proportion of 30/30/20/20. Actual cutting points in acreage are as follows. Low = 1–7; Low middle = 8–13; High middle = 14–24; High = 25–282

[g] Approximation of ranks in the proportion of 25/25/25/25. Actual cutting points in acreage are as follows. Low = 1–6; Low middle = 7–11; High middle = 12–19; High = 20–213.

[h] Approximation of ranks in the proportion of 30/30/20/20. Actual cutting points in acreage are as follows: Low = 1–7; Low middle = 8–13; High middle = 14–23; High = 21–213.

rank structure, is related to the adoption of innovations in a manner directly opposite to that predicted by Cancian. Furthermore, examination of the variation of Stage 1 percentage rates over the four ranks reveals a direct gradient extending from low to high rank with the exception of a dip occurring at the low middle rank. In effect, the data suggest the existence of a curvilinear pattern. Contrary to Cancian's hypothesized upper middle rank conservatism, however, the data indicate a pattern of lower middle rank conservatism.

Area cultivatable

Turning attention to the quartile breakdown of the area cultivatable variable, we note that Hypothesis 1 ($9.8 \ngtr 24.8$) and Hypothesis 2 ($9.5 \ngtr 17.8$) are refuted by the findings. Moreover, when we consider the data presented for the Cancian T-Distribution breakdown, Hypothesis 1 ($15.3 \ngtr 25.7$) and Hypothesis 2 ($-5.4 \ngtr 21.1$) are both rejected. Taken as a whole, the data do not lend support to the argument that those of high middle rank adopt significantly less than their low middle rank counterparts in the early stages of adoption, nor that the difference in adoption rates between the early and late stages of adoption for those of low middle rank is greater than the similar figure for those of high middle rank. Further, as noted for the area owned variable, inspection of the variation of Stage 1 adoption rates over the four ranks reveals the existence of a curvilinear pattern. That is, the variation of percentage rates is characterized by a rising gradient extending from low to high rank, with the exception of the low middle rank which exhibits a lower rate than either of the other three ranks. Thus, contrary to Cancian's understanding of the relationship, these findings denote a pattern of lower middle rank conservatism.

SUMMARY AND DISCUSSION

We have examined the relationship between economic rank and the adoption of agricultural innovations with data collected from 173 farmers residing in 10 villages in the Punjab province of Pakistan. More specifically, this investigation has centered on an assessment of Cancian's upper middle class conservatism thesis as represented in two specific hypotheses. Utilizing acres of land owned and acres of land cultivatable as measures of rank and an index based on the summation of eight weighted agricultural innovations as a measure of adoption, we presented four tests for each hypothesis. Regardless of the rank variable used in the assessment, the findings fail to confirm either of the hypotheses.

Although the findings fail to confirm the two hypotheses, an unexpected finding emerges from the analysis. That is, contrary to the direct and linear relationship reported in the traditional literature (Chaudhari, et al., 1968; Rogers and Shoemaker, 1971:354-63) and by previous researchers replicating Cancian's research (Gartrell, et al., 1973; Morrison, et al., 1976; Gartrell, 1977), the current findings suggest the existence of a curvilinear pattern. Unlike the curvilinear pattern of upper middle rank conservatism reported by Cancian, however, the present findings indicate a curvilinear pattern of lower middle rank conservatism. This finding represents a serious anomaly for Cancian's theory, for it would appear that the "facilitating effect" is operating in the earliest stage of adoption. And as Cancian (1977b:Chapter 2:12) has noted: "According to the theory developed here, ... (the "inhibiting effect") is most likely to occur in the early stages of the spread of an innovation." Consequently, we suggest that Cancian's theory is incomplete, for it cannot adequately explain the existence of the pattern of lower middle rank conservatism reported here. If the curvilinear relationship between rank and adoption is, in fact, a valid empirical generalization, further theoretical work must be undertaken to provide a more adequate explanation for its existence.

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APPENDIX 16

AGRARIAN STRUCTURE, NEW TECHNOLOGY AND DISTRIBUTION OF BENEFITS: THE CASE OF PAKISTAN[1]

by

M. Lowdermilk, J. Layton, and W. R. Laitos[2]

Rural sociologists and students of international agricultural development have been concerned for a long time with the ways by which institutional structures distribute the benefits of new technology. Karl Marx (1906), made the problem explicit in his theoretical writings and many students of agrarian reform have provided descriptive historical data which shows the powerful and influential reaping the major benefits from technological change (Lenski, 1966). Rather than studying the more general characteristics of an agricultural technology, this paper examines the specific components of the Green Revolution's high yielding variety technologies in an effort to identify who benefited from what, how much, and why. It will be the major tenet of this paper that the particular characteristics of those technologies, coupled with the distribution of institutional services and productive assets, have a direct effect on the income and power of a region. The Pakistan case provides a setting for such a study because the agrarian structure is still semi-feudal, HYVs gained initial international recognition in West Pakistan, and in recent years Pakistan's institutional problems have brought the Green Revolution to a near standstill. Given the new focus on basic human needs and small farmers, it is essential to understand the process of distribution of benefits in order to develop specific policies for more equitable and efficient agricultural production. The institutional problems of Pakistan, however, are by no means unique. Other developing nations are now facing similar problems of distributing the benefits of the HYVs more broadly to all classes of farmers.

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THEORETICAL FRAMEWORK AND METHODOLOGY

The conceptual framework of Gotsch (1972) used for this paper is taken from the institutional approaches of Mosher (1969); Mellor and Johnston (1967). As shown in Figure 1, the framework gives focus to five major components with "feedback loops" between components to indicate that the process of distribution of benefits of new technologies is both dynamic and reinforcing. In brief, the theory states that the absolute size and distribution of productive assets (land, water) will determine who adopts the technologies, who receives institutional services to support the technology, and who finally reaps the major benefits of increased personal income from the innovation. This increased income then operates to increase political power and maintain local customs and traditions, which favor the landed elites. In turn, those with political power have influence over institutional services and price policy which reinforce their privileged position. The five major components of this framework will be discussed in detail and supported by data from the Pakistan experience with the HYVs of wheat.

The empirical field data used are from 350 farms of the Punjab province in 1970 when the adoption of the HYVs of wheat was at its height. Other data utilized are from 251 farms in the Punjab province collected in 1976 as a part of a larger study. All data are from irrigated farms in the Punjab province where by 1976 about 75% of the irrigated region had been sown with the HYV wheat (Dalrymple, 1978). This province is the most abundantly endowed agricultural area of Pakistan in terms of land resources, water availability and control, and institutional services (Michael, 1967 and Lowdermilk, et al., 1978).

A major limitation of the data is that they represent two different samples and cannot be compared statistically in some respects. All farms of less than one hectare in size are excluded from the 1976 data to correspond to the 1970 data base. Also, the 1970 data are from a nonproportional random sample stratified on-farm size in 30 villages of a Tehsil* selected randomly from 38 villages. The 1976 data are taken from a random sample of farms in 12 villages selected purposively in eight agricultural districts. Despite these limitations, the data are useful for the purposes of this study and do provide valid insights concerning the "how" and "why" of the distribution of benefits of the HYV technology. Unlike most studies which "lump" all

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* A government administrative unit roughly equivalent to a large U.S. country.

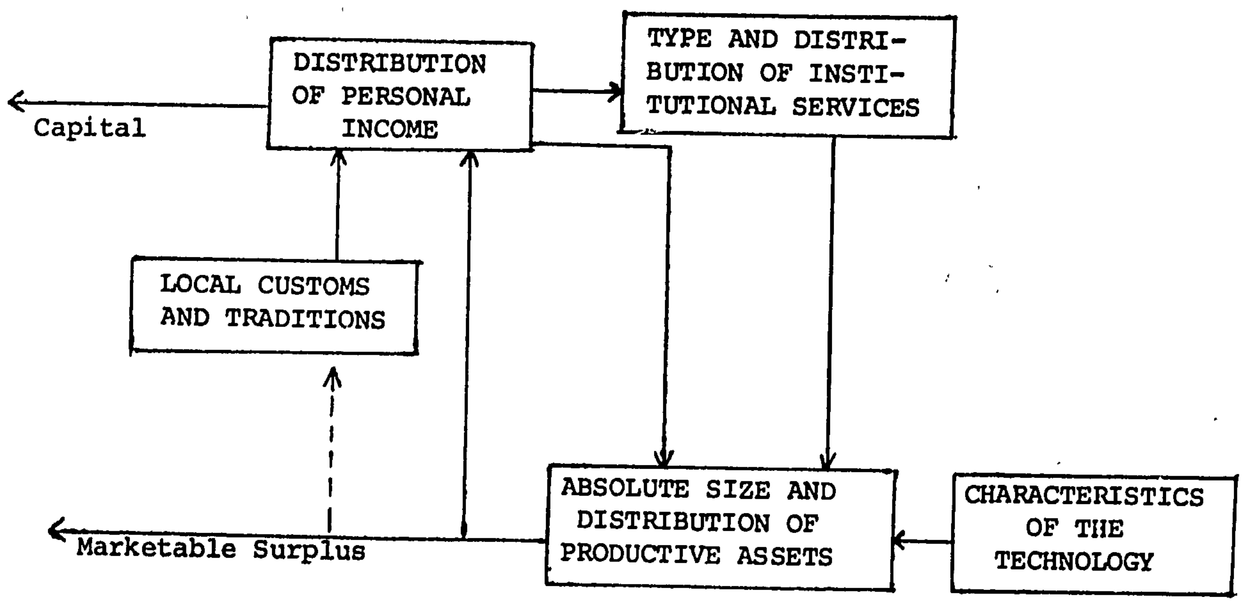

Figure 1. Growth and distribution of farm income at the community level (Gotsch, 1972).

HYV technology into one scale, we examine each innovation of the HYV technical package and its characteristics in relationship to farm size classes.

The paper will examine the following major dimensions of the theoretical framework as presented in Figure 1. These are:

1. Characteristics of the agrarian structure into which the HYVs were introduced.

2. Characteristics of the specific components of the HYV technologies.

3. Type and distribution of institutional services.

4. Distribution of income and power and maintenance of rural social norms.

5. Recommendations for a new strategy for equity and growth.

CHARACTERISTICS OF THE AGRARIAN STRUCTURE

The institutional context in which the HYVs were introduced in Pakistan is one where land ownership is highly skewed and political power and influence in the rural areas belongs to large landlords. Though there have been two weak attempts at land reforms, the semi-feudal agrarian structure of the Punjab is still characterized by 85 percent of the farmers with holdings under 5 hectares owning 43 percent of all agricultural land, and 5.2 percent of the farmers with holdings over 10 hectares owning 43 percent of the land. As Hirashima (1978) has shown, two token land reforms did little to change the rural power relationships. Saleen Khan (1978) estimates that in the Punjab province one percent own 18 percent of the land; in Sind province one half of one percent own 7 percent of the land, and one-tenth of one percent of the big landlords in the Northwest Frontier own 11 percent of the land. Of all holdings, roughly 37 percent are cultivated by tenants, 24 percent by owner-cum-tenants, and only 42 percent by owner operators (Agricultural Census, 1972).

Figure 2 presents Lorenz curves to show the inequality of land distribution in the Punjab of Pakistan and in one of the three districts where the HYVs of wheat have been primarily concentrated.

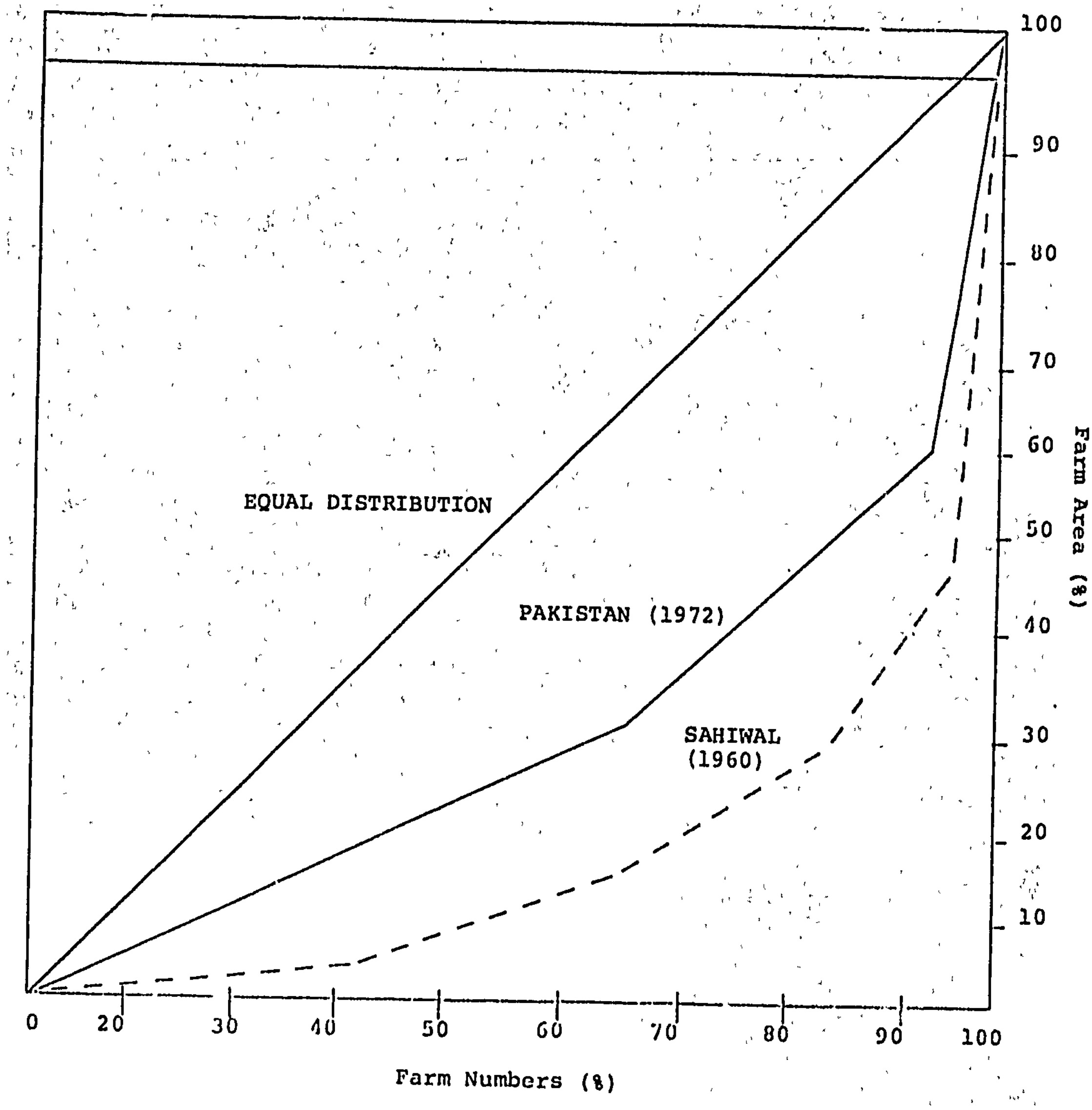

Figure 2. Distribution of owned land in Pakistan (1972) and in a major agricultural district of Punjab, Sahiwal (1962) (Gotsch, 1972).

The agrarian structure of Pakistan is also characterized by a high degree of tenancy and absentee land lordism. Table 1 shows the classification of farms according to land tenure classes and operational size (Agricultural Census, 1972).

In the two major provinces where the 1976 study was made, Punjab and Sind, 39% and 71%, respectively, of the farms were operated by tenants according to the 1972 agricultural census. Alavi estimated in 1960 that while roughly 70 percent of the rural elite controlled 70 percent of the land, nearly half the total farm area was in the hands of sharecroppers (Alavi, 1976).

The two land reforms of 1959 and 1972 resulted in little change in the agrarian structure. The 1959 reform benefited 56,906 or 2.8 percent of the pure tenant population in 1960 and only 2,562 or 0.04 percent of the pure owners or small farmers. About 60 percent of the land appropriated was not cultivated land. In the 1972 reform only about 200,000 hectares were appropriated and only 32 percent was cultivated land allotted to 7,828 tenants who received about 1.2 hectares each (Hirashima, 1978).

The characteristics of the agrarian structure of Pakistan suggest that the HYV technologies were introduced into a semi-feudal agricultural setting. According to the theoretical framework depicted in Figure 1, the magnitude and relative distribution of landholdings will determine who controls the inputs and services, who benefits in terms of increased yields and income from marketable surplus, and the degree to which the rural status quo maintains and supports the rural elite. The theory also suggests that the characteristics of the technologies are related to whom adopts and with what success.

CHARACTERISTICS OF THE TECHNOLOGY

Several studies refer to HYV technology as though all the components of the package are congruent in terms of characteristics. In fact, the innovations range from highly divisible seed, divisible fertilizer, divisible to fairly divisible management practices, to highly indivisible tractors and tubewells for supplementary irrigation water. These technologies can also be viewed as private and collective goods. In Pakistan public tubewells and government tractor stations represent public goods. Public irrigation water is supplied to farmers on a perennial or nonperennial basis, and as a collective, good farmers organize to maintain the farm system. Seed and fertilizer, on the other

Table 1. Classification of farms according to land tenure and operational farm size in Pakistan, 1972.

Farm Size in Acres	Type of Land Tenure			Total
	Owner	Owner-cum-Tenant	Tenant	
1	2	3	4	5
		(Percent)		
Up to 7.5	54	16	30	100
7.5 - 12.5	29	26	46	100
12.5 - 25.0	31	32	37	100
25.0 - 50.0	38	34	28	100
50.0 -150.0	49	35	16	100
Above 150.0	63	28	9	100
Total Farms (Number 1,000)	1,569	897	1,296	3,762
Percent	42	24	34	100

Source: Government of Pakistan, 1972 Pakistan Census of Agriculture, Ministry of Agriculture (Provisional data).

hand, are private goods. The main point to be stressed is that the nature of a specific technology determines to a degree who will adopt and who can benefit from the innovation.

Three major characteristics of the HYV technology are important for determining distribution of benefits of this technology. First, the new seed has all the positive attributes usually associated with rapid adoption. The attributes include relative advantage over the local varieties, congruence with the older practice, simplicity, high visibility, divisibility, low reversibility, compatibility, communicability, and timeliness (Rogers, et al., 1971; and Zaltman and Duncan, 1977). Data from Pakistan and many other countries show whatever the institutional context, the seed technology spread like a tidal wave to all classes of farmers (Dalrymple, 1976, 1977, 1978).

Tables 2 and 3 show the relationship of the size and tenure class of farmers to adoption of the HYVs over time. Adoption is defined as 50 percent or more of total wheat acreage sown to the HYV of wheat for given years. Note that in terms of our adoption definitions, only after the 1970 season do we find that the larger farmers with 10 to 20 hectares have adopted significantly more than the smaller farmers. Only in the 1976 study do we find owner operators slightly ahead of tenants in Table 3. In fact, tenants and small farmers have often been ahead of larger farmers and owners in adoptions. Though not shown in tabular form, in the 1970-71 study of 61 percent of those with 1-3 hectares in holdings and 59 percent of all tenants had 100 percent of total wheat acreage in the new varieties. This is compared to only 54 percent of the owner operator and 65 percent of the farmers with 20 or more hectares of land. Overall, one third of the Pakistani farmers who first tried the new wheat seed utilized it on 50 percent or more of their total acreage (Lowdermilk, 1972). The characteristics of the new seed were such that even in a traditional society the Pakistani farmers adopted the seed at a rate comparable to the adoption of hybrid maize by USA farmers in the 1930's.

In terms of profitability or relative advantage, the HYV yields were from 50 to 100 percent higher than local varieties with only minimum levels of fertilization. Even without extra fertilizer or water, using traditional practices, the HYVs were superior to local varieties (Lowdermilk, 1972). The new seeds were simple and compatible with farmers' past experiences with wheat production.

As suggested, the new seed was highly trialable in that farmers could try it on a very small scale. The attributes

Table 2. Percentage of farmers adopting HYVs for 1970 and 1976 studies by farm size classes.

Year and Study	Farm size classes (acres)				
	1-3 Ha (N=62) (1)	3-5 Ha (N=56) (2)	5-10 Ha (N=71) (3)	10-20 Ha (N=75) (4)	20 Ha (N=86) (5)
1970 study					
1966-67	5.2	5.4	1.4	2.6	2.3
1967-68	25.8	16.2	15.4	23.9	37.6
1968-69	59.1	60.9	67.8	69.1	78.5
1969-70	69.4	72.1	74.5	81.1	90.3
1970-71	74.2	78.9	84.5	89.3	93.5**
1976 Study	84.0 (N=58)	81.0 (N=52)	98.0 (N=61)	100.0* (N=17)	100.0* (n=8)

* Farm size classes (4) and (5) significantly different from (1) and (2) at 0.07 level (1976 study).
** Farm size class (5) significantly different from (1) at 0.01 level (1970-71 study).

Table 3. Percentage of farmers adopting HYVs for 1970 and 1976 studies by tenure class.

Year and study	Tenants (N=63) (n)	Owner-cum-Tenants (N=52) (2)	Owner/operators (N=235) (3)
1970 study			
1966-67	0.0	2.8	5.2
1967-68	16.0	26.1	21.9
1968-69	73.0	52.1	61.3
1969-70	83.8	58.0	75.7
1970-71	92.9**	71.4	77.6
1976 study	86.4	77.1	93.6*

* Tenure class (3) significantly different from (2) at 0.001 level (1976 study).
** Tenure class (1) significantly different from (2) and (3) at 0.001 level for 1970-71.

of the new seed, therefore, did not constrain the wide and rapid adoption of these HYV technologies. Other factors, noted below, were responsible for the ultimate maldistribution of benefits.

A second major characteristic of the HYV technology is that like most agricultural innovations, the new seed require a definite set of associated or complimentary practices and inputs for optimal yields. Few studies have given adequate attention to the role of associated practices (Roy, et al., 1968). The conventional view in Sociology and Economics has been that divisible innovations such as seed and chemical fertilizers can be tried and adopted in small increments without large initial cash outlays. Indeed, the assumption often made is that farmers who adopt a new technology also adopt the associate practices which make it profitable (Rogers and Shoemaker, 1971). Theoretically, therefore, there should be no major impediments to small farmer adoption (Probhat and Ashok, 1973). Few studies, however, show the relationship between the adoption of these innovations and the social system or contextual effects. It is crucial to realize that the social context which received the innovation affects adoption rates and distribution of benefits (Vand den Ban, 1960; Qadir, 1966; Saxena, 1968; and Davis, 1968).

The contextual effect of rural Pakistan on the adoption of the associated practices of HYV wheat is shown in Table 4. The associated practices are actual recommendations researched extensively in Pakistan and India (Lowdermilk, 1972). As Wharton (1969) has shown, the new seed technology requires "new skills and expertise of a higher order than was required in traditional methods of cultivation." These include deep plowing for seedbed preparation, proper sowing dates, sowing method for improved seed placement, seed rates higher than traditional varieties, a critical seeding depth of not more than 2.5 inches, adequate levels of nitrogen and phosphorous fertilizer, and split nitrogen applications. Note that none of these practices require large outlays of cash and all are divisible. Also note that there is a significant relationship between utilization of these practices and farm size which indicates that the larger the farm size, the greater the use of the recommended practice. Data under B in Table 4 suggest that there is a low level of knowledge of these practices by all classes of farmers. As will be shown later, farmers are not provided with adequate extension and information services.

A third major characteristic of HYV technologies such as tubewells and tractors is that of indivisibility. Though both of these technologies can be labor saving through hire

Table 4. Percentage of HYV wheat farmers utilizing selected recommended practices and having correct knowledge about selected practices (1969-1970 and 1975-1976).

Recommended Practices	1970 Survey N=324	1976 Survey N=200
A. Utilization		
Seedbed preparation	28*	30**
Sowing date range	NA	64
Sowing method	5*	24**
Seed Rate	39*	55
Depth of seeding	NA	39*
Nitrogen fertilizer	7*	18*
Phosphorous fertilizer	7*	8*
Nitrogen application	41*	42
B. Knowledge of:		
Seedbed preparation	NA	40*
Sowing date range	70	60
Sowing method	NA	66
Seed rate	NA	63
Depth of seeding	44	37
Nitrogen fertilizer	NA	38
Phosphorous fertilizer	NA	52
Nitrogen application	60	42

** and * respectively denote significant differences of 0.01 0.05 level using chi square test in relationship to farm size, i.e., the larger the farm size, the greater use or knowledge of the recommended practice indicated.

schemes or collective ownership, the tendency in Pakistan is ownership by large landlords. Over 90 percent of the tractors in the Punjab are owned by farmers with large landholdings of over 10 hectares. Lowdermilk (1972) found that only 3 percent of tractor farmers had less than 5 hectares, and Mubasher (1978) reports in 1975 that of about 36,000 tractors in Pakistan, less than 4 percent were owned by farmers with less than 5 hectares of land. Though there is a big demand for tractor hire, primarily for land preparation between crops for increased cropping intensity by farmers of all classes, large landlords do not make this service available (Lowdermilk, 1972).

Another technology that is important for the HYV of wheat is supplemental irrigation water from tubewells which not only provide more water, but also allow for improved water control which is essential for good yields.

In Pakistan about 70 to 75 percent of the private tubewells belong to farmers owning 12.5 hectares or more (Ghulam Mohammed, 1965 and Lowdermilk, 9972). Table 5 provides data on private tubewell ownership.

Tubewell farms as compared to non-tubewell farms have higher cropping intensities, utilize more fertilizer, and have higher yields per hectare (Lowdermilk, 1972). It is interesting, however, that of the 118 private tubewells, only 49 percent reported selling water to other farmers. The larger the farm, the less the selling of tubewell water. It is the smaller tubewell farmers who make water available to other farmers.

Table 6 shows that availability of supplemental supplies of water to the canal supplies is significantly related to farm size for both the 1970 and 1976 studies: private tubewell farmers have greater control over irrigation in relationship to crop demand, higher yields and consequently higher income per hectare (Lowdermilk, Layton, et al., 1979). The relative indivisibility of tractors and private tubewells, therefore, is another strong factor in the skewed distribution of benefits of the HYV technologies.

TYPE AND DISTRIBUTION OF INSTITUTIONAL SERVICES

As suggested in the discussion about associated practices and complimentary inputs, it is essential that farmers adopt these inputs and practices for optimum benefits from the HYVs. In most low income nations initially, physical inputs, extension services, credit, and relevant information reaching farmers are in short supply. In such an environment,

Table 5. Frequency and percentage distribution of tubewells in two field studies in Punjab.

Farm Size Hectares	1972 Lowdermilk Study		1965 G. Mohammad Study	
	no.	% of Total Tubewells	no.	% of Total Tubewells
Less 12.5	16	0.13	2	0.06
12.5 - 20	35	0.30	10	0.29
20 - 60	45	0.38	20	0.57
Over 60	22	0.19	3	0.08
All Sizes	118	1.00	35	1.00

Table 6. Percentage of sample farms and availability of irrigation water supplemental to canal supply (1969-1970 and 1975-1976).

	Availability of Supplemental Supplies								
	1969-1970 Study				1975-1976 Study				
Farm Size (Ha)	No.	Very Diff %	Easy %	Private Tubewell	No.	None %	Diff %	Easy %	Private Tubewell
1-3 I	62	76	24	6	56	41	22	37	14
3-5 II	56	76	24	5	54	30	37***	33	18
5-10 III	71	63	37	13	57	23	21	56	13
10-20 IV	75	32	68	47	16	25	19	56	29
20 > V	86	18*	83*	78*	8	12*	--	88*	50**
All sizes (Weighted)	350	65	35	34	191	30	25	45	17

Difference in proportions by farm size classes:
* V over I, II, III, IV: significant at 0.01 level.
** V over I, II, III, IV: significant at 0.05 level.
*** II over I, III: significant at 0.04 level.

large landlords who dominate local and provincial politics have the power and influence to acquire fertilizer, affect market prices, obtain credit for tubewells and tractors, and commondeer extension services. Both corruption and coercion are methods used whether the institutional services are provided by the private or public sector. As Alam (1974), Alavi (1971), and Gotsch (1972) suggest there is little that cannot be obtained in Pakistan with the right power and influence. The Punjabi Proverb often used by the small farmer is essentially true, "No one will listen to me because I do not have influence, strong relatives, or a bribe."

The major services analyzed for the purpose of this paper include credit for fertilizer, availability of fertilizer and extension services. As depicted in our theoretical framework, the distribution of income and power will eventually be affected by the aggrandizement of these elites.

Table 7 provides data about the percentage of farmers obtaining credit or capital for fertilizer and the availability of commercial fertilizer when needed for the HYV of wheat. Note that with both credit and fertilizer the small farmers are at a great disadvantage. Though not shown in Table 7, the percentage of small farmers (holdings of less than 3 hectares) receiving institutional credit for fertilizer for the 1975-1976 wheat crop was only 8 percent in 1976 compared with 36 percent of farmers with 10 or more hectares of land. The new fertilizer loan program is a great improvement over the loans provided by cooperative credit societies, which were virtually controlled by large landlords. Subsidized credit for tubewells and tractors has been provided almost solely to large landlords because loans were simply not made available to farmers with less than 5 hectares of land for tubewells or tractor investments.

Scarce resources of information about the HYVs which Wharton (1969) and others consider essential for management decision making also accrue to the larger farmers. Not only is the extension service in Pakistan both quantitatively and qualitatively weak due to inadequate numbers of field personnel and inadequately trained personnel, but the few services available seldom reach small farmers. Lowdermilk (1972) found that extension field workers played an insignificant role in the diffusion of the HYVs of wheat. For example, at the trial and adoption stages in the 1969-1970 study and the 1975-1976 study, only 16 and 17 percent of the farmers respectively reported using some information or advice from extension personnel.

Table 7. Percentages of farmers obtaining credit or capital for fertilizer and commercial fertilizer when needed for HYV of wheat (1969-1970 and 1975-1976).

Farm Size (Ha)	Percentage of Farmers Obtaining Credit for Fertilizer When Needed					
	No. Farms	Credit for Fertilizer (1969-1970)	Fertilizer	No. Farms	Credit for Fertilizer (1975-1976)	Fertilizer
1-3 I	51	24	23	58	22	39
3-5 II	51	33	24	52	38	51
5-10 III	65	35	25	61	48	63
10-20 IV	71	56	25	17	53	88
20 V	86	71	61	8	100	100
All Sizes	324	47	32	196	40	56

Table 8. Percentage of farmers having some and no contacts with extension personnel (1969-1970 and 1975-1976), (Lowdermilk, 1972).

Farm Size (Ha)	Extension Contacts with Farmers in six months					
	1969-1970 Study			1975-1976 Study		
	No.	Some %	None %	No.	Some %	None %
1-3 I	62	11	89	70	14	86
3-5 II	56	16	84	68	13	87
5-10 III	71	21	79	64	30	70
10-20 IV	75	35	65**	17	41	59
20 V	75	64	36*	18	63	37***
All Sizes	350	20	80	227	22	78

* Difference in V over all classes at 0.001 level.
** Difference in IV over I at 0.001 level.
*** Difference in V over I at 0.001 level.

Table 8 provides information about the low level of contacts small farmers have with extension workers. Note that while 80 percent of the farmers reported no contacts in six months, almost 65 percent of the large farmers had contacts for both the 1969-1970 and 1975-1976 studies. Though not shown in the table for the two studies, 51 percent and 84 percent of the farmers interviewed respectively in 1969-1970 and 1975-1976 could not report the name of the extension worker assigned to their area but almost all farmers could report the name of the officials who collect water and land revenue. As Lowdermilk (1972) and other observers (World Bank, 1976) have shown, the current extension service hardly touchs the small farmers whatever the quality of information provided. The senior author knows of several occasions when a deputy director of agriculture was ordered to station an extension worker on the farm of a prominent political leader.

DISTRIBUTION OF INCOME, POWER, AND MAINTENANCE OF RURAL SOCIAL NORMS

The theoretical framework of this paper suggests that those who control land and water resources have influence over essential services. These elites, therefore, reap benefits from the new technology which adds to both their income and power. In turn, the maintenance of the status quo results in little change in local norms and customs.

First, power and influence in most rural areas of low income nations are highly correlated with landholdings for individuals and social groups (Ullah, 1963; Raza, 1969; Lowdermilk, 1975: Vol. III). Lenski (1966) documents this relationship across cultures and across time. In a recent comprehensive survey of 50 farm irrigation systems in Pakistan, farmers rated all other farmers with respect to power and influence of individuals over watercourse cleaning and settling disputes. As expected, there is a significant relationship between this measure of power and influence and area of land owned (Lowdermilk, Freeman, and Early, 1978).

Power and influence of large landlords is expressed in other ways which include influence over local officials, contacts with important officials and politicians, and even influence over agricultural policy (see Alan, 1974 and Alavi, 1971). This power is reinforced by the benefits received from the HYVs.

Two examples will suffice to show how this takes place through additional income earnings. First, larger farmers have a larger marketable surplus. In 1968-1969 and 1969-1970, the average proportion of the wheat crop marketed by farmers of various farm size classes was as follows (Lowdermilk, 1972):

1 - 3 Ha.	3 - 5 Ha.	5 - 10 Ha.	10 - 21 Ha.	20+ Ha.
15%	29%	31%	38%	59%

This indicates that farmers profited in relationship to their control of the scarce resource of land. Second, farmers who control the land resources also tend to dominate the ownership of private tubewells. As suggested earlier, water control is essential for optimum yields for the HYVs. Table 9 data show the net returns to management for wheat under various water control situations. Note that the net return per acre for private tubewell farmers is 1.7 times that for farmers with no tubewell water supplements. Though not shown in tabular form, the net returns per acre for rice and cotton for private tubewell farms and non-tubewell farms respectively is Rs. 380 and Rs. 429 as compared with Rs. 145 and Rs. 55 for non-tubewell farmers for the two crops.

It is evident that all classes of farmers benefited from the new technology. Given the particular institutional structure of Pakistan, however, the larger farmers not only benefited in proportion to their control over land, but further solidified their social position and control over the rural areas. Alam (1974) is correct in his statement that agricultural modernization in Pakistan without radical reforms in the agrarian structure will only accentuate the feudal power of the big landlords. As Hirashima (1978) has shown, two token land reforms did little to change the rural power relationships. Khan (1978) states that the large landlords cherish no change in the status quo and have missed no opportunity to sabotage land reforms. In spite of the land reforms, "the land aristocracy appears to be deep-rooted and firm on all political and economic institutions of the country" (Khan, 1978).

Though current income data are not available for the rural areas, 1963-1964 data indicate that roughly 29 percent of rural households received Rs. 100/month which was a biologically "lower subsistence" level, and 54 percent received only 7 percent of the rural income as compared to 43 percent by the top 20 percent of the households (Bergan, 1967).

Observers of the Pakistan scene realize that the landed elite are almost as well established today as at the time of partition when the Muslim league was predominantly controlled by landed interests. Kizilbash (1973) suggests that there

Table 9. Average per acre returns to land, risks, and management for selected types of wheat farms (1975-1976).

	Type Farm				
			No Tubewells		
	Public Tubewell	Private Tubewell	No Tubewell[1]	Head Farm	Tail Farm
Seed	40.0	40.0	40.0	40.0	40.0
Fertilizer	82.5	82.5	67.5	90.0	87.0
Labor	77.5	77.5	77.5	77.5	77.5
Bullock Power	185.0	185.0	185.0	185.0	185.0
Taxes (Land/Water)	35.0[2]	45.0[3]	24.6	24.6	24.6
Harvest Costs	75.2	90.3	67.7	75.2	67.7
Payments Artisans/Tools	31.4	31.4	31.4	31.4	31.4
Farm Manure	20.0	20.0	20.0	20.0	20.0
Miscellaneous	32.95	32.95	32.95	32.95	32.95
Total Cost per Acre	579.55	604.65	546.65	576.65	566.15
Yields/Acre in Maunds	20	24	18	20	18
Maunds at Rs. 40 ea	800.00	960.00	720.00	800.00	720.00
Straw at Rs. 4/md[5]	160	192	144	160	144
Gross Income	960.00	1,152.00	864.00	960.00	864.00
Net Income Income Total (Gross Cost)	RS 380.45	RS 547.35	RS 317.35	RS 383.35	RS 297.85

[1] "No Tubewells" represents all commands both perennial and non-perennial, head, middle, and tail farms plus those farms with portions of land at more than one location.

[2] Land and canal water revenue combined. In case of public tubewell water the assessment is included in the abania or canal rate.

[3] The cost of tubewell water included with irrigation water is estimated as 3 extra irrigations from private tubewell at a cost of Rs. 5.00 per hour for 6 hours assuming 50% delivery efficiency.

[4] Harvest costs are related to the yield of the crop.

[5] Bhoosa or straw sells at various rates depending [illegible]

is little security of property, of livelihood, of residence, or of employment for the tenant farmer or the landless labor class because these are influenced by the rural structure and the power of the large landlords. Attempts by local government and two major externally financed programs for village development have failed due to the vested interests of feudal landlords and the threat to the power and privileges of government officials who have many incentives to maintain the colonialistic patterns of administration (Kizilbash, 1973; see also Alavi, 1971).

As landlords have gained from the new technology they have maintained their power in the rural areas. Therefore, local customs and traditions have changed but little. For example, landlords have unusual control over servants and tenants and their wives and children, and they still demand special services from tenants such as firewood and house repairs, which are not permissible under the new tenure agreements of 1972. Though legally tenants cannot be evicted without just cause, landlords have many extra-legal means to evict tenants; though the 1972 land reforms legislation established terms for sharecropping, local custom still largely prevails. Frankel (1973) shows that the new technology, while helping to change norms of crop sharing, actually works to benefit the landlord and not the tenant. Given the use of tubewells, tenants must now pay a share of the cost of extra water and borrow money from the landlord for fertilizer. The traditional one-twentieth of the harvest for cutting grain is now replaced by a fixed amount of grain which favors the landlord. In 1972 Lowdermilk found that while the median rate for winnowing grain was 1.4 kilos per 64 kilos of grain for landlords with 30 hectares or more of landholding, it was 1.8 kilos per 64 kilos of grain for farmers with less than 3 hectares of land. Though by law the share basis for the crop is 60 percent for the tenant and 40 percent for the landlord, in actual practice the old norm prevails (Khan, 1978). While many old norms remain, it also is true that there is today much ferment in the rural areas which results from growing income disparity, political instability, and rising inflationary pressures. As Frankel (1973) suggests, the HYV technologies have also played a role in creating rural awareness and discontent.

SUMMARY AND RECOMMENDATIONS FOR A NEW STRATEGY

Pakistan today is at an economic and political crossroads. In terms of agricultural growth, there has been little or no progress in relation to population increases since 1970. Pakistan had a good start with HYVs of wheat, but for the last few years it has imported from 1.0 to 1.5

million tons of wheat per year, while India is self-sufficient. Politically, Pakistan is undergoing a difficult period and has yet been unable to evolve a workable form of local government or a national government based on adult franchise.

As this paper has demonstrated, all farmers benefited from HYVs, but benefits to large landholders have eclipsed benefits to small farmers. This occurs because large landholders are able to adopt more practices. They have a greater access to tubewells and have power and influence to obtain tractors, fertilizer, and extension services. Given the ability of large landholders to obtain needed resources, their use of HYVs results in a much larger marketable surplus per hectare. This larger surplus solidifies and enlarges large landholder's power, prestige, and influence which in turn gives them easier access to resources...creating a continuing cycle of wealth and power.

The small landowner, however, continues to suffer. While adoption of HYVs may have created a small surplus for him, his inability to tap into other resources prevent him from optimizing the possibilities inherent in innovation adoption. He still has no power, no influence, no wealth. He is caught in a continuous cycle; a cycle of insufficiencies, insecurities, and inequities.

To break out of the vicious cycle a concentrated effort must be made by Pakistani policy makers, researchers and extension personnel. A set of policies must be implemented which takes into consideration the nature of the technology, and the distribution of productive assets, income, power, and institutional services.

First, neither effective local government, development planning, nor long-term agricultural development can take place without reduction in the power and influence of the rural elite. This will require specific and tough agrarian reform laws which emphasize a more equitable distribution of productive resources.

Second, a complementary package of inputs must be devised which should be accessible to the small farmer and tenant. Without the complementary resources and practices at his disposal, the small farmer will never realize the full benefits of the HYV technologies.

Third, a new attitude on the part of government officials is required. Small farmers should not be looked upon as the <u>problem</u> of rural development in Pakistan, but rather as the <u>solution</u> to a host of vexing issues. Given Islam's emphasis on equity and brotherhood, such an attitudinal change should not be beyond the realm of possibility.

While the eventual outcome of Pakistan's future cannot be predicted, many observers are increasingly convinced that immediate changes in Pakistan's social structure are necessary. The technologies of the HYVs can play a significant part in that change. While many of the aspects of the new technology cannot be changed, the alteration of the social context into which the technology is introduced can have a profound effect on the long-term equitable growth of Pakistan's rural areas.

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APPENDIX 17

THE LOOMIS SOCIAL SYSTEM FRAMEWORK: APPLICATION TO IRRIGATION SYSTEM RESEARCH[1]

By
James J. Layton and Max K. Lowdermilk[2]

Many researchers who are involved in the studying of irrigation systems with the purpose of utilizing their findings for the development of programs to change those systems, and/or the resulting farm practices, generally pursue a strategy of first identifying critical areas of the particular systems which should be subject to change before any activity is initiated. The purpose of this paper is to discuss one analytical format which may be used as a mechanism to systematically delineate such sociological problem areas. This format is created by using the concepts which make up the Loomis Social System Framework and organizing those concepts under criteria found to be of importance in the literature on irrigation systems. A general statement pertaining to the dimensions of the institutional environment permeating an irrigation system will provide an introduction to the development of the research format. After the format has been developed, the use of it will be demonstrated on a particular problem identification study of an irrigation system in Pakistan. The effectiveness of the format will then be discussed in the final section of this paper.

Social Dimensions of an Irrigation System

When examining an irrigation system, a researcher must be cognizant of two general environments into which the irrigation system is placed: the physical environment and the institutional environment (Figure 1). The physical environment constitutes such natural parameters as topography, soil types, quantity of water available, quality of water available, climate, and so on. Dimensions which constitute the institutional environment are the network of rules encompassing the irrigation system, the organizational network surrounding the system, interaction patterns within the system, and beliefs and feelings about the system.

Both of these environments interact with each other in a mutually influential manner. The physical nature of the irrigated area will affect what type of system may be developed;

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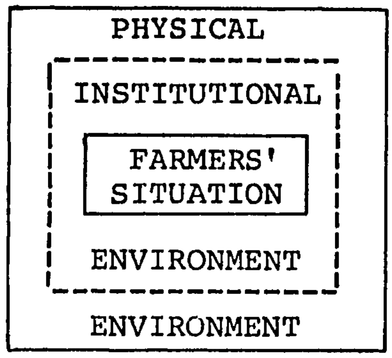

Figure 1. General environments surrounding an irrigation system.

but the demographic characteristics, the historical background of the area, and the institutional network encompassing the people of that irrigated area will affect how the irrigation system will be established. In addition, the combination of these two environments will influence how an individual farmer irrigates and manages his farm.

The physical environment will not be considered in this paper for the focus of the argument will rest on the institutional environment. What is of concern here is to extract a workable research format which taps this environment in a manner that will yield an understanding of how the irrigation system functions. Based on information emerging out of the utilization of this format, specific solutions to problems in the irrigation system can be established, assessed, and implemented.

Various authors focusing on the institutional environment examine five major areas of the irrigation system: characteristics of the area; the organizational network surrounding the storage, delivery, application, and drainage of the irrigation water; the normative situation permeating the use of the water; the relationships between the actors involved in the irrigation system; and specific problems encountered in the development of those systems. The characteristics of an irrigation system, studied in addition to the physical aspects, include the technology available to manage the irrigation system (World Bank, 1976) (Thornton, 1975) (Wiener, 1972), and the farm setting which included, among others, size and tenancy (World Bank, 1976). Many authors also examined the organizational network created to manage the irrigation waters (Chin, 1970) (Wiener, 1972) (Caponera, 1970) (Coward, 1976) (Harriss, 1976) (Gillespie, 1975) (World Bank, 1976). Other researchers focused on the norms surrounding the irrigation system which included laws, decision making aspects, and various individual practices (World Bank, 1976) (Caponera, 1970) (Hunt, 1976) (Pasternak, 1972) (Thornton, 1975) (Radosevich, 1975). All of the above mentioned authors also focused on relationships among farmers on the irrigation system, between government agencies managing such systems, and between the farmers and the government. Of special concern was the effect modern irrigation practices and management had on existing traditional institutions (Coward, 1976) (Harriss, 1976) (Duewel, 1976).

The major areas of research recognized for the study of irrigation systems may be subsumed under the more general social system framework presented by Charles Loomis. Therefore, in the attempt to construct a format which will be used in the problem identification phase of a study of an irrigation system, the Loomis framework will serve as the foundation for the study of the institutional environment. A brief description of the Loomis framework will be presented and then following that discussion the problem identification format will be constructed.

The Sociological Frame of Reference: Loomis

The sociological frame of reference as defined by Loomis is as follows:

> "The frame of reference yields the discipline's particular phenomena which is interaction, characterized by patterned social relations that display in their uniformities social elements, articulated by social processes, the dynamics of which account for the emergence, maintenance, and change of social systems." (Loomis, 1960:1)

As stated in the definition, the core phenomenon is interaction which is characterized by patterned social relations. This means that when one is examining the institutional network of an irrigation system, the focus of interest should be on the relationships that occur over time which determine how a farmer manages his operation or how an agency performs its particular function.

In describing these relationships, three categories are used as organizational references: elements, processes, and conditions for social action. Conditions for social action are components of the social system which are not completely controlled by the members. They provide the foundation from which the interaction evolves. Elements are units of analysis which are employed to explain interaction. These are the dimensions from which the relationships can be built. Processes contain those conditions which alter, stabilize, or mesh the relationships between the elements through time. Thus the elements provide the framework which defines the structure of the relationships, and the processes influence that framework to the point that it either remains in a similar condition or undergoes changes. In order to narrow the focus of this paper, the major actor to be considered in these various relationships that will be discussed is the farmer.

A Format for Sociological Analysis

Loomis' framework provides the basis for constructing a format for problem identification of the social system. Presentation of the framework in an action oriented environment was developed by Santopolo, Gallaher and Johnston (Johnston, 1969) and it will be based upon this latter framework that a format for problem identification will be discussed. Figure 2 depicts the basic aspects of the problem identification format.

SITUATION				ACTION
SETTING	CULTURE	STRUCTURE	PROCESS	RESULT

Figure 2. The basic format for problem identification.

Problem identification centers on identifying the existing conditions surrounding a farmer which leads to a specified set of behavioral responses performed by that farmer. Therefore, the construction of any format must be dichotomized into 1) what the situation is regarding the farmers, and 2) what type of action is a result of the farmer's response to that situation. Under the situation, four categories of phenomenon emerge. These categories are based upon Loomis' elements, processes, and conditions for social action. The setting corresponds to the conditions for social action. Culture and structure yield two distinct types of elements which provide a network of factors which places an individual in a particular position in the social system. Processes are those conditions which will either be facilitators or constraints to changing the existing network surrounding the farmer. The result is the behavior performed by the farmer with respect to his situation. This general framework will now be further specified to provide the researcher with some guidelines for implementing a problem identification study.

Loomis has detailed a number of dimensions which are used as benchmarks to describe a social system. The following format takes many of these dimensions, and with the addition of a few other concepts a map of a social system is beginning to evolve (Figure 3).

The Setting

The setting refers to the arena into which the social system is placed. There are many physical measures of the setting but four of a social science nature include:

SETTING	CULTURE	STRUCTURE	PROCESS	ACTION RESULT
Size	Activities (sentiments & beliefs)	Placement of the individual (status-role position)	Communication	
Time				
Territoriality	Relationships (sentiment & beliefs)	Characteristics of the individual	Boundary maintenance	Decision making
Facilities	Rules (sentiments & beliefs)	Capacity of individual (stratification)	Systemic linkage Social control	

Figure 3. A format consisting of general social system dimensions.

- Territoriality: The spatial arrangements and requirements of a social system. Example: the placement of the village with regard to the fields.

- Size: The geographic area comprising the social system. Example: how large the irrigation canal is.

- Time: The time frame within which a social system operates. Example: seasonality of crops and that influence on the farmer's work habits.

- Facilities: Means to achieve the ends. Example: establishment of a credit system to buy the fertilizer to use on the fields.

Culture

Culture describes the patterned ways of thinking, feeling and behaving in the social setting. Three general dimensions that provide the parameters for examining culture are:

- Activities: Those deeds and actions performed by the farmers. Example: the application of water on the farmers' fields.

- Relationships: The social interaction between actors involved in a specific activity. Example: the relationship between the farmer and the official in charge of distributing the irrigation water.

- Rules: The normative behavior governing what relationships are established and what activities are defined as socially acceptable or unacceptable. Example: trading water by the farmers.

As can be seen in Figure 3, behavior is not the only criteria used to describe cultural conditions, under each of the dimensions beliefs and sentiments are also important to acknowledge. Beliefs are aspects of the social system that are accepted as true (knowledge) while sentiments are feelings about the world.

Structure

Structure is the aspect of a social system which describes the relationships established in that setting. Structural dimensions include 1) placement of the individual in a social system, 2) characteristics of the individual, and 3) the capacity of the individual.

- Placement of the individual (the status-role position): These are organized subsystems of acts of actors occupying related positions and acting toward one another via reciprocal orientations. Example: two status positions are a farmer and an irrigation official. Each has a particular set of behaviors that they perform, i.e., plant crops, raise animals, etc., for a farmer and distribute the water for an irrigation official. These two status positions interact with each other when the farmer is allowed to take only so much water for his irrigation turn. The rules governing the interaction provide the orientation surrounding that interaction between the two actors.

- Characteristics of the individual: These include personal descriptors of the individual such as age, sex, marital status, etc.

- Capacity of the individual:

  Power: the ability to control others. Example: large landlords can force their tenants to perform specific work for the landlord.

  Stratification: the overall appraisal of social positions. The unequal distribution of valued resources; i.e., wealth, power, prestige. Example: farmers along a watercourse are stratified according to the amount of land they own, the amount of income they have, their relative position on the watercourse, etc.

Processes

Processes are long continued actions that create a different ordering and arrangement of the elements of a social system. They determine the development, the persistence, and the change of a social system. Included in the processes are communication, boundary maintenance, linkage, and social control.

- Communication: the process by which information, decisions, and directives pass through a social system, and the ways in which knowledge, opinions, and attributes are formed or modified. Example: the extension program communicates to farmers new programs concerning hybrid crops, new fertilizers, etc., to change their old farming habits so that the farmers may increase their yields.

- Boundary Maintenance: the process where the social system maintains its identity and interaction patterns. Example: some brotherhood groups in a village will not allow their members to marry with other specific brotherhood groups.

- Systemic Linkage: the process where the elements of at least two social systems come together so that in some way they function as a unit. Example: the university extension program linking with the farmer as to new farm techniques.

- Social Control: the process by which deviance is counteracted. Example: enforcement of laws to make sure farmers do not trade water amongst themselves if trading water is illegal.

The Results

The result constitutes the action position in this format. In the sense of problem identification the result only infers to the decisions farmers make about their operations given the situations in which they are placed. Thus decision making is the critical dimension describing this category. Decision making will be defined as the process where alternative courses of action are available and acted upon so some sort of action proceeds within the social system. An example would be where a farmer decides on what crops to plant based on his perception of climate, water supply, credit, seed availability, and other inputs.

Utilizing the Format for Sociological Analysis

The major purpose of this format is to provide a means by which an irrigation system may be systematically explored.

One method to achieve that goal is to provide a network of possible questions that may be asked to delineate critical points of study and of possible actions. Such a network can be constructed by setting up a matrix of the major categories put forth in Figure 3. Figure 4 represents the initial establishment of such a matrix.

The matrix will comprise the same categories on both axes in order to set up possible interaction patterns. With an overall focus of where one wants to examine, the interactions will generate questions and hypotheses which in themselves will direct the researcher along relevant paths of inquiry. Figure 5 provides an example of this procedure.

	SITUATION				ACTION
	SETTING	CULTURE	STRUCTURE	PROCESS	RESULT
SETTING	Size	Size-Relationships	Size-Placement	Size-Communication	Size-Decision Making
	Time	Size-Rules	Size-Characteristics	Size-Boundary Maintenance	
	Territoriality	Size-Activities	Size-Capacity	Size-Systemic Linkage	
	Facilities			Size-Social Control	

Figure 5. Setting up the matrix: an example.

Taking size as an independent variable one can construct a number of questions which may be examined with regard to irrigation behaviors:

- Does the size of the area affect the types of activities performed by the farmer?

- Does the size of the area affect what types of relationships are incurred by the farmers in the area?

- Does the size of the area determine the types of normative rules governing the farmer's activities?

- Does the size of the area influence the farmer's status-role position?

Figure 4: The Sociological Format in Matrix Form

		SITUATION				ACTION
		SETTING	CULTURE	STRUCTURE	PROCESS	RESULT
SITUATION	SETTING	Size Time Territori-ality Facilities				
	CULTURE		Activities Relation-ships Rules			
	STRUCTURE			Placement of Individual Characteris-tics of Individual Capacity of Individual		
	PROCESS				Communica-tion Boundary Mainte-nance Systemic Linkage Social Control	
ACTION	RESULT					Decision Making

- Does the size of the area define individual's personal characteristics differently?

- How does the size of the area affect a farmer's position in the stratification setup of the social system, based on the condition of the farmer?

- How does the size of the area affect the communication network of a farmer?

- Does the size of the area contribute to specific boundary maintenance actions by the family/group?

- How does the size of the area contribute to specific linkages between the farmers and their community?

- Does the size of the area affect the social control mechanisms regarding a farmer's behavior?

The above list serves as nothing more than an example to demonstrate what questions may be asked. For it is these questions which will provide the direction of inquiry. How these questions may substantively evolve depends on the types of variables utilized to serve as measures for the dimension previously examined.

Application of the Format to Irrigation Behavior

Figure 6 demonstrates how the above constructed format may be focused on irrigation management. Under each of the major dimensions constituting the categories of the setting, culture, structure, and process are specific variables which should be taken into consideration when one is exploring the irrigation behavior of a farmer. The variables depicted in Figure 6 do not comprise a complete list, for in other situations other specific variables may be important. The important point to be made is that through such a framework a direction for the pursuance of problem identification can be established.

Essentially, the research format described is a modification of the Loomis social system framework put into a matrix. The matrix provides the forum for questions to emerge which can focus on critical aspects of the situation being investigated. Each matrix contains dimensions and variables deemed appropriate to the specific situation; i.e., different variables will be present for studies of housing in an urban area versus studies of irrigation in the rural sector. However, no matter what the arena of study, the general categories in the format may be viewed as suggestive guidelines for directing one's thinking.

An example of how this format may be utilized will be presented from a study of on-farm water management in Pakistan. The purpose for this example is to take one portion of the format as illustrated in Figure 6 and demonstrate how lines of inquiry may develop in a problem identification process. What will also be demonstrated is the complexity of the situation into which solutions of problems will be implemented.

A researcher is interested in seeing if the amount of land owned by a farmer, a structural variable, has any effect on the use of water by that farmer, a cultural variable. The portion of the matrix utilized is shown in Figure 7.

The amount of land owned is to be categorized in acres while the use of water is to be operationalized by the use of irrigation wells which supplement the surface deliveries from the canal. Table 1 presents the cross tabulation of the two variables.

There is a significant difference among the different categories of land ownership with respect to the use of irrigation wells. Overall, a plurality of the farmers do not have supplemental wells and it is only in the range of ownership from one-to-seven acres that the use of private wells becomes predominant. The use of public wells becomes more significant for farmers who do not own any land and those farmers who own more than fifty acres. In pursuing this initial relationship to understand what is happening more fully, the researcher can utilize the format to evolve various control variables.

A Pakistani irrigation system is composed of watercourse command areas. These areas are supplied with irrigation water through a channel which diverts that water from a government canal. There are two types of watercourse command areas: perennial and nonperennial. A perennial area is an area which contains a year-round water supply while the nonperennial area only furnishes water to the farmers during the warm season (from April to October). A possible source of influence on the above relationship between area owned and the use of irrigation wells may be the setting into which the use of wells are present; i.e. the perennial versus the nonperennial watercourse command areas. Tables 2 and 3 illustrate the effect of the control variable.

While the significance level of this relationship is less than it was when the total population was included, the reason could be due to the N, the various percentages are similar to the previous table. Both the use of private wells and the non-use of supplemental water were up a couple of percentage points. The use of public wells was down with the greatest change occurring in the categories of no land ownership and eight-to-twelve acres. Still, the categories of one to seven acres have a majority of farmers using private tubewells.

On the nonperennial watercourse, the percentage difference between the nonuse of wells and the use of private tubewells is about the same, approximately 5%, as in the other two tables; however, the use of public tubewells has increased dramatically.

SITUATION | **ACTION** / **RESULT**

Size:
- Size of irrigation area
- Length of water-course
- Length and size of diversions

Time:
- Seasonality of crops
- Multicrop
- Time of irrigation delivery

Territoriality:
- Placement of village
- Placement of farmers to each other
- Fragmented plots
- Placement of services to farmer ( )
- Placement of irrigated area to urban areas
- Placement of irrigated area to government services

Facilities:
- Technology available
- Qualitative level of structures
- Areal level of canal and laterals
- Infrastructure support material
- Farm equipment availability and quality of that equipment
- Other physical parameters (amount of water, etc.)

Activities: (B&S)
- Farming procedures (sowing, planting, caring for crop, harvesting, etc.
- Irrigation procedures: (diverting water, application of water, drainage of water)
- Use of groundwater and surface water
- Use of infrastructure (obtaining credit, buying fertilizer and other inputs, selling crop, extension, etc.)

Relationships: (B&S)
- Farmer to family
- Farmer to farmer
- Farmer to organization in infrastructure of local area
- Farmer to government
- Farmer to non-agricultural sector

Rules: (B&S)
(Formal & Informal)
- Rules governing family relations (i.e., fragmentation)
- Rules governing association and interaction among farmers
- Rules governing farmer interaction with infrastructure
- Rules governing farmer interaction with government (i.e., water laws, etc.)
- Rules governing farmer interaction with non-agricultural sector

Placement of Indiv.
(Status Role)
- Ownership
- Tenure
- Brotherhood/caste/family
- Position in organization (if any) in agric. infrastructure (co-op, WUA, etc.)
- Position (if any) in the village
- Position (if any) in the government

Characteristics of the Individual:
- Demographic char. (age, place of residence, migration, marital status, size of family, etc.
- Attitudinal characteristics

Capacity of the Individual
- Power
- Prestige
- Wealth
- Linkage (influence) with other farmers
- Linkage (influence) with organizations in agricultural infrastructure
- Linkage (influence) with government
- Linkage (influence) with nonirrigation organizations

Communication:
- Farmer with other farmers
- Farmers with organizations in infrastructure
- Farmers with government
- Farmers with non-agricultural organizations

Boundary Maintenance:
- Among the farmers
- Among infrastructure organizations
- Between ultrastructure organizations and farmers
- Between agricultural organizations and nonagricultural organizations
- Between the government and local area

Systemic Linkage
- Refer to boundary spanning section

Social Control
(Formal & Informal)
- Between farmers
- Between farmers and infrastructure organization
- Within infrastructure organization
- Outside infrastructure

Decision Making:

Farm management & irrigation behavior

Figure 6. Format for studying irrigation behavior.

	SITUATION				ACTION
	SETTING	CULTURE	STRUCTURE	PROCESS	RESULT
CULTURE ACTIVITIES (Use of water)			Status-Role Ownership		

Figure 7. Delineating the relationship between ownership of land and the use of water.

Table 1. The degree of influence of land ownership on the use of irrigation wells.

Use of irrigation wells	Land Ownership (acres)							
	0	1-3	4-7	8-12	13-25	26-49	50+	TOTAL
NONE	34 (44.2)	20 (44.4)	23 (38.3)	36 (48.6)	39 (48.1)	16 (53.3)	10 (45.5)	178 (45.8)
PRIVATE	26 (33.8)	23 (51.1)	33 (55.0)	31 (41.9)	31 (38.3)	9 (30.0)	5 (22.7)	158 (40.6)
PUBLIC	17 (22.1)	2 (4.4)	4 (6.7)	7 (9.5)	11 (13.6)	5 (16.7)	5 (31.8)	53 (13.6)
TOTAL	77	45	60	74	81	30	22	389 (100.0)

Chi square: 24.71
Degrees of freedom: 12
Significance level: .02

Table 2. The degree of influence of land ownership on the use of irrigation wells in a perennial watercourse command area.

Use of irrigation wells	Land ownership (acres) 0	1-3	4-7	8-12	13-25	26-49	50+	TOTAL
NONE	29 (56.9)	11 (44.0)	12 (29.3)	29 (50.9)	29 (48.3)	12 (50.0)	7 (58.3)	129 (47.8)
PRIVATE	16 (31.4)	13 (52.0)	26 (63.4)	26 (45.6)	24 (40.0)	8 (33.3)	2 (16.7)	115 (42.6)
PUBLIC	6 (11.8)	1 (4.0)	3 (7.3)	2 (3.5)	7 (11.7)	4 (16.7)	3 (25.0)	26 (9.6)
TOTAL	51	25	41	57	60	24	12	270 (100.0)

Chi square: 21.06
Degrees of freedom: 12
Significance level: .05

Table 3. The degree of influence of land ownership on the use of irrigation wells in a nonperennial watercourse command area.

Use of irrigation wells	Land ownership (acres) 0	1-3	4-7	8-12	13-25	26-49	50+	TOTAL
NONE	5 (19.2)	9 (45.0)	11 (57.9)	7 (41.2)	10 (47.6)	4 (66.7)	3 (30.0)	49 (41.2)
PRIVATE	10 (38.5)	10 (50.0)	7 (36.8)	5 (29.4)	7 (33.3)	1 (16.7)	3 (30.0)	43 (36.1)
PUBLIC	11 (42.3)	1 (5.0)	1 (5.3)	5 (29.4)	4 (19.0)	1 (16.7)	4 (40.0)	27 (22.7)
TOTAL	26	20	19	17	21	6	10	119 (100.0)

Chi square: 19.55
Degrees of freedom: 12
Significance level: .08

This is especially evident in the no ownership category and the larger ownership categories. Also in the categories of one-to-seven acres, the previous relationship of a plurality of private wells being used is not existent in the nonperennial command area, instead the non-use of supplemental water is more prevalent.

One can see through this very brief exercise that the relationship between the amount of land ownership and the use of irrigation wells is not that straight forward. Questions that arise include why are public wells more prevalent in the nonperennial command areas, why does the category of no land ownership fluctuate as much as it does and does that category in itself have any significance, and what is so unique about the acreage between one and seven acres that allowed it to have more private wells than public wells and nonsupplemental water? These questions are of interest to the researcher who is examining what are the factors that determine what type of supplemental water is utilized and why such factors are important, and the same questions are of importance to the policy maker who wishes to establish a particular program for utilizing supplemental water in a particular region.

Focusing on the format presented in Figure 6, one can look for directions of inquiry. For instance, perhaps the use of supplemental water is related to the size of the watercourse, or the length of the watercourse and the subsequent amount of water available for the farmers to irrigate. Maybe the degree of fragmentation causes the particular use of supplemental water as presented in the tables. One may also look at the particular farming practices of the farmer to see if any explanation can be put forth with regard to their use of irrigation water. Maybe the laws regarding trading of water, the use of water, and the method of water delivery affect practice of using supplemental water. Another aspect of the situation that may determine what type of supplemental water is utilized may be the farmer's wealth, his position on the watercourse, the farmer's linkage with government authorities, and the farmer's status in the village. A researcher may also want to examine the various processes involved in the irrigation system and how they may affect the use of supplemental water. There are a number of paths by which the understanding of how supplemental irrigation water is being used and if the researcher can systematically initiate a design strategy which effectively guides the conduct of that study, then the travel along those paths may become much more fruitful. The purpose for constructing such a format as depicted in Figure 6 is to provide a map by which such strategies may evolve.

Conclusion:

When an individual researcher enters into an irrigation system, a complex set of conditions and interactions greet that person. If that researcher is pursuing a study that will eventually contribute to a policy making decision, then proper understanding of that irrigation system becomes much more than a pursuit to satisfy one's intellectual curiosity. Given such a situation, this paper has presented one type of format that may be used as a mechanism to provide a means which the researcher may utilize to tap the information needed to obtain that understanding.

The research format is based on the general dimensions making up the Loomis social system framework. Modifications have been made to make Loomis' framework more applicable to irrigation systems. What must be emphasized is that the contents of the framework as described in Figure 6 focuses on the individual farmer's irrigation behavior. A different focus will yield to other variables but the major categories should remain intact.

Such categories are seen as viable aspects of an irrigation system but how those aspects are interrelated will depend on the knowledge, skill, and work of the researcher. This format is not intended to be a cookbook detailing every possible relationship. Selectivity of variables and relationships is of critical concern because as one can see from Figure 6 and from the example presented measuring everything would lead to a morass of data with questionable payoffs. What the format is intended to provide is a general guideline which will give to the researcher a greater sensitivity to possible causes in the operation of an irrigation system. A lot of responsibility is placed upon the researcher to examine the situation with a skill that will allow any study to be performed in as effective a manner as possible.

If the format can serve the limited purpose of providing a set of parameters that will sensitize the researcher to what possibly may be happening in the irrigation system, then this may prove to be a very effective tool. This format still has to be tested and it undoubtedly will be modified to improve its capability. Yet, it is felt that the potential is there to help many people secure some direction in this complex arena of an irrigation system that will allow the researcher and the policy maker to better understand the mechanisms governing the operation of that system.

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APPENDIX 18

ANALYSIS OF SAMPLING VARIATION WITHIN AND AMONG WHEAT FIELDS IN PUNJAB

by

J. Reuss[1]

I. SUMMARY AND CONCLUSIONS

The variance encountered in harvesting four adjacent 3m x 4m quadrants from wheat fields in the Punjab has been analyzed. This analysis shows that the confidence intervals for mean yields are surprisingly insensitive to the size of the area harvested within each field.

Measurements of mean yields within plus or minus 1 to 2 mds/acre will require the sampling of some 100 to 200 fields. Confidence intervals of less than 1 md per acre will require 300-500 fields for the 95% confidence level and 500-800 fields to attain a 99% confidence level.

A breakdown of the variance estimates into within and among field components revealed that the within field component for subplots was very small compared to the among field component. This is, of course, the reason that yields estimated from crop cutting over many fields are insensitive to size of harvest area. The analysis also revealed that the within field standard deviation of $12m^2$ plots is linearly related to the mean and can be estimated by:

$$S_w = 0.16y \qquad (I.1)$$

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where S_w is the standard deviation and $\bar{y}$ is the mean yield of the subplots in mds/acre. The estimate can be extended to adjacent subplots of any size by:

$$S_w^2 = 0.307\bar{y}^2/H \qquad (I.2)$$

where S_w^2 is the within variance and H is the harvest area in m^2.

The survey data did not provide an estimate of the effect of taking more than one cutting location per field. However, by utilizing data available from CSU Water Management Research Project files it was possible to generate an estimate of this component, such that:

$$S_L^2 = 0.048\bar{y}^2 \qquad (I.3)$$

where S_L^2 is the variance component due to different locations within the same field. Further analysis establishes that the variance observed among fields for any combination of harvest area and number of locations within fields will be estimated by:

$$S_{\bar{A}}^2 = 0.307\bar{y}^2/HN_L + 0.048\bar{y}^2/N_L + 71.5 \qquad (I.4)$$

where $S_{\bar{A}}^2$ is the observed variance and N_L is the number of locations. The confidence interval CI can then be estimated by:

$$CI = \pm_P t_P \ (S_{\bar{A}}^2/N_F)^{1/2} \qquad (I.5)$$

Here, t is the tabular value of the t statistic at any probability level P and N_F is the number of fields sampled.

Tables and graphs developed from these relationships demonstrate that for any given harvest area the confidence interval is reduced by dividing it into multiple harvest locations within the field. The increased precision thereby attained, however, is quite small, particularly if more than two locations are taken and/or the number of fields sampled is large.

Finally the confidence interval for the yield of any particular field can be estimated by:

$$CI = t_p\bar{y}\ (0.307/HN_L + 0.048/N)^{1/2} \qquad (I.6)$$

Tables based on this relationship reveal that very intense sampling is required to obtain accurate estimates of the yield of any particular field. For instance, if a $10m^2$ harvest area is cut at each location within the field some 30 locations are required for a 95% confidence of plus or minus 10% of the mean. These results indicate that in general it is impractical to attempt to accurately evaluate the yield of particular fields by cutting subsamples from that field.

II. RECOMMENDATIONS

In order to obtain accurate estimates of mean wheat yields in the Punjab, harvest areas should be kept small so that resources can be concentrated on sampling a large number of fields. The actual number of fields required depends on the precision needed for any particular purpose. In general, a 95% confidence interval within plus or minus 2 mds/acre will probably require about 100 fields and plus or minus 1 md/acre will require about 500 fields.

Total harvest area of $10m^2$ or at the most $20m^2$ per field should be sufficient. The author suggests that two locations be sampled in each field with a harvest area of between $5m^2$ and $10m^2$ for each location.

Yield estimates of particular fields obtained by cutting samples within that field are generally very imprecise. In general, it is probably not practical to attempt to relate inputs or cultural practices to yields obtained by cutting samples within the fields, unless very intense sampling can be undertaken. Yield estimates within $\pm$ 10% of the mean of a given field will probably require the sampling of at least 30 sampling locations within that field.

III. INTRODUCTION

At the request of USAID Mission staff I have undertaken statistical analysis of a data set collected by the Punjab Crop Reporting Service. These data were collected as part of a cooperative program with USAID with the objective of determining the effect of different harvest areas within the fields sampled on the precision of estimates of wheat yield.

This report covers two related sets of analyses of these data. The first analysis is statistically rather simple and empirical, and deals largely with the direct question of effect of harvest area on the estimates of mean yield derived from a set of samples cut from randomly selected fields within a district or province. Even though this analysis is rather simple it is statistically sound.

The second analysis is somewhat more sophisticated and deals more explicitly with the more fundamental problem of the various components of variance arising from sampling within and among fields. Evaluation of these components provides information necessary to develop rational sampling plans in regard to size of harvest area, number of locations to sample per field, and number of fields to be sampled. This evaluation also allows us to address the problem of sampling to determine the yield levels of individual fields.

IV. FIELD PROCEDURES

Each Field Assistant Crop Reporter was instructed to randomly select two villages followed by random selection of a field within the village area and a harvest plot location within the field. He was then instructed to harvest four contiguous quadrants each 3m x 4m in size and determine the yield of each of these $12m^2$ plots. The layout of the quadrants is shown in Figure IV.1.

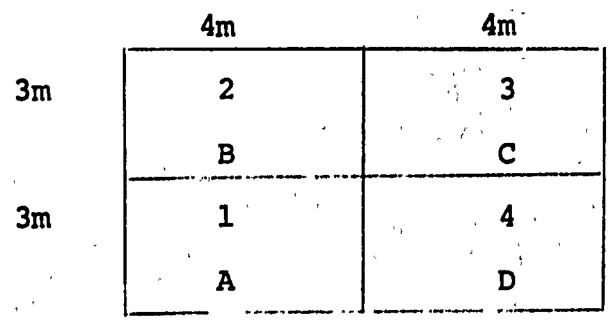

Figure IV.1. Field layout of the four quadrants each 3m x 4m in size.

Thus, yield was determined on 4 quadrants, each with an area of $12m^2$, within each field. Unfortunately, the design called for all four quadrants within a field to be contiguous, so that no information can be obtained on the effect of location of more than one randomly selected harvest area in each field. In the instructions given to Field Assistants these quadrants were designated by number 1, 2, 3, and 4. For our purposes we will find it less confusing to designate them A, B, C, and D.

The number of fields (villages) sampled in each district was directly proportional to the number of Crop Reporting Field Assistants in that district and was not directly designed to be proportional to the acreage of wheat in that district. However, it is generally related to the acreage as numbers of Field Assistants in the district are generally related to acreage.

V. BASIC ANALYSIS

In this analysis we will use a minimum of statistical sophistication consistent with reliable interpretation. First, we will calculate the sum of the grain harvested from the four quadrants in each field. From this total we calculate the mean yield in mds/acre based on a harvest area of 6m x 8m or 48m^2. From this we calculate mean yields, variances, standard deviations, and standard errors for each district as shown in Table V.I. The name of the districts associated with the district numbers is given in Appendix Table A 1.

District means vary from less than 9 mds/acre to more than 29 mds/acre while standard deviations vary from about 1 to more than 13 mds/acre.

The next question is whether these variances can be pooled to calculate a single variance and standard deviation that can be applied to all districts. For this purpose we calculate a "Chi-Square" statistic using Bartletts test of homogeneity of variances for variances with different number of degrees of freedom (Snedecor Chap. 9). Results are shown in Table V.2. The variances are not homogeneous if all districts are considered.

Table V.2. Bartletts test of homogeneity of the variances from individual districts based on 4 quadrants per field.

	df	Chi-Square	Probability
Districts 1-21	20	35.87	< 0.025
Districts 4-21	17	17.63	< 0.25

Table V.1. Mean yields by districts using the full 6m x 8m harvest area with variance, standard deviations and standard errors among fields (villages) within districts.

Dist	N	Mean	Variance	Std. Dev.	Std. Err.
1	4	11.34	2.25	1.50	0.75
2	4	8.95	1.07	1.03	0.52
3	6	15.78	56.71	7.53	3.07
4	12	22.07	112.14	10.59	3.06
5	8	16.82	131.76	11.48	4.06
6	16	29.10	148.32	12.18	3.04
7	12	21.89	69.36	8.33	2.40
8	12	19.99	145.62	12.07	3.46
9	12	23.41	45.63	6.76	1.95
10	12	25.15	109.16	10.45	3.02
11	10	23.56	36.77	6.06	1.92
12	4	22.55	47.58	6.90	3.45
13	8	22.51	37.58	6.13	2.17
14	14	27.35	103.18	10.16	2.71
15	12	21.79	120.69	10.99	3.17
16	10	14.44	43.27	6.58	2.08
17	4	10.99	57.18	7.56	3.78
18	6	32.08	140.17	11.84	4.83
19	8	18.41	91.07	9.54	3.37
20	10	19.21	181.96	13.49	4.27
21	6	26.81	58.02	7.62	3.11

However, inspection of Table V.1 suggests that perhaps districts 1 and 2 are contributing very strongly to the lack of homogeneity. These are districts Attock and Rawalpindi. This suggests that perhaps the barani areas are actually less variable than the irrigated areas. District 3 is Jhelum which is also heavily barani. Accordingly, these districts are dropped and Bartletts test was again run on districts 4-21. The Chi-Square value of 17.64 with 17 degrees of freedom indicates satisfactory homogeneity. Therefore, in the remainder of this section we have used only the data from districts 4-21, and the results in general should be applied only to the predominately irrigated districts. The lower variance among the fields from the barani districts implies that these may be less variable than the irrigated areas, but the number of fields is too small to draw reliable inferences. Eliminating the three districts reduces the total fields from 190 to 176.

The pooled variance is calculated by multiplying the variance from each district by the degrees of freedom (number of fields minus one), and summing those products. The total sum is then divided by the total degrees of freedom (159) to obtain the pooled variance of 99.25.

A weighted grand mean is calculated by multiplying the number of fields (villages) in each district times the district mean. These are then summed and the total divided by the total number of fields.

Next the individual quadrants (3m x 4m) were considered. A pooled mean and variance were calculated assuming quadrant A was the only quadrant harvested. This was repeated for quadrants B, C, and D (Table V.3). When these four are pooled we have 109.0 which is our best estimate of the district variance that will result from harvesting a single

Table V.3. Pooled variances and grand means for single 3m x 4m harvest quadrants, different combinations of two quadrants, and 4 quadrants per field.

Quadrants No. per field	Designation	Weighted Grand Mean	Variance (1)*	Variance (2)*	F	Std. Dev.
1	A	22.17	101.1			10.05
1	B	22.50	116.1			10.77
1	C	23.13	117.2			10.83
1	D	22.69	101.4			10.07
				109.0	1.10	10.44
2	A+B	22.33	102.75			10.14
	C+D	22.91	103.25			10.16
				103.0	1.04	10.15
2	A+D	22.43	95.55			9.77
	B+C	22.81	110.70			10.52
				103.1	1.04	10.15
2	A+C	22.65	101.3			10.06
	B+D	22.60	101.4			10.06
				101.3	1.02	10.06
4	A+B+C+D	22.62	99.25	99.25	--	9.96

*Variance 1. Pooled over fields.

*Variance 2. Pooled over fields and over sets of quadrants.

3m x 4m quadrant. Pooling in this case may be accomplished by taking a simple mean as the degrees of freedom are the same in each estimate.

Note that the estimate of variance derived from single 3m x 4m quadrants is greater than that derived from taking the variance of the mean of four plots. The ratio of these is the F value with 158 df in the numerator and 632 df in the denominator. This F value can be used to test whether the confidence interval about the mean derived from single quadrants is significantly greater than that derived from 2 or 4 quadrants. This F value is 1.10 and the probability of the effect being real is about 10%. The weighted mean yields calculated from single plots varied from 22.17 to 23.13 and the standard deviation varied from 10.05 to 10.83.

The means and variances for three different combinations of two subplots each were then considered.

There are three sets of means of 2 quadrants each. The first half of the first set is the mean of A+B which would represent a plot 6m x 4m, as would C+D, the other half of the first set. The best estimate of the variance to be achieved by a 6m x 4m plot is the pooled variance of the (A+B) and (C+D) set. These variances and standard deviations are just slightly higher than that for the four plot set A+B+C+D but are not significantly so.

The (A+D) and (B+C) sets give us the means and variances from plots 3m x 8m. The B+C set was slightly more variable than the A+B+C+D set, while the A+D set was slightly less variable. Finally the (A+C) and (B+D) each give us the yield from two 3m x 4m harvested areas with adjoining corners.

Generally, the results in Table V.3 tell us that as harvest area is decreased from $48m^2$ to $12m^2$ there is only a slight increase in variability as expressed by the variances or standard deviations among fields. We shall next consider how this translates into confidence intervals for the mean of any number of fields per district.

The confidence interval on each side of the mean for any level of probability is calculated by multiplying the appropriate t value times the standard error as shown in equations V.1 and V.2.

$$(CI)_{.95} = \pm t_{.05}(\text{Std. error}) \qquad (V.1)$$

$$(CI)_{.99} = \pm\ _{.01}(\text{Std. error}) \qquad (V.2)$$

The standard error here is calculated by dividing the standard deviation by the square root of the number of fields per district.

Let us now consider three possible plot sizes, $12m^2$, $24m^2$, and $48m^2$, and the associated standard deviations from Table V.3.

The 95% and 99% confidence intervals for any number of fields for these plot sizes can be calculated from Table V.4. Calculated values are shown in Table V.5 and results for the $12m^2$ and $48m^2$ harvest areas are shown graphically in Figure V.1.

Table V.4. Effect of harvest area on standard deviation, standard error, and confidence interval of district means.

Dimension	Area	Std. Dev.	Std. Error*	$CI_{.95}$*	$CI_{.99}$*
3m x 4m	$12m^2$	10.44	$10.44/\sqrt{n}$	$20.46/\sqrt{n}$	$26.94/\sqrt{n}$
4m x 6m	$24m^2$	10.15	$10.15/\sqrt{n}$	$19.98/\sqrt{n}$	$26.19/\sqrt{n}$
6m x 8m	$48m^2$	9.96	$9.96/\sqrt{n}$	$19.89/\sqrt{n}$	$25.70/\sqrt{n}$

Table V.5. District confidence intervals for three harvest areas at the same location within fields, and various numbers of fields (villages) per district.

Number of fields	95% Level			99% Level		
	$12m^2$	$24m^2$	$48m^2$	$12m^2$	$24m^2$	$48m^2$
			Confidence Intervals ± mds/acre			
1	20.46	19.98	19.89	26.94	26.19	25.70
2	14.47	14.13	14.06	19.05	18.52	18.17
5	9.15	8.94	8.90	12.05	11.71	11.49
10	6.47	6.32	6.29	8.52	8.28	8.13
15	5.28	5.16	5.14	6.96	6.76	6.64
20	4.57	4.47	4.45	6.02	5.86	5.75
30	3.74	3.65	3.63	4.92	4.78	4.69
40	3.24	3.16	3.14	4.26	4.14	4.06
50	2.89	2.83	2.81	3.81	3.70	3.63
75	2.36	2.31	2.30	3.11	3.02	2.97
100	2.05	2.00	1.99	2.69	2.62	2.57
150	1.67	1.63	1.62	2.20	2.14	2.10
200	1.45	1.41	1.41	1.90	1.85	1.82
250	1.29	1.26	1.26	1.70	1.66	1.63
300	1.18	1.15	1.15	1.56	1.51	1.48
400	1.02	1.00	0.99	1.35	1.31	1.29
500	0.91	0.89	0.89	1.20	1.17	1.15

*Confidence Interval for $(CI)_{.95}$, t = 1.96
$(CI)_{.99}$, t = 2.58
n = number of fields per district.

From either Table V.5 or Figure V.1 we can quickly see that the difference in district level confidence interval between a $12m^2$ and a $48m^2$ harvest area is very small. It can also be seen that at any of these harvest areas a large number of fields is required to accurately estimate yields. Twenty fields per district would result in a 95% confidence interval of approximately ± 4.5 mds/acre about the mean while at the 99% confidence level the interval would be about ± 6 mds/acre. With 100 fields the 95% level would have an interval of about ± 2.0 mds/acre while the 99% level confidence interval would be near ± 2.6.

To attain a ± 1 md/acre confidence interval at the 95% level would require some 400 fields.

From the above we can conclude without much doubt that in the range of $12m^2$ to $48m^2$, harvest area has little effect on the precision of the estimate of the mean yields of a group of fields. However, even moderate precision about the district mean would seem to require a large number of fields.

This shows that increasing sample size at a single location in the field is not effective in improving precision. It says nothing about what improvement might result from additional samples at different locations in the field.

It seems to establish the "among" variation quite well. However, this is still the sum of the measurement error arising from taking a single location for harvest area, plus the true among field component. The real goal is not to attain a low within field variation but to design our sampling such that we include as much of the real within field

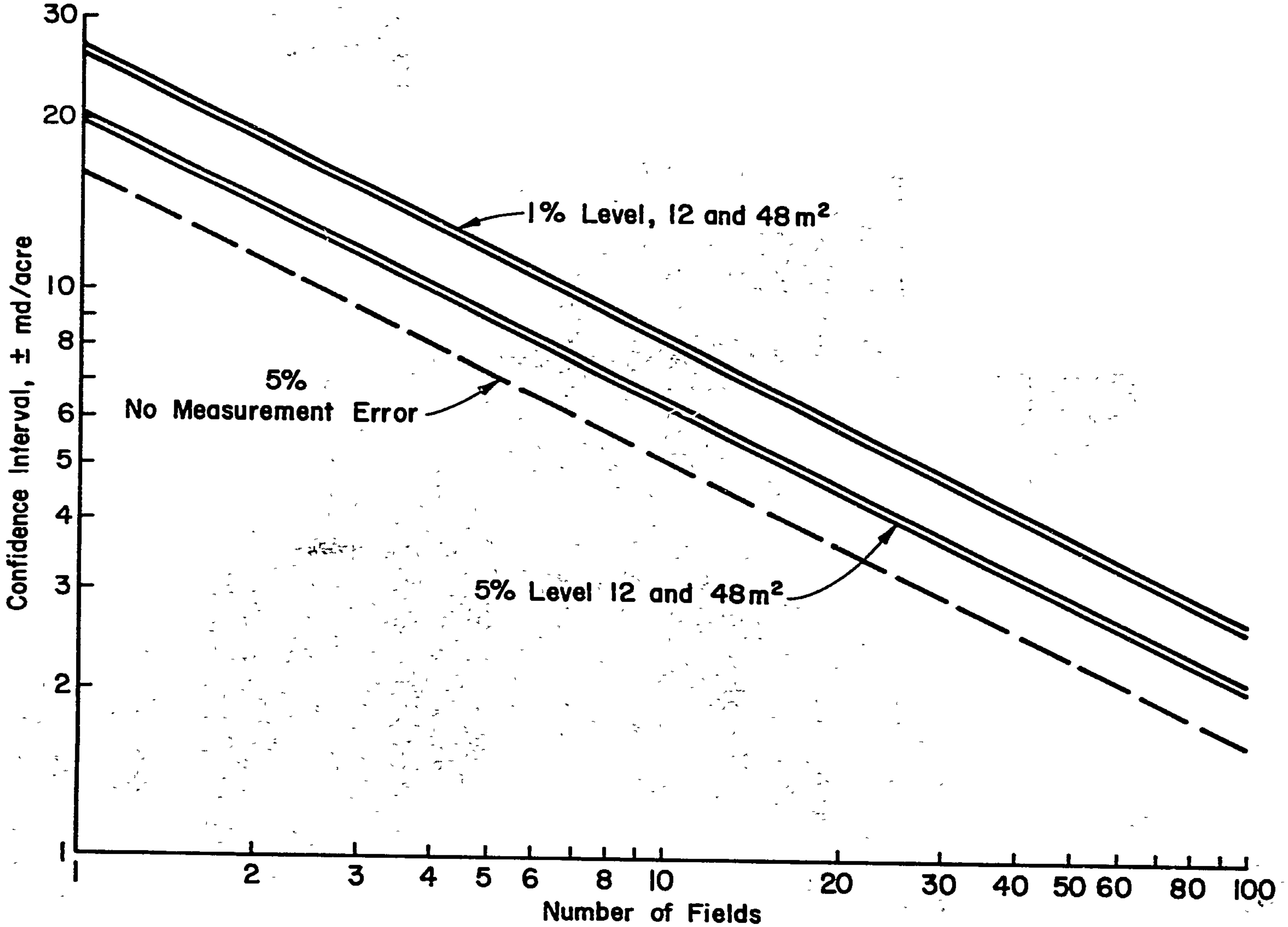

Figure V.1. Confidence intervals in ± maunds per acre for the .05 and .01 probability levels as a function of number of fields sampled with $12m^2$ and $48m^2$ harvest areas.

variation as possible. Thus, we will reduce our apparent "among field" variation to near the true "field component." In this way we can estimate district yields with a maximum precision with a minimum number of fields.

VI. ANALYSIS OF COMPONENTS OF VARIANCE

The preceding analysis considered only the variance among fields within districts, and a pooling of those variances to arrive at an overall variance among fields. The next analysis considers the components of this variance. If we consider closely, we have at least two sources of variation that contribute to the previously used variance among fields. The first and most obvious source of variability is that which arises because different fields have different yield levels. The second source of variability arises from the fact that our samples do not accurately measure the yield of the field from which they were taken. In reality, the reason this experiment was undertaken was concern over this second source of error.

The effect of the field variability can be reduced either by increasing the harvest area at the location randomly chosen, or by randomly choosing more than one harvest area in the field. Thus, in fact we have two components of error within fields. We shall designate the variances associated with these two within field errors S_W^2 and S_L^2. S_W^2 we will define as the variance component within locations within fields. S_L^2 we will define as the variance component that arises among locations within fields. In the design of this experiment increasing the number of quadrants at a location decreases the contribution of S_W^2 by a factor of $1/N_W$ where N_W is the number of quadrants. The contribution of S_L^2 cannot be estimated from the present experiment but we will consider possible estimates of this parameter later.

Let us return to the variance that arises because fields have different yields. We will designate this component S_F^2. We now have three individual variance components all of which contribute to the variance among fields. The variances combine in a manner that depends on the sampling design to produce the observed variance among fields such as was used in the previous section. The general formula for these components would be given as:

$$S_A^2 = S_W^2 + N_W S_L^2 + N_W N_L S_L^2 \qquad \text{(VI.1)}$$

where N_W = is the number of samples taken within each location in the field.

N_L = is the number of locations samples within the field.

S_A^2 = is the observed variance among fields.

S_F^2 = is the component of the observed variance arising due to the inherent difference in yields of different fields.

S_W^2 = is the variance that arises as a result of the variation in yield due to number (or size) or subplots cut at each location.

Because there were samples taken from only 1 location in each field $N_L = 1$, and we cannot separate the effect of S_L^2 and S_F^2 , we will therefore combine these for the moment and designate the combined variance as $S_{F'}^2$. Equation VI.1 now reduces to:

$$S_A^2 = S_W^2 + N_W S_{F'}^2 \qquad \text{(VI.2)}$$

$$\text{(where } S_F = S_L^2 + N_L S_F^2\text{)} \qquad \text{(VI.2A)}$$

We must therefore remember that $S_{F'}^2$ is not the real field component, as it actually includes the locations within field component. We shall therefore refer to $S_{F'}^2$ as the "apparent" field component.

Again, N_w is the number of samples (here designated quadrants) taken at each location, and if all quadrants are used, N_w is 4.

Next, we again use district Gujerat as an example. Individual quadrants yields, means, and variances are shown in Table VI.1. The variances and standard deviations shown for each field are those for among quadrants within fields, i.e., S_w^2. The among variance at the bottom of the page is the same as that used in section V. However, because we are here calculating it using the yields of 4 individual quadrants rather than the mean, the numerical value is four times as great. The within variance at the bottom of the page is S_w^2 and is the pooled variance from within the individual field. In this case where an equal number of quadrants were harvested from within each field, it represents the mean of those within field variances.

The "apparent" field component $S_{F'}^2$, is calculated by rearranging Equation VI.2 as follows:

$$S_{F'}^2 = \frac{S_A^2 - S_w^2}{N_w} \qquad \text{(VI.3)}$$

In our example, N_w is equal to four.

$$S_{F'}^2 = \frac{448.59 - 8.946}{4} = 109.91$$

The district 4 (Gujerat) sums of squares, variances, and components are shown in the common analysis of variance format in Table VI.2.

Table VI.1. Individual $3m^2 \times 4m^2$ quadrant yields from the fields sampled in district Gujerat along with means and within field variances.

District	C1	C2	C3	C4	Sum	Mean	Variance	Std. Dev.
4	28.83	28.38	26.58	27.93	111.74	27.93	0.95	0.97
4	13.52	10.09	15.77	15.32	54.69	13.67	6.65	2.58
4	31.54	22.53	27.03	31.54	112.63	28.16	18.60	4.31
4	33.79	31.54	42.80	29.28	137.40	34.35	35.09	5.92
4	18.47	13.06	18.65	13.52	63.70	15.93	9.30	3.05
4	13.52	18.02	18.20	16.22	65.95	16.49	4.73	2.17
4	29.46	31.54	27.93	31.08	120.01	30.00	2.70	1.64
4	9.46	9.91	9.55	9.82	38.74	9.69	0.05	0.21
4	4.51	4.51	4.69	4.69	18.38	4.60	0.01	0.10
4	18.02	15.54	15.32	13.52	62.39	15.60	3.43	1.85
4	31.54	27.93	30.63	36.94	127.04	31.76	14.27	3.78
4	40.55	32.44	36.04	37.84	146.86	36.72	11.57	3.40

DISTRICT MEAN = 22.07 AMONG VARIANCE = 448.580 DF = 11

WITHIN VARIANCE = 8.946 DF = 36 FIELD COMPONENT = 109.908

Table VI.2. Example of analysis of variance for district Gujerat.

Source	df	SSQ	MnSQ	Components
Total	47	5255.56		
Among Fields	11	4933.50	448.58	$s_w^2 + 4s_{F'}^2$
Within Fields	36	322.06	8.946	s_w^2

where s_w^2 = Within field variance

$s_{F'}^2$ = Field component (in this case includes s_L^2 or location within field variance)

Note that we can also calculate the within variance by taking the difference between the total corrected sums of squares and the among sums of squares, then dividing the difference by the within degrees of freedom, in this case 36.

The pooled within field variance along with standard deviations, standard errors, and coefficients of variation (C.V.) for each district are shown in Table VI.3.

We previously tested the among field variances for homogeneity and found them to be reasonably homogeneous if the major barani districts are excluded. Our next step is to test the within field variances, both within districts and among districts, again using Bartletts test. Results are shown in the first variance column in Table VI.4. Obviously, the within field variances are not homogeneous within districts. Some fields are much more variable than others, so our next step is to try to identify the source of this difference. The first method used was to plot the pooled variances and standard deviations (within) against the district means. The best relationship is with standard

Table VI.3. Pooled within field variances and associated statistics by districts.

Dist	N	Mean	Var	Adj Var	Std Dev	Std Err	CV
1	4	11.34	0.12	4.43	0.35	0.17	0.03
2	4	8.95	4.28	17.91	2.07	1.03	0.23
3	6	15.78	2.87	7.28	1.69	0.85	0.11
4	12	22.07	8.95	8.55	2.99	1.50	0.14
5	8	16.82	7.43	12.61	2.73	1.36	0.16
6	16	29.10	12.43	5.12	3.53	1.76	0.12
7	12	21.89	20.33	20.01	4.51	2.25	0.21
8	12	19.99	4.53	5.84	2.13	1.06	0.11
9	12	23.41	13.62	11.54	3.69	1.84	0.16
10	12	25.15	6.65	3.95	2.58	1.29	0.10
11	10	23.56	20.30	17.53	4.51	2.25	0.19
12	4	22.55	23.74	22.33	4.87	2.44	0.22
13	8	22.51	5.53	4.89	2.35	1.18	0.10
14	14	27.35	20.88	13.00	4.57	2.28	0.17
15	12	21.79	13.56	13.43	3.68	1.84	0.17
16	10	14.44	3.50	9.62	1.87	0.94	0.13
17	4	10.99	4.65	15.79	2.16	1.08	0.20
18	6	32.08	52.54	30.04	7.25	3.62	0.23
19	8	18.41	10.40	14.30	3.23	1.61	0.18
20	10	19.21	16.03	19.57	4.00	2.00	0.21
21	6	26.81	8.62	4.26	2.94	1.47	0.11

Pooled: Among = 378.09, Within = 12.68
Weighted grand mean = 21.88
Dist. 4-18; Pooled: Among = 396.98
Within = 13.39, Weighted grand mean = 22.62

Table VI.4. Bartletts test of homogeneity of within field variance for the various districts.

District	N	Variance	Adjusted Variance[1]
		X^2	X^2
1	4	0.47	0.17
2	4	4.01	0.54
3	6	31.87**	7.07
4	12	38.72**	34.89**
5	8	28.21**	6.20
6	16	45.43**	28.69*
7	12	41.42**	41.45**
8	12	42.42**	14.77
9	12	39.99**	47.31**
10	12	19.73**	23.66**
11	10	9.37	5.38
12	4	8.39*	4.22
13	8	12.78	19.76**
14	14	34.00**	61.87**
15	12	44.72**	22.92*
16	10	22.56**	15.28
17	4	8.59	0.37
18	6	16.80**	20.14**
19	8	18.11*	16.94*
20	10	57.21**	16.16
21	4	16.04**	10.53

[1]Adjusted variance explained in text
* significant at 5% level
** significant at 1% level

deviations, and is shown in Figure VI.1. Using linear regression a highly significant relationship was found of the form:

$$\text{Std. dev.} = 0.16\ (\text{District Mean})$$

$$r^2 = 0.53^{**}$$

The intercept of the regression was very small, and not significantly different from zero. Therefore, the regression method used was that for zero intercept.

When districts 1, 2, and 3 were dropped the slope (0.16) was almost identical, but the r^2 value dropped to 0.41, still highly significant. This tells us that the variances of the within components are dependent on the district means and the pooling of "within" error terms (S_w^2) from districts with different means could result in errors of interpretation.

Next the variances were recalculated after adjusting the standard deviations to a constant yield, in this case the grand mean of 21.68. These variances are included in Table VI.3. After this adjustment was complete, Bartletts test was again run on the within variances in each district. These results are also shown in Table VI.4. In most cases the Chi-Square values decreased. The number of highly significant nonhomogeneous pooled variances (1% level) decreased from 13 to 7, while the number significant at the 5% level remained at 3. It appears that only part of the differences in variances among districts could be explained by the dependence of standard deviation on the district means.

Another similar approach was to divide the fields into yield classes disregarding districts, using a 5 md/acre increment. A plot was then constructed of pooled within

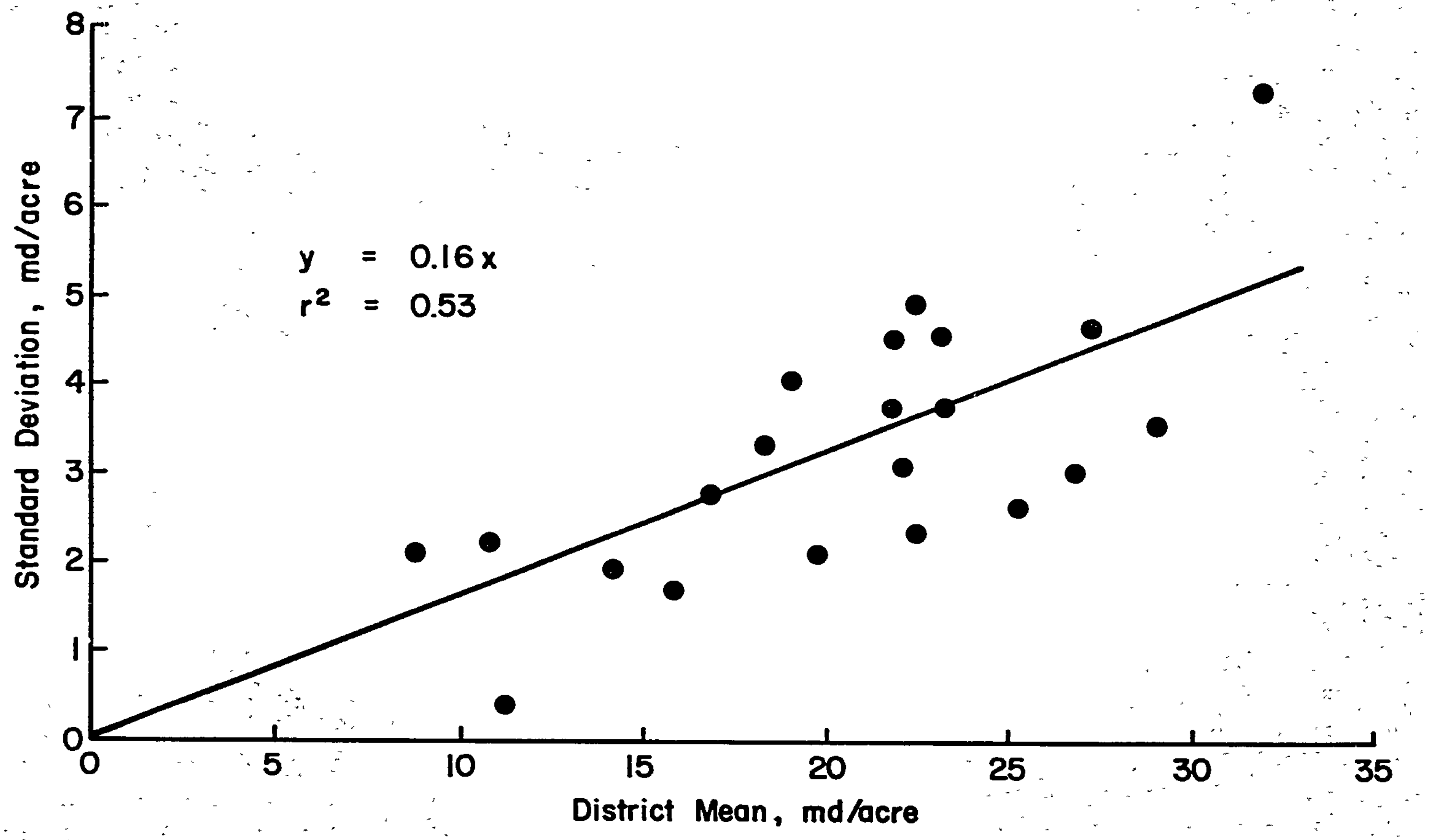

Figure VI.1. Standard deviations <u>within</u> fields pooled within districts as a function of district means.

standard deviation of each class as a function of the class means (Fig. VI.2). Again this convincingly demonstrates the linear dependency of "within" standard deviation on the yield. Unfortunately, within variances for the individual classes were still generally not homogeneous. This tells us that there are real differences in the within field variability that cannot be explained by the effect of the mean yield. This need not surprise us as we can easily conceptualize that several factors may be contributing to variability within fields. Some of these factors operate in such a way that fields with higher mean yields tend to be more variable while other sources of variability are not particularly related to the mean yield.

Populations in which the standard deviation is a linear function of the mean are not uncommon and have several interesting properties. The logarithms of these populations are normally distributed rather than the observations. The standard deviations will be a constant percentage of the mean, resulting in fairly constant coefficients of variation from samples with widely differing means. Here we are undoubtedly dealing with a system where some of the factors contributing to within-field variations tend to be log-normal and others do not.

In this case we have a nested design, and even though the within variation tends to have some log-normal properties, it would probably not be appropriate to use an analysis involving transformations to logarithms. This is because the within field components are combined with the "field component" when the variance "among" fields is calculated. This "field component" is probably not log-normal and is much larger than the "within" components.

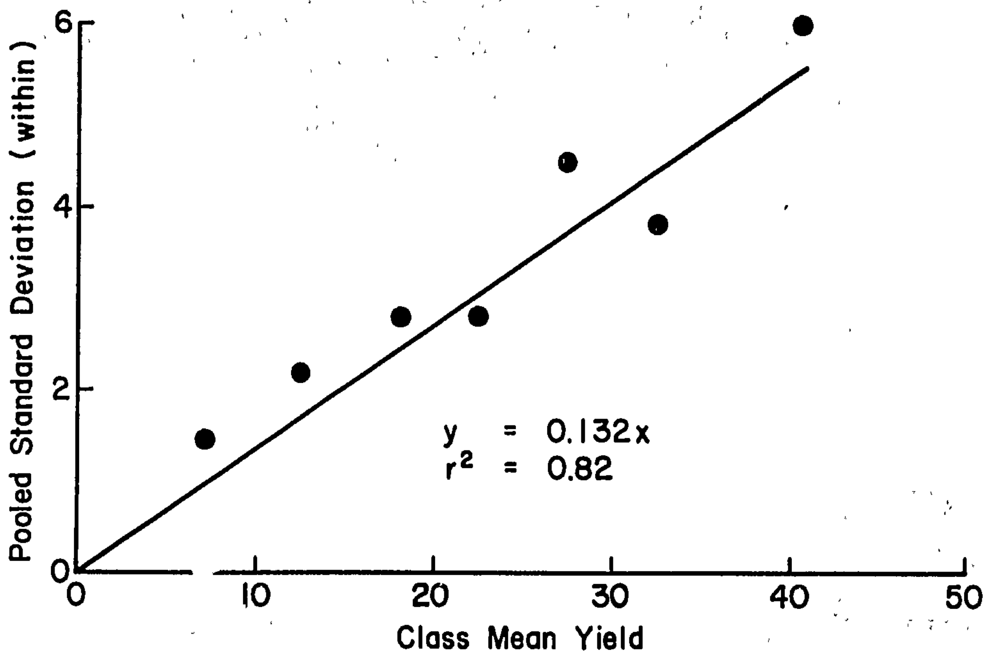

Figure VI.2. Standard deviations within fields pooled within 5 md/acre yield class intervals as a function of class mean yield.

The similarities in slopes of Figures VI.1 and VI.2 do give us a reasonable confidence that we can estimate the "within" standard deviation S_W at about 16% of the mean. From Table VI.3 we can see coefficients of variation (within) are not really constant but 0.16 represents a good overall estimate. We also find that the pooled standard deviation "within" is 16% of the grand mean, both for all districts and districts 4 to 18.

For our purposes we c n conclude that the most satisfactory estimate of t ...chin" standard deviation (S_W) is about 16% of the m ... should apply to the lower yielding barani are ... well as the irrigated area. However, the lack of h ...neity of the among variances in the preceding section su...ests that our remaining analysis would also be best confined to districts 4-21.

Values of $S_{F'}^2$ for each district are shown in Table VI.5. These were calculated from pooled "among" variances using Equation VI.3. The first column represents $S_{F'}^2$ values calculated using S_W^2 values pooled across fields within districts, while the second column assumes $\sqrt{S_W^2}$ is equal to 16% of the district mean. Differences between columns are negligible, as S_W^2 values are much less than the variances among fields (S_A^2). Therefore, the value of $S_{F'}^2$ is largely controlled by S_A^2. Bartletts test indicates that we may pool the variances over districts. Using the pooled value from the second column our overall estimate of $S_{F'}^2$ is not the true field component but still contains the effect of locations within fields, S_L^2. Previously (Eq. VI.2), we have given the relationship between S_A^2, S_W^2, and $S_{F'}^2$ as:

$$S_A^2 = S_W^2 + N_W S_{F'}^2$$

Table VI.5. Field components ($S^2_{F'}$) of variance by districts calculated using both pooled S^2_w values and the assumption that S_w is equal to 16% of district means. Note that $S^2_{F'}$ includes the location component within fields.

District	N	Mean	$S^2_{F'}$ Pooled S^2_w	$S^2_{F'}$ $S_w = 0.16\bar{y}$
4	12	22.07	109.91	109.03
5	8	16.82	129.91	129.95
6	16	29.10	145.21	142.99
7	12	21.89	64.28	66.30
8	12	19.99	144.89	143.07
9	12	23.41	42.23	42.14
10	12	25.15	107.50	105.11
11	10	23.56	31.70	33.22
12	4	22.55	41.64	44.32
13	8	22.51	36.19	34.33
14	14	27.35	97.96	98.40
15	12	21.79	117.29	117.65
16	10	14.44	42.39	41.94
17	4	10.99	56.02	56.40
18	6	32.08	127.04	133.59
19	8	18.41	88.47	88.90
20	10	19.21	177.95	179.60
21	6	26.81	55.87	53.42
$S^2_{F'}$ pooled over districes			95.93	95.84
Bartletts test	X^2	(17df)	18.93	18.79

In this form S_A^2 is the total variance among subplots or quadrants at any field. If subplots or quadrants are cut at a single location within fields the variance of the yield estimation among fields is the variance of the subplots, which we will designate as $S_{\bar{A}}^2$, where:

$$S_{\bar{A}}^2 = S_A^2/N_w \quad \text{(VI.4)}$$

Comparisons of the among field variance for different harvest areas should then be made using $S_{\bar{A}}^{2*}$. Substituting from Equation VI.4 into VI.2 and rearranging for the case where subplots are cut from a single location we have:

$$S_{\bar{A}}^2 = \frac{S_w^2}{N_w} + S_{F'}^2 \quad \text{(VI.5)}$$

From Equation VI.5 it is apparent that as N_w increases $S_{\bar{A}}^2$ approaches $S_{F'}^2$. Thus, the minimum $S_{\bar{A}}^2$ that can be attained by increasing size of harvest area at one location in the field is $S_{F'}^2$.

For use in Equation VI.5 we will take the overall S_w^2 value of 13.1, which is 0.16 times the weighted grand mean of 22.62 (the S_w^2 value obtained from pooling is 13.4). Equation VI.5 then becomes:

$$S_{\bar{A}}^2 = \frac{13.1}{N_w} + S_{F'}^2 \quad \text{(VI.6)}$$

In this case N_w is the number of $12m^2$ plots so that the first term on the right is actually $13.1/12m^2$ or $157/m^2$.

---

*Confusion can easily arise over this point. If we harvest 4 quadrants and run the AOV as shown in Table VI.2, the among variance S_A^2 is the sum of the variances for the 4 subplots. If, on the other hand, we harvest the same area in two subplots, the S_A^2 calculated will be 1/2 that observed using 4 subplots. Comparisons then should be made using S_A^2/N_w or as we have designated it, $S_{\bar{A}}^2$.

Defining H as the harvest are in m^2 and replacing S_F^2 with our best estimate of 95.8 (from Table VI.5) we can write:

$$S_{\bar{A}}^2 = 157/H + 95.8 \qquad \text{(VI.7)}$$

Equation VI.7 assumes that the effect of the shape of the harvest area is negligible, an assumption that appears valid from the results in Section V above. We can now calculate the effect of harvest area at a single location within each field on the confidence interval for any number of fields:

$$CI = \pm\, t_P \, (S_{\bar{A}}^2/N_F)^{1/2} \qquad \text{(VI.8)}$$

Where CI is the confidence interval, N_F is the number of fields sampled, t_P is the t statistic at any level of probability P. Taking $t_{.95}$ as 1.96 and substituting for $S_{\bar{A}}^2$ from Equation VI.7 we have:

$$CI_{.95} = \pm\, 1.96 \, \left(\frac{157/H + 95.8}{N_F}\right)^{1/2} \qquad \text{(VI.9)}$$

Taking various harvest areas starting with 1 m^2, we show the effect of number of fields and harvest areas on the confidence interval ($P > 0.95$) in Figure VI.3. Here we can see that no matter how large our harvest area* if only 10 fields are taken the CI will be about ± 6 mds/acre while if 100 fields are sampled we could expect a CI of about ± 1.9 md/acre. Certainly it would not appear necessary to harvest more than about 10m^2. To achieve the same precision of the estimate of the mean a 5m^2 harvest area would require about 20% more fields than a 10m^2 harvest area.

*This, of course, assumes that the harvest area does not include a significant portion of the total area, perhaps $< 5\%$ or at the most $< 10\%$.

You will note that we have chosen to use a log-log scale for these graphs and that the confidence intervals are a linear function of number of fields at any particular harvest area. This follows because taking the log of both sides of Equation VI.9 we find:

$$\log CI = \log t + 1/2\log(157/H + 95.8) - 1/2\log N_F \qquad \text{(VI.10)}$$

Equation VI.10 shows that when harvest area is constant log CI is a linear function of log N_F.

If the conclusions above and Figure VI.3 were the only output of our more detailed analysis there would be little point in the task, as so far our conclusions are essentially the same as those taken from the first section. Indeed, due to the limitations inherent in a design with only one location per field, we have about reached the limit of useful interpretation of the crop survey data alone. We have however located one other data set that may allow us to include at least a rough evaluation of the effects of locations within fields.

Johnson, et al., took two $9.9m^2$ harvest samples from each of 52 wheat fields in Sargodha district. These authors only reported mean yields for their purposes but the original data has been made available for this analysis. These data were divided into 10 md yield classes and the pooled standard deviations within fields calculated. The plot of standard deviations as a function of class means is shown in Figure VI.4. Our best estimate of the within standard deviation from their data is 28% of the mean. However, this is the combined effect of location and plot size while our previous standard deviation (S_W) is only the effect of plot size. Returning to Equation VI.1 and dividing through by N_W we have:

$$S_A^2/N_W = S_W^2/N_W + S_L^2 + N_L S_F^2 \qquad \text{(VI.11)}$$

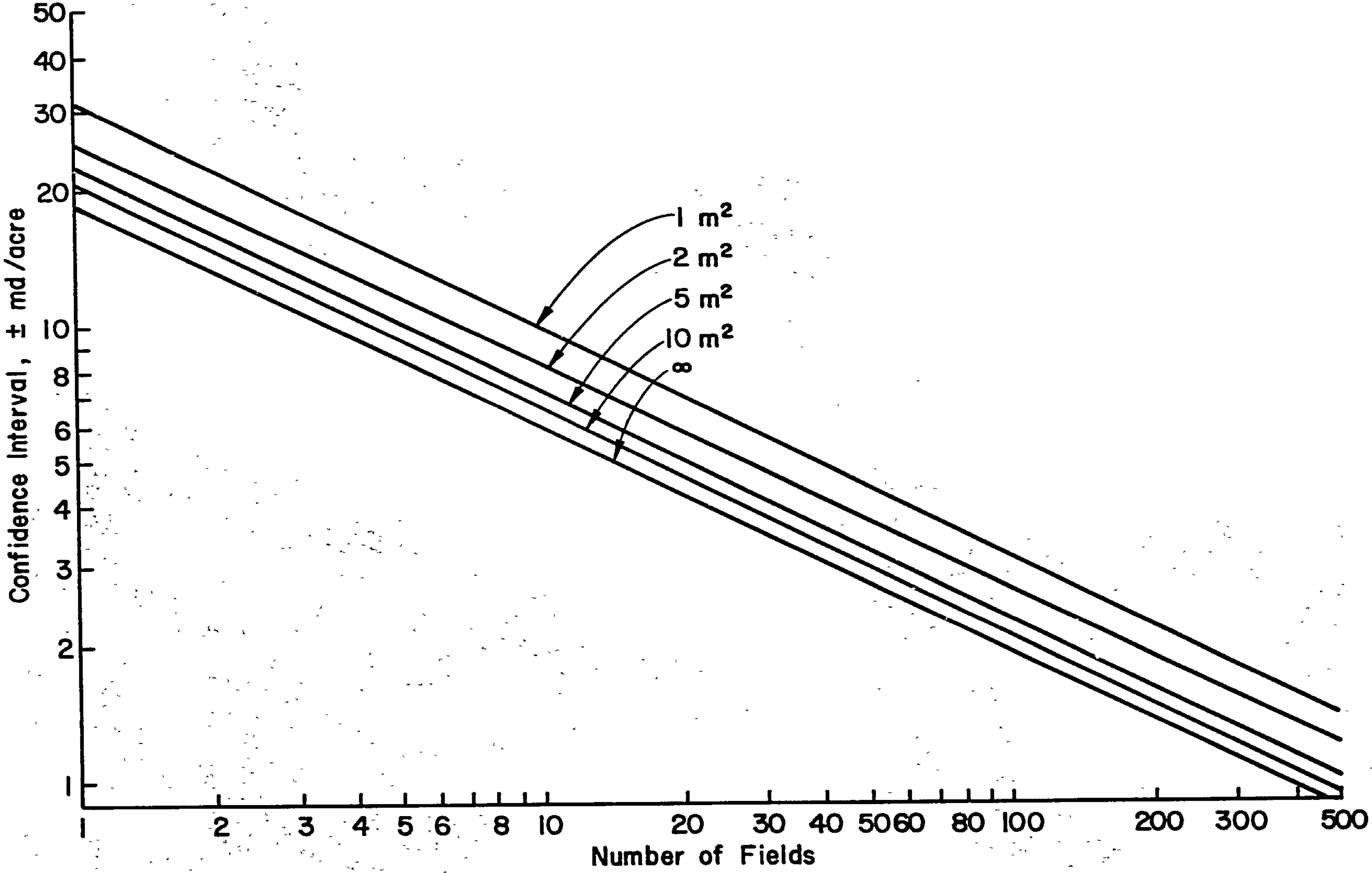

Figure VI.3. Effect of number of fields on confidence interval at different harvest areas.

The problem of different harvest areas in their experiment from that used in the present study complicates the computation somewhat. They cut a single $9.9m^2$ plot at each location, so their observed among variance, which we will designate by S_{AJ}^2, would have been equal to the S_A^2/N_W of Equation VI.11. They would then observe a single component within fields, which we will designate as S_{wJ}^2, consisting of the sum of the components $S_W^2/N_W + S_L^2$ from Equation VI.11. Thus their breakdown would be:

$$S_{AJ}^2 = S_{wJ}^2 + N_L S_F^2 \qquad \text{(VI.12)}$$

Because S_A^2/N_W in Equation VI.11 is the same as S_{AJ}^2 in VI.12, it is apparent that:

$$S_{wJ}^2 = S_W^2/N_W + S_L^2 \qquad \text{(VI.13)}$$

However, from Fig. VI.4 we find S_{wJ}^2 can be estimated by $0.28\bar{y}$, so that:

$$S_W^2/N_W + S_L^2 = (0.28\bar{y})^2 \qquad \text{(VI.14)}$$

S_W^2/N_W can be estimated by $12(0.16\bar{y})^2/H$ or $\frac{(0.554\bar{y})^2}{H}$ for any harvest area. For a $9.9m^2$ plot this becomes $(0.176\bar{y})^2$. Substituting into VI.14 we find:

$$(0.176\bar{y})^2 + S_L^2 = (0.28\bar{y})^2$$

$$S_L^2 = 0.218\bar{y} \qquad \text{(VI.15)}$$

Applying this to the weighted mean of 22.62 our estimate of S_L is 4.93 and $S_L^2 \approx 24.3$. This estimate of S_L^2 should be independent of harvest area. From Equation VI.7 we can calculate our observed $S_{\bar{A}}^2$ as 108.9. Again, defining S_A^2/N_W for any given harvest area as $S_{\bar{A}}^2$ we can substitute into Equation VI.11 as follows:

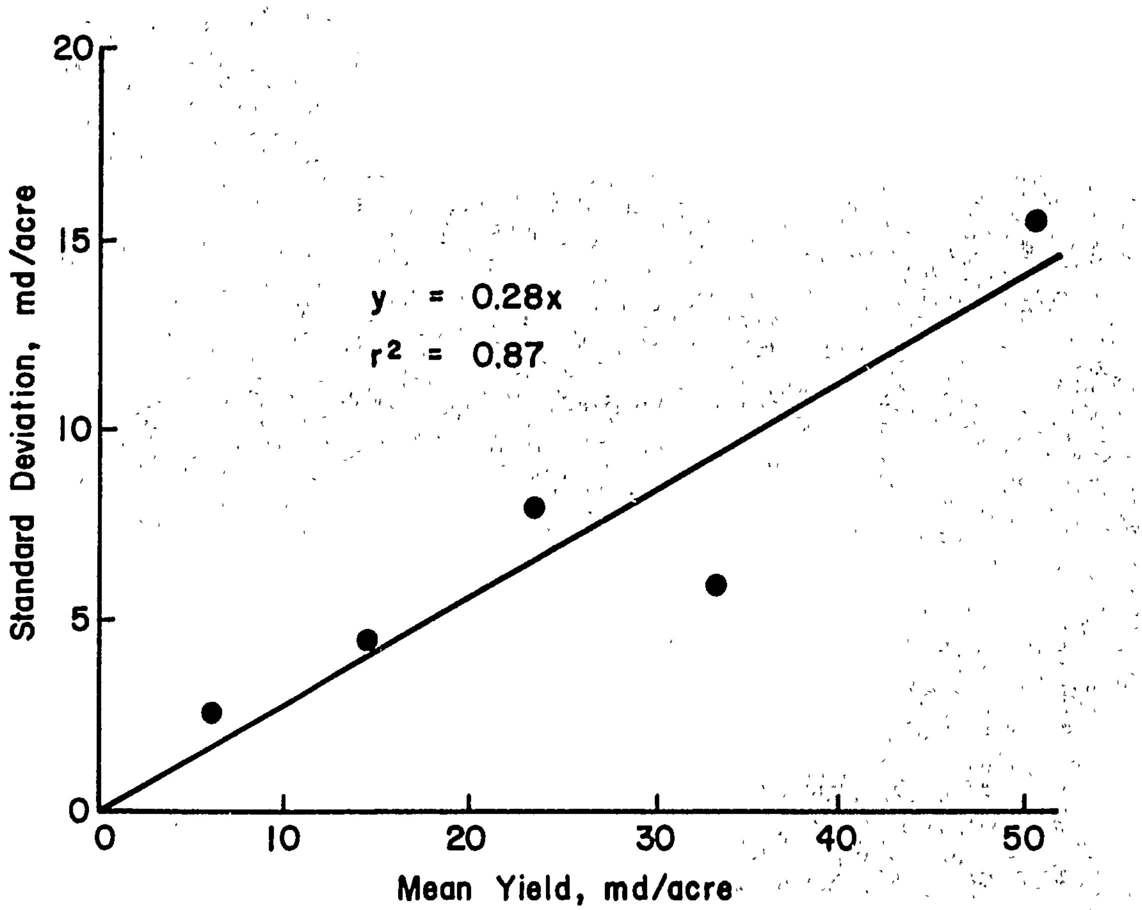

Figure VI.4. Standard deviation within fields as a function of class means. Data of Johnson et al. from 52 wheat fields with 2 randomly located 9.9m^2 quadrants from each field.

$$S_A^2/N_W = S_{\bar{A}}^2 = 108.9$$

$$S_W^2/N_W = (0.554\bar{y})^2/H = 13.09$$

$$S_L^2 = (0.218\bar{y})^2 = 24.3$$

Using our present data, where $N_L = 1$ we have:

$$108.9 = 13.09 + 24.3 + S_F^2$$

$$S_F^2 = 71.5$$

Previously, we could only calculate expected confidence intervals for varying harvest areas assuming one sample location per field, because we were not able to separate the location variance S_L^2 from the true among fields component S_F^2. By substituting for each of the components in Equation VI.11 and with some rearrangement we obtain:

$$S_{\bar{A}}^2 = 0.307\bar{y}^2/HN_L + 0.048\bar{y}^2/N_L + 71.5 \qquad \text{(VI.16)}$$

This allows us to calculate the expected error variance for any combination of harvest area and location per field. This calculation assumes we have a previous estimate of mean yield. For any district we may apply Equation VI.16 using estimates of $\bar{y}$ from previous years, or for a general case we may use our weighted mean of 22.62. We can then calculate the confidence interval at any level of probability P from:

$$CI_{(P)} = t_{(P)}(S_{\bar{A}}^2/N_F)^{1/2} \qquad \text{(VI.17)}$$

Brief tables of expected confidence intervals at the 0.05 and 0.01 probability levels for varying numbers of fields, locations per field, and harvest areas are shown here (VI.6 and VI.7). More extensive tables are shown in the appendix (A2 - A17). These tables are based on the expected mean value of 22.62 md/acre, but moderate differences in the mean values would not change the confidence intervals (CI) significantly.

Several important points can be illustrated using these tables. First, for a given harvest area within fields, the CI is always slightly smaller if the area harvested is divided into multiple locations within the field. For instance, the confidence interval at P = 0.99 for 5 fields cutting $10m^2$ at one location is 12.18 and cutting $5m^2$ at 2 locations in 5 fields gives a CI of 11.50. The advantage gained by multiple locations within fields is not great and drops off rapidly when more than two locations are taken.

As we have previously noted, the effect of increasing harvested area is surprisingly small, particularly if more than one location is taken in each field and/or the number of fields sampled is large. At P = 0.99 and taking two locations per field, the effect of increasing harvested area from $5m^2$ to $20m^2$ reduces the CI for 10 fields from 8.13 to 7.64, and for 100 fields the change is from 2.57 to 2.41. There seems to be little point in taking large harvest areas, particularly if we harvest at more than one location per field.

For illustration, the relationship between the confidence intervals and number of fields using different numbers of harvest locations in each field is shown for a $5m^2$ harvest area in Figure VI.5. A particularly important concept is illustrated by the bottom line in Figure VI.5 and by the right hand column (inf.) in Tables VI.6 and VI.7. These represent the theoretical minimum confidence interval that can be obtained by increasing intensity of sampling within fields, either by increasing cut area, increasing number of locations within fields, or both. It is very

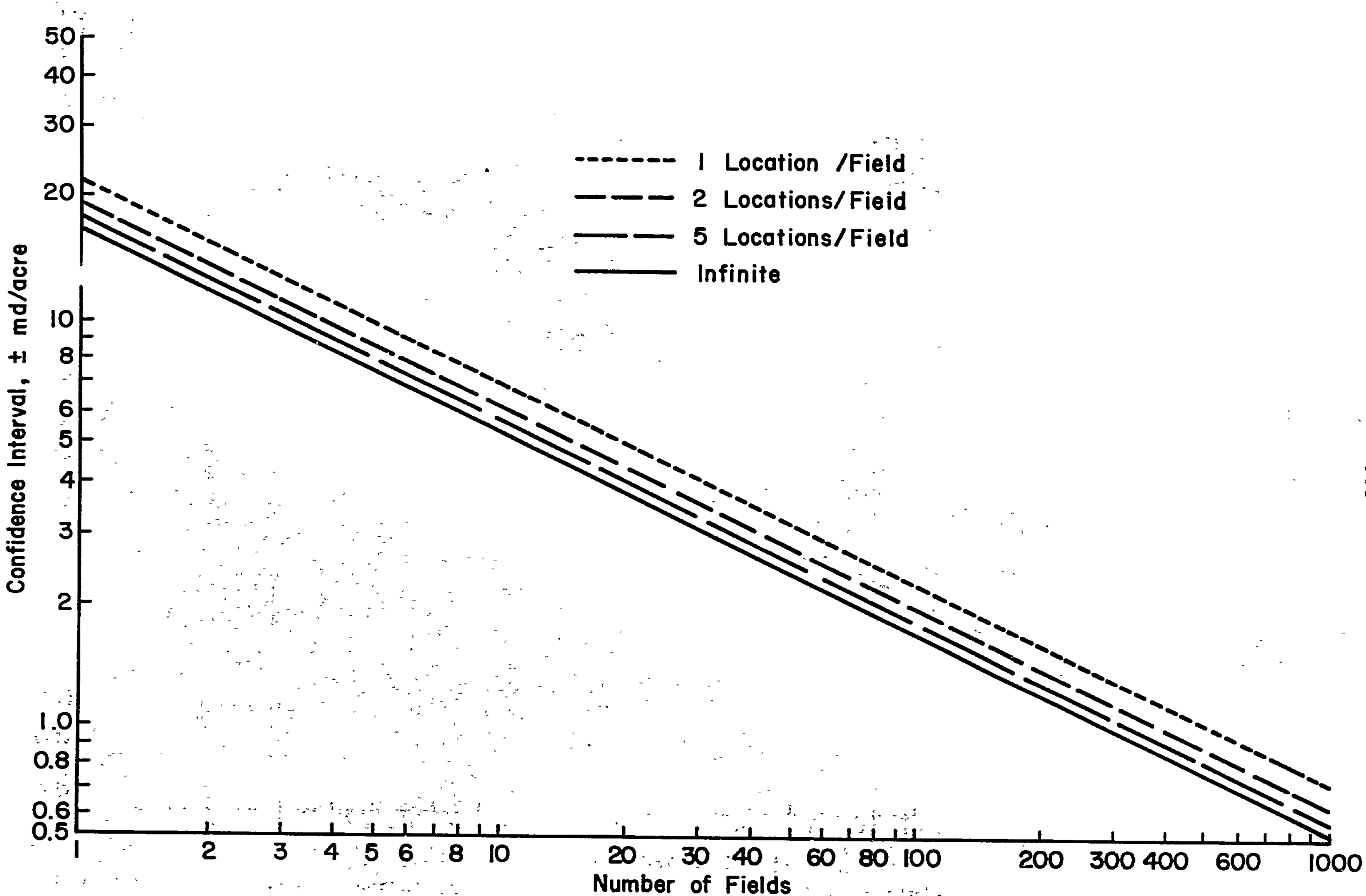

Figure VI.5. Confidence interval (± md/acre) as a function of number of fields and number of locations within fields assuming a harvest area of $5m^2$.

Table VI.6. Confidence interval of mean yields, (+) or (-) maunds per acre, P = 0.45.

	Number of Locations per Field				
Fields	1	2	3	5	(inf)
Harvest area = 1 sq meters					
1	31.16	24.96	22.51	20.35	16.57
3	17.99	14.41	13.00	11.75	9.57
5	13.94	11.16	10.07	9.10	7.41
10	9.85	7.89	7.12	6.43	5.24
30	5.69	4.56	4.11	3.71	3.03
100	3.12	2.50	2.25	2.03	1.66
300	1.80	1.44	1.30	1.17	0.96
Harvest area = 2 sq meters					
1	25.88	21.73	20.16	18.81	16.57
3	14.94	12.55	11.64	10.86	9.57
5	11.57	9.72	9.01	8.41	7.41
10	8.18	6.87	6.37	5.95	5.24
30	4.72	3.97	3.68	3.43	3.03
100	2.59	2.17	2.02	1.88	1.66
300	1.49	1.25	1.16	1.09	0.96
Harvest area = 5 sq meters					
1	22.11	19.54	18.60	17.82	16.57
3	12.76	11.28	10.74	10.29	9.57
5	9.89	8.74	8.32	7.97	7.41
10	6.99	6.18	5.88	5.63	5.24
30	4.04	3.57	3.40	3.25	3.03
100	2.21	1.95	1.86	1.78	1.66
300	1.28	1.13	1.07	1.03	0.96
Harvest area = 10 sq meters					
1	20.70	18.75	18.05	17.48	16.57
3	11.95	10.82	10.42	10.09	9.57
5	9.26	8.38	8.07	7.82	7.41
10	6.54	5.93	5.71	5.53	5.24
30	3.78	3.42	3.30	3.19	3.03
100	2.07	1.87	1.81	1.75	1.66
300	1.19	1.08	1.04	1.01	0.96
Harvest area = 20 sq meters					
1	19.95	18.34	17.77	17.30	16.57
3	11.52	10.59	10.26	9.99	9.57
5	8.92	8.20	7.95	7.74	7.41
10	6.31	5.80	5.62	5.47	5.24
30	3.64	3.35	3.24	3.16	3.03
100	2.00	1.83	1.78	1.73	1.66
300	1.15	1.06	1.03	1.00	0.96

Table VI.7. Confidence interval of mean yields, (+) or (-) maunds per acre, P = 0.

	Number of Locations per Field				
Fields	1	2	3	5	(inf)
Harvest area = 1 sq meters					
1	41.02	32.85	29.63	26.78	21.82
3	23.68	18.97	17.11	15.46	12.60
5	18.35	14.69	13.25	11.98	9.76
10	12.97	10.39	9.37	8.47	6.90
30	7.49	6.00	5.41	4.89	3.98
100	4.10	3.29	2.96	2.68	2.18
300	2.37	1.90	1.71	1.55	1.26
Harvest area = 2 sq meters					
1	34.06	28.60	26.53	24.75	21.82
3	19.67	16.51	15.32	14.29	12.60
5	15.23	12.79	11.87	11.07	9.76
10	10.77	9.07	8.39	7.83	6.90
30	6.22	5.22	4.84	4.52	3.98
100	3.41	2.86	2.65	2.48	2.18
300	1.97	1.65	1.53	1.43	1.26
Harvest area = 5 sq meters					
1	29.10	25.72	24.49	23.45	21.82
3	16.80	14.85	14.14	13.54	12.60
5	13.01	11.50	10.95	10.49	9.76
10	9.20	8.13	7.74	7.42	6.90
30	5.31	4.70	4.47	4.28	3.98
100	2.91	2.57	2.45	2.35	2.18
300	1.68	1.48	1.41	1.35	1.26
Harvest = 10 sq meters					
1	27.24	24.68	23.76	23.00	21.82
3	15.73	14.25	13.72	13.28	12.60
5	12.18	11.04	10.63	10.29	9.76
10	8.62	7.80	7.51	7.27	6.90
30	4.97	4.51	4.34	4.20	3.98
100	2.72	2.47	2.38	2.30	2.18
300	1.57	1.42	1.37	1.33	1.26
Harvest area = 20 sq meters					
1	26.27	24.14	23.39	22.78	21.82
3	15.17	13.94	13.51	13.15	12.60
5	11.75	10.80	10.46	10.19	9.76
10	8.31	7.64	7.40	7.20	6.90
30	4.80	4.41	4.27	4.16	3.98
100	2.63	2.41	2.34	2.28	2.18
300	1.52	1.39	1.35	1.31	1.26

clear that precision of estimates of mean yields among fields must depend largely on increasing the numbers of fields sampled rather than on increased intensity of sampling within fields.

Ultimately, it becomes necessary to recommend a sampling plan. I would submit that a reasonable trade-off for within field sampling would be to harvest areas of between $5m^2$ and $10m^2$ at <u>two</u> locations within each field. Appropriate dimensions might be 2m x 3m, 2.5m x 3m, or perhaps 3m x 3m. A 2.5m x 3m sampling area ($7.5m^2$) taken at each of two locations would give a confidence interval of about 1.15 times the theoretical minimum. Thus, we would expect that complete harvesting and measuring of all fields selected would reduce the confidence interval among fields by about 13% (0.15/1.15 x 100) from that obtained by taking two samples, each 2.5m x 3m from each field. This relationship would hold true for any number of fields that might be selected, or for any probability level. If we prefer to think in terms of number of fields required to produce a given confidence interval, if we cut 2 plots each $5m^2$ it will require 1.39 times as many fields as would be required if we used the entire field as our sample. If a single $20m^2$ plot is taken from each field the number of fields required for a given confidence interval would be 1.45 times as great as would be expected from cutting the entire field.

The foregoing seems to be sufficient to establish general guidelines for within field sampling and the approximate number of fields required to achieve a given confidence interval. Unfortunately, it appears as though about 300 fields will be required to establish a confidence interval at the 0.95 level of 1.13 mds/acre or $\pm$ 5% of the mean. From 1,000 fields we would expect a confidence interval of about $\pm$ 0.62 or some 2.7% of the mean.

In practice a stratified procedure will be required so that the districts with the largest acreage will be sampled more intensely than those with smaller acreages. It is beyond the scope of this paper to examine the precision of production estimates but a few comments arising from consideration of these data may be appropriate.

In the first place, the distribution of yields from the fields in this sample are not normal. Histograms (Appendix Fig. A1 and A2) reveal a moderate skewness with the upward tail somewhat more pronounced than the downward tail, particularly if the barani districts are excluded. This would not cause any problem if sampling were taken randomly from the total population, as the "central tendency" property would tend to give a normal distribution of means.

It is not immediately apparent, however, how well the weighted means of the stratified sampling by district would tend to correct for this non-normality. Probably the estimates of confidence intervals as a function of number of fields taken from the figures and tables presented here would be satisfactory. A more complete evaluation of this aspect is probably in order if major economic decisions are to be based on the results of crop cutting yield surveys.

A possible major source of inaccuracy or bias is the acreage estimate used to calculate the production once the yield has been estimated. The accuracy of these acreage figures is equally as important as the yield estimate.

It should also be understood that the use in this paper of a second data source from a single district to achieve separation of the location and field component is less than satisfactory. While certainly better than no estimate, it should be regarded as an interim measure until more satisfactory data can be collected. Again, if major economic decisions are to be based on results of these surveys a repeat experiment of slightly different design should be conducted. This would again involve four samples from each field but two samples should be taken at each of two randomly selected locations within each field. This would allow a reliable separation of the effect of plot size, location within fields, and variations among fields.

Finally, up to this point, we have based our interpretation on the assumption that the objective was to estimate the expected mean yield over a large number of fields. The accuracy of estimation of this mean is our major concern, while the accuracy of the yield estimate for individual fields is not particularly important. Crop cuttings are sometimes used for the somewhat different purpose of relating yields of individual fields to treatments of cultural practices applied to that field. For instance, in conjunction with a crop cutting survey the cultivators may be asked what amount of fertilizer was applied to the fields. The investigator would then try to relate fertilizer application to yield, most likely using multiple regression techniques. In this case we are very much concerned with the accuracy of yield estimates of the individual fields.

Previously, we have considered the variance of an individual field as composed of two components, one related to size of harvest area and the other to the number of locations harvested within the field. Both components are functionally related to the mean yield. These components were estimated as

$$s_W^2 = (0.554\bar{y})^2/H = 0.307\bar{y}^2/H$$

$$s_L^2 = (0.22\bar{y})^2 = 0.048\bar{y}^2$$

The approximate confidence interval of the mean yield for any particular field can be estimated by:*

$$CI = t_p\bar{y}(0.307/HN_L + 0.048/N_L)^{1/2} \qquad (VI.18)$$

From this we can calculate confidence intervals, expressed as percentage of the mean, as a function of harvest area, and number of locations. A selected set of these confidence intervals for the 0.95 and 0.99 confidence levels are given in Table VI.8, and the 0.95 intervals are given in Figure VI.6.

The results are somewhat horrifying. Large samples at many locations will be required to attain a degree of precision that is likely to allow us to detect even gross effects of treatments of cultural practices. One simply could not expect high coefficients of determination (R^2) when relating cultural practices to yields obtained from cutting a few samples of 10 or 20m^2 each. If an investigator intends to conduct such a survey he must be prepared to sample each field intensively or else rely on some other method of yield determinations. Conversely, if one does detect significant effects, but finds the R^2 values low it does not necessarily

*These confidence intervals must be considered approximate at best. As previously pointed out the components are functionally related to the mean in a manner indicative of log-normal properties. Confidence intervals for log-normal distribution are asymmetrically distributed about the geometric mean. When this procedure is used on the present data upper confidence limits are higher than that shown in Table VI.8. Lower confidence limits are also higher, i.e., the absolute value is smaller and never greater than 100%. However, confidence limits that deviate by less than 50% from the mean are in reasonable agreement for both methods. While standard deviations vary with the field means the distribution of samples drawn from any particular field is probably more nearly normal. Therefore, the symmetric confidence limits based on the normal distribution are presented here.

Table VI.8. Approximate confidence intervals of yield of wheat fields as a function of harvest area and number of locations taken within the field. Expressed as percent of mean yield.

	Harvest area m^2				
Locations	1	2	5	10	50
	± Percent of mean				
Probability = 0.95					
1	117	88	65	55	46
2	83	62	46	39	32
5	52	39	29	25	20
10	37	29	21	17	14
20	26	19	15	12	10
50	17	12	9	8	6
Probability = 0.99					
1	154	101	85	72	60
2	141	71	60	51	42
5	69	45	38	32	27
10	49	32	27	23	19
20	34	23	19	16	13
50	22	14	12	10	8

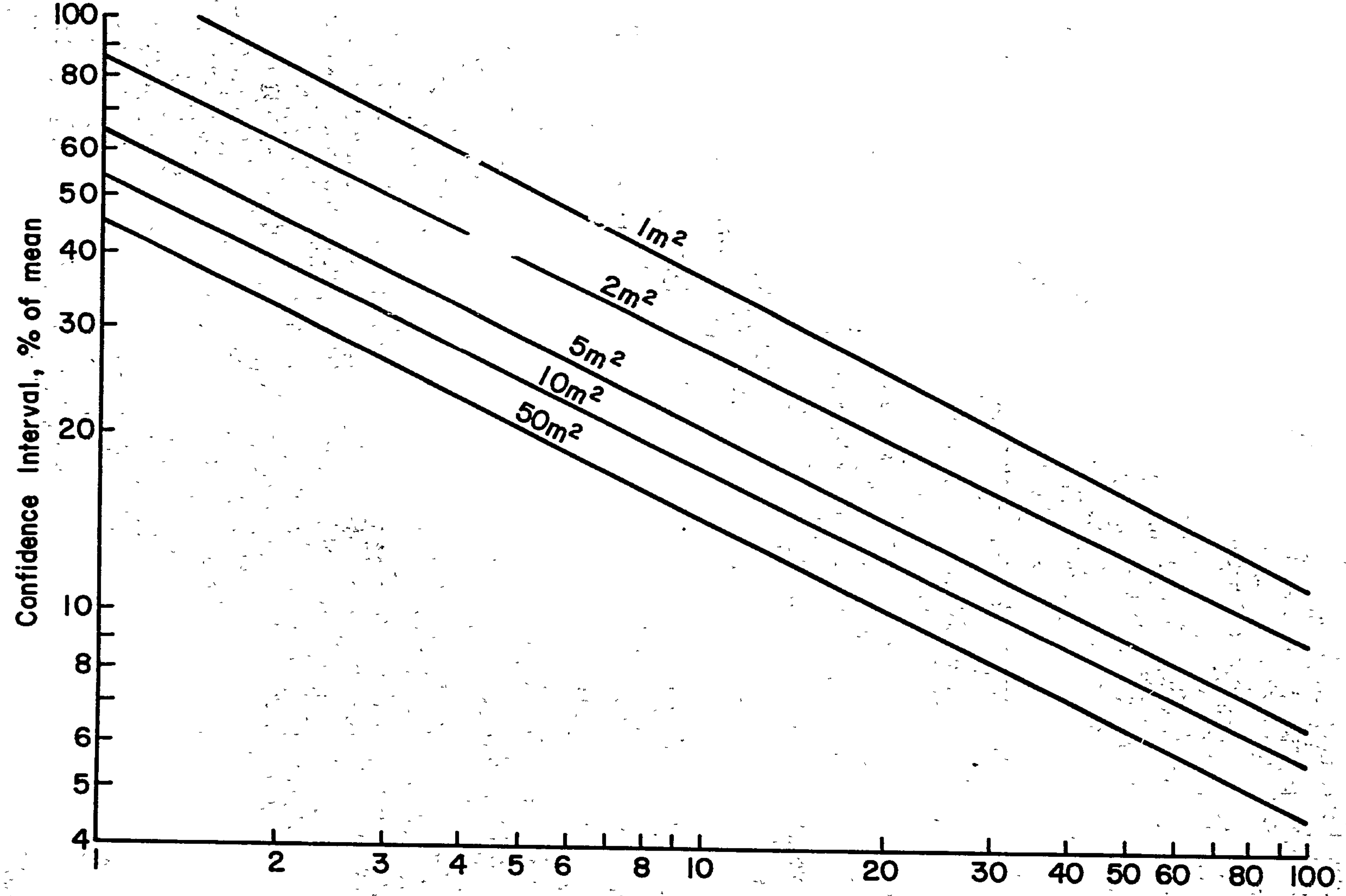

Figure VI.6. Effect of harvest area and number of locations harvested on the confidence interval of the mean for that field, expressed as a percentage of the mean yield.

mean there is not a close relationship between the independent variable and yield, as high R^2 values are unlikely considering the low precision of the yield estimates.

In some ways the conclusions reached above appear inconsistent. In the first place we decided that estimates of mean yield over a number of fields are not really much affected by harvest area, and that in general it is not worthwhile to take more than two locations per field, each with a harvest area of 5 to $10m^2$. Secondly, we say that to accurately estimate the yield of an individual field, intensive sampling is required. In fact, the two conclusions are not inconsistent but simply reflect the hard facts of the variation encountered within and among fields.

APPENDIX TABLE A1

Key to district numbers

1. Attock
2. Rawalpindi
3. Jhelum
4. Gujerat
5. Sargodha
6. Faisalabad
7. Jhang
8. Mianwali
9. Sialkot
10. Gujranawala
11. Sheikhupura
12. Kasur
13. Lahore
14. Sahiwal
15. Multan
16. Muzaffargarh
17. D. G. Khan
18. Vehari
19. Bahawalpur
20. Bahawalnagar
21. Rahim Yar Khan

APPENDIX FIGURE A1

Histogram showing distribution of field means from all districts.

```
0.0 *****
to  ***** 5.0
5.0 *****

5.0 **********************
to  **********************22.0
10.0**********************

10.0***********************
 to ***********************23.0
15.0***********************

15.0*************************************************
 to *************************************************49.0
20.0*************************************************

20.0*********************
 to *********************21.0
25.0*********************

25.0****************************
 to ****************************28.0
30.0****************************

30.0******************
 to ******************18.0
35.0******************

35.0***********
 to ***********11.0
40.0***********

40.0*********
 to *********9.0
45.0*********

45.0****
 to ****4.0
50.0****
```

Total number observations = 190

APPENDIX FIGURE A2

Histogram showing distribution of field means from districts 4-21.

```
0.0 *****
to  *****5.0
5.0 *****

5.0 *****************
to  *****************17.0
10.0*****************

10.0*****************
 to *****************17.0
15.0*****************

15.0************************************************
 to ************************************************48.0
20.0************************************************

20.0********************
 to ********************20.0
25.0********************

25.0***************************
 to ***************************27.0
30.0***************************

30.0******************
 to ******************18.0
35.0******************

35.0***********
 to ***********11.0
40.0***********

40.0*********
 to *********9.0
45.0*********

45.0****
 to ****4.0
50.0****
```

Total number observations = 176

Table A2. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 1.0 sq meters. P = 0.950

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	31.16	24.96	22.51	21.18	20.35	19.02	18.56
2	22.04	17.65	15.92	14.98	14.39	13.45	13.12
3	17.99	14.41	13.00	12.23	11.75	10.98	10.71
4	15.58	12.48	11.26	10.59	10.17	9.51	9.28
5	13.94	11.16	10.07	9.47	9.10	8.51	8.30
8	11.02	8.82	7.96	7.49	7.19	6.72	6.56
10	9.85	7.89	7.12	6.70	6.43	6.01	5.87
20	6.97	5.58	5.03	4.74	4.55	4.25	4.15
30	5.69	4.56	4.11	3.87	3.71	3.47	3.39
40	4.93	3.95	3.56	3.35	3.22	3.01	2.93
50	4.41	3.53	3.18	3.00	2.88	2.69	2.62
80	3.48	2.79	2.52	2.37	2.27	2.13	2.07
100	3.12	2.50	2.25	2.12	2.03	1.90	1.86
200	2.20	1.76	1.59	1.50	1.44	1.34	1.31
300	1.80	1.44	1.30	1.22	1.17	1.10	1.07
400	1.56	1.25	1.13	1.06	1.02	0.95	0.93
500	1.39	1.12	1.01	0.95	0.91	0.85	0.83
800	1.10	0.88	0.80	0.75	0.72	0.67	0.66
1000	0.99	0.79	0.71	0.67	0.64	0.60	0.59

Table A3. Confidence intervals of mean yields, (+) or (-) maunds per acre.
Harvest area = 2.0 sq meters. P = 0.950

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	25.[illegible]	21.73	20.16	19.32	18.81	18.00	17.72
2	18.30	15.36	14.25	13.66	13.30	12.73	12.53
3	14.94	12.55	11.64	11.16	10.86	10.39	10.23
4	12.94	10.86	10.08	9.66	9.40	9.00	8.86
5	11.57	9.72	9.01	8.64	8.41	8.05	7.93
8	9.15	7.68	7.13	6.83	6.65	6.36	6.27
10	8.18	6.87	6.37	6.11	5.95	5.69	5.61
20	5.79	4.86	4.51	4.32	4.21	4.03	3.96
30	4.72	3.97	3.68	3.53	3.43	3.29	3.24
40	4.09	3.44	3.19	3.06	2.97	2.85	2.80
50	3.66	3.07	2.85	2.73	2.66	2.55	2.51
80	2.89	2.43	2.25	2.16	2.10	2.01	1.98
100	2.59	2.17	2.02	1.93	1.83	1.80	1.77
200	1.83	1.54	1.43	1.37	1.33	1.27	1.25
300	1.49	1.25	1.16	1.12	1.09	1.04	1.02
400	1.[illegible]	1.09	1.01	0.97	0.94	0.90	0.89
500	1.16	0.97	0.90	0.86	0.84	0.81	0.79
800	0.91	0.77	0.71	0.68	0.66	0.64	0.63
1000	0.82	0.69	0.64	0.61	0.59	0.57	0.56

Table A4. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 3.0 sq meters. P = 0.950

Number Locations per Field

Fields	1	2	3	4	5	8	10
1	23.86	20.54	19.31	18.66	18.26	17.65	17.44
2	16.87	14.52	13.65	13.20	12.91	12.48	12.33
3	13.77	11.86	11.15	10.77	10.54	10.19	10.07
4	11.93	10.27	9.65	9.33	9.13	8.82	8.72
5	10.67	9.19	8.63	8.35	8.17	7.89	7.80
8	8.43	7.26	6.83	6.60	6.46	6.24	6.17
10	7.54	6.50	6.11	5.90	5.78	5.58	5.51
20	5.33	4.59	4.32	4.17	4.08	3.95	3.90
30	4.36	3.75	3.53	3.41	3.33	3.22	3.18
40	3.77	3.25	3.05	2.95	2.89	2.79	2.76
50	3.37	2.90	2.73	2.64	2.58	2.50	2.47
80	2.67	2.30	2.16	2.09	2.04	1.97	1.95
100	2.39	2.05	1.93	1.87	1.83	1.76	1.74
200	1.69	1.45	1.37	1.32	1.29	1.25	1.23
300	1.38	1.19	1.11	1.08	1.05	1.02	1.01
400	1.19	1.03	0.97	0.93	0.91	0.88	0.87
500	1.07	0.92	0.86	0.83	0.82	0.79	0.78
800	0.84	0.73	0.83	0.66	0.65	0.62	0.62
1000	0.75	0.65	0.61	0.59	0.58	0.56	0.55

Table A5. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 5.0 sq meters. P = 0.950

Fields	Number Locations per Field: 1	2	3	4	5	8	10
1	22.11	19.54	18.60	18.12	17.82	17.36	17.21
2	15.63	13.81	13.15	12.81	12.60	12.28	12.17
3	12.76	11.28	10.74	10.46	10.29	10.02	9.93
4	11.05	9.77	9.30	9.06	8.91	8.68	8.60
5	9.89	8.74	8.32	8.10	7.97	7.76	7.70
8	7.82	6.91	6.58	6.40	6.30	6.14	6.03
10	6.99	6.18	5.88	5.73	5.63	5.49	5.44
20	4.94	4.37	4.16	4.05	3.98	3.88	3.85
30	4.04	3.57	3.40	3.31	3.25	3.17	3.14
40	3.50	3.09	2.94	2.86	2.82	2.75	2.43
50	3.13	2.76	2.63	2.56	2.52	2.46	2.43
80	2.47	2.18	2.08	2.03	1.99	1.94	1.92
100	2.21	1.95	1.86	1.81	1.78	1.74	1.72
200	1.56	1.38	1.32	1.28	1.26	1.23	1.22
300	1.28	1.13	1.07	1.05	1.03	1.00	0.99
400	1.11	0.98	0.93	0.91	0.89	0.87	0.86
500	0.99	0.87	0.83	0.81	0.80	0.78	0.77
800	0.78	0.69	0.66	0.64	0.63	0.61	0.61
1000	0.70	0.62	0.59	0.57	0.56	0.55	0.54

Table A6. Confidence intervals of mean yields, (+) or (-) maunds per acre.
Harvest area = 8.0 sq meters. P = 0.950

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	21.06	18.95	18.19	17.80	17.56	17.20	17.07
2	14.89	13.40	12.86	12.59	12.42	12.16	12.07
3	12.16	10.94	10.50	10.28	10.14	9.93	9.86
4	10.53	9.47	9.10	8.90	8.78	8.60	8.54
5	9.42	8.47	8.14	7.96	7.85	7.69	7.64
8	7.44	6.70	6.43	6.29	6.21	6.08	6.04
10	6.66	5.99	5.75	5.63	5.55	5.44	5.40
20	4.71	4.24	4.07	3.98	3.93	3.85	3.82
30	3.84	3.46	3.32	3.25	3.21	3.14	3.12
40	3.33	3.00	2.88	2.81	2.78	2.72	2.70
50	2.98	2.68	2.57	2.52	2.48	2.43	2.41
80	2.35	2.12	2.03	1.99	1.96	1.92	1.91
100	2.11	1.89	1.82	1.78	1.76	1.72	1.71
200	1.49	1.34	1.29	1.26	1.24	1.22	1.21
300	1.22	1.09	1.05	1.03	1.01	0.99	0.99
400	1.05	0.95	0.91	0.89	0.88	0.86	0.85
500	0.94	0.85	0.81	0.80	0.79	0.77	0.76
800	0.74	0.67	0.64	0.63	0.62	0.61	0.60
1000	0.67	0.60	0.58	0.56	0.56	0.54	0.54

Table A7. Confidence intervals of mean yields, (+) or (-) maunds per acre.
Harvest area = 10.0 sq meters. P = 0.950

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	20.70	18.75	18.05	17.69	17.48	17.14	17.03
2	14.63	13.26	12.77	12.51	12.36	12.12	12.04
3	11.95	10.82	10.42	10.22	10.09	9.90	9.83
4	10.35	9.37	9.03	8.85	8.74	8.57	8.52
5	9.26	8.38	8.07	7.91	7.82	7.67	7.62
8	7.32	6.63	6.38	6.26	6.18	6.06	6.02
10	6.54	5.93	5.71	5.60	5.53	5.42	5.39
20	4.63	4.19	4.04	3.96	3.91	3.83	3.81
30	3.78	3.42	3.30	3.23	3.19	3.13	3.11
40	3.27	2.96	2.85	2.80	2.76	2.71	2.69
50	2.93	2.65	2.55	2.50	2.47	2.42	2.41
80	2.31	2.10	2.02	1.98	1.95	1.92	1.90
100	2.07	1.87	1.81	1.77	1.75	1.71	1.70
200	1.46	1.33	1.28	1.25	1.24	1.21	1.20
300	1.19	1.08	1.04	1.02	1.01	0.99	0.98
400	1.03	0.94	0.90	0.88	0.87	0.86	0.85
500	0.93	0.84	0.81	0.79	0.78	0.77	0.76
800	0.73	0.66	0.64	0.63	0.62	0.61	0.60
1000	0.65	0.59	0.57	0.56	0.55	0.54	0.54

Table A8. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 20.0 sq meters. P = 0.950

Fields	Number Locations per Field: 1	2	3	4	5	8	10
1	19.95	18.34	17.77	17.48	17.30	17.03	16.94
2	14.11	12.97	12.57	12.36	12.23	12.04	11.94
3	11.52	10.59	10.26	10.09	9.99	9.83	9.78
4	9.98	9.17	8.89	8.74	8.65	8.52	8.47
5	8.92	8.20	7.95	7.82	7.74	7.62	7.58
8	7.05	6.48	6.28	6.18	6.12	6.02	5.99
10	6.31	5.80	5.62	5.53	5.47	5.39	5.36
20	4.46	4.10	3.97	3.91	3.87	3.81	3.79
30	3.64	3.35	3.24	3.19	3.16	3.11	3.09
40	3.16	2.90	2.81	2.76	2.74	2.69	2.68
50	2.82	2.59	2.51	2.47	2.45	2.41	2.40
80	2.23	2.05	1.99	1.95	1.93	1.90	1.89
100	2.00	1.83	1.78	1.75	1.73	1.70	1.69
200	1.41	1.30	1.26	1.24	1.22	1.20	1.20
300	1.15	1.06	1.03	1.01	1.00	0.98	0.98
400	1.00	0.92	0.89	0.87	0.87	0.85	0.85
500	0.89	0.82	0.79	0.78	0.77	0.76	0.76
800	0.71	0.65	0.63	0.62	0.61	0.60	0.60
1000	0.63	0.58	0.56	0.55	0.55	0.54	0.54

Table A9. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 40.0 sq meters. P = 0.950

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	19.57	18.14	17.63	17.37	17.22	16.98	16.90
2	13.84	12.82	12.47	12.28	12.17	12.00	11.95
3	11.30	10.47	10.18	10.03	9.94	9.80	9.76
4	9.79	9.07	8.82	8.69	8.61	8.49	8.45
5	8.75	8.11	7.88	7.77	7.70	7.59	7.56
8	6.92	6.41	6.23	6.14	6.09	6.00	5.97
10	6.19	5.73	5.58	5.49	5.44	5.37	5.34
20	4.38	4.06	3.94	3.88	3.85	3.80	3.78
30	3.57	3.31	3.22	3.17	3.14	3.10	3.09
40	3.09	2.87	2.79	2.75	2.72	2.68	2.67
50	2.77	2.56	2.49	2.46	2.43	2.40	2.39
80	2.19	2.03	1.97	1.94	1.92	1.90	1.89
100	1.96	1.81	1.76	1.74	1.72	1.70	1.69
200	1.38	1.28	1.25	1.23	1.22	1.20	1.19
300	1.13	1.05	1.02	1.00	0.99	0.98	0.98
400	0.98	0.91	0.88	0.87	0.86	0.85	0.84
500	0.88	0.81	0.79	0.78	0.77	0.76	0.76
800	0.69	0.64	0.62	0.61	0.61	0.60	0.60
1000	0.62	0.57	0.56	0.55	0.54	0.54	0.53

Table A10. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 1.0 sq meters. P = 0.990

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	41.02	32.85	29.63	27.89	26.78	25.04	24.43
2	29.01	23.23	20.95	19.72	18.94	17.70	17.27
3	23.68	18.97	17.11	16.10	15.46	14.45	14.10
4	20.51	16.43	14.82	13.94	13.39	12.52	12.21
5	18.35	14.69	13.25	12.47	11.98	11.20	10.92
8	14.50	11.62	10.48	9.86	9.47	8.85	8.64
10	12.97	10.39	9.37	8.82	8.47	7.92	7.72
20	9.17	7.35	6.63	6.24	5.99	5.60	5.46
30	7.49	6.00	5.41	5.09	4.89	3.96	3.86
40	6.49	5.19	4.69	4.41	4.23	3.96	3.86
50	5.80	4.65	4.19	3.94	3.79	3.54	3.45
80	4.59	3.67	3.31	3.12	2.99	2.80	2.73
100	4.10	3.29	2.96	2.79	2.68	2.50	2.44
200	2.90	2.32	2.10	1.97	1.89	1.77	1.73
300	2.37	1.90	1.71	1.61	1.55	1.45	1.41
400	2.05	1.64	1.48	1.39	1.34	1.25	1.22
500	1.83	1.47	1.33	1.25	1.20	1.12	1.09
800	1.45	1.16	1.05	0.99	0.95	0.89	0.86
1000	1.30	1.04	0.94	0.88	0.85	0.79	0.77

Table A11. Confidence intervals of mean yields, (+) or (-) maunds per acre.
Harvest area = 2.0 sq meters. P = 0.990

Number Locations per Field

Fields	1	2	3	4	5	8	10
1	34.06	28.60	26.53	25.44	24.75	23.70	23.33
2	24.09	20.22	18.76	17.99	17.50	16.76	16.50
3	19.67	16.51	15.32	14.69	14.29	13.68	13.47
4	17.03	14.30	13.27	12.72	12.38	11.85	11.67
5	15.23	12.79	11.87	11.38	11.07	10.60	10.43
8	12.04	10.11	9.38	8.99	8.75	8.38	8.25
10	10.77	9.04	8.39	8.04	7.83	7.49	7.38
20	7.62	6.40	5.93	5.69	5.54	5.30	5.22
30	6.22	5.22	4.84	4.64	4.52	4.33	4.26
40	5.39	4.52	4.20	4.02	3.91	3.75	3.69
50	4.82	4.04	3.75	3.60	3.50	3.35	3.30
80	3.81	3.20	2.97	2.84	2.77	2.65	2.61
100	3.41	2.86	2.65	2.54	2.48	2.37	2.33
200	2.41	2.02	1.88	1.80	1.75	1.68	1.65
300	1.97	1.65	1.53	1.47	1.43	1.37	1.35
400	1.70	1.43	1.33	1.27	1.24	1.18	1.17
500	1.52	1.28	1.19	1.14	1.11	1.06	1.04
800	1.20	1.01	0.94	0.90	[illegible]	0.84	0.82
1000	1.08	0.90	0.84	0.80	[illegible]	0.75	0.74

Table A12. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 3.0 sq meters. P = 0.990

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	31.40	27.04	25.42	24.57	24.04	23.23	22.96
2	22.20	19.12	17.97	17.37	17.00	16.43	16.23
3	18.13	15.61	14.67	14.18	13.88	13.41	13.25
4	15.70	13.52	12.71	12.28	12.02	11.62	11.48
5	14.04	12.09	11.37	10.99	10.75	10.39	10.27
8	11.10	9.56	8.99	8.69	8.50	8.21	8.12
10	9.93	8.55	8.04	7.77	7.60	7.35	7.26
20	7.02	6.05	5.68	5.49	5.38	5.19	5.13
30	5.73	4.94	4.64	4.49	4.39	4.24	4.19
40	4.96	4.27	4.02	3.88	3.80	3.67	3.63
50	4.44	3.82	3.59	3.47	3.40	3.29	3.25
80	3.51	3.02	2.84	2.75	2.69	2.60	2.57
100	3.14	2.70	2.54	2.46	2.40	2.32	2.30
200	2.22	1.91	1.80	1.74	1.70	1.64	1.62
300	1.81	1.56	1.47	1.42	1.39	1.34	1.33
400	1.57	1.35	1.27	1.23	1.20	1.16	1.15
500	1.40	1.21	1.14	1.10	1.08	1.04	1.03
800	1.11	0.96	0.90	0.87	0.85	0.82	0.81
1000	0.99	0.85	0.80	0.78	0.76	0.73	0.73

Table A13. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 5.0 sq meters. P = 0.990

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	29.10	25.72	24.49	23.85	23.45	22.85	22.65
2	20.58	18.18	17.31	16.86	16.58	16.16	16.02
3	16.80	14.85	14.14	13.77	13.54	13.19	13.08
4	14.55	12.86	12.24	11.92	11.73	11.43	11.32
5	13.01	11.50	10.95	10.66	10.49	10.22	10.13
8	10.29	9.09	8.66	8.43	8.29	8.08	8.01
10	9.20	8.13	7.74	7.54	7.42	7.23	7.16
20	6.51	5.75	5.48	5.33	5.24	5.11	5.06
30	5.31	4.70	4.47	4.35	4.28	4.17	4.14
40	4.60	4.07	3.87	3.77	3.71	3.61	3.58
50	4.12	3.64	3.46	3.37	3.32	3.23	3.20
80	3.25	2.88	2.74	2.67	2.62	2.56	2.53
100	2.91	2.57	2.45	2.38	2.35	2.29	2.26
200	2.06	1.82	1.73	1.69	1.66	1.62	1.60
300	1.68	1.48	1.41	1.38	1.35	1.32	1.31
400	1.45	1.29	1.22	1.19	1.17	1.14	1.13
500	1.30	1.15	1.10	1.07	1.05	1.02	1.01
800	1.03	0.91	0.87	0.84	0.83	0.81	0.80
1000	0.92	0.81	0.77	0.75	0.74	0.72	0.72

Table A14. Confidence intervals of mean yields, (+) or (-) maunds per acre.
Harvest area = 8.0 sq meters. P = 0.990

Fields	Number Locations per Field: 1	2	3	4	5	8	10
1	27.72	24.94	23.95	23.43	23.12	22.64	22.48
2	19.60	17.64	16.93	16.57	16.35	16.01	15.89
3	16.00	14.40	13.83	13.53	13.35	13.07	12.98
4	13.86	12.47	11.97	11.72	11.56	11.32	11.24
5	12.40	11.15	10.71	10.48	10.34	10.12	10.05
8	9.80	8.82	8.47	8.28	8.17	8.00	7.95
10	8.77	7.89	7.57	7.41	7.31	7.16	7.11
20	6.20	5.58	5.35	5.24	5.17	5.06	5.03
30	5.06	4.55	4.37	4.28	4.22	4.13	4.10
40	4.38	3.94	3.79	3.70	3.66	3.58	3.55
50	3.92	3.53	3.39	3.31	3.27	3.20	2.18
80	3.10	2.79	2.68	2.62	2.58	2.53	2.51
100	2.77	2.49	2.39	2.34	2.31	2.26	2.25
200	1.96	1.76	1.69	1.66	1.63	1.60	1.59
300	1.60	1.44	1.38	1.35	1.33	1.31	1.30
400	1.39	1.25	1.20	1.17	1.16	1.13	1.12
500	1.24	1.12	1.07	1.05	1.03	1.01	1.01
800	0.98	0.88	0.85	0.83	0.82	0.80	0.79
1000	0.88	0.79	0.76	0.74	0.73	0.72	0.71

Table A15. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 10.0 sq meters. P = 0.990

Fields	Number Locations per Field: 1	2	3	4	5	8	10
1	27.24	24.68	23.76	23.29	23.00	22.57	22.42
2	19.26	17.45	16.80	16.47	16.27	15.96	15.85
3	15.73	14.25	13.72	13.45	13.28	13.03	12.94
4	13.62	12.34	11.88	11.65	11.50	11.28	11.21
5	12.18	11.04	10.63	10.42	10.29	10.09	10.03
8	9.63	8.73	8.40	8.23	8.13	7.98	7.93
10	8.62	7.80	7.51	7.37	7.27	7.14	7.09
20	6.09	5.52	5.31	5.21	5.14	5.05	5.01
30	4.97	4.51	4.34	4.25	4.20	4.12	4.09
40	4.31	3.90	3.76	3.68	3.64	3.57	3.54
50	3.85	3.49	3.36	3.29	3.25	3.19	3.17
80	3.05	2.76	2.66	2.60	2.57	2.52	2.51
100	2.72	2.47	2.38	2.33	2.30	2.26	2.24
200	1.93	1.75	1.68	1.65	1.63	1.60	1.59
300	1.57	1.42	1.37	1.34	1.33	1.30	1.29
400	1.36	1.23	1.19	1.16	1.15	1.13	1.12
500	1.22	1.10	1.06	1.04	1.03	1.01	1.00
800	0.96	0.87	0.84	0.82	0.81	0.80	0.79
1000	0.86	0.78	0.75	0.74	0.73	0.71	0.71

Table A16. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 20.0 sq meters. P = 0.990

Fields	Number Locations per Field 1	2	3	4	5	8	10
1	26.27	24.14	23.39	23.01	22.78	22.42	22.30
2	18.57	17.07	16.54	16.27	16.10	15.85	15.77
3	15.17	13.94	13.51	13.28	13.15	12.94	12.88
4	13.13	12.07	11.70	11.50	11.39	11.21	11.15
5	11.75	10.80	10.46	10.29	10.19	10.03	9.97
8	9.29	8.54	8.27	8.14	8.05	7.93	7.88
10	8.31	7.64	7.40	7.28	7.20	7.09	7.05
20	5.87	5.40	5.23	5.15	5.09	5.01	4.99
30	4.80	4.41	4.27	4.20	4.16	4.09	4.07
40	4.15	3.82	3.70	3.64	3.60	3.55	3.53
50	3.71	3.41	3.31	3.25	3.22	3.17	3.15
80	2.94	2.70	2.62	2.57	2.55	2.51	2.49
100	2.63	2.41	2.34	2.30	2.28	2.24	2.23
200	1.86	1.71	1.65	1.63	1.61	1.59	1.58
300	1.52	1.39	1.35	1.33	1.31	1.29	1.29
400	1.31	1.21	1.17	1.15	1.14	1.12	1.12
500	1.17	1.08	1.05	1.03	1.02	1.00	1.00
800	0.93	0.85	0.83	0.81	0.81	0.79	0.79
1000	0.83	0.76	0.74	0.73	0.72	0.71	0.71

Table A17. Confidence intervals of mean yields, (+) or (-) maunds per acre. Harvest area = 40.0 sq meters. P = 0.990

	Number Locations per Field						
Fields	1	2	3	4	5	8	10
1	25.76	23.87	23.21	22.87	[illegible].66	22.35	22.24
2	18.22	16.88	16.41	16.17	16.02	15.80	15.73
3	14.88	13.78	13.40	13.20	13.08	12.90	12.84
4	12.88	11.94	11.60	11.43	11.33	11.17	11.12
5	11.52	10.68	10.38	10.23	10.13	9.99	9.95
8	9.11	8.44	8.20	8.08	8.01	7.90	7.86
10	8.15	7.55	7.34	7.23	7.17	7.07	7.03
20	5.76	5.34	5.19	5.11	5.07	5.00	4.97
30	4.70	4.36	4.24	4.17	4.14	4.08	4.06
40	4.07	3.77	3.67	3.62	3.58	3.53	3.52
50	3.64	3.38	3.28	3.23	3.20	3.16	3.15
80	2.88	2.67	2.59	2.56	2.53	2.50	2.49
100	2.58	2.39	2.32	2.29	2.27	2.23	2.22
200	1.82	1.69	1.64	1.62	1.60	1.58	1.57
300	1.49	1.38	1.34	1.32	1.31	1.29	1.28
400	1.29	1.19	1.16	1.14	1.13	1.12	1.11
500	1.15	1.07	1.04	1.02	1.01	1.00	0.99
800	0.91	0.84	0.82	0.81	0.80	0.79	0.79
1000	0.81	0.75	0.73	0.72	0.72	0.71	0.70

APPENDIX 19

WATER LOSSES AS A FUNCTION OF WATER LEVEL IN WATERCOURSES AND RESULTANT EFFECTS OF CLEANING ON DELIVERY EFFICIENCY[1]

by

M. Akram, W. D. Kemper and J. D. Sabey[2]

Loss of water in "mature" earthen watercourses increases exponentially as the level of water in the watercourse rises. Average losses were found to increase about 9% per cm of water level increase in Colorado and 12% in Pakistan. Vegetation growing in watercourses increased the operating levels above the designed levels.

Cleaning vegetation from watercourses lowered the operating level of water by decreasing the roughness of the banks. Regular cleaning to keep the water levels at or below designed levels keeps losses at a small fraction of what they can be when vegetative growth is not controlled.

INTRODUCTION

A major portion of farmers' water is being lost from their watercourses before it reaches their fields (e.g. Clyma, et al., 1975). The Clyma, et al., data were obtained using flumes and flow meters and the resulting loss rates were higher than those obtained by the Pakistan Irrigation Department in their limited, but carefully, conducted studies using the ponding and recession rate method for determining losses. Consequently, it was decided that the two methods should be used on watercourses to determine whether they gave the same results. It was found (i.e., see Ashraf, et al., 1977) that when the two methods were properly used that the rates of loss measured by the two methods were practically the same. However, it was also found (Kemper,

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et al, 1975a) that the rate of loss was highly dependent on the elevation of the water surface in the watercourse. On the average, the rate of loss was almost doubled for each five centimeter increase in the level of the watercourse. This observation, coupled with observations that the water level in watercourses commonly dropped from 7 to 10 centimeters when farmers cleaned their watercourse, led to the tentative conclusion that a primary mechanism by which cleaning and maintenance reduced watercourse losses was by lowering the operational level. This factor and its effect on the rates of watercourse losses was discussed by Kemper, et al., 1975b, and estimates of the benefits of a consistent cleaning and maintenance program were made. However, a complete set of data showing the water levels before and after cleaning, and the rates of loss before and after cleaning have not been available. The purpose of this study is to provide such a set of data, and to obtain water loss data from sections of watercourses in other areas to determine whether this is a general phenomena. The data help clarify the role of cleaning in reducing watercourse losses and can be used by extension personnel to educate farmers to the good investment opportunity which is available to them in the cleaning and maintenance of watercourses.

PROCEDURE

Two types of watercourses were selected for improvement. The first of these was an "improved" watercourse. This improvement consisted of removing the old hole riddled banks and cross section similar to those shown in Figure 8. Improvement occurred about 16 months before the cleaning involved in this study took place. Three consecutive sections, each 30 meters long, were selected for this study at the top end of Branch I of the watercourse serving Tubewell 78 in the Mona Reclamation Experimental Project (Pakistan). The soil in the fields adjacent to this stretch is a sandy loam. However, immediately along the watercourse the soil has been mixed with sediment which has been cleaned out of the watercourse during the past 70 years. The cooperatively maintained portion of this branch is about 760 meters long and was cleaned at the time of this study.

The second watercourse selected was a private branch about 490 meters long belonging to an individual farmer. The first 300 meters of this branch were cleaned and the three test sections were in the first 90 meters. The soil in the fields adjacent to this watercourse were sandy loams. Since the section was over 2,500 meters from the canal, water reaching this point had comparatively less sediment than was the case of Branch I at Tubewell 78. This private branch had not been improved prior to this study and as is the case with most private branches is not cleaned as frequently as those branches which are more frequently used and cooperatively maintained.

The general procedure followed on these two watercourses was:

1. To determine the operating level in the test sections of the watercourse when the farmers were using this water to irrigate fields near the lower end of the watercourse. An elevation marker was then set 3 centimeters higher than this full supply operating level and all further measurements of water surface elevations were made from this benchmark or "datum."

2. The rate of flow in the watercourse was determined.

3. Just before the conclusion of the irrigation turn of the farmers using this branch, this watercourse was filled to 3 centimeters above the operating level. Earthen dams were constructed at the bottom and top ends of each of these sections and the rate at which the water level receded in each of these sections was determined. The average width of the water surface of the watercourse was also determined at these times. From these widths and rates of recession the rate of water loss was calculated as a function of the elevation of the water in the watercourse.

4. The watercourse was then cleaned, recording the approximate number of hours spent by the farmers and laborers on the watercourse. On Branch I at Tubewell 78 these cleaning operations were primarily a removal of the grass from the sides of the watercourse with a small amount of sediment taken with the grass. On the unimproved watercourse at Tubewell 56 cleaning the grass from the banks and beds uncovered a substantial number of rodent holes which were generally filled by the laborers who recognized them as potential avenues for water loss. This extra effort involved in filling these obvious sources of potential leakage required about three hours of extra time per thousand feet of watercourse cleaned.

5. After cleaning, when the farmers used this watercourse again, the operating level was determined with respect to the datum markers set before

cleaning. At the conclusion of the farmer's irrigation turn the water level was again brought up to 3 centimeters above the operating level which was observed before cleaning. The dams between the sections are constructed as before the recession rates and watercourse widths were again determined as a function of time until all the water had left the watercourse.

The ponding and recession method (#3 above) was used on 36 watercourse sections in Pakistan and 31 watercourse sections in Colorado to determine loss rates as a function of water surface level in the watercourses.

On one of these sections, loss rate measurements were taken before reconstruction of the watercourse, after farmers had reconstructed the watercourse, and after a section had been reconstructed by engineers, who compacted the moist soil in the banks in 2 or 3" layers with a compacting load of about 0.7 kgm/cm^2, applied by stepping on the soil.

RESULTS AND DISCUSSION

The rate at which the surface level of the water receded in the test sections of Branch I of Tubewell 78 are shown in Figures 1, 2, and 3. The "A" portions of the figures show the recession rate in detail for the first 5 or 6 hours as was necessary to get good estimates on the rate of water loss when the water surface was at these higher levels. The "B" portions of the figures show the complete recession curve to the time when all of the water was seeped out of the watercourse.

The slopes of these curves in Figures 1, 2, and 3 were then used with the respective watercourse surface widths to obtain the data indicated in Figures 4, 5, and 6 where loss rates are plotted against the level of the water surface below the datum markers.

In section 1, as indicated in Figure 4, the rate of loss following cleaning was considerably less than prior to cleaning when the water was within 5 centimeters of the datum elevation. This was apparently a result of the closure of a couple of rat holes which were just a few centimeters below the "before cleaning full supply level." After the water level had fallen below the level of these rat holes the rate of water loss before cleaning down to the depth of about 14 centimeters below this datum. This tendency for the water loss after cleaning to be greater than the water loss before cleaning, when comparing them at equal levels of

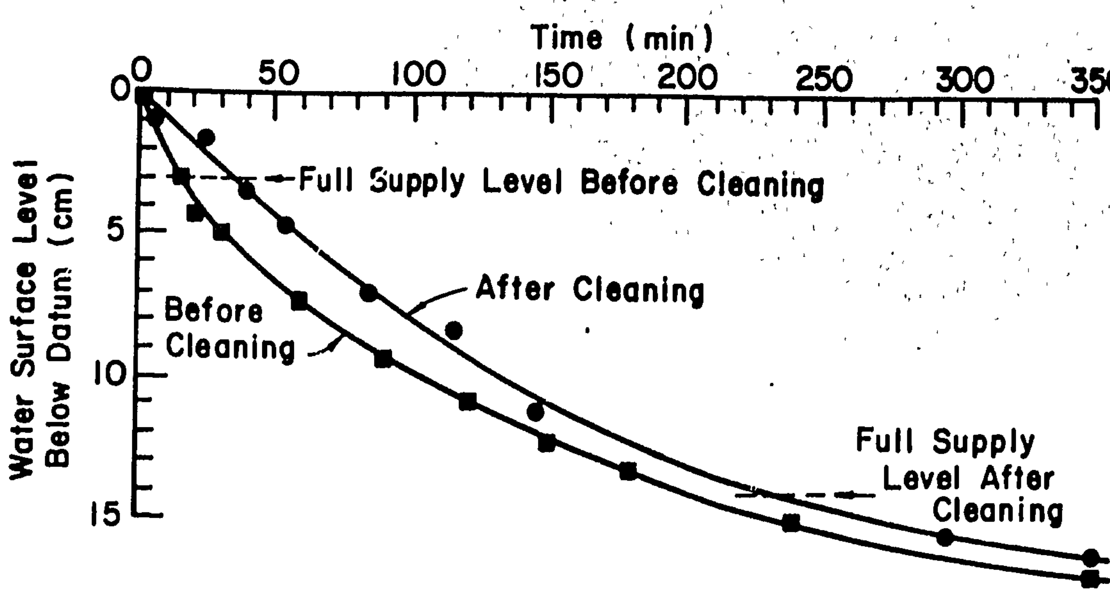

Figure 1A. Initial portion of recession curves (Section No. 1, Branch I, Tubewell 78) prior to and after cleaning.

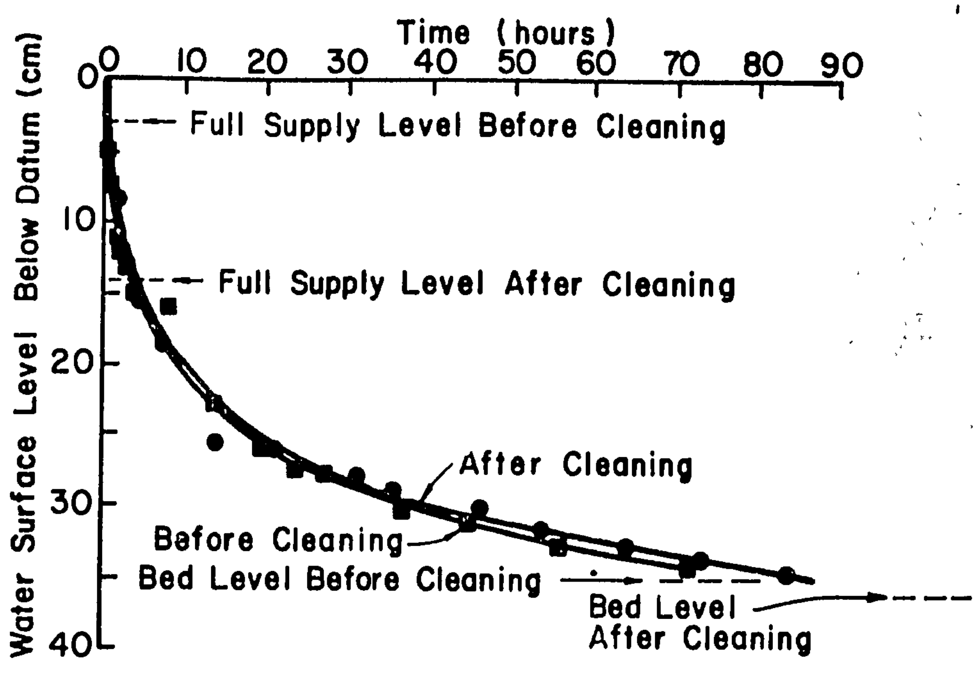

Figure 1B. Complete recession curves (Section No. 1, Branch I, Tubewell 78) prior to and after cleaning.

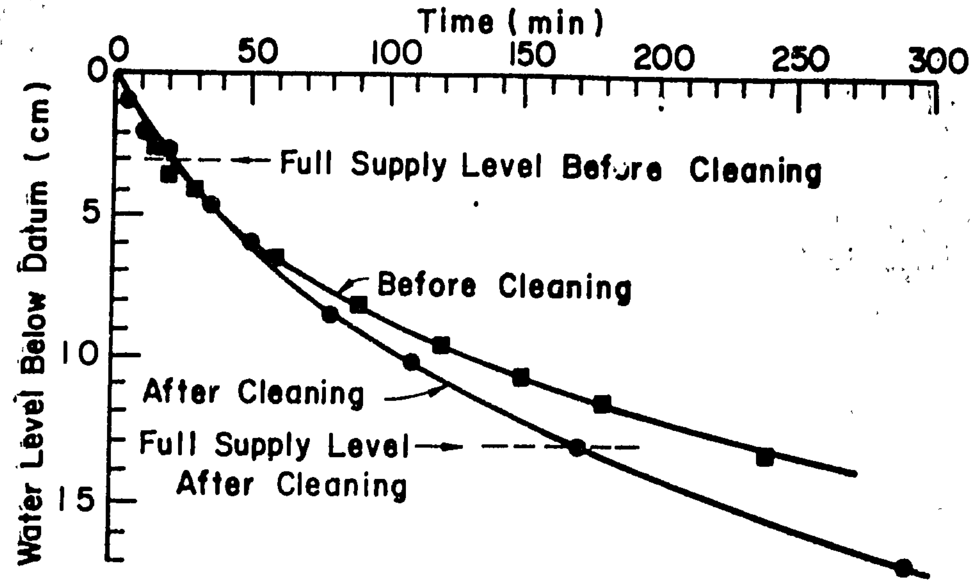

Figure 2A. Initial portion of recession curves (Section No. 2, Branch I, of the watercourse serving Tubewell 78) prior to and after cleaning.

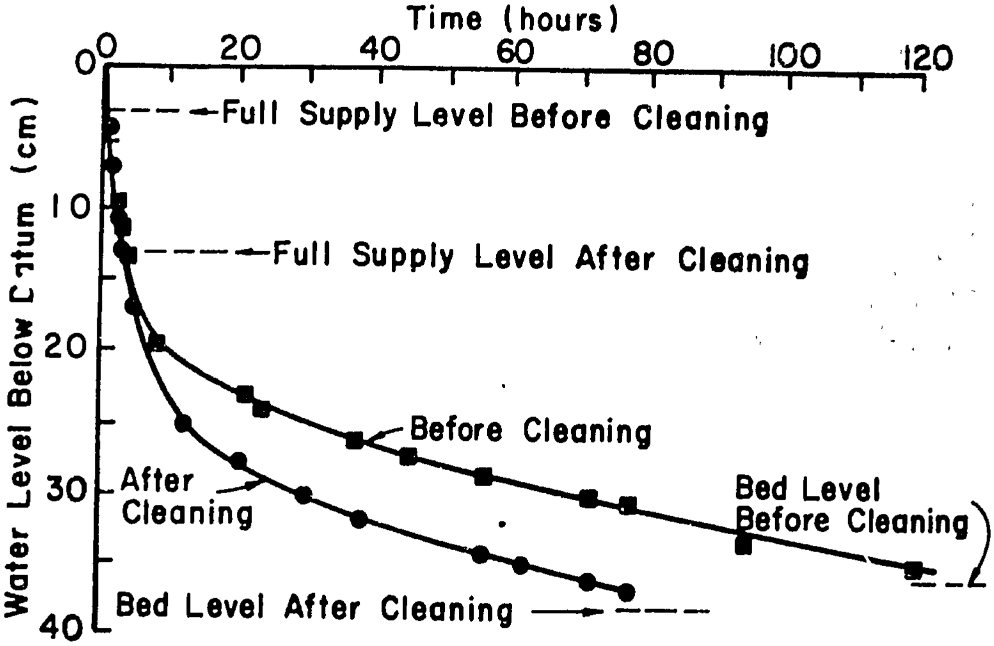

Figure 2B. Complete recession curves (Section No. 2, Branch I, Tubewell 78) prior tc and after cleaning.

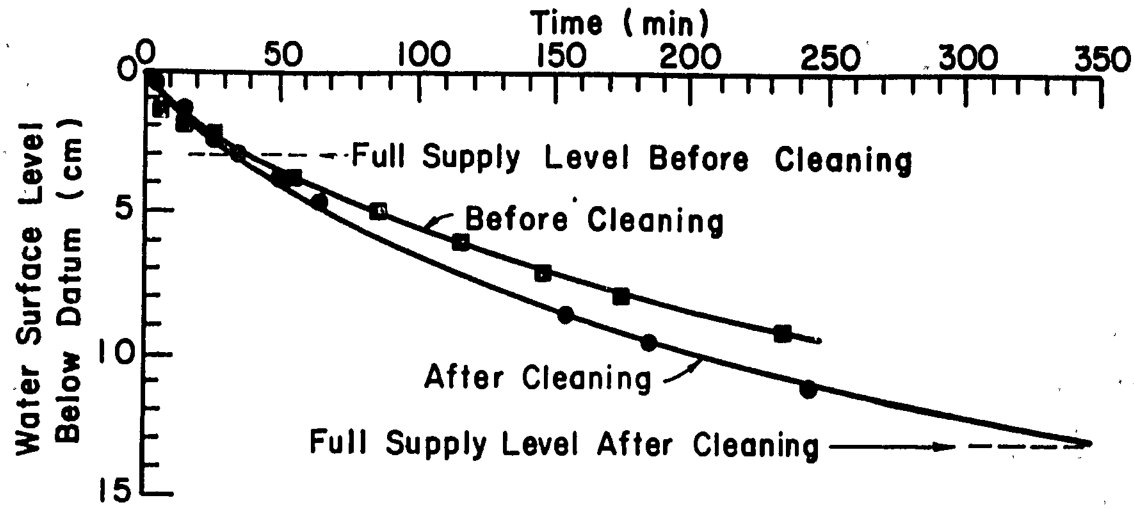

Figure 3A. Initial portion of recession curves (Section 3, Branch I, Tubewell 78) prior to and after cleaning.

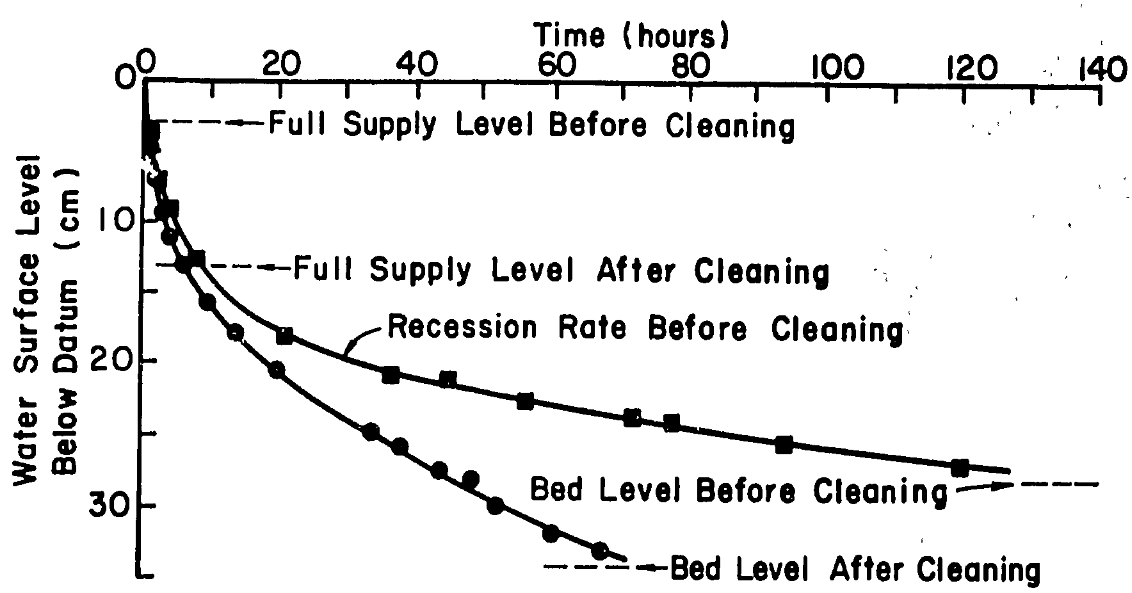

Figure 3B. Complete recession curves (Section 3, Branch I, Tubewell 78) prior to and after cleaning.

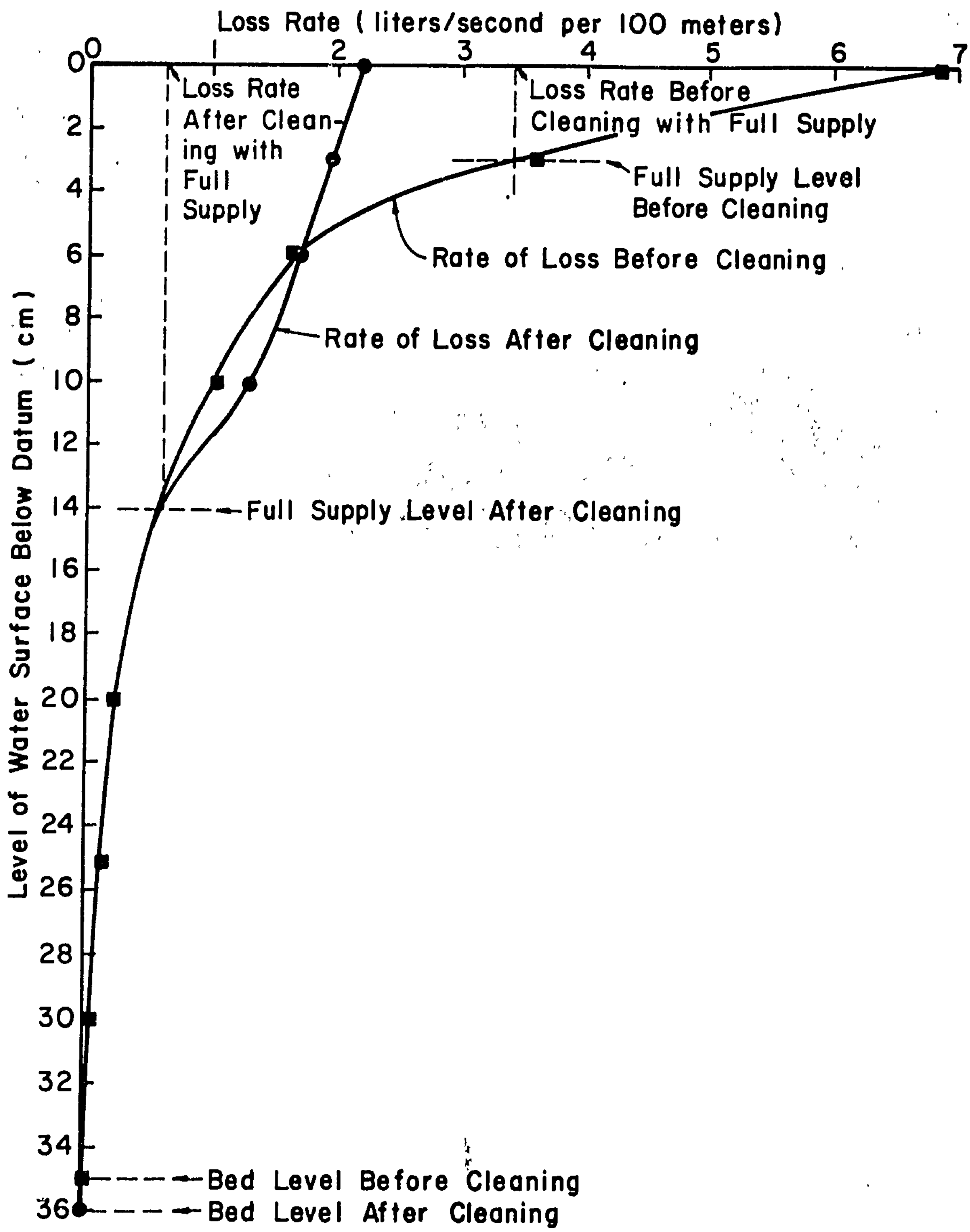

Figure 4. Effect of water surface elevation on loss rate of Section No. 1 before and after cleaning.

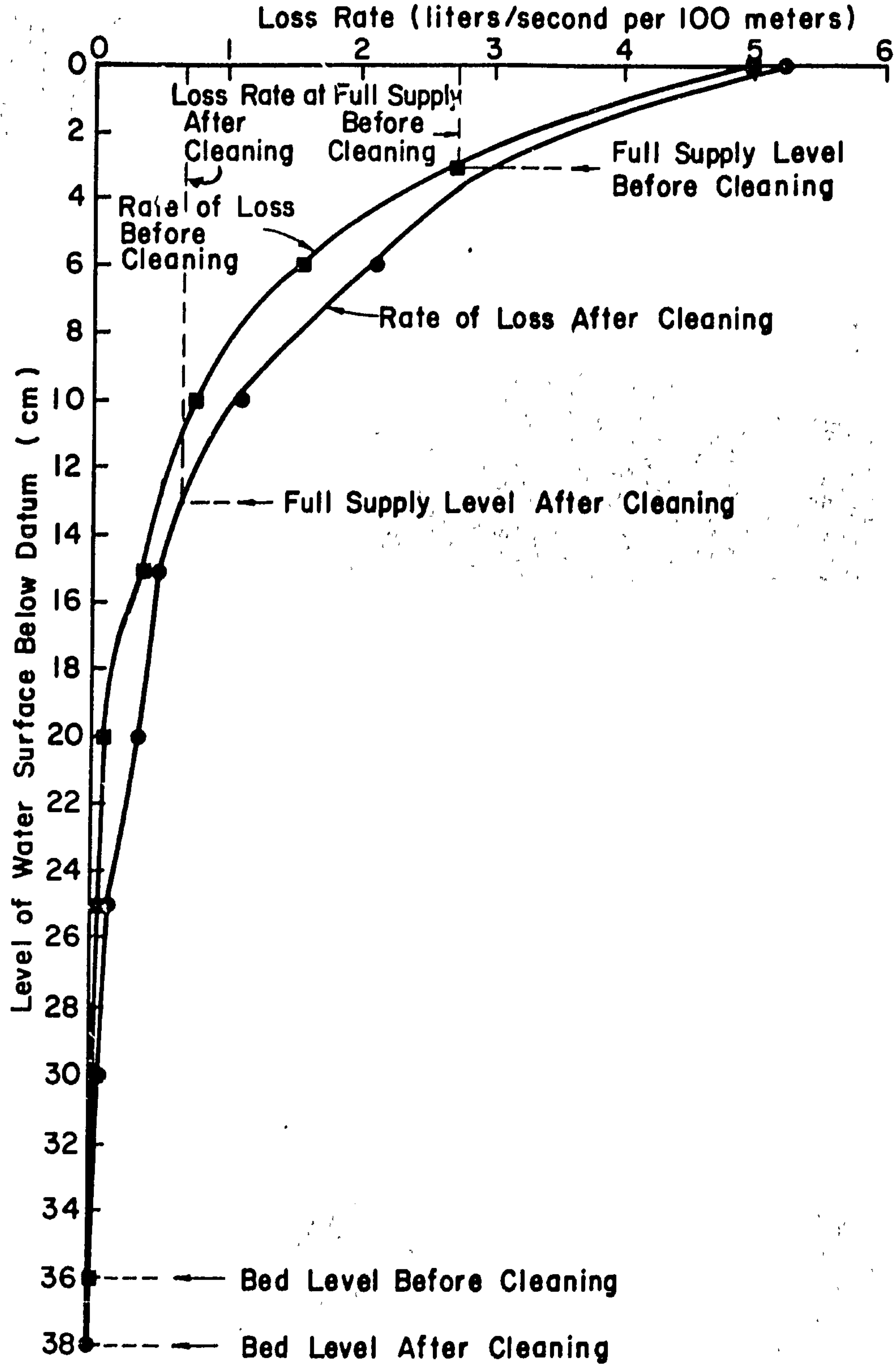

Figure 5. Water surface elevations and loss rates on Section No. 2 (Tubewell 78) before and after cleaning.

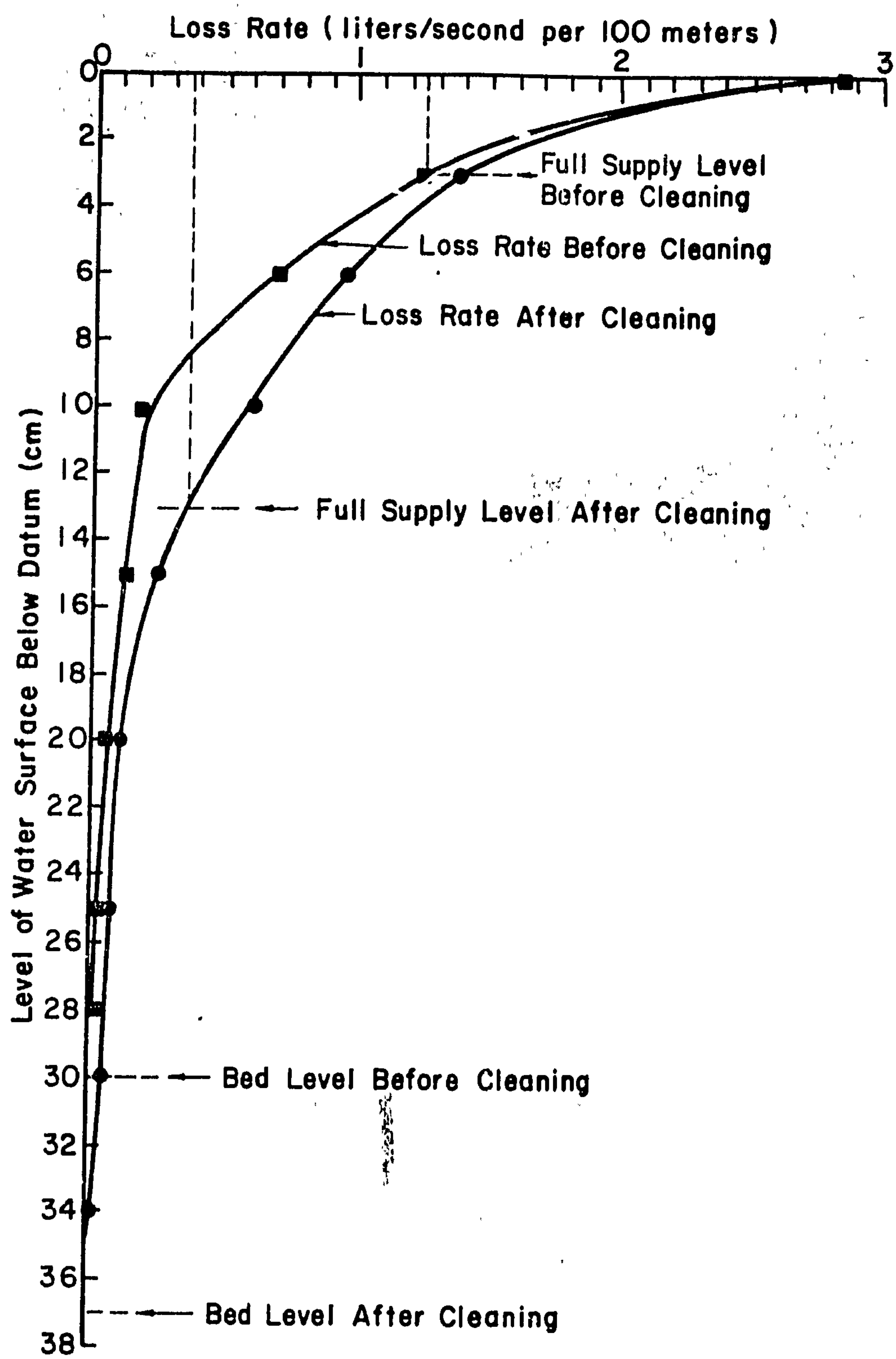

Figure 6. Water surface elevations and loss rates on Section No. 3 (Tubewell 78) before and after cleaning.

water, was corroborated in sections 2 and 3 as indicated in Figures 5 and 6. Apparently this slight increase in water loss when the surface is at a comparable level is due to the removal of the sediment which had settled on the sides and bottom of the watercourse. Removal of this sediment, along with the grass, during the cleaning process, leaves an open, somewhat porous soil with a large number of open earthworm holes. These small holes tend to silt in and cover over again as irrigation water is brought into this section but immediately following the cleaning they increase the rate of outflow.

The operating levels of water in these test sections following cleaning was 10 to 11 centimeters below the operating level prior to cleaning. In section 3 this was due partially to the excavation of about 7 centimeters of grass roots and sediments from the bottom of the channel as indicated in Figure 7. However, in sections 1 and 2 only 1 or 2 centimeters of the soil were taken away with the roots. While there was also some expansion of the channel by taking away some soil on the sides, the removal of this soil alone cannot account for the reduction in operating level following cleaning.

The major factor which lets this water flow faster and thereby allows a reduction in the average filled cross sectional area of the channel is illustrated in Figure 8. Before cleaning there was considerable grass along the sides and some grass on the bottom of the channels. This caused Mannings roughness coefficients in the range of 0.07 to 0.10. After the cleaning the roughness coefficient had been reduced down to about 0.035. The resulting rapid flow of water in the extended channel allowed the operating level near the head of this channel to be reduced from 17 centimeters above the level of the adjacent fields down to only 7 centimeters above the level of the adjacent fields. This reduction in the operating full supply level of water in the watercourse caused the decreases in loss that occurred following cleaning, as indicated in Figures 4, 5, and 6 and summarized in Table 1. The average loss rate in liters per second per hundred meters of watercourse was 2.4 prior to the cleaning and only 0.5 after the cleaning (Table 1). It should be emphasized here, as was pointed out by Ashraf, et al., 1977, that these losses in the straight sections of the watercourse should not be confused with the overall operational losses occurring from such watercourses. Losses at junctions, dead storage losses, and losses involved in wetting dry banks and so forth will be in addition to the losses considered in this study.

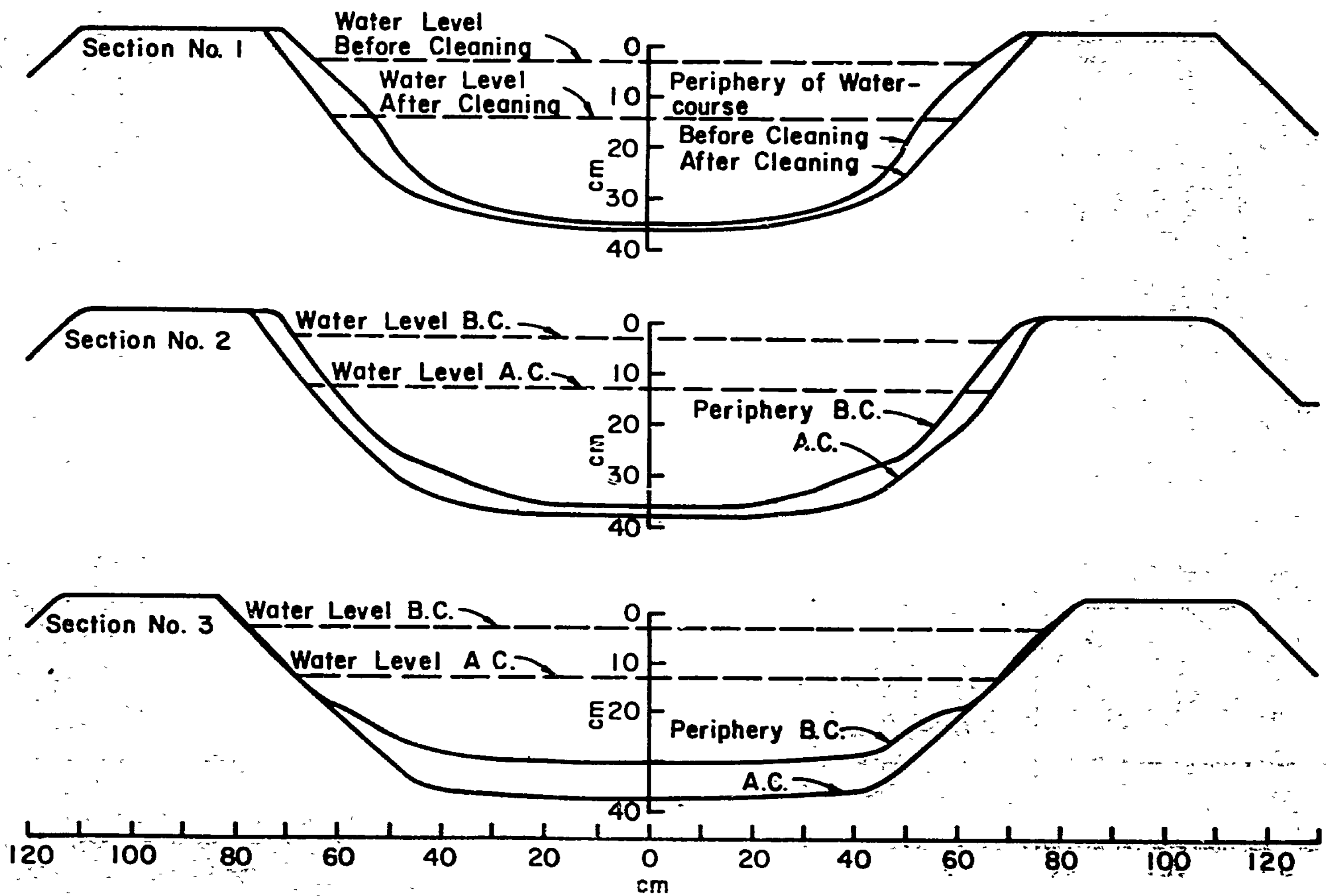

Figure 7. Watercourse cross sections at Tubewell 78 prior to and after cleaning.

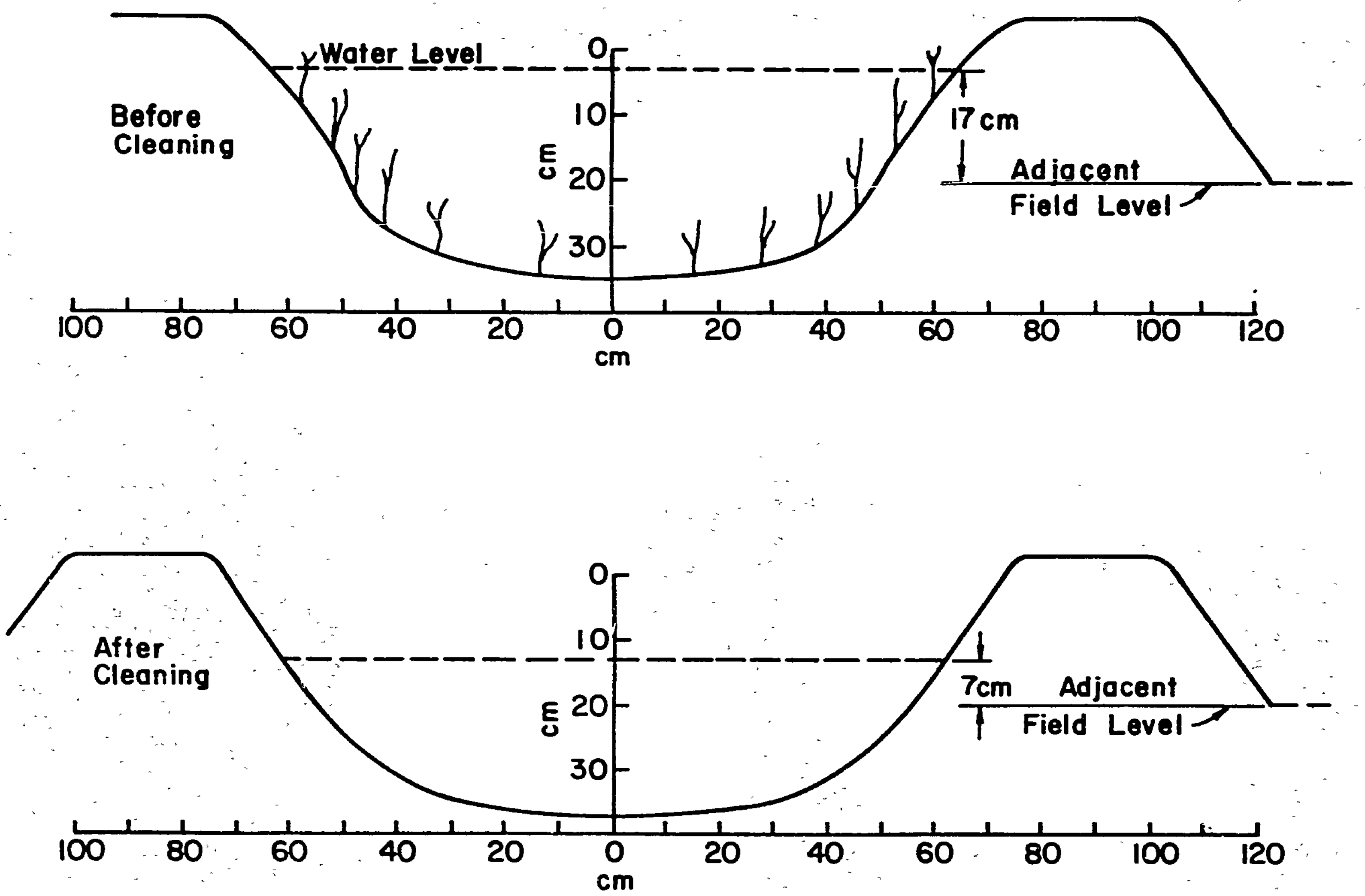

Figure 8. Average conditions at Tubewell 78 watercourse before and after cleaning.

Table 1. Watercourse loss rates (liters/sec/100m) at observed operating levels as affected by cleaning.

	Branch I, T.W. 78 (Previously improved)		Private branch, serving T.W.56 (No previous improvement)	
Section #	Before cleaning	After cleaning	Before cleaning	After cleaning
1	3.4	0.65	3.6	1.10
2	2.7	0.50	3.5	1.55
3	1.2	0.37	5.7	0.50
Average	2.4	0.51	4.3	1.05

In the unimproved section on the branch watercourse serving Tubewell 56, the loss rates were higher before cleaning than at Tubewell 78 and the closing of obvious rat holes by the laborers during cleaning caused such marked reductions in the rate of loss that increases in the infiltration rates into the banks due to removal of the sediment was not apparent (Figures 9, 10 and 11).

The reduction in full supply level at the head of this branch as a result of cleaning was about 7 or 8 centimeters. This reduction in full supply level, coupled with filling some of the rat holes, resulted in the average loss of water from these sections reducing from 4.3 liters per second per hundred meters of watercourse to 1.05.

The loss resulting from a farmer not cleaning his branch watercourse is generally not restricted to losses from his private branch. His losses resulting from allowing the head loss in his branch of the watercourse to be larger than those designed are illustrated in Figure 12. The top half of that figure shows a designed operating level for both the cooperatively maintained section (sarkari khal) and the farmer's branch. Watercourses are designed with sufficient slope and cross section to carry the authorized supply of water to the farmers' fields--generally assuming that the sides and bottoms of the watercourse are made of earth and have a roughness coefficient of about 0.04. In the sakari khal where the water flows most of the time and cleaning takes place frequently, the roughness of the bottom and sides of the channel may stay near the design criteria and consequently the surface level of the water may stay near the design level. If the farmer also cleans the grass from his branch regularly, the level of the water in the whole watercourse will stay near the design level as indicated in the top half of Figure 12. However, as grass is allowed to grow it increases resistance to flow and head loss becomes larger, which raises the water level in the branch causing much more leakage through these banks and also raises the water level in the sarkari khal causing more of this farmer's water in the watercourse to be used by the farmer who has the next turn. There is also a possiblity that the water may rise clear back to the mogha and if the level of water in the canal is only a few inches higher than the designed watercourse level a rise in the water level in the watercourse may also reduce the rate of flow from the canal.

Since ponding and recession measurements cannot take place while the watercourse is in use, but water must be available, the choices of time for this measurement are immediately before or immediately after the farmer's irrigation turn. Loss from the watercourse during initial

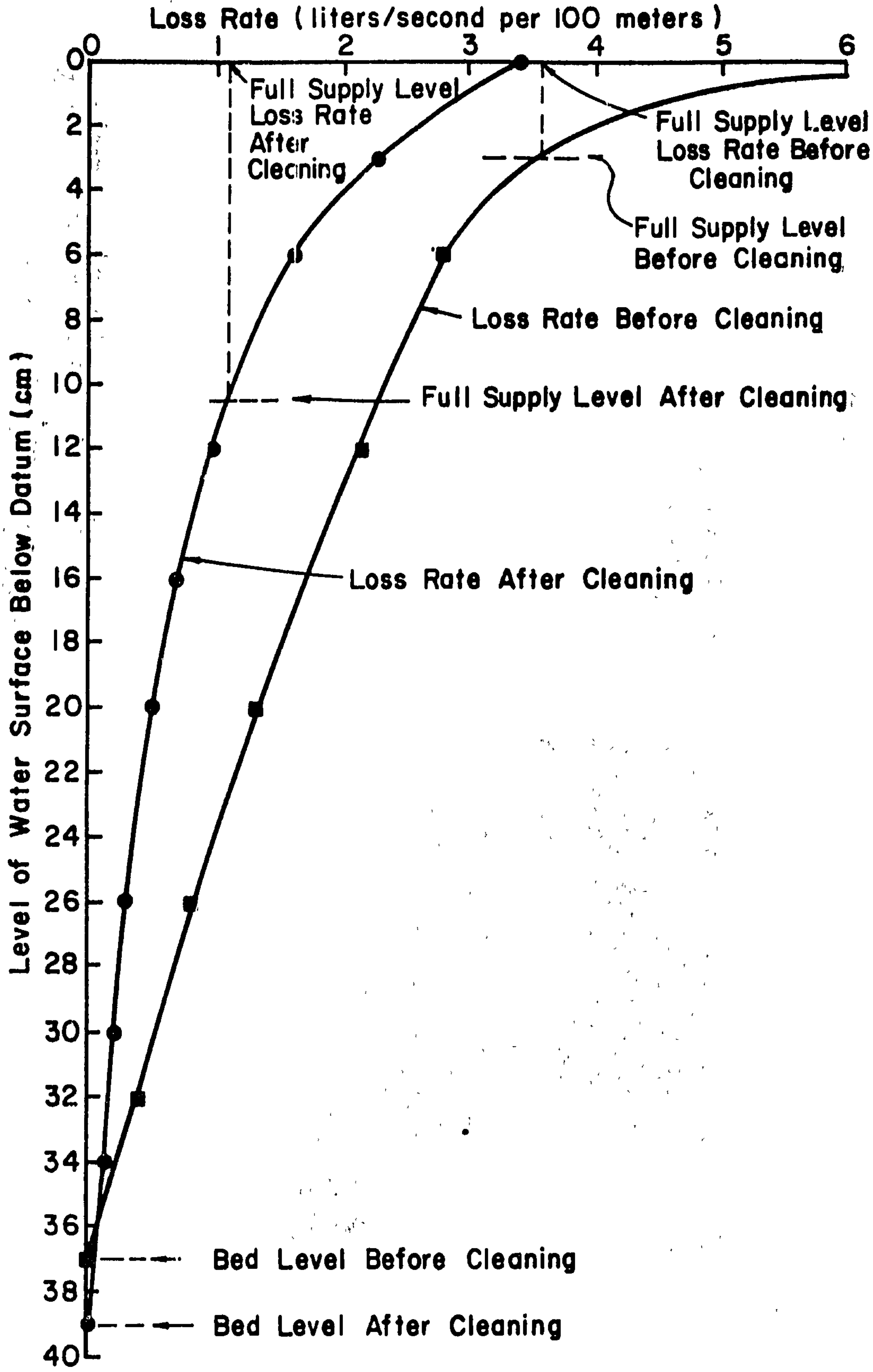

Figure 9. Water surface elevations and loss rates before and after cleaning Section No. 1 of the watercourse at Tubewell 56.

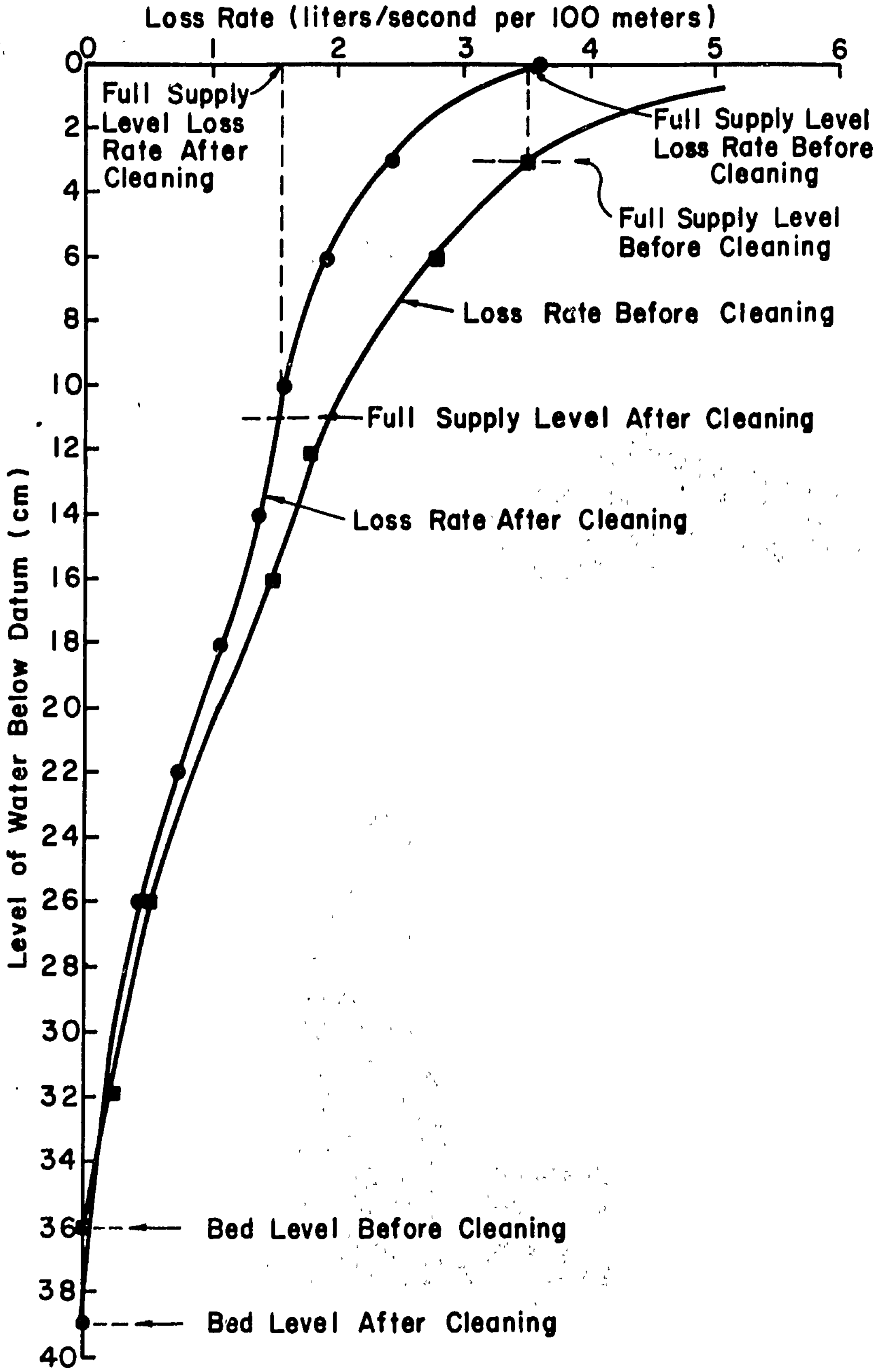

Figure 10. Water surface elevations and loss rates before and after cleaning Section No. 2 of the watercourse at Tubewell 56.

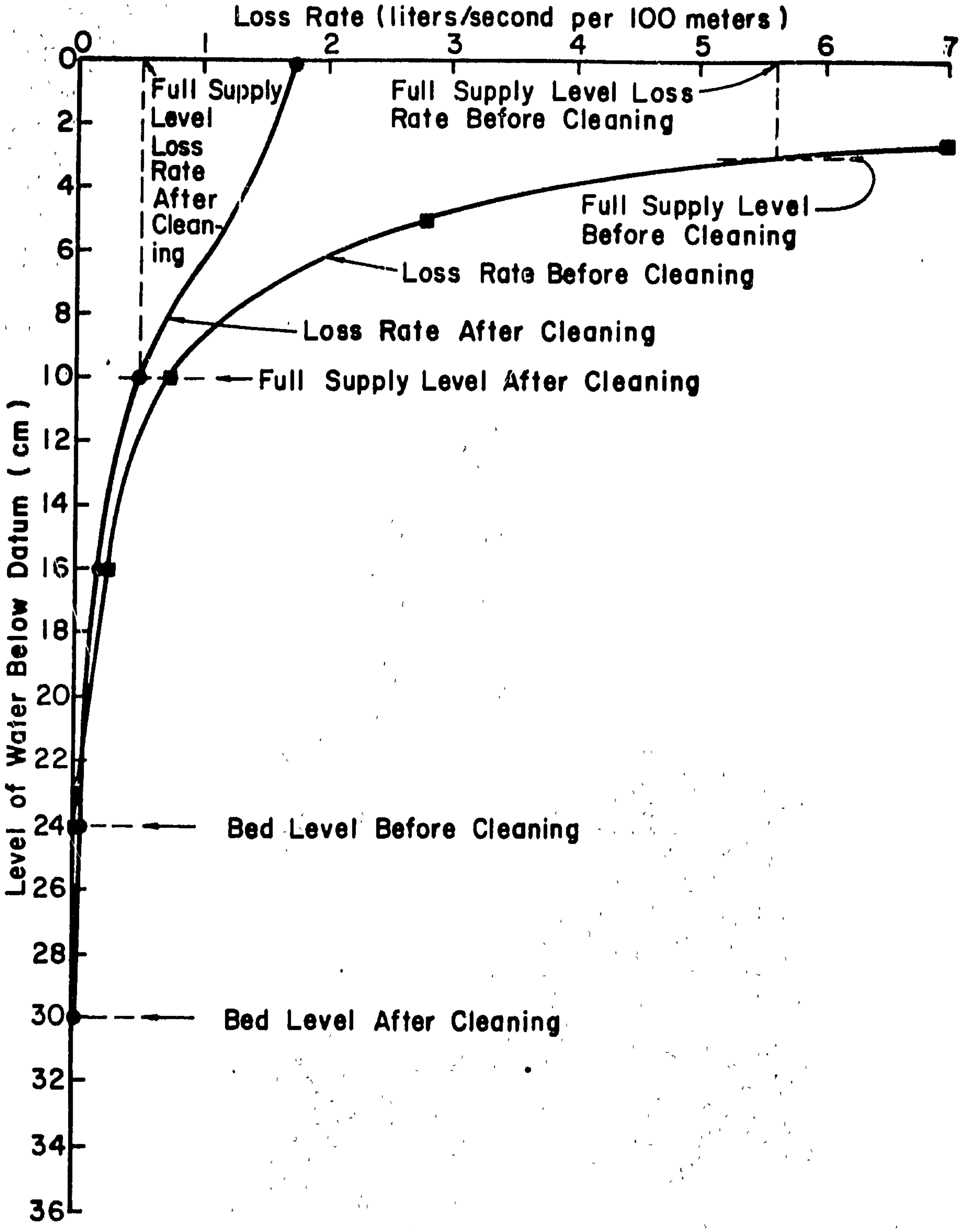

Figure 11. Water surface elevations and loss rates before and after cleaning Section No. 3 of the watercourse serving Tubewell 56.

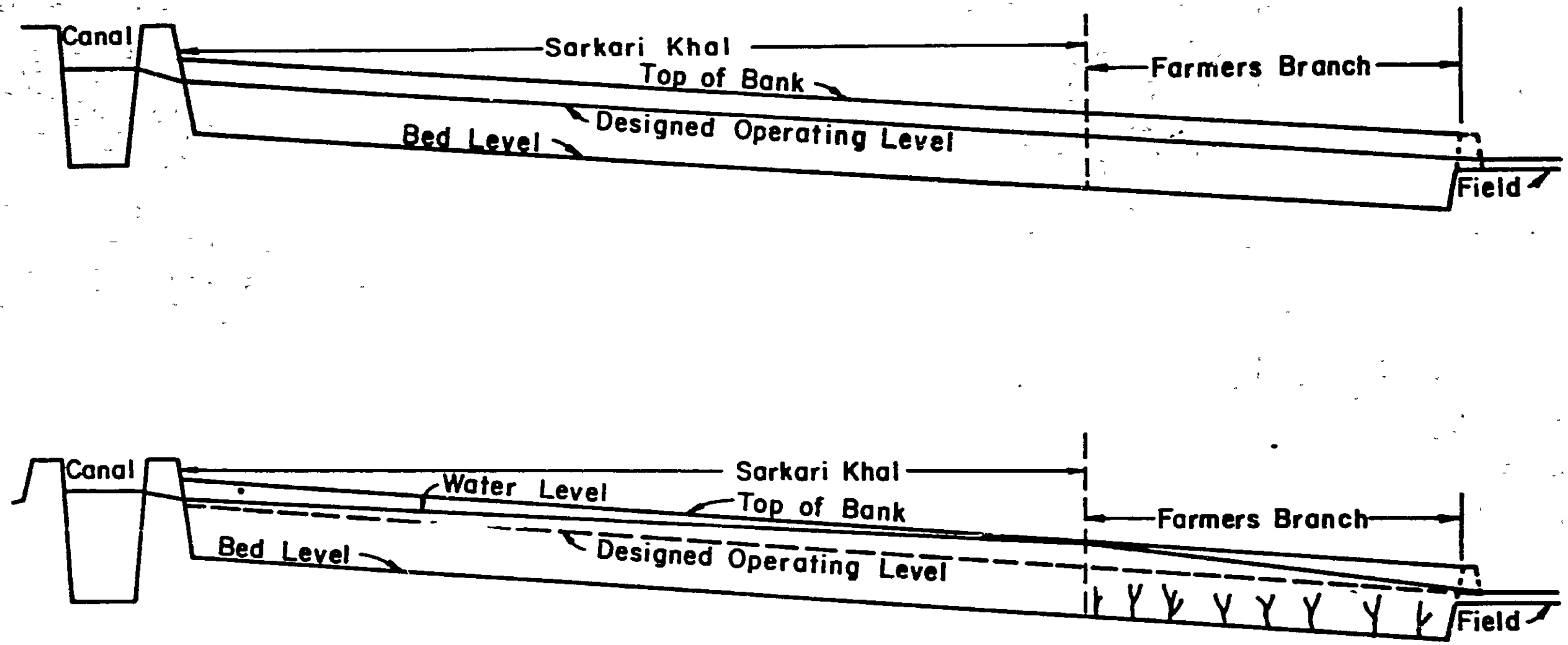

Figure 12. Why the farmers should keep the grass cleaned from their branch watercourses.

filling is generally high. By the time a section is filled to 3 cm above the operating level and dams are installed at both ends, a large portion of the initial wetting has taken place. However, the rate of loss generally decreases with time as the soil near the watercourse fills with water as indicated in Figure 13 where average loss rates[3] obtained after filling four initially dry watercourses are compared with loss rates obtained after the same watercourses had been used for an average of 16 hours (at the end of the farmer's use periods). Actual average loss rates occurring during use would be approximately the average of the two lines in Figure 13.

Obvious leaks are more common when watercourses are situated high so the operating level of water is high above the adjacent fields. Paired comparisons were made at four locations on watercourses which had high sections (where the operating levels averaged 41 cm above the adjacent fields) and low sections (where operating levels averaged 7 cm above the adjacent fields). The average rates of loss in these high plus low sections are shown in Figure 14. A probable explanation for greater loss from the higher watercourses is the greater hydraulic head difference pushing water through holes leading from the wetted perimeter of the watercourse down through the banks and exiting from the sides of the banks or in the adjacent fields.

Having identified bank leakage as the problem, a branch of a watercourse was improved by removing the old banks and replacing them with adjacent soil. Most of this work was done by farmers who had been told that the banks should be compacted, but were unsupervised during most of the improvement. Two short sections of the bank were improved under closely supervised conditions where the moist soil used in the banks was compacted in layers about 7 cm thick by workers stepping on it.

Figure 15 shows the decrease in water loss resulting from the improvement by the farmers. However, the much lower losses on the closely supervised and better compacted sections indicate that careful compaction of the banks could reduce the losses on this watercourse to about one liter per second per 100 meters of watercourse. The soil used to build the new banks on this watercourse was a andy loam.

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[3]These average loss rates were calculated by computing the arithmetic values of a and b in the equation Loss Rate = ae^{-bx} which was fitted to the data, using a computer and least squares procedure for each watercourse. The arithmetic mean values were calibrated and used to compute the average loss rates indicated in Figures 13, 14, and 16.

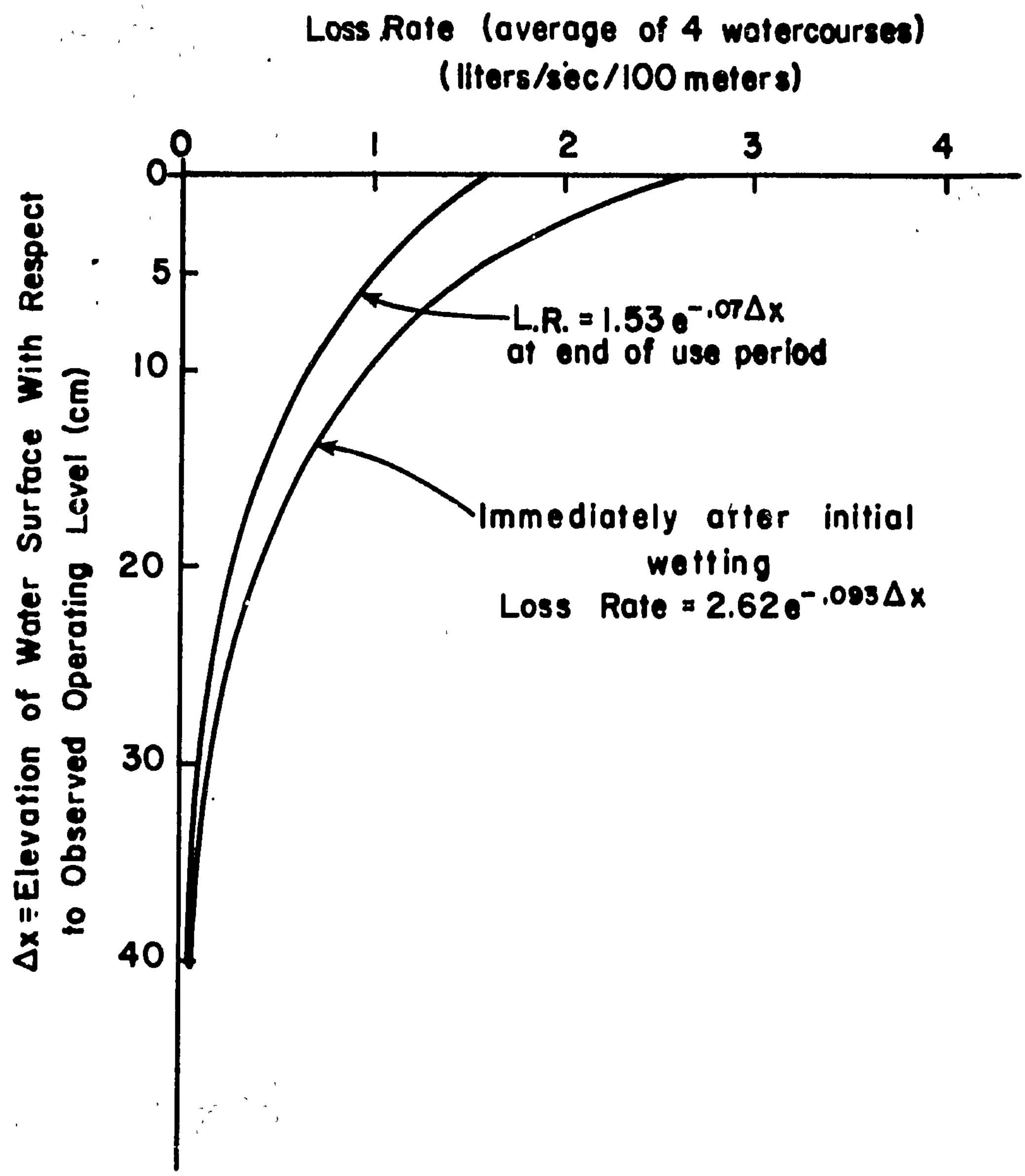

Figure 13. Water loss rate decrease from beginning to end of the use period (average for 4 watercourses used for an average of 16 hours).

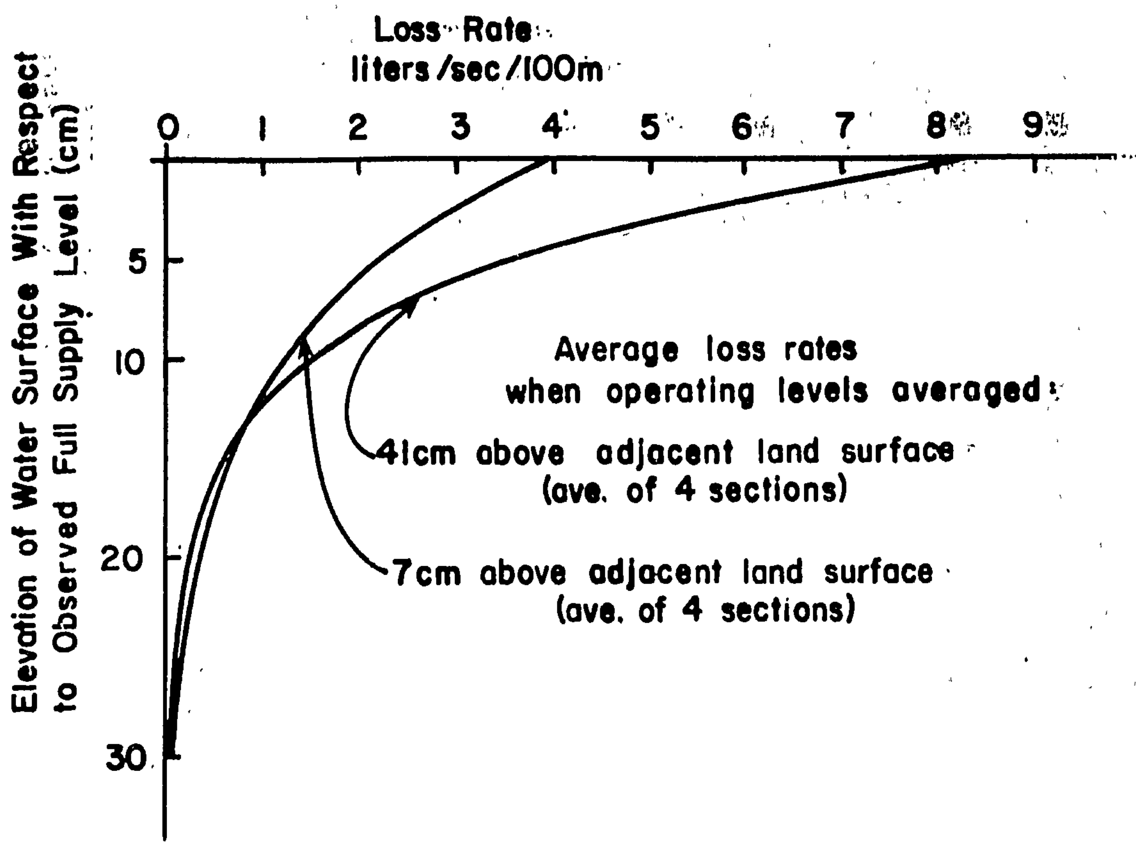

Figure 14. Loss rates as affected by elevation of operating water surface level with respect to adjacent land surface.

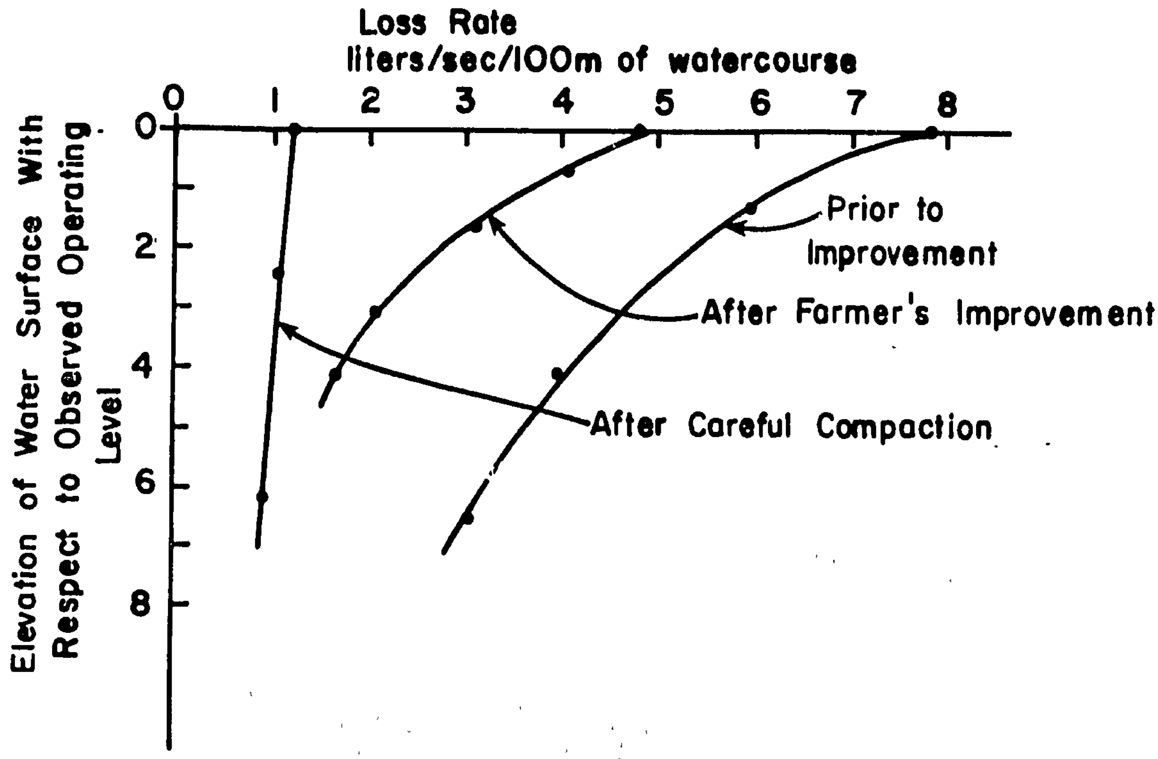

Figure 15. Loss rates as affected by reconstruction and compaction of the banks.

The data discussed above was taken in the Mona project area of the Indus River irrigation system in Pakistan. Data obtained by Trout, et al., 1978, and in a survey by Lowdermilk, et al., 1978, indicate that these large rates of loss are characteristic of existing watercourses in this system providing water to thirty million irrigated acres. Data obtained by Trout, et al., also indicate that the observed exponential relationship between the flu tuating level of water in a watercourse and water loss is a general relation in watercourses in Pakistan. The probability appeared high that different populations of worms, ins cts and rodents, different climates and use of application methods other than the basin flooding system would cause watercourse losses to be less and/or differently distributed in other countries. To evaluate this probability, the ponding and recession method as described in #3 in the procedure was used to determine loss on 31 sections of watercourses in the Fort Collins-Greeley area of Colorado. The average loss rates as a function of elevation of the water surface with respect to the observed operating level are shown for watercourses in Pakistan and Colorado in Figure 16. The exponential relationship is a reasonably accurate relation between the loss rate and elevation differences in the Colorado soils, accounting for over 90% of the observed differences in loss rate at a given section. While there was a wide range of loss rates at both locations, the average loss rate from the Colorado watercourses was surprisingly similar to the average loss rates of the watercourses in Pakistan (Fig. 16). This similarity of loss rates and their distributions indicate that frequent cleaning of watercourses to keep the water level at or below the designed level could save considerable water in Colorado and probably in most other countries for the same reasons as were observed in Pakistan.

The slightly higher loss rates from the Colorado watercourses in the lower portions of the watercourses may be a result of the formation of ice lenses in the soils of the Colorado watercourses during freezing weather. The Pakistan watercourses are not subject to this factor.

The management question is--how frequently should the watercourse be cleaned and maintained? This is a function of vegetation, rates of growth, portion of the time during which the watercourse is used, etc. The best criteria for deciding when to clean a watercourse appears to be the elevation of water in the watercourse. When this elevation rises appreciably above the designed level, cleaning will save appreciable water on the average watercourse. Since earthen watercourses are generally designed assuming a roughness coefficient in Mannings equation of 0.04 and since

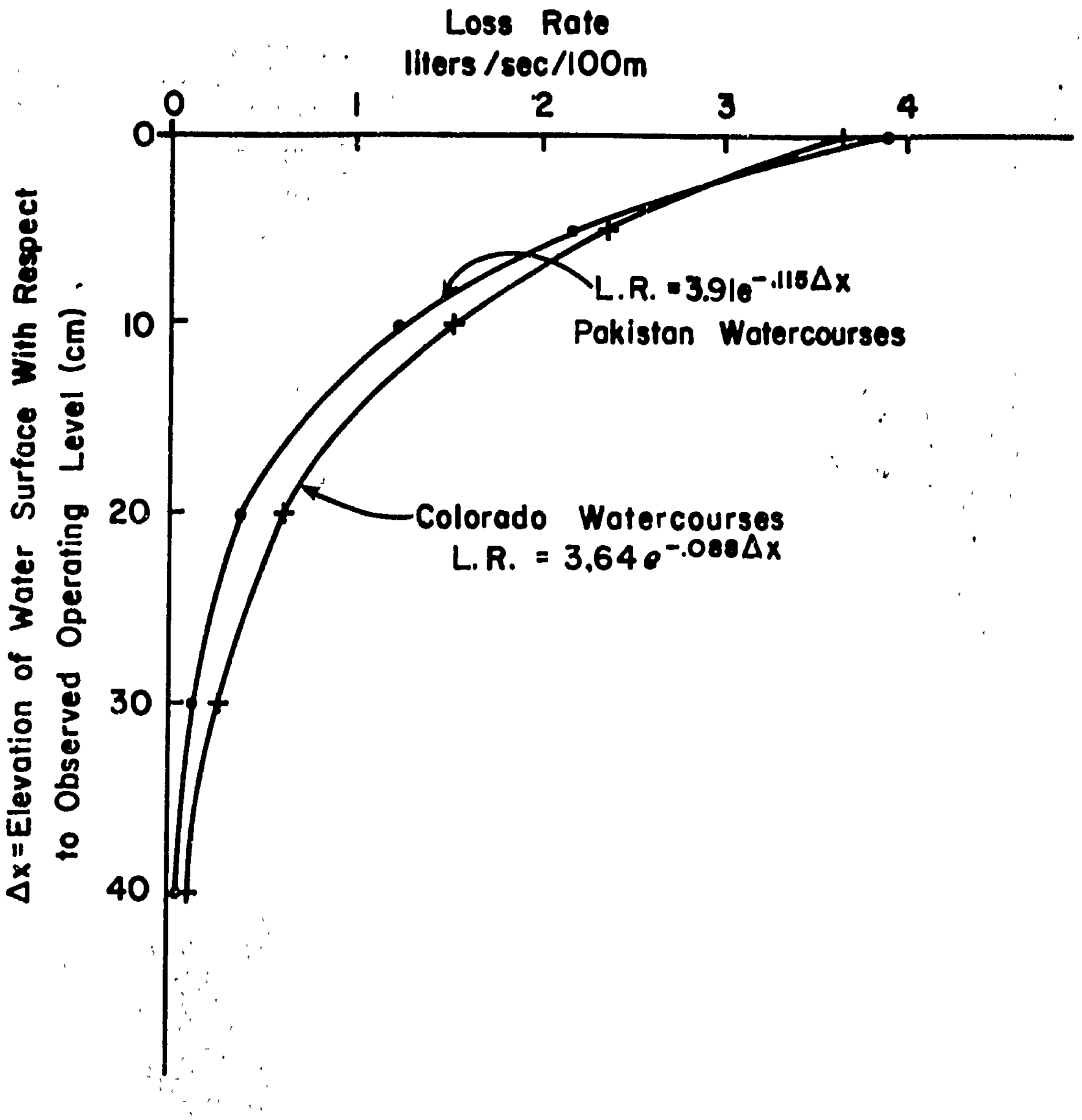

Figure 16. Comparison of average loss rates measured in Pakistan and Colorado watercourses.

the roughness coefficient of a smooth earthen ditch is closer to 0.03, the water level in a clean watercourse will normally be a few centimeters lower than the designed level.

The economically optimum time for cleaning depends on the value of the water that can be saved, the cost of cleaning and the functional relation between loss rate and water surface level in the watercourse. This relationship is commonly approximated by an equation of the type

$$\text{Loss Rate} = ae^{-b\Delta x}$$

where Δx is the difference in elevation of the level of water in the watercourse. However, the a and b coefficients vary widely depending on soil type, compaction of the banks, degree and duration of rodent, insect and worm infestation and other factors. Since a ponding and recession measurement of water loss is easily made with a minimum of equipment, such a measurement is suggested as part of the computations to determine the economically optimum schedule for cleaning a watercourse.

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APPENDIX 20

SPECIAL EQUIPMENT FOR ANIMAL POWERED LAND LEVELING[1]

by

N. Illsley[2]

Precision land leveling (PLL) is one of the most important inputs for farm water management in Pakistan. Farmers report higher crop yields, and the excess water applied during irrigation is reduced.

Unfortunately, very few small farmers (less than 12.5 acres) have been leveling their fields in spite of government incentive programs. This problem was studied by Renfro,[1] who reports the lack of bullock-drawn equipment is one of the constraints limiting the small farmers' participation in PLL.

Two pieces of equipment are needed for proper land leveling: a scraper for moving soil from one location to another, and a land plane for finishing the small unevenness left by the scraper. At present, the small farmers use a karah (Fig. 1) in an attempt to level their fields. This tool is slow and inaccurate.

Several other bullock-powered and leveling implements have been tried in Pakistan, but these have not been adopted by the farmers. They include the Fresno scraper and several of the blade and drag implements described in the intermediate technology literature.

The two principal constraints on bullock machinery are the limited power input of a team of bullocks ($p < 1.5$ HP per team) and the small size of typical fields which makes maneuvering of a long implement difficult. In an effort to help the small farmers realize the benefits of PLL, two versions of wheeled scrapers were designed.

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[1]Renfro (Constraints on Small Farmers in the Precision Land Leveling Program in the Pakistani Punjab. Pakistan Report #44, Colorado State University, September 1978).

[2]Agricultural Engineer, Water Management Research Project, Colorado State University.

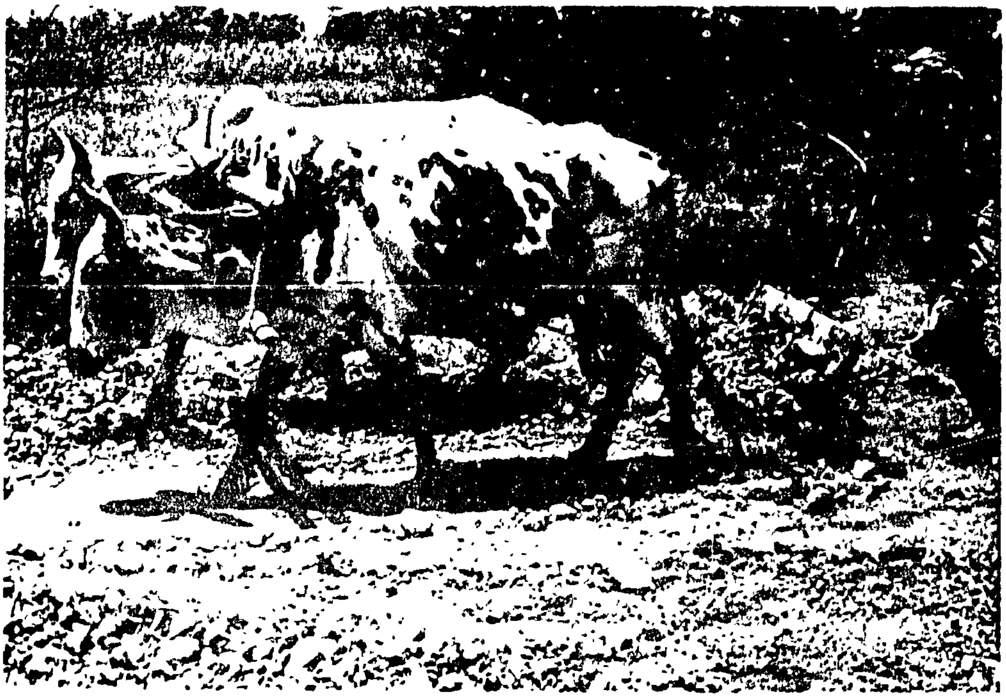


Figure 1. Bullock drawn karah.

The criteria for design were as follows:

1. A power requirement low enough that an average team of bullocks could pull the scraper.

2. The turning radius be no greater than 15 feet.

3. If possible, that the implement serve both as a scraper and a land plane.

4. The cost should be within reach of the average small farmer.

5. The implement should be strong and made of locally available materials with local shop facilities.

The first concern in designing this scraper was to minimize the load on the draft animals. Depending on the animals, bullocks can pull about 150 lbs for a short distance, and about a 25 lb steady load for two or three hours. On the first model (Fig. 2), automobile wheels were used immediately behind the bucket and at the front of the long tongue. To have the length necessary for planing, the tongue was extended 12 feet ahead of the scraper bucket. The bucket is lifted by a spring assisted pivot where the tongue joins the main frame.

The bucket serves as both a scraper and a plane blade by making the bottom of the bucket separate from the back. To make the bottom or floor rigid and keep it lightweight, it is hollow. Two pieces of 1/8" steel plates are welded to a cutting edge made of 1/2" x 4" bar sharpened on one edge. At the rear, the plates are spaced 1" apart where the floor contacts the back. To unload the bucket, the floor swings forward and upward so that the load spills off the rear of the floor. The back of the bucket then acts as a blade for smoothing the spill. For land planing, the flow is locked in the dump position and the back of the bucket (now a blade) is adjusted to the desired height with a hand lever.

Testing

The first field testing was done using a tractor to pull the scraper. All of the functions--loading, transporting, and dumping--worked satisfactorily. Draft requirements in a typical loosely plowed field were:

empty	20 lbs
loaded (transport)	40 lbs
loading 1" cut	80-160 lbs

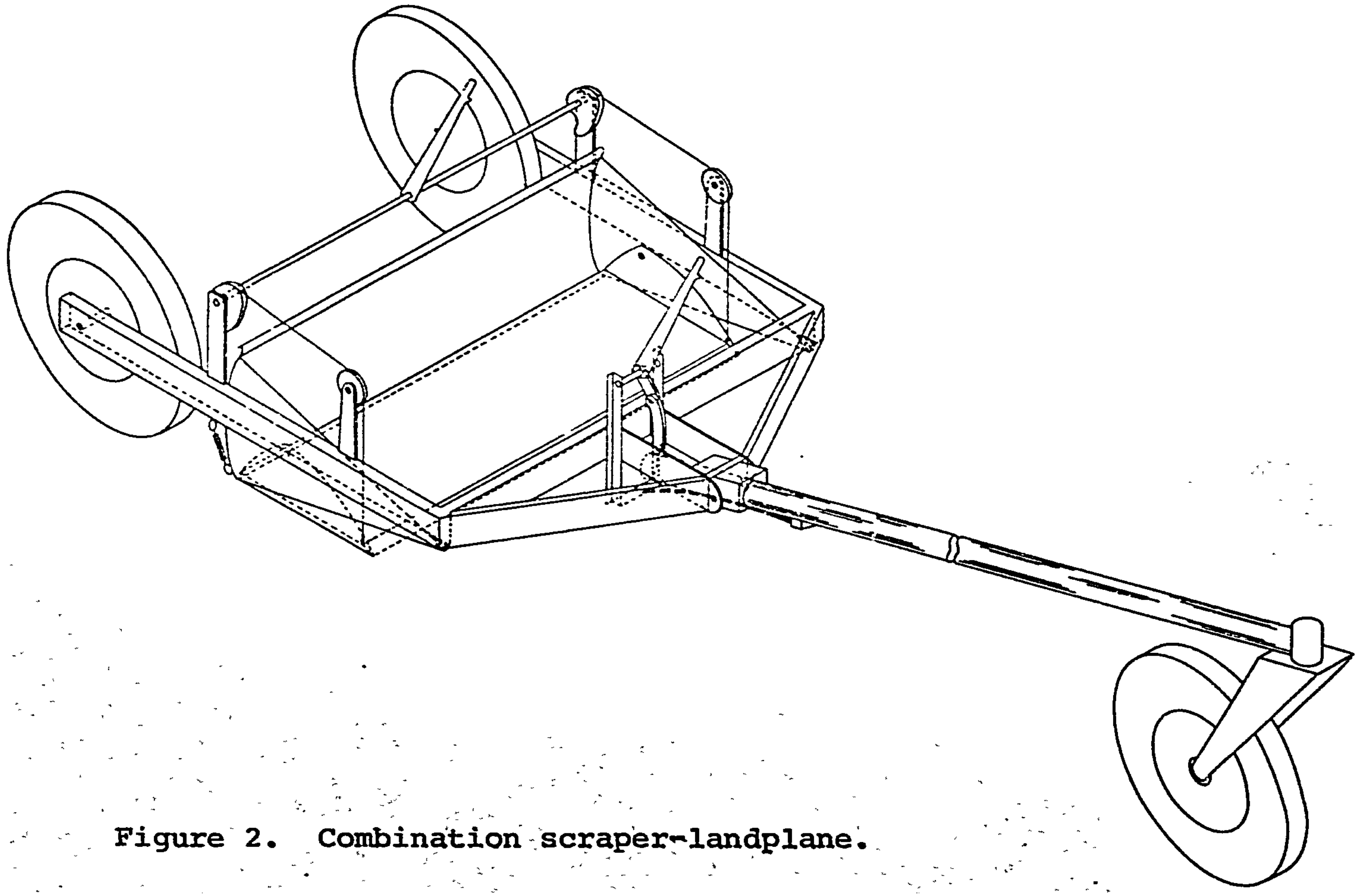


Figure 2. Combination scraper-landplane.

These figures are approximate and will vary with soil conditions and depth of cut when loading.

The planing action, with the bucket floor in the raised position, is comparable in the direction of travel to that of the three-point hitch planes being made in Pakistan. Lateral unevenness (at right angles to the direction of travel) is not as good as with the wider (8') land planes. When planing the first cut diagonally across furrows, unevenness from high points to low points was on the order of 2" maximum. This would be smoothed out in a second, or at most, a third pass.

A field was surveyed and the scraper was tried with bullocks. The first pair of animals pulled the scraper satisfactorily, but a second pair were smaller and balky. The scraper was taken to the shop for some minor modifications, and unfortunately, before it could return for further testing, the CSU program was terminated.

Certain observations can be made even on the scanty testing done. The basic concept of one machine for both scraping and planing appears sound. The method used for unloading the bucket works well and does not increase the draft the way conventional rollover buckets do.

The planing action using the long tongue with the rear wheels directly behind the blade is good. This should be more carefully tested in a controlled research project to determine what, if any, advantage there is in placing the rear wheels of a land plane much farther behind the blade. The long tongue with the single swivel wheel supporting the front gave both good maneuvering and planing action.

This design of scraper/plane would not be cheap, and probably not within the reach of small farmers. On a yardage capacity basis, it would be more expensive than the larger scrapers because the number of parts. weldments, wheels, etc. are the same on both size machines. Only the total weight of steel is less, and that is of minimal significance in the overall cost.

The second scraper was designed for only earth moving and not as a land plane (Fig. 3). The bucket is a one piece pan, 4' wide with a handle on the rear. The bucket is suspended from an axle with two chains. Two more chains slope down from the tongue to the front corners of the bucket for pulling. The cutting edge of the bucket can be raised or lowered by lifting or pushing down on the rear handle. The whole bucket can be raised by rotating the drop center axle. The axle drops 3" at the spindles giving a total 6" lift to the bucket.

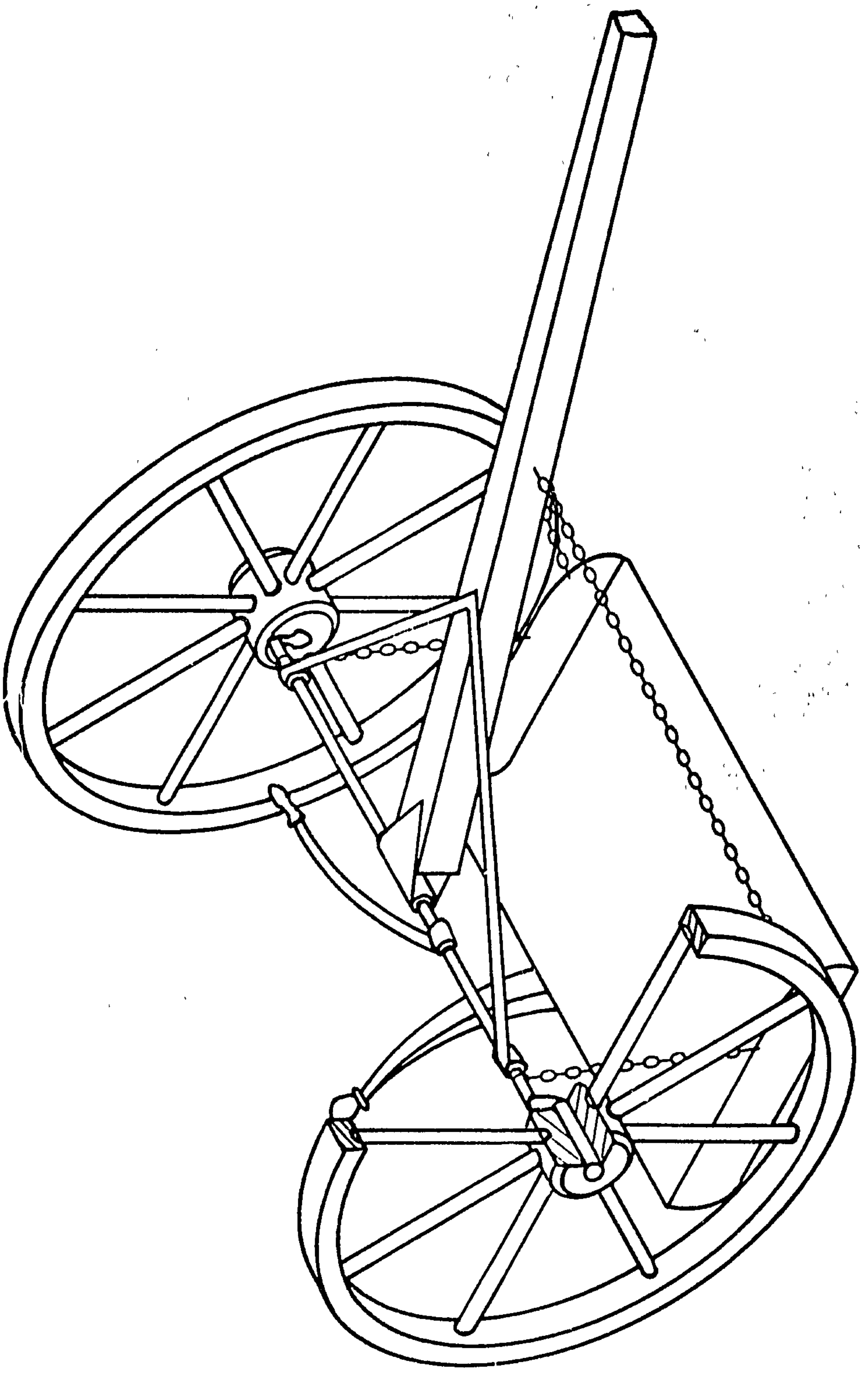


Figure 3. Tonga-wheel scraper.

The wheels are locally made tonga wheels and most farmers already have at least one pair. They are about 4' in diameter and therefore, roll easily in rough fields. Their normal 2" width can be tripled easily by adding wooden rim blocks to give more flotation. A normal tongue with diagonal braces pulls the axle.

This scraper was in the final stages of assembly at the time of the U.S. evacuation from Pakistan and therefore could not be tested. Hopefully, the local men who were helping make the scraper will follow through and make it available to local farmers.

The cost of this scraper will be well within the reach of small farmers, particularly if the farmer can use existing wheels.

Using new or good quality recycled material, the costs in Pakistan as of September, 1979, were as follows:

1.	Tonga wheels (2)		US$ 80.00
2.	Steel for bucket	Rs 5/kilo, 25 kilo	12.50
3.	Chains	Rs 3/ft, 14 ft	4.20
4.	Axle		7.50
5.	Tongue (wood)		8.00
			112.20

The only labor involved is in forming and welding the bucket and then assembling the parts. This should not run over Rs 100, or $10. With these costs in mind, and the fact that most farmers would already have wheels, the cost of the machine is well within the range of the average small farmer.

APPENDIX 21

AIDS AND SUGGESTIONS FOR THE SUCCESSFUL MANUFACTURE OF CONCRETE NACCAS

by

N. Illsley and A. 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 branch watercourse; to drop the elevation of the watercourse where the natural ground slope is greater than the designed watercourse slope; and to terminate or check 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 have weak banks and are 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[3]; however, when some contractors have tried to duplicate these naccas, they have had difficulty in achieving the performance of the naccas manufactured by the original contractor, Hasnain RCC, Sargodha. It is obvious that there are no shortcuts 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

[1]Agricultural Engineers, Water Management Research Project, Colorado State University.

[2]Evaluation of Pucca Naccas in Watercourse Improvement, Trout, et al., 1978.

[3]Low Cost Farm Irrigation Control Structures for Pakistan. Munir, Shafiq, Trout 1978.

picking up moisture from the air. In this case, it will become hard and lumpy. If too much moisture has been absorbed, the strength of the concrete will be impaired (see Fig. 1).

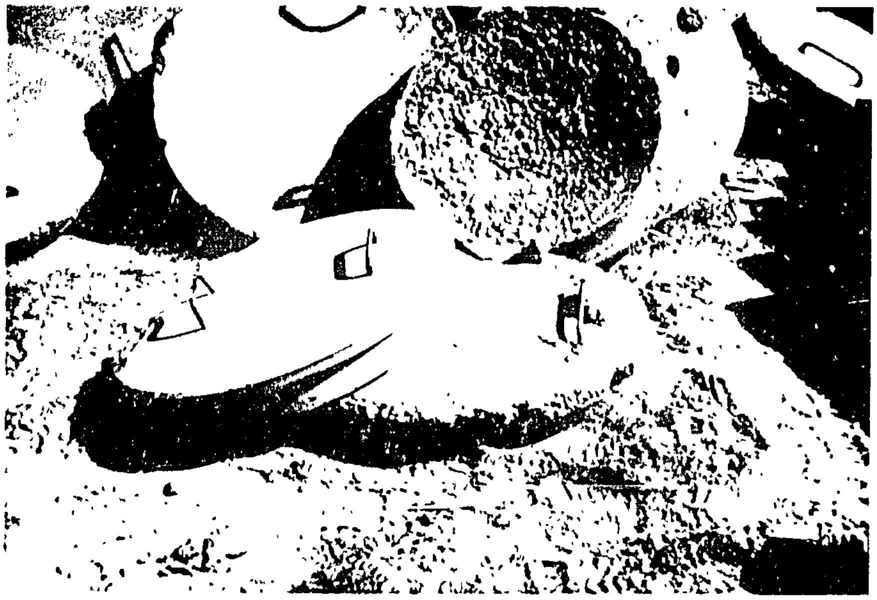
The most important single factor controlling the strength of concrete is the water/cement ratio (see Fig. 2). A ratio of 0.5 (1 kg water to 2 kg cement) should produce a concrete of about 4,000 psi/strength (281 K/cm^2) if made with reasonable quality aggregate, sand and water.

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 sulfur 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 affect the ultimate strength of the concrete. The cooler the temperature the stronger the concrete, so long as it remains above freezing (see Fig. 3). 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 underwater 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 set. The hardening process slows down but never stops (see Fig. 4).



Poorly mixed and placed concrete shows poor consolidation, cracking and severe chipping.

At no additional cost of materials, properly mixed and placed concrete gives a durable, water tight nacca.

Figure 1. The need for quality control in concrete.

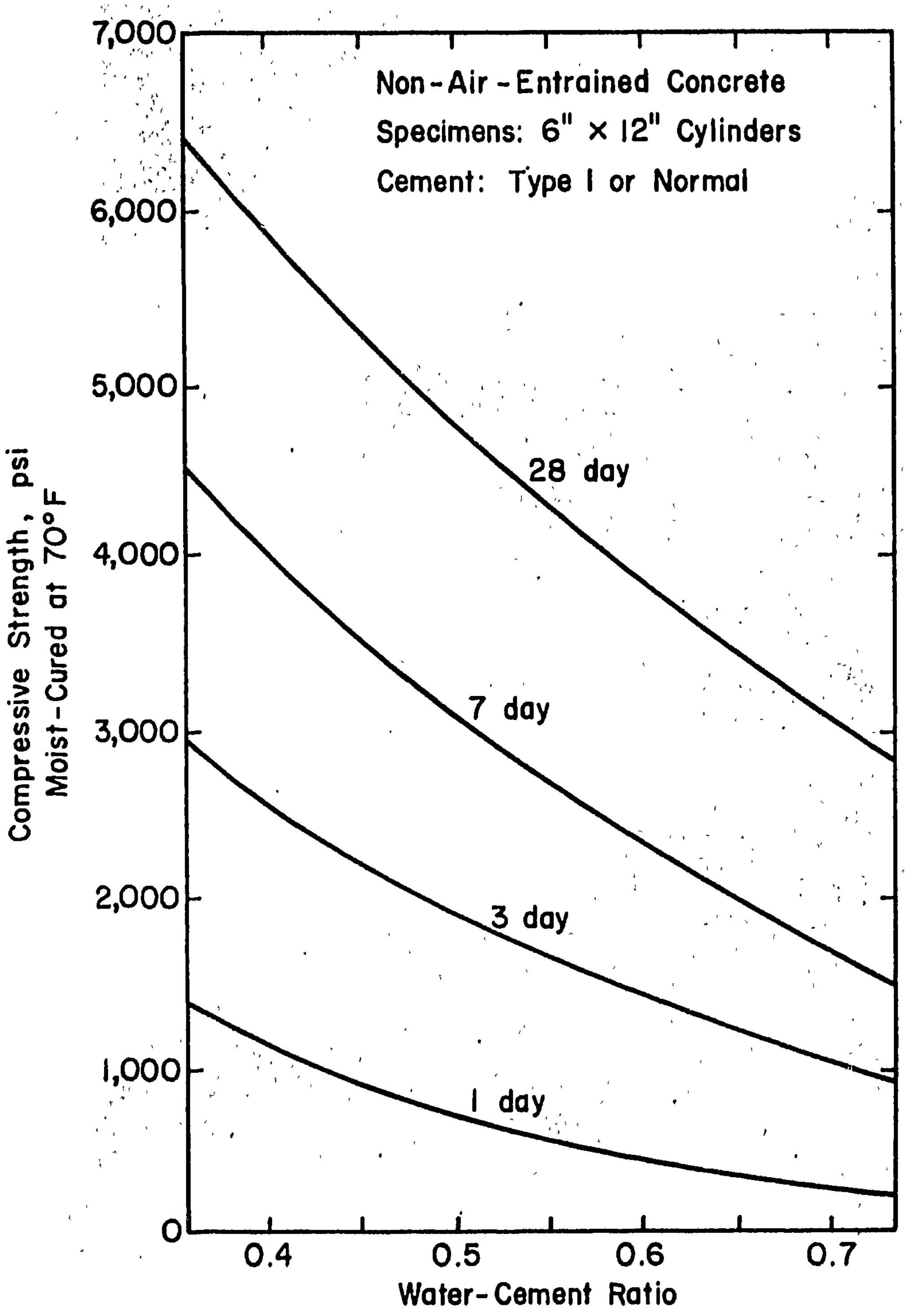


Figure 2. Water-cement ratio (from "Design and Control of Concrete Mixtures," Portland Cement Association, 11th Edition, 1968, pp. 115).

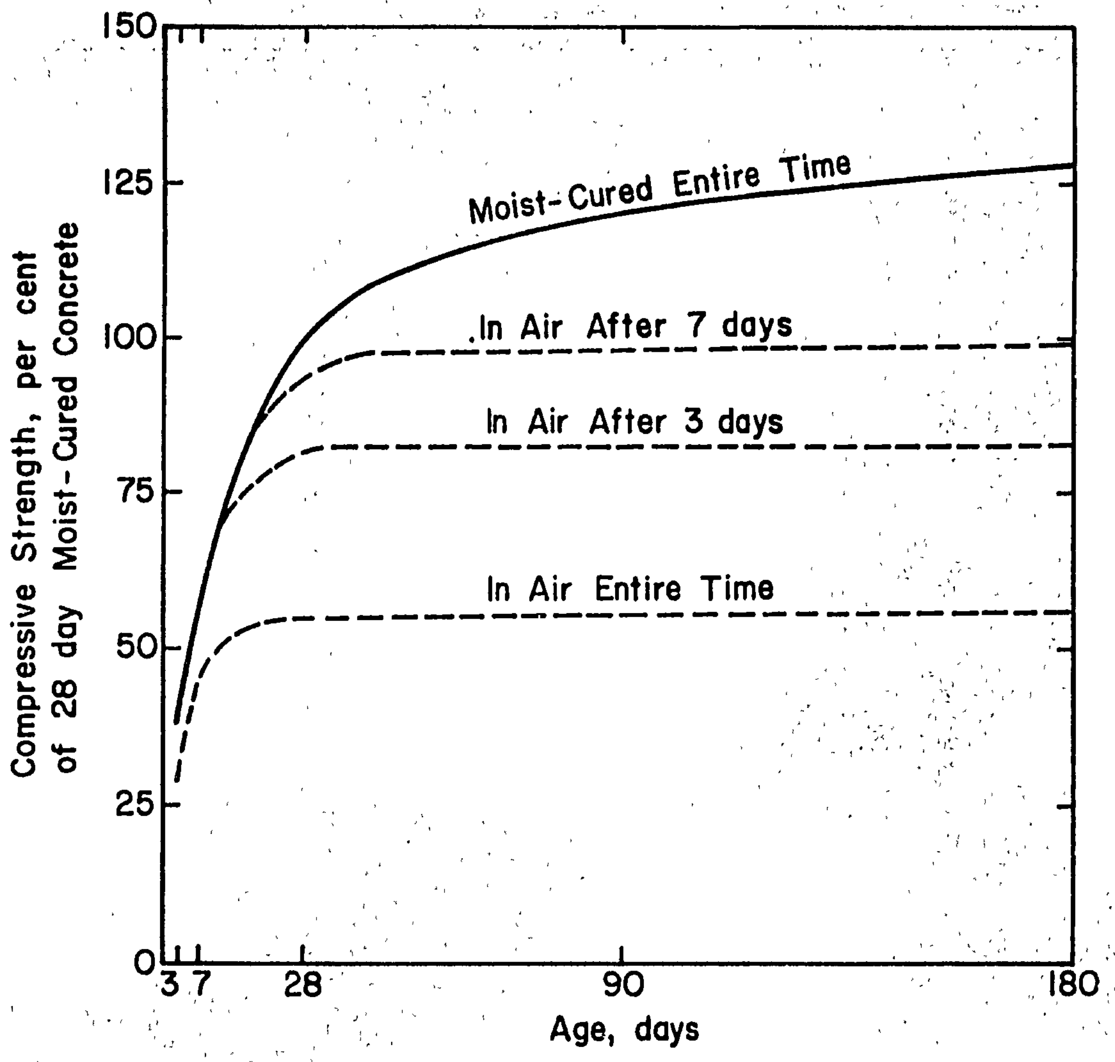


Figure 3. Compressive strength of cured concrete (from "Design and Control of Concrete Mixtures," Portland Cement Association, 11th Edition, 1968, pp. 115).

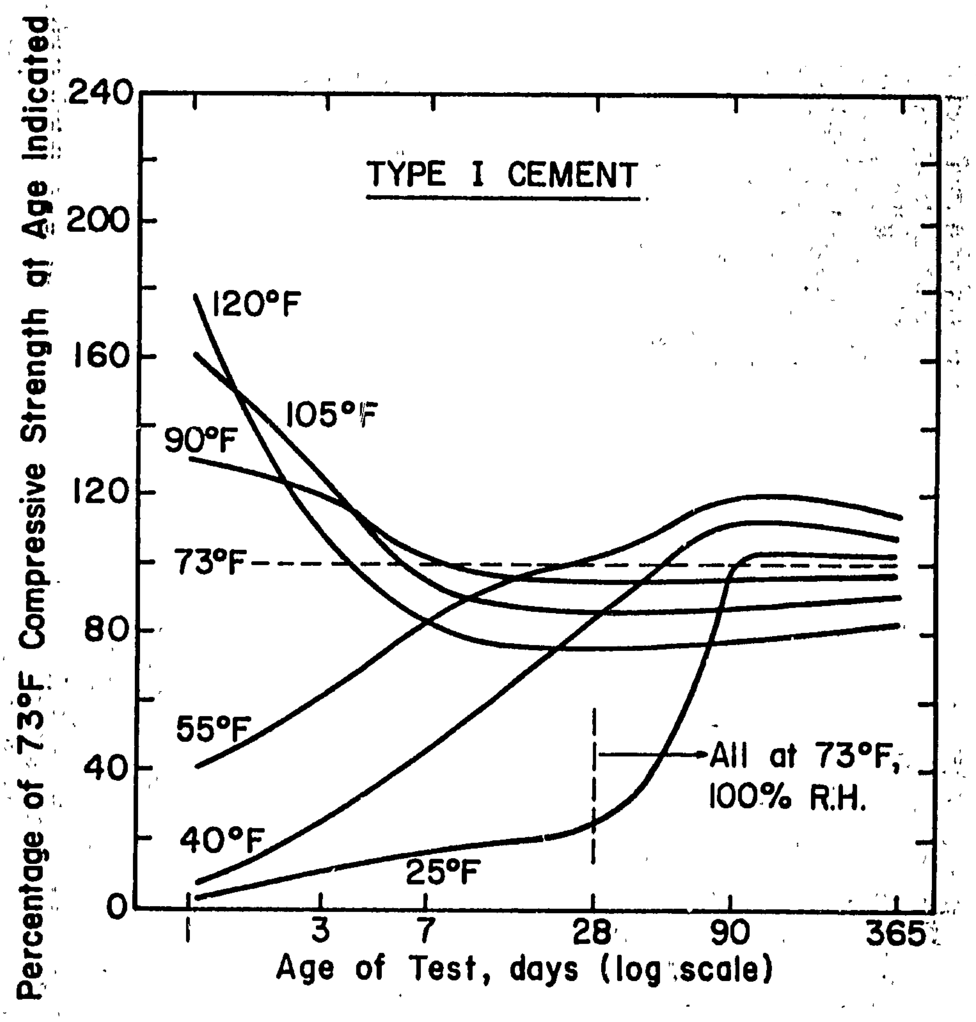


Figure 4. Compressive strength of concrete at age indicated. ("Low Pressure Steam Curing," reported by ACI Committee 517, ACI Manual of Concrete Practice, Part 3, 1979.

PLACING CONCRETE

If a proper water/cement ratio is used, the resulting concrete should be still 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 the vibrating table. 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 naccas, any air bubbles on the surface of the form where the lid is to seal would cause leaks. It is esential to vibrate this portion of the concrete sufficiently to remove all entrapped air bubbles in both the nacca 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 such surfaces as the sealing portion of the nacca panel must be cast against a hard, rigid material (e.g., 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 (Fig. 5A) and an inner ring form (Fig. 5B) that is about 10 cm larger in diameter than the lid. This ring is slightly tapered so that it is easily removed as soon as the concrete is in place and vibrated. After the ring is removed, the cast iron form (Fig. 5C) 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 result in water leaks when placed in a watercourse.

By using the cast iron ring as a pattern 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

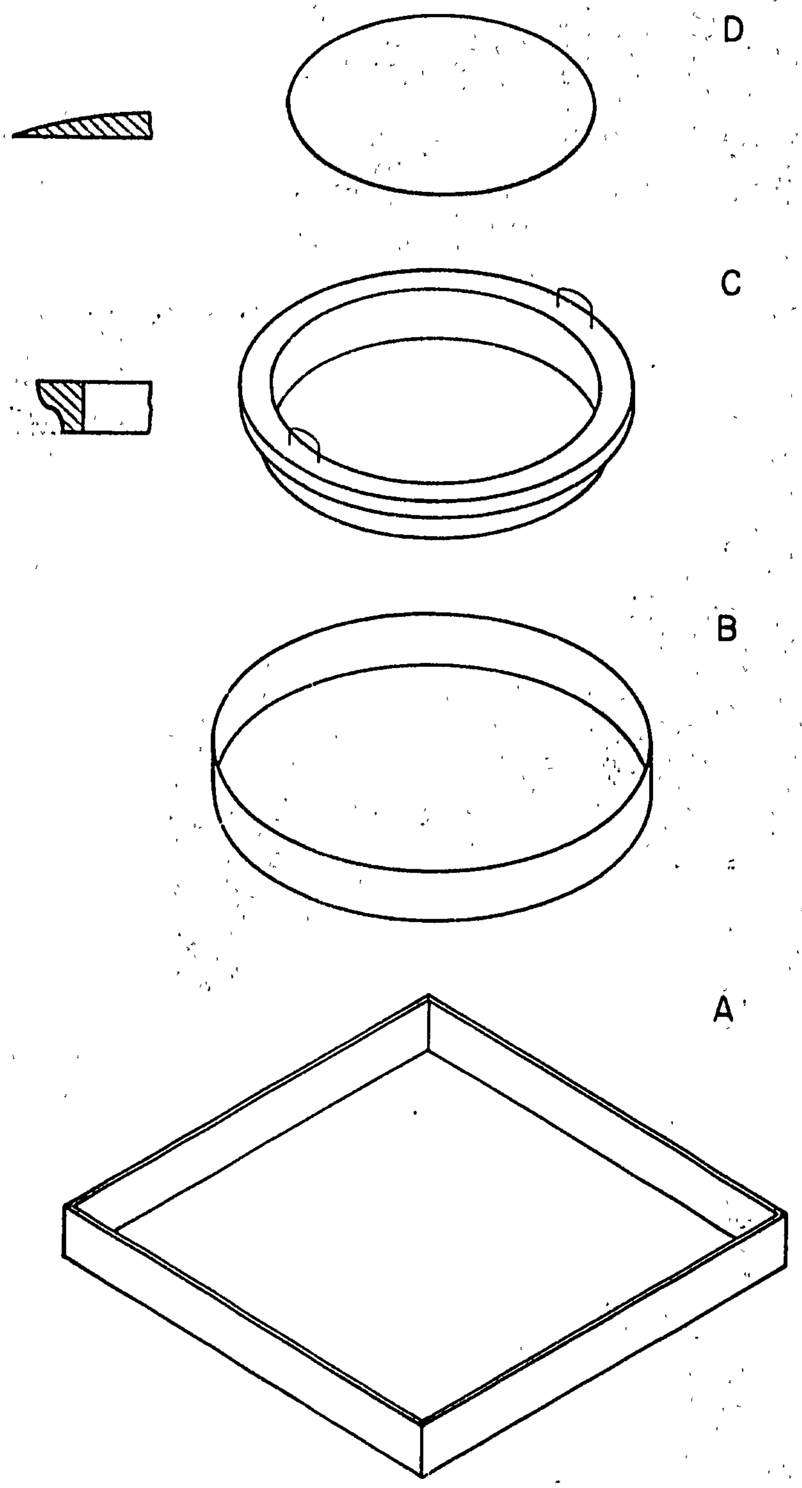


Figure 5. Forms for casting concrete naccas.

convex disc (Fig. 5D) 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 centimeters thick to assure no aggregate from the remaining concrete can penetrate it. Finally, good vibration is essential for concrete 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 to wash out the ground grout material. This can be done by hand but requires about twenty minutes of hard work per panel. The starting torque on an unground panel and lid is on the order of 250 ft-lbs. The running torque is about 1/4 of 250 ft-lb. 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. Steam is fast but requires special equipment. A simple pond that the concrete pieces can be stored in is simple and adequate. Hasnain RCC found that storing underwater for one month gave appreciably harder naccas than the usual storage time of one week. Where time and facilities permit, this is good practice.

GRINDING MACHINE

The most difficult problem in making naccas, whether concrete or any other material, is to get a tight seal. The "S" shaped seals 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 nacca with a "tight" seal. Therefore, a machine was designed and built to do this one operation of lapping the lids to their panels (Fig. 6).

The machine requirements were:

1. Sufficient torque to rotate the lids (over 250 ft-lb);

2. Made of locally available material with local shop facilities;

3. Flexible enough that it could grind any anticipated shape of nacca;

4. Reasonable cost; and

5. Portable and simple.

Electric power is used because of its simplicity, cheapness and low maintenance. This imposes one constraint; namely, the power for the machine is delivered at 1,500 rpm. If a final turning speed of one half revolution per second is adequate, a 1/4 HP motor will have sufficient power. This requires a 50:1 speed reduction. To keep pulleys and sprockets reasonable in size, this speed reduction is 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. Therefore, the total reduction is 64:1. (This is greater than the required 50:1 and resulted from what was locally available in sprockets). 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 lbs on a 12" (6" radius) sprocket. The torque on the hub of the 3" sprocket would be 62.5 ft-lbs. This gives a tension on the intermediate belt of 93 lbs. The torque on the hub of the first step-down pulley would be 15 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 frictional inputs.

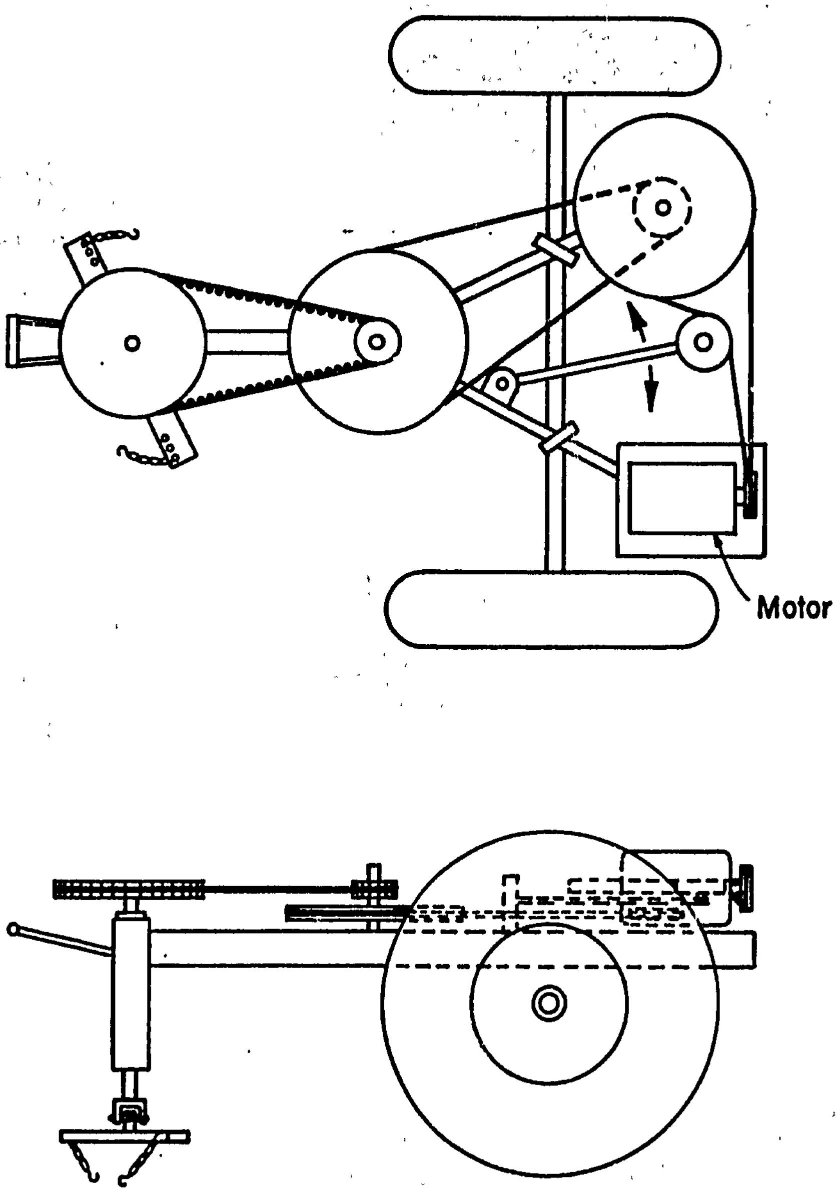


Figure 6. Nacca grinding machine.

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 places, the shaft 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 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 the nacca 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.

Initially, there was an intention 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" diameter 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 twenty minutes of hard physical work can now be done better in three minutes. Undoubtedly, other helpful techniques will be developed over the course of time, but very few shortcuts will be found successful. This is not a definitive work on either naccas or quality concrete but should serve as an aid to those willing to put in the necessary time, effort and capital to produce good quality naccas.

APPENDIX 22

THE DEVELOPMENT OF A FRONT-MOUNTED "BULLDOZER" FOR WHEEL TRACTORS TO BE USED IN PAKISTAN

by

N. Illsley[1]

Among the many implements that have been developed for earth moving, the bulldozer, or front blade, is probably the most common and the simplest in concept. Basically, it is a vertical blade used for pushing which is attached to the front of a prime mover.

The degree of sophistication in the design of front blades depends on its manufacturer and the intended application. Simple wooden planks mounted on the front of automobiles have been used as improvised snow removal blades. At the other extreme are some of the very large bulldozers mounted on both rubber tire and crawler tractors made by such firms as Caterpillar, Fiat and Komatsu.

In agriculture, front blades are commonly used for clearing land, cleaning livestock yards and for simple construction work. Land clearing involves brush removal and occasionally tree removal, as well as rough leveling of fields where soil is moved short distances (for efficiency, not more than two or three tractor lengths). Backfilling of ditches and building up beds for roads or banks for canals are examples of agricultural construction operations commonly employing front blades.

In all of these operations, with the exception of tree removal, the material being pushed is relatively loose and the blade is not subjected to either heavy loads or shock loads. Therefore, a relatively light implement that is an attachment to a common wheel tractor is suitable.

Two of the limitations of a front blade for agricultural work are its inability to do precise leveling and its inefficiency when moving soil over long distnaces. Inefficiency is a relative problem and can often be tolerated, but the lack of precise control of the depth of cut or fill and

[1]Agricultural Engineer, Water Management Research Project, Colorado State University.

and the resulting unevenness of the finished field preclude the use of a front blade for precision land leveling for flood irrigation. Therefore, this task must be reserved for scrapers and land planes. This does not mean that the front blade is completely useless in land leveling. If its limitations are borne in mind, it can be a useful supplemental tool for the scraper. It is usually difficult to fill ditches, remove bunds and work in inaccessible corners of fields with a scraper because the tractor must precede the scraper over the surface that the scraper is trying to level. By contrast, the front blade can push earth into a ditch or hole while the tractor remains on even ground. In these situations, the front blade is a more effective implement than the scraper. If the front blade is equipped with scarifier teeth, it can also serve as a harrow for loosening soil which can then be picked up easily by a scraper being pulled by the tractor.

A front blade for wheel tractors has been imported into Pakistan, and several local manufacturers have been making implements similar to it. Most of the complaints about the blades now being made in Pakistan are that the hydraulic systems leak, the frames bend and break, the mounting bolts come loose and break off, and the quality of work they do is poor. Most of these blades use locally made hydraulic cylinders which cost about Rs. 3000 (U.S. $300). Within a few months their seals leak. The hydraulic control valves which operate these cylinders cost an additional Rs. 1000. The locally made hoses and fittings also have problems of leakage and breakage, as reported by the tractor operators. Some of these problems may be due to poor service or careless operation, but the end result is that the systems have too high a breakdown rate.

The frames for these dozers are usually made of angle iron, and because they mount under the engine, or on the sides of the engine, the thrust arms which push the blade must have a bend in them to clear the front axle of the tractor. This bend becomes a weak point in the frame on the machines inspected in the field, all of which had been welded and repaired at this point. Also, mounting the dozer frame on the sides of the engine limits the width of the frame, thereby making it weak laterally. The use of angle iron and the narrow width make the frames weak torsionally as well. The mounting plates for these frames are bolted directly to the engine in such a way that the bolts must carry the thrust load of the blade in shear rather than in tension. The bolts first work loose and then shear off. In a sense, this is a safety feature: if the operator hits anything too solid, the bolts shear and nothing else is damaged. However, the shearing strength of a tight bolt is much greater than that of a loose bolt, so the safety limit is not constant and merely becomes a nuisance.

A few of the dozers use a very short frame that bolts directly onto the front of the tractor. This system has two advantages: there is no restriction to ground clearance underneath the tractor, and the thrust is taken on the front vertical frame of the tractor so the mounting bolts are not sheared by the thrust load of the blade. The principal shortcomings of this system are: to have enough vertical movement the blade must extend too far in front of the tractor; the pitch angle of the blade changes drastically as it is raised or lowered; and the front of the tractor has a tendency to "pole vault" over the blade if the blade meets heavy resistance, because the line of thrust of this system makes too steep an angle with the ground.

With these problems in mind, Bethlehem Technical Foundation, a private manufacturer in Rawalpindi with a tradition of emphasizing quality in its products, was asked by a government department to develop a better bulldozer blade for road building and agricultural land preparation. The design described here is in answer to that request (Fig. 1).

The design criteria for this implement were as follows:

1. The implement is to be used with the Fiat 640 tractor.
2. It should be simple and quick to remove or install on the tractor.
3. It should be made of locally available materials, at a reasonable cost, by local manufacturing techniques.
4. The tractor with the blade mounted should be easy to control and able to perform the operations normally expected of a dozer, i.e., raise, pitch, tilt and angle.
5. It should be strong enough to avoid breakdowns when being operated with reasonable care.
6. The blade should be able to work together with, or independently from, a chisel or other implement on the tractor's three-point hitch.
7. The prototype was to be delivered in fifteen days.

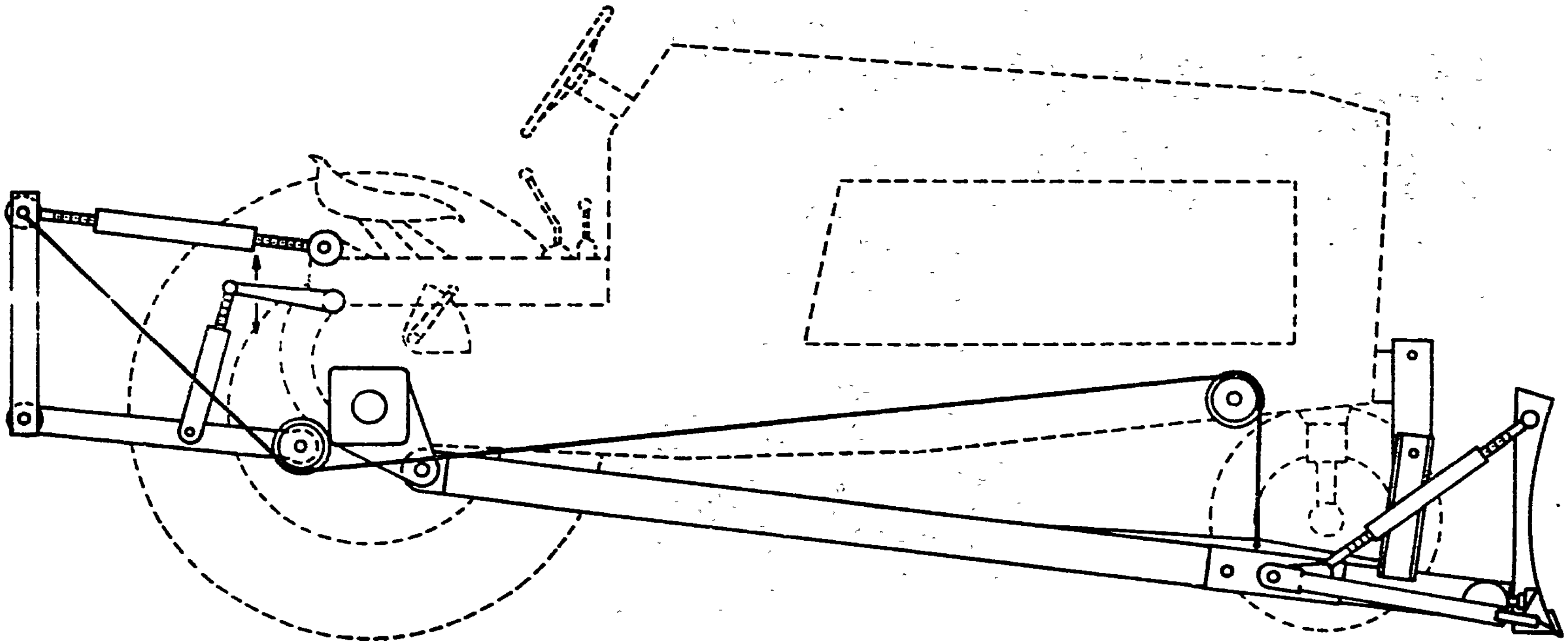


Figure 1. Cable operated bulldozer attachment.

METHOD OF ATTACHMENT

Geometrically, it is best to attach any pushtype implement, such as a bulldozer, below the rear axle center line. By doing this, the thrust on the blade tends to rotate the front of the tractor downwards around the rear axle rather than making the tractor rear up on its hind wheels. This improves front wheel traction and steerability when it is most needed.

The pitch of a blade (the angle at which the cutting edge of the blade strikes the ground) should remain relatively constant when the blade is raised or lowered. Therefore, the thrust arms should be as long as possible.

The blade must be stable in tilt so that it can be adjusted to cut level or dig in on one side or the other at the operator's will. Therefore, the frame must resist twisting.

Keeping these three factors in mind, it was logical to mount the frame for holding the blade just underneath the rear axle and as widely spaced as possible. This mounting position also meant that the thrust of the blade would be taken directly upon the rear axle, which is the part of the tractor closest to the wheels which generate the thrust. Pipe was used for the frame members because its cylindrical shape gives greater strength than channel or angle iron in both bending and torsion for the amount of steel used.

The frame is tapered toward the front for three reasons. First, it was necessary to give front wheel clearance when turning and yet have the wide support at the rear for tilt stability of the blade. Second, the resulting trapezoidal shape is stronger than a rectangular shape under lateral or diagonal stresses. Finally, the thrust arms of the frame are closer to the center of the blade, which is the main point of thrust transfer from the blade to the frame, and the bending moment on that cross member of the frame is reduced accordingly. The frame is held to the tractor by two pins in the mount at the rear axle. With these two pins removed and the lifting cable disconnected, the frame drops free for quick removal of the whole assembly from the tractor.

The blade is attached to the frame at three points: the center and the two sides. The center attachment uses the ball joint from the front suspension of a truck. These parts are available in good supply and at reasonable prices at used auto parts bazaars. This ball joint has ample strength and yet gives full flexibility of movement to the blade. It is welded to the back of the blade and bolts to the frame with a single large nut. This attachment point is about 10 cm above ground level so that the thrust from the cutting edge of the blade is a straight compressive load with minimum bending moment on the frame or blade. The ends of the blade are supported by two arms running from the top and bottom corners of the blade back to a common mounting bracket on the frame. The upper arm on each side of the blade is a turnbuckle.

The pitch of the blade can be adjusted by extending or shortening these turnbuckles together. The tilt of the blade can be adjusted by extending one turnbuckle while shortening the other, and the angle of the blade can be adjusted by shifting the arms forward in the mounting bracket on one side and to the rear on the other side. Three sets of mounting holes are provided for this adjustment. Again, automotive ball joints are used at these points to give flexibility without looseness to these mountings.

The side thrust of the blade is accommodated by two vertical channel iron rails that are mounted on the frame and slide between two angle irons that are bolted to the front of the tractor. This transfers any severe side load from the blade through the frame directly to the front of the tractor, preventing possible damage to the frame or mounting brackets at the rear axle.

The lifting mechanism of the blade makes use of the geometry of the three-point hitch. The hitch is essentially a parallelogram (Fig. 1). By running a cable between diagonally opposite corners of the hitch, the cable length increases or decreases when the hitch is raised or lowered. Two cables are used, and by running them under a pair of pulleys, they go first to the front of the tractor where another pair of pulleys direct them down to the frame. As the hitch is raised, the frame is lifted. This system has much more potential travel than is required in the normal operation of the blade. Therefore, by adjusting the cable so the blade is in its highest position when the three-point hitch is also at its highest position, a chisel can be mounted on the hitch and the blade raised or lowered to the ground without the chisel touching the ground. If the chisel is to be used, two pins can be inserted through the channel iron and angle iron assembly used for side thrust to hold the frame in the fully raised position. Then the chisel can be used with the lower reaches of the hitch, allowing the cables to hang slack.

The cable mechanism has certain advantages over a wholly hydraulic system. Cables are cheaper and simpler, and can be repaired by anyone in the field without disabling the tractor or losing the transmission lubricant, which is usually used for the hydraulic system. Hydraulic hoses and cylinders which typically leak and/or fail are avoided. Finally, in operation, a cable system can do a much smoother job of leveling than a hydraulic system when the blade is being used for back-blading (running the tractor in reverse so that the blade is dragging behind).

However, a front blade on a wheel tractor should not be confused with a bulldozer mounted on a crawler tractor. On a wheel tractor, a blade is only for light duty scraping or pushing. It is not meant for the heavy digging and ripping that a crawler tractor does. Neither the tractor nor the blade can be designed for this severe service. Further, a crawler tractor has a maximum forward speed of about 5 miles per hour (Caterpillar) and a dozer working speed of not over 2 miles per hour. Wheel tractors have road speed of over 20 miles per hour and frequently do field operations in excess of 5 miles per hour. If an inexperienced operator tries to operate a front blade on a wheel tractor at speeds greater than 2 miles per hour, he is eventually going to do serious damage to the dozer, the tractor, and even to himself. But, if the tractor and blade are used properly, the system can be the most efficient means of moving soil for short distances, filling holes and ditches, or smoothing out banks and bunds. It is not a replacement for either a crawler bulldozer or a scraper, but rather an additional implement with its own attributes and limitations.

APPENDIX 23

ROLLER BEDSHAPER FOR BASIN-FURROW IRRIGATION

by

N. Illsley and A. Cheema[1]

INTRODUCTION

Good irrigation water management implies getting enough water to the root zone to satisfy the evapotranspiration needs of the crop. At the same time, a minimal amount of water should be allowed to penetrate below the root zone to maintain a proper salt balance in the soil. This requires a uniform application of water over the surface of the field. With surface or flood irrigation, this uniformity is partially dependent on how precisely the field has been leveled. The degree of precision felt necessary and yet practicable for Pakistani fields (2 ha) is ± 2.5 cm from the average elevation.

To achieve this degree of precision, accurate surveying and staking are required, followed by tractor-drawn scrapers and land planes to transport and level the soil. This is expensive and time consuming. Due to the size of the machinery used, it becomes less practical to level the smaller fields, with two acres being about the minimum size.

A possible alternative to precision land leveling is the cultivation of crops on beds, with irrigation water applied through small (15 cm deep by 25 cm wide) furrows between the beds. Assuming the beds to be 50 to 100 cm wide with furrows about 15 cm deep, the levelness of the field can vary ± 7 cm, as compared with ± 2.5 cm for flood irrigation, and still deliver water to the root zone of all the crop without flooding any portion of the beds. Water will always reach to within less than a half-bed width of the plants. There will still be portions of the field which are either over or underirrigated, but because the method of water movement through the soil from the furrows to the root zone is capillary, at the end of an irrigation period, the only excess water will be that standing in the furrows. This is about one quarter the amount that would be standing in the same field if it were not bedded.

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ADVANTAGES OF BASIN-FURROW IRRIGATION

Depending on local conditions advantages of this method over level basin flooding include:

1. Energy consumption in land preparation is lower.
2. Greater field unevenness can be tolerated without over or underirrigating portions of the crop.
3. Small field size does not limit use of this method.
4. Lower water delivery rates may be used.
5. Crusting is minimized and a porous mulch seedbed is easier to maintain.
6. The furrows can act as guides for controlling cultivation implements.
7. Beds can be walked on sooner after irrigation.
8. This method can be used in more saline conditions.
9. Deep percolation losses are reduced.
10. There is less risk of crops being drowned by heavy rains.
11. Fertilizer can be applied during bedshaping.

Energy Consumption

Because of the nature of the operation, precision land leveling for flood irrigation requires scrapers and land planes. These implements are best operated with medium sized tractors in the 40 to 60 HP range (depending on the type of soil being moved). Less powerful tractors have difficulty loading and unloading the scraper bucket. A bedshaper making two beds and two furrows can be pulled with a 35 HP tractor.

Precision land leveling requires large amounts of soil to be moved from the high areas to the low areas. For example, if a one acre field has half of its surface averaging 7.5 cm higher than the desired final field elevation, it would involve moving 303 m^3 of soil from the high areas to the low areas with an average travel distance of half the length of 11 cm producing 4 cm of fill to form the bed. This amounts to about 93 meters^3 of soil dug per acre.

Once dug, the soil would be moved an average of about 25 cm to form the bed. A bedded field having 15 cm deep furrows should be able to have undulations of as much as ± 6 cm without their causing either dry areas or flooded areas. Typically, the bedshaper leaves the texture and surface of the field in an ideal condition for planting. Once the transporting with scrapers is done, the field must still be finished with a land plane, requiring at least three passes over the field for adequate levelness. Finally, after leveling, the seedbed must be prepared by plowing, discing and/or harrowing.

On lands that have a gentle slope in one direction, beds can be established on the contour. This will reduce or even eliminate the need for earth moving. If a field is too uneven, it can be leveled in one direction to within tolerances acceptable for bed cultivation. In the second direction, that is, across the beds, a slope does not interfere because the water does not flow in that direction.

Therefore, preparation of fields for bedded irrigation should require far less energy than leveling the same fields for level basin irrigation.

Field Unevenness

With beds using furrows that are at least 15 cm deep, a tolerance in elevation of ± 5 cm will still leave 1/2 cm for water depth and freeboard in the furrows. Water will be within a few centimeters laterally of all the plants. Although over and underirrigation will still exist, it will be less severe than with flooding. Even if the furrow is too shallow at the high areas of the field, it is very easy to dig these sections deeper by hand by walking along on the bed which remains unsaturated.

With a 6 cm average depth of water in the furrows, the lowest elevation portions of the furrows would have 12 cm of standing water when irrigation is finished. With a 60 cm bed width, this would result in an overirrigation of about 9.6 liter/m^2 of bedded area. If the field was flood irrigated, there would be 60 liter/m^2 over the same area.

Field Size

Scrapers and land planes are typically large implements that are not suited for use on small fields, with about two acres being the minimum feasible size. Scrapers could conceivably be scaled down in size to work with animal power in smaller fields, but land planes must be of sufficient length to accomplish their planing action. On the other hand, a bedshaper mounted on a three-point hitch is as maneuverable as the tractor it is mounted on and can even be backed into corners of fields. The bedshaper, like any other piece of equipment, loses efficiency when used in small fields due to the proportion of time spent in turning around. But it is not as costly a problem as with trailing implements such as scrapers. The bedshaper is a machine that can be scaled down. The limitations are the size of furrow required for the irrigation water and the energy input required to operate it. A small model that made a single furrow 12 cm deep with 20 cm of bed on either side was used experimentally with a team of two bullocks.

Water Delivery Rate

Flood irrigation requires a large enough stream flow into the field so that the infiltration rate of the water into the ground is insignificant compared to the rate at which the water is progressing across the field. With furrows, uniform irrigation can be accomplished with much smaller flow rates for two reasons; first, the irrigator has the choice of how many furrows he wishes to turn the water into at any one time, thus regulating the rate of flow of water into the field and usually the irrigation water advances much more rapidly in a furrow than it does over a flat field. This reduces the time lag between when the head of the furrow and the tail of the furrow are wetted. Therefore, the water penetration is more uniform over the length of the field.

Also, the compacting effect of the bedshaper roller reduces the infiltration rate of the bottom of the furrow allowing the use of smaller stream flows in the furrows.

Crusting and Mulch

Crusting of the soil surface can become a serious problem, especially with fine soils that are alkaline. Crust forms either after flood irrigation or heavy rains. Crust can seriously impair the emergence of delicate seedlings and thus reduce the crop stand. A crust will also have a higher soil moisture evaporation rate than a coarse textured soil surface. The problem of crusting from irrigation is eliminated with bed irrigation, and crusting caused by rain is reduced because the furrows provide field storage for rain so that there is less chance of water standing on the surface of the bed where the crop is grown. In addition, standing water in the furrows after rainfall would move laterally into the beds, with the soil moisture then rising vertically by capillarity, which would soften any crust that might have formed around the plant.

Guiding Machinery

Furrows provide a permanent guide in the field for other equipment. Tractor wheels and implement wheels can follow the furrows for precise positioning of equipment with respect to the crop. The furrow openers of the bedshaper can be used alone to clean out the furrows, and cultivator sweeps can be attached for precision weeding at the same time. The roller portion of the bedshaper is an effective crust breaker and has been successfully used to break up crusts when heavy rain fell before the crop had sprouted. It can also be used after sprouting so long as the plants are tender enough not to be damaged by being bent to the ground.

Walking on Beds

The center of the bed will receive the least water and will dry out the soonest after irrigation. This will allow walking through the field sooner after irrigation for weeding or other cultural practices, than if the entire field had been flooded.

Salinity Tolerance

Salts move through the soil with the soil moisture. This is why saline soils with a high water table frequently display the white concentrated salt on the surface. With furrows and beds the moisture is moving horizontally from the furrow toward the center of the bed. This movement will concentrate the salt at the center of the bed which is beyond the root zone of the crop growing at the edge of the furrow.

Minimize Deep Percolation

By using the roller to compact the bottom of the furrows, the moisture cross section profile will be shallower and broader than with a simple furrow. This will reduce the proportion of water lost to deep percolation. The degree of spread is dependent on both the soil and pressure exerted by the roller. The moisture cross sections should resemble those drawn in Figure 1. The compacted furrows allow for more rapid advance of the furrow stream, which allows smaller depths of application for a single irrigation, which in turn will result in less deep percolation loss.

Crop Drowning

The usual problem from heavy rains is the actual drowning of a crop from excessive water standing on the surface of the ground for extended periods of time. Again, the water storage capacity of the furrows will alleviate this problem. This was well demonstrated at the Cotton Research Center at Multan during the heavy rains of 1978. Level fields containing cotton plants 15 to 20 cm high were completely destroyed, while adjoining fields planted on beds maintained a reasonable stand.

Fertilizing

Fertilizer can be placed in the bed at the original ground level. This can be done by dropping the fertilizer just ahead of the bedshaper so that the fertilizer is covered by the soil from the furrow when it is spread by the roller. This would place the fertilizer at about the 5 cm depth with the heaviest concentration at the edge of the furrow.

Hand broadcasting is the typical method of fertilizing now. The fertilizer is not uniformly distributed. It is mixed into the upper 25 cm of soil by plowing prior to seeding. This results in only part of the fertilizer reaching the potential root zone of the crop.

DEVELOPMENT OF BEDSHAPER

The bedshapers designed and made in Pakistan were developed to test the concept of bed cultivation under local conditions and to test the concept of a roller to shape the bed. It was also of interest to see if a suitable machine could be fabricated locally. The machines fabricated to date, although successful, are not the ultimate design, and no doubt could be improved. Further, time did not permit the development of the attachments such as planters and cultivators which would be desirable additions to the basic bedshaper.

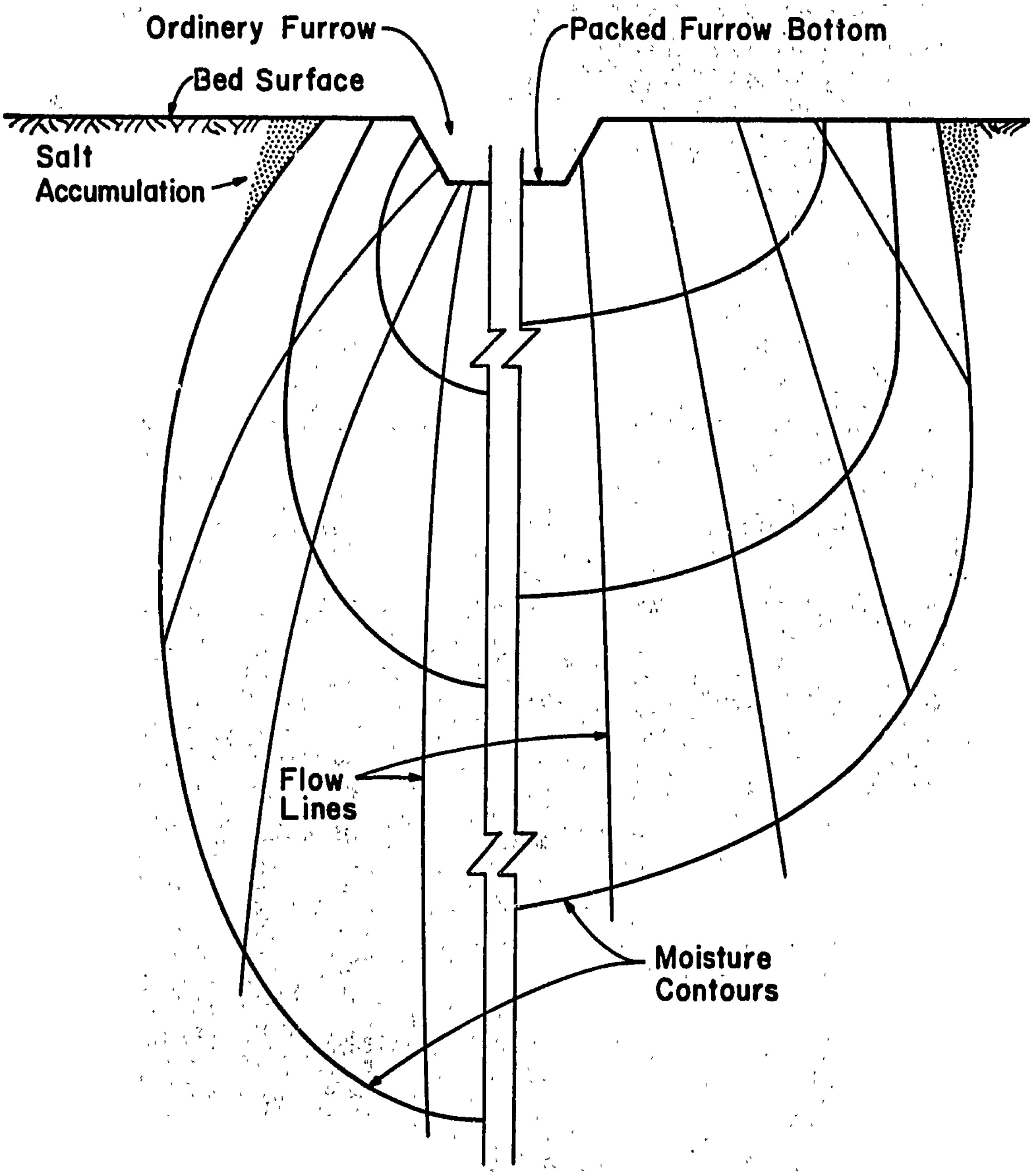


Figure 1. Moisture and salt movement in compacted and loose furrows.

Purpose

Bed cultivation is not a new idea and is commonly used for a variety of reasons. The overriding reason to try beds in Pakistan is to help manage the use of irrigation water on the fields. Water is in short supply and too much is being wasted. It was expected that with a given quantity of water more land could be irrigated producing more crops, with less water lost to deep percolation, which contributes to the rising water table problem.

Criteria

When developing an implement to perform a certain task, many factors must be considered both as to the functioning of the machine and the conditions under which it is to be made. Do not use a sledge hammer to drive a tack, nor use a tack to hang a sledge hammer.

When the proper size and sophistication of machine is decided, consideration must also be given to what equipment, materials, and skills are available for fabricating the machine.

With this in mind, the following criteria were considered in designing the bedshaper.

1. The implement must be able to shape beds of the various widths typically used and make furrows adequate for good irrigation practices.

2. Only locally available materials and local shop skills and facilities should be used for its fabrication.

3. The cost of the implement should not be beyond the reach of the average tractor owner.

4. The bedshaper should require as little energy as practical to operate.

5. The implement should be both simple and rugged so that repairs are both infrequent and easily made.

6. The bedshaper should be compatible with other field equipment both presently in use and anticipated in the near future.

Existing Bedshapers

Two versions of bedshapers have been introduced in Pakistan. The first is a design brought in by USAID. It consists of a flat steel plate about two meters wide by one meter long. Two adjustable furrow packers that are shaped like a small boat hull are mounted underneath the plate. The whole assembly is built on a three-point hitch for mounting on a tractor. Its weight, of about 300 kilos, is necessary in order to pack the beds smoothly. This bed shaper does not actually dig its own furrows, but rather must follow another implement such as a lister which digs the furrows; then, the bedshaper smooths and shapes the beds. Thus far, the one unit that has been built was only used on a few demonstration plots.

The second bedshaper was imported from Australia by the Cotton Research Center at Multan. This machine has proven very successful at the Cotton Research Center, but there has been no effort to introduce it into the mainstream of Pakistani agriculture. It remains a tool for research on cotton and is both larger and more costly than the CSU machine.

Roller Bedshaper Design

This machine consists of a furrow opener followed by a roller system (Fig. 2). The furrow opener lifts and windrows the soil, and the roller system spreads the soil, crushes the clods and smooths the top of the bed, compacting both the bed surfaces and furrow surfaces. The roller thus controls the shape of the bed and the furrows.

The bed shaper is a bolt-on attachment to the cultivator frames commonly used in Pakistan. Although made by many manufacturers, these frames are virtually identical because they have been copied from just a few original imports. The frame consists of two parallel 2.5 m pieces of 5 cm angle iron, spaced 50 cm apart on a three-point hitch. The angle iron is drilled at 2.5 cm spacings so that attachments can be bolted onto the frame at any desired spacing.

The furrow opener is made of sheet metal about 2 mm thick (Fig. 3). It is a "V" shaped plow, with a 30^{o} included angle. The wings are 45 cm high by 50 cm long. The sides of the opener are bent inwards diagonally so that the bottom is 12 cm wide, and the sides rise to give a 30^{o} or 45^{o} slope to the furrow banks (both slopes were tried). The front edge of the opener curves forward at the bottom, and the bottom is arched concave to improve penetration (Fig. 3).

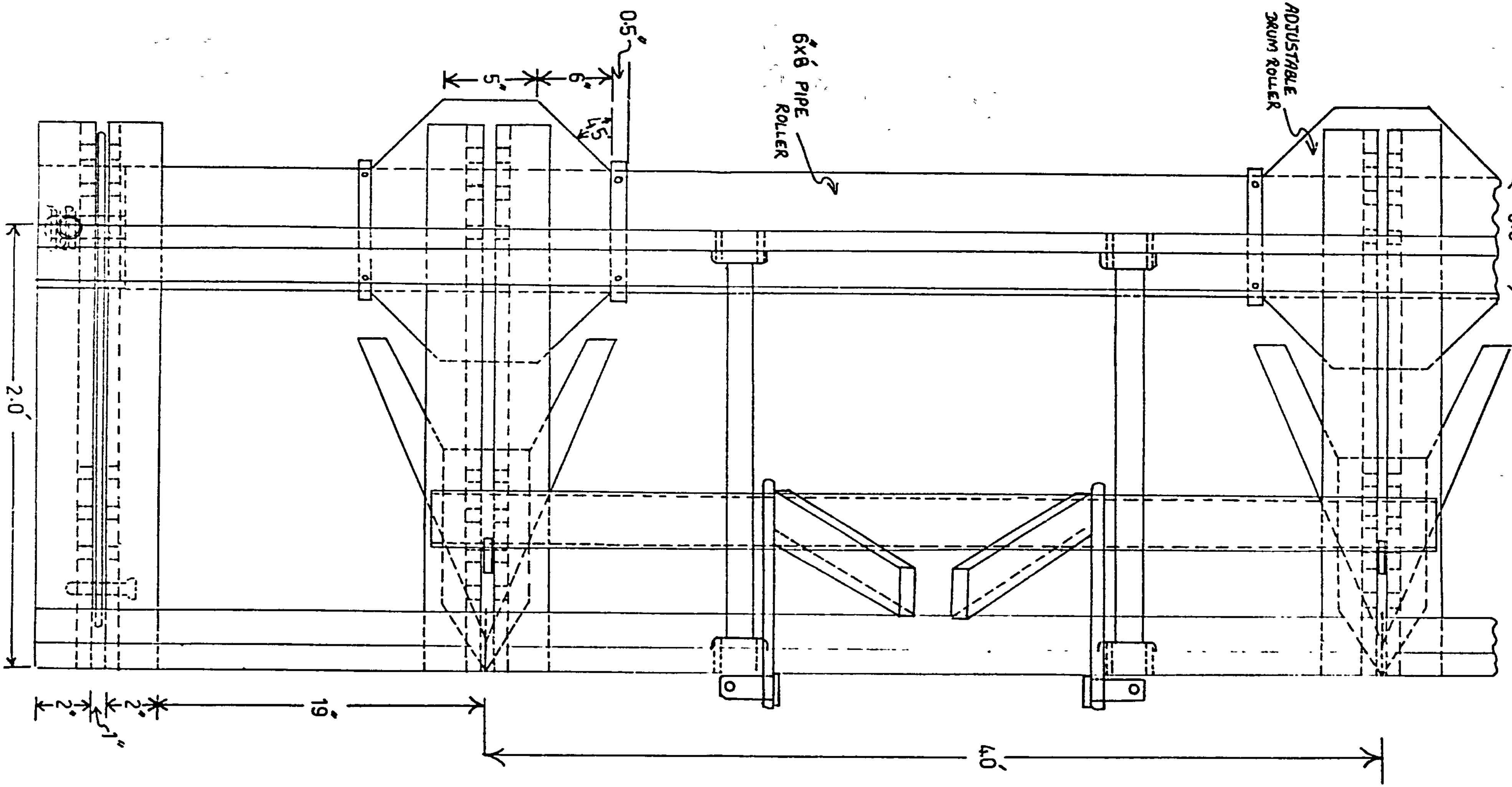


Figure 2a. Plan view of bedshaper showing frame, furrow openers, and roller assembly.

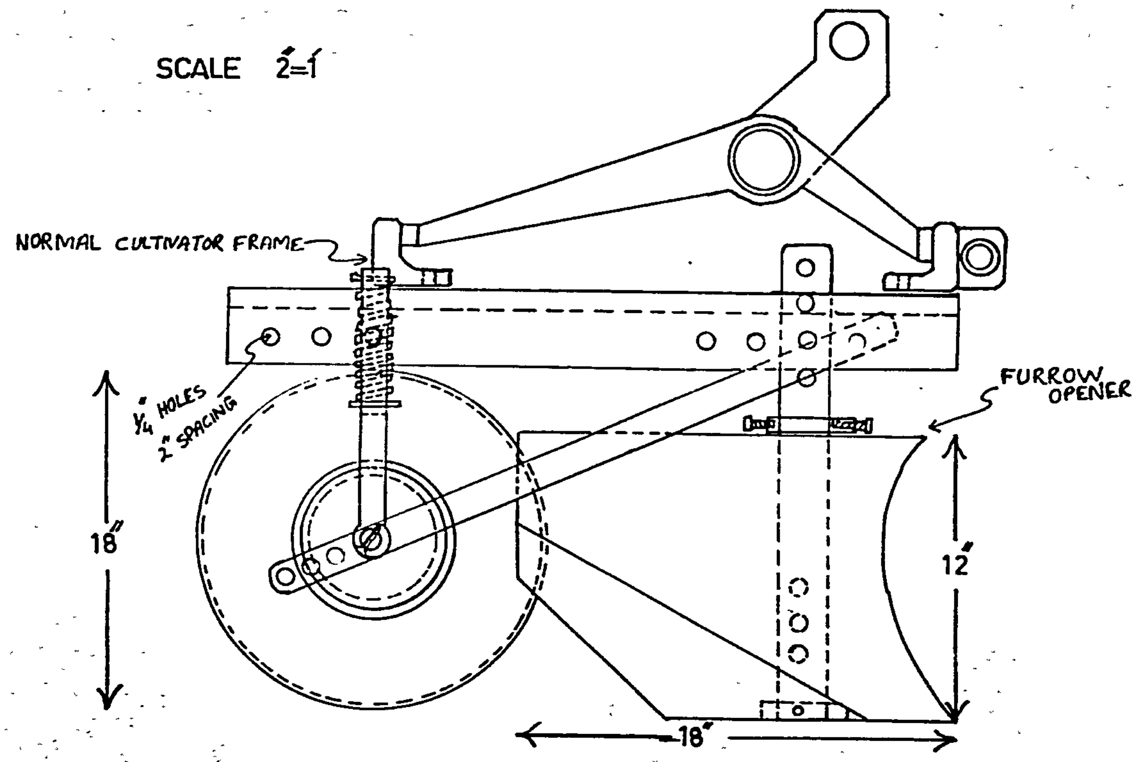
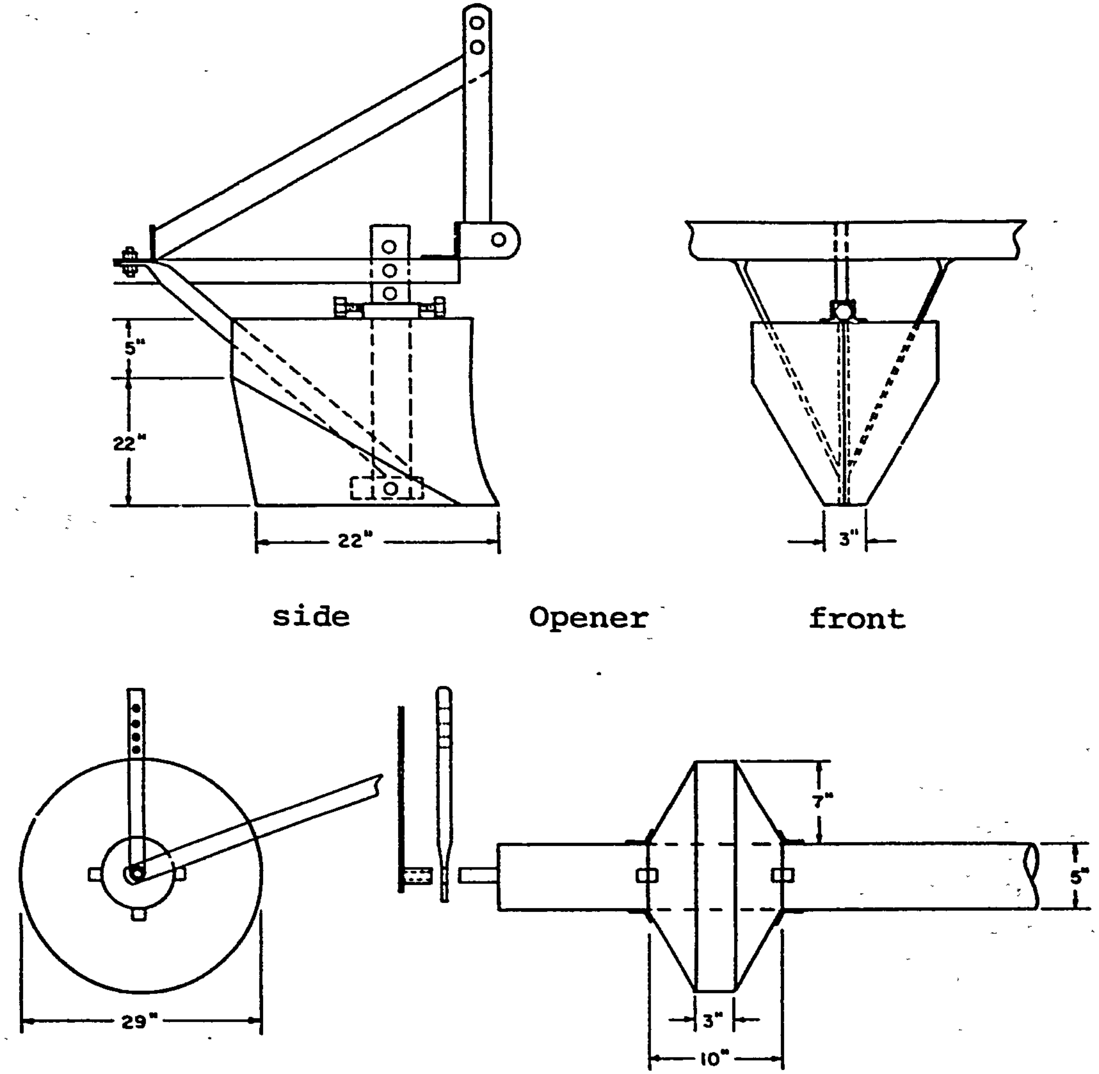


Figure 2b. Side view of bedshaper.



side Opener front

side Roller front

Figure 3. Essentials of bedshaper components.

The opener is supported on a vertical shank that is pinned to the inside sole about 20 cm back from the tip. The shank passes through an adjusting slot on the top of the opener. The adjusting slot allows precise adjustment of the tilt of the opener in order to control penetration. To attach the opener to the frame, two pieces of angle iron are bolted between the front and rear frame bars in such a way that they form a slot for the shank to pass through and be held with a bolt onto the angle iron braces. Multiple holes in both the shank and the angle irons provide adjustment of the opener position.

The shank of the opener absorbs the vertical loads. The lateral and longitudinal loads are taken up by braces that run from the bottom of the shank up diagonal to the rear frame member. This method of mounting allows any number of openers to be used on the frame, and any desired bed width can be made.

The roller assembly is essentially one long piece of pipe with furrow cones fastened on it at the desired spacings. The pipe is thin wall steel, 2.4 m long and 13 cm in diameter. The ends of the pipe, 5 mm steel, are capped with discs and 25 mm stub axles, 5 cm long, are welded on the caps. The cones are made of 1.5 mm sheet steel and held to the rollers either by set screws or band type clamps.

The roller is attached to the frame by two arms at each end. One arm is vertical and spring mounted to keep constant downward pressure on the roller. The second arm is a draft arm, running diagonally up to the forward frame member. Both arms are mounted on a short piece of pipe that acts as a bearing on the stub axle of the roller. The pipe is welded to the vertical arm and the diagonal arm is drilled to slip over the pipe. There is no need for diagonal bracing for the roller because the cones must follow in the furrows left by the openers.

A unique feature of the roller is that it rotates at less than ground speed. The cones that shape the furrows are three times the diameter of the pipe that rolls the bed. These cones are wedged in the furrow where there is greater traction than on the bed, and the cones, with their greater radius, have a mechanical advantage over the pipe in determining the speed at which the roller rotates. The result of this lower speed of the pipe is that it has a bulldozing action on the windrow of soil and spreads the soil more evenly across the bed before it is actually rolled. As only one point on the radius of the cone will be turning at actual ground speed, all the rest of the cone and roller assembly will be having a troweling effect on the soil surface. At the bottom of the furrow, this gives some compaction which should facilitate even water distribution across the field.

Results and Discussion

Using a 35 HP tractor, this bedshaper will pull two 20 cm deep furrows and smooth the equivalent of two beds (one full bed between the furrows and two half beds on the outside of the two furrows). If the implement is not penetrating deeply enough, the furrows will still be properly shaped, but the center of the bed will not be finished due to insufficient soil in the windrow for spreading. If the penetration is too deep, the draft increases and the windrows tend to spill over the top of the opener and the inside corners of the roller, leaving this loose spill in the furrow. Regardless of the depth adjustment, the edges of the bed are well shaped and firm. This is the critical area where the crop is normally planted.

Although this machine was developed to work as a unit for making complete beds, it was found that either the openers alone or the roller alone could be used for certain field conditions. In one instance, heavy rain had fallen after planting and before emergence. The resulting crust was effectively broken by using the roller alone on the beds. Although it was not tried, the furrow openers should be able to work independently for reconditioning the furrows, or for acting as guides which follow the furrows and control the position of other equipment such as seeders or cultivators.

A seeder attachment should be developed to follow the bedshaper, and a precision cultivator could replace the rollers, using the furrow openers to guide the implement along the established furrows.

A bedshaper was developed during the summer of 1978. Since then, five tractor-drawn units have been manufactured for government departments, and two additional units have been sold to private farmers. The shop making these units is keeping one bedshaper for display.

A small bullock-drawn model was made using a single furrow opener and two bed rollers of 75 mm PVC pipe. The implement made suitable small beds and could be pulled by an average pair of bullocks. However, the implement rocked sideways on the opener, making it difficult to hold level because it was only making one furrow. A team of bullocks does not have enough strength to pull two furrows. Furthermore, it is difficult to drive bullocks in a line straight enough that the resulting beds will be of uniform width.

The initial machines were demonstrated to both farmers and government officials at the Mona Research Center on private farmers' fields; at Niaz Begh on the On-Farm Water Management Research fields; at Chichiwatni, Khaniwahl, and near Multan on farmers' fields; and at the Agricultural University, Faisalabad, where the engineers are working with the firm that has been making the bedshapers.

Hopefully, the advantages of bed cultivation will become sufficiently obvious that the machine will gain general acceptance by the farmers.

APPENDIX 24

THE EFFECT OF CHEMICAL AND TRADITIONAL WEED CONTROL METHODS ON THE YIELD OF WHEAT

D.G. Westfall, Abdul Ghaffar, Mushtaq Gill and Zaffar Iqbal[1/]

Introduction

The growth of weeds in wheat is a major production problem in Pakistan. Weeds compete with the wheat plant for moisture, nutrients, space and sunlight and heavy weed infestations result in a reduction in yield. Traditional methods of weed control vary from no control to hand weeding or bar harrowing. Hand weeding is very laborous and farmers are generally not willing to devote the time and labor to this operation. Bar harrowing is helpful in eliminating some weeds but does not eradicate all the weeds that cause yield reduction plus it is not presently being practiced by a large percentage of farmers. The vast majority of farmers do not control the weeds in their wheat. Hence, weed infestations are a major problem and reduce yields substantially.

Weed control with herbicides has been established in developed countries to be an efficient and economical method of controlling weeds in all cash crops. There is no reason why this technology cannot be adopted to meet the needs of farmers in developing countries such as Pakistan. Farmer education is one factor that would have to be addressed but the problem is not insurmountable.

The objectives of this demonstration program are four fold: (1) To demonstrate to farmers that chemical herbicides can be an effective tool in controlling weeds in wheat, (2) to compare traditional vs. herbicide methods of weed control and their effects on yield, (3) to screen the available herbicides as to their spectrum of weed control and optimum dose and, (4) determine the economics of traditional and herbicide weed control methods.

Materials and Methods

The location of the demonstration was on the On-Farm Water Management demonstration farm near Niaz Beg. Wheat (var. Chenab-76) was planted on November 9, 1978. A fertilizer application of 70 lbs N/A, 100 lbs P_2O_5/A was made

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1/Associate Professor, Department of Agronomy, Colorado State University; Soil Scientist, CSU Field Party, Pakistan; Deputy Director, On-Farm Water Management, Pakistan; Agronomist, On-Farm Water Management, Pakistan.

before planting and an additional 70 lbs N/A was applied before the second irrigation. Urea and diammonium phosphate were the fertilizer materials used. The first irrigation was applied on November 30. The plots received 3 irrigations this year. The demonstration was established in a field that already had borders pulled. Each border varied from 58 feet to 94 feet wide by 532 feet long. Since it is desired to have the entire area under the demonstration, plot width varied from 14.5 feet to 20.25 feet by 532 feet long, which occupied the entire border. Plot size varied from 0.07 - 0.1 ha. A randomized block experimental design was used with three replications. Weed counts, number and species, were made before spraying, 30 days after spraying (January 28), and at harvest (April 4). Weed counts at 30 days after spraying and at harvest were taken in the same one meter square location in each treatment. Three locations per treatment were counted.

Three herbicides were used at two rates of application. Chlorotoluron 60 WP at 2.23 and 2.77 lb material/A, Decamba 40.6% EC at 0.25 and 0.31 lb material/A and Methabenythiayuron 70% WP at 1.78 and 2.00 lb material/A. Three traditional treatments were one weeding with a bullock drawn bar harrow, one hand weeding using a khurpa and no weed control. The herbicides were applied with a back pack sprayer at the 3-6 leaf stage of wheat development in about 30 gal H_2O/A. Costs of labor and materials for all treatments were kept in order to determine the return on the various treatments. Yield samples were hand harvested from three subplots per treatment 2 sq. m. in size. These subplot sample yields were averaged to determine acre yields.

Results and Discussion

Weed Population

The major weed in wheat in the irrigated area of Pakistan is Falaris minor. Chlorotoluron, at both rates of application, gave excellent control of the weed (Table 1). Decamba gave very little control at the 0.25 lb/A application rate. Its performance increased slightly at the 0.31 rate. Methabenythioyuron gave good control also, but not as good as Chlorotoluron. Hand weeding with a khurpa resulted in a reduced weed population much less than bar harrowing. The % control compared to the check treatment for all weed species ranged from 43 to 98% at the first count to 39 to 97% at harvest. Chloroloturon at both rates of application consistantly showed the best weed control, ranging from 97 - 98%. Methabenythioyuron also performed very well on all species of weeds with 83 - 88% control. The weed control with Decamba was much lower, ranging from 39 - 43%. This is in the same range, or slightly less, than was obtained with one bar harrow treatment. It was surprising that bar harrowing gave about 50% control. Observations during the observation did not indicate bar harrowing was killing that many weeds. The weed counts of 377 - 412 weeds/m^2 in the weedy check show the enormous weed infestations that occur in wheat. It is obvious that some weed control practices need to be incorporated into every farmer's production practices.

Yields

The differences in yields of the various weed control methods were substantial. The weedy check treatment yielded 25.8 md/A while the lower rate of Chlorotoluron treatment yielded 43.3 md/A, 68% more than the check. The differences in yield between the two Chlorotoluron treatments and the higher rate of Methabenythioyuron were not statistically significant. It was observed during threshing that there was a large mound of weed seeds present in the Decamba treatment plots. It is estimated that weeds accounted for about 20% of the total weight of the sample but no correction in the yield data is made. This observation should be kept in mind when one evaluates the results.

The yields from the hand hoeing and bar harrow weed control methods are not as high as would be expected based on the weed counts. The weed counts (Table 1) were twice as high in the bar harrow treatment but the yields were not significantly different (Table 2). The hand hoeing treatment was not significantly different from the weedy check. Evidently, the wheat plants were damaged enough using these two methods that yields are reduced.

Costs and Returns

The herbicide costs ranged from 5.9 to 71.3 Rs/A (Table 3) with Chlorotoluron being the most costly. Decamba was much less expensive than the other two herbicides. The total cost of each weed control method was estimated, it varied from 24 to 101 Rs/A. The important consideration is return above the treatment costs. These are presented in Table 4. The official procurement price of wheat of Rs. 45/md was used to calculate returns. Gross returns varied from 1119 to 1956 Rs./A with Chlorotoluron at the lower rate giving the highest and no weed control the lowest. The net return also followed the same relationship. The net return from Chlorotoluron at 2.23 lb/A was over Rs. 200/A higher than any other herbicide. Returns compared to the three traditional methods of weed control are also shown. It is obvious that any of the three herbicides gives much higher returns than do the traditional weed control methods.

Summary

A weed control demonstration was conducted using three herbicides at two rates each and three traditional methods

Table 1. Weed populations as influenced by the various weed control methods.

Treatment	Application Rate (lb/A)	Weed Counts: 30 Days After Spraying **FM	Ca	Cl	Md	O	Total	Control compared to check	Before Harvest Fm	Ca	Cl	Md	O	Total	Control Compared to check
		--weeds/m^2--						%	--weeds/m^2--						%
Chlorotoluron	2.23	6	1	1	2	0	10	97.5	6	1	1	2	0	10	97.0
Chlorotoluron	2.77	4	2	0	1	1	8	98.0	8	1	1	1	0	11	97.0
Decamba	0.25	205	8	2	4	16	235	43.0	200	8	2	4	15	229	39.0
Decamba	C.31	197	6	2	3	19	237	43.0	193	6	3	3	16	221	41.0
Methabenythiayuron	1.78	35	10	3	2	14	64	84.5	34	9	4	2	15	64	83.0
Methabenythiayuron	2.00	31	8	3	2	5	49	88.0	30	9	3	2	8	52	86.0
Bar Harrow	Once	150	9	7	6	27	202	51.0	152	8	5	9	26	200	47.0
Hoeing	Once	52	9	7	6	25	99	76.0	52	9	6	6	25	98	74.0
Check	No weed Control	250	15	47	29	71	412	-	240	14	35	25	62	377	-

* The average weed counts over the entire experimental area on December 24 before weed control treatments were initiated were as follows: Falaris minor-70/m^2; Convolvulus arrensis-13/m^2 Chenopedium album-33/m^2; Medicago denticulate-5/m^2; All others-53/m^2.

**Fm=Falaris minor; Ca=Convolvulus arrensis; Cl=Chenopodium album; Md=Medicago denticulate; O=All others.

Table 2. The effect of chemical and traditional weed control methods on the yield of wheat.

Treatment	Application Rate (lb/A)	Yield (maunds/A)
Chlorotoluron 60 WP	2.23	43.3
Chlorotoluron 60 WP	2.77	40.1
Dicamba 40.6% EC	0.25	37.5
Decamba 40.6% EC	0.31	35.3
Methabenythioyuron 70% WP	1.78	35.6
Methabenythioyuron 70% WP	2.00	39.2
Bar Harrow	Once	31.7
Hoeing	Once	29.1
Check	No weed control	25.8

$L.S.D._{(0.05)} = 4.4$

$L.S.D._{(.01)} = 6.0$

Table 3. The cost of material and labor for each weed control treatment.

Treatment	Application Rate	Chemical Cost	Sprayer Cost (hired)	Labor Cost (hired)	Total Cost
	--lb/A--		----Rs/A----		
Chlorotoluron	2.23	57.0	10	20	87
Chlorotoluron	2.77	71.3	10	20	101
Decamba	0.25	5.9	10	20	36
Decamba	0.31	7.3	10	20	37
Methabenythioyuron	1.78	48.0	10	20	78
Methabenythioyuron	2.00	54.0	10	20	84
Bar Harrow	Once	0	0	24	24
Hoeing	Once	0	0	96	96
Check	No Weed Control	0	0	0	0

Table 4. Comparison of costs and returns of the chemical and conventional methods of weed control in wheat. Weed control costs only are considered.

Treatment (lb/A)	Treatment Cost	Gross Return	Net Return	Return compared to Bar Harrowing	Return compared to Hoeing	Return compared to no weed control
	Rs/A					
Chlorotoluron (2.23)	87	1956	1869	461	650	750
Chlorotoluron (2.77)	101	1812	1711	303	492	592
Decamba (0.25)	36	1692	1654	248	437	537
Decamba (0.31)	37	1597	1560	152	341	441
Methabenythioyuron (1.78)	78	1609	1531	123	312	412
Methabenythioyuron (2.00)	84	1770	1686	278	467	567
Bar Harrow	24	1432	1408	–	189	189
Hoeing	96	1315	1219	189 (loss)	–	100
Check	0	1119	1119	289 (loss)	100 (loss)	–

of weed control. Excellent weed control was achieved with Chlororoluron which averaged about 97%. Methabenythiayuron gave 83 - 86% weed control while Decamba's control was 39 - 43%. Hand hoeing weed control ranged from 74 - 76¢ while bar harrowing ranged from 47 - 50%.

The highest yield of 43.3 mds/A was obtained with Chlorotoluron 60 WP at an application rate of 2.23 lb material/A. The yield from the weedy check treatment was 25.8 md/A. This treatment yield was not statistically different than the other Chlorotoluron treatment of 2.77 lb/A or the Methabenythiayuron treatment of 2.0 lb/A.

The greatest net return was also received by the same three treatments. The net return was calculated using only the cost of the weed control treatment. It was Rs. 1869/A for Chlorotoluron at 2.23 lb/A and only 1119 Rs./A when no weed control measures were taken. This is a Rs. 750/A increase in return from Chlorotoluron compared to no weed control. When the returns were compared to hand hoeing or bar harrowing they were Rs. 650 and Rs. 401/A, respectively, for the same Chlorotoluron treatment.

These results point out the potential of herbicidal weed control in wheat. Additional field screening of potential new herbicides needs to be continued and the ones that have completed evaluation should be approved for use. There is no question as to the favorable economic relationship of chemical weed control if it is used properly. Farmers need to be educated in the practice. A great potential exists for increased production of wheat if weeds are controlled properly. As has been learned in other countries, this can only be achieved with the use of herbicides.

APPENDIX 25

THE EFFECT OF CHEMICAL AND TRADITIONAL WEED CONTROL METHODS ON THE YIELD OF WHEAT AT TUBEWELL-56 AND THE PHULARWAN FARM

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INTRODUCTION

Wheat is a very important crop and is grown on about one-third of the total cultivated area in Pakistan. Autarky in food grains depends largely on the acceptance and implementation of modern agricultural technology by the growers in the form best suited to the local conditions. Combination of factors such as better seed, proper fertilization, optimum irrigation, insect pest and weed control are the key to higher yields. Among all factors, weed control is one of the most serious factors limiting high yields. Weed infestations in wheat fields are increasing every year because of ineffective traditional weed control measures due to lack of labor and lack of recognizing the need of weed control. Weeds like Falaris minor and Convolvul-us arrensis are the major problem weeds and compete with the wheat plant for moisture, nutrients, space and sunlight. Their heavy infestations result in reduction in yields.

Weed control with chemical herbicide is an efficient and economical method in cash and cereal crops. Its effectiveness has been demonstrated in many countries. It has a great potential in Pakistan and much more research and extension activity should be directed into this area.

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 wheat as compared to conventional methods, (2) to determine the efficacy and selectivity of several herbicides, and (3) to determine the potential economics of herbicide use.

MATERIALS AND METHODS

This demonstration was laid out on the Phularwan farm and TW-56 in the Mona Reclamation Experimental Project area. Wheat (Tricicum-aestivum) cultivar Yacora was planted in

1/ Soil Scientist, CSU Field Party, Assistant Agronomist, SRO Agronomy (Presently Extension), SRO Agronomy and Agronomist CSU Field Party, respectively.

lines on November 19-20, 1978. A seed rate of one maund (92.5 lb) and a fertilizer dose of 125 lbs. N, 114 lbs. P_2O_5, and 30 lbs. K_2O per acre were used. All of the P and K with 1/2 of nitrogen was applied before planting while the rest of nitrogen was applied with the second irrigation. A total of four irrigations were given to the wheat crop this year. A randomized block experimental design was used with three replications. Weed counts were made four times during the season. First counting was made before post-emergence spray on December 31 at TW-56 and January 5 at Phularwan the second two weeks after post-emergence spray. The third weed counts were made about one month after spray, and the last counts at harvest time. Weeds were differentiated into broad leaf and narrow leaf at the Phularwan farm only. However, Chenopodium album, Culvolvulus arrensis, and Medicago denticulate were the main weeds in both fields. All the four weed counts were taken in 0.42 meter square area in each treatment. Three random locations per treatment were counted.

Five different herbicides were used at varying rates of application. The combination of two herbicides, i.e. flamprop-methyl plus methabenythiayuron 70% WP, as a post-emergence spray was recommended for testing for methabenythiayuron was not available for the Phularwan farm location, therefore flamprop-methyl 60 WP was used in its place. By this time the weeds were 8 inches high, whereas all other herbicides were applied with a back pack sprayer at the 3-6 leaf stage of wheat development. Two traditional treatments were employed: (1) one hand weeding using khurpa and (2) no weed control. All the treatments used are shown in Table 1. Unless indicated otherwise, the rates are lbs. of material/A. Pre and post indicates material was applied pre-emergence or post-emergence of weeds. Cost of labor and material for all treatments were determined, in order to calculate the return on the various treatments. An area of 17.3 meter square was harvested from each plot and hand threshed.

RESULTS AND DISCUSSION

Weed Population: Phularwan Farm

The weed control ratings are relative to the no weed control treatment. Chlorotoluron applied post-emergence at both rates (Table 1) gave excellent control of the weed; i.e., 82-85% two weeks and one month after application. The effect lasted all season because the control was from 86-93% at harvest. Methabenythiayuron performed similar to Chlorotoluron. Increasing the rate above 1.8 lb/A did not increase weed control. Decamba is the only registered chemical of the five herbicides tested. It gave good weed control. The weed control shown by chlorotoluron was not as good as the other

Table 1. Weed count population as influenced by the various weed control methods at Phularwan Farm.

Treatment	Rate (kg/ha)	Before spraying		15 Days after spray			One month after spray			At harvest		
		B.L.[1]	N.L.[2]	B.L.	N.L.	Control %	B.L.	N.L.	Control %	B.L.	N.L.	Control %
Flamprop-methyl post	0.50 a.i	34	7	43	37	27	44	39	18	28	17	36
Flamprop-methyl post	0.75 a.i	56	14	78	18	13	64	28	9	41	11	26
Clorotoluron post	2.50	53	12	12	7	83	11	7	82	4	3	86
Clorotoluron post	3.00	119	5	13	6	83	11	4	85	2	3	93
Lenuron pre	1.00	27	8	16	8	78	14	9	77	22	4	63
Lenuron pre	1.50	33	17	36	27	43	22	27	51	25	4	59
Lenuron post	0.80	91	11	14	4	84	13	4	83	3	2	93
Lenuron post	1.30	39	9	6	4	91	12	5	83	1	0	99
Decamba post	0.28	118	12	45	18	43	40	23	38	0	3	96
Decamba	0.42	59	4	32	10	62	25	17	58	6	3	87
Methabenythioyuron	2.40	50	15	23	3	76	20	4	76	4	1	93
Methabenythioyuron	1.80	34	10	9	2	90	7	3	90	3	0	96
Methabenythioyuron	2.40	87	8	18	8	76	25	9	66	9	4	81
Methabenythioyuron	3.00	98	17	16	5	81	26	9	65	3	2	93
Flamprep-methyl pre + Chloroloturan post[3]	0.50 a.i 2.40	29	13	36	16	53	35	17	49	1	2	96
Flamprep-methyl pre + Chloroloturan post[3]	0.75 a.i 3.00	37	13	63	19	25	46	18	37	2	0	97
Flamprep-methyl pre + Chloroloturan post[3]	0.50 3.00	36	6	54	10	42	46	13	42	2	1	96
Normal weed control		46	15	56	18	33	47	24	30	47	17	9
No weed control		63	18	93	17	-	80	21	-	57	13	-

1. Broad leaf.
2. Narrow leaf.
3. Applied when weeds were 6-8 inches high.

chemicals. It is recommended for control of wild oats (Avena sp.) and most of the weeds present were not of this species. As far as observations in the field are concerned, decamba was a slow acting herbicide. Most of the weeds were not immediately eradicated. Convolvulus arrensis was not affected and Chenopodium album showed only slight symptoms of wilting 3 days after application. Weed control ratings one month after spraying showed 38-58% control but at harvest, the plots were essentially free (87-96% control). Linuron showed phytotoxic effects both at pre-emergence and post-emergence stage. Along with the weed, many wheat plants were also killed and those that survived became pale and showed stunted growth. Phytotoxicity was particularly severe under the high rate of Linuron application. Chlorotoluron pre-emergence plus flamprop-methyl post-emergence gave 96-97% control at all rates. The Chlorotoluron in the combinations was applied in February and controlled six inch high weeds. This increased the weed control from about 40% on February 5 to about 96% at harvest. The normal weed control treatment included on manual hoeing with khurpa which always gave much less weed control (9% at harvest) as compared to the herbicides.

Weed Population: Tubewell-56

The post-emergence spray of Linuron, Chlorotoluron and methabenythiayuron, with lower rates of application resulted in a weed control of 97%, 89% and 74%, respectively (Table 2). Pre-emergence application of flamprop-methyl and Linuron did not give better performance. Weed population was almost the same as in other plots, counted before post-emergence spray (December 31, 1979). Decamba, with its lower application rate (0.25 lbs material/AO) approached 61% weed control as compared to check. Hoeing once with khurpa eradicated only 21% of the weeds at this time. These weeds competed for space, nutrients, moisture, and sunlight with crop plants throughout the growing season. Chenopodium album and Convolvulus arrensis were similar in height to wheat plants at the time of the last irrigation. At harvest, the best weed control was obtained with treatments that included flamprop-methyl and methabenythioyuron. Linuron gave good weed control but was also very toxic to the wheat.

Yields: Phularwan Farm

Wheat yield as affected by chemical and traditional weed control methods was shown in Table 3. Chlorotoluron at 2-4 and 6-8 leaf stage application gave outstanding yield as compared to all other treatments. They were significantly higher than the weedy check and normal weed control treatments. Weedy check treatment yielded 27.10 maunds/A while chlorotoluron at its lower rate yielded 37.75 maunds/A, 39% more than the check. Flamprop-methyl gave a yield of 27.48 maunds/A with lower dose of application and there

Table 2. Weed count population as influenced by the various weed control methods at Tubewell-56

Treatment	Rate (kg/ha)	Weed Counts: Before Spraying Counts	One Month After Spraying Counts	One Month After Spraying Control Compared to Check	Before Harvest Counts	Before Harvest Control Compared to Check
		--No. of Weeds--		%	No. Weeds	%
Flamprep-methyl post	0.50 a.i.	88	57	19	39	34
Flamprep-methyl	0.75 a.i.	70	53	24	40	32
Chlorotoluron post	2.50	112	8	89	2	97
Chlorotoluran	3.00	141	10	86	8	86
Lenuron pre	1.00	54	25	64	0	100
Lenuron pre	1.50	55	19	73	11	81
Lenuron post	0.80	143	2	97	0	100
Lenuron post	1.30	64	3	96	0	100
Decamba post	0.28	76	27	61	14	76
Decamba	0.42	66	31	56	10	83
Methabenythioyuron	2.40	65	11	84	0	100
Methabenythioyuron	1.80	99	18	74	5	92
Methabenythioyuron	2.40	111	44	37	25	58
Methabenythioyuron	3.00	46	30	57	9	85
Flamprep-methyl pre + Chloroloturan post[3]	0.50 a.i. 2.40	81	24	66	27	54
Flamprep-methyl pre + Chloroloturan post[3]	3.75 a.i. 3.00	77	21	70	4	93
Flamprep-methyl pre + Chloroloturan post[3]	0.50 a.i. 3.00	83	30	57	0	100
Normal Weed Control		102	55	21	40	32
No Weed Control		106	70	-	57	-

Table 3. The effect of chemical and traditional weed control methods on wheat yield at the Phularwan Farm

Treatment	Weed Height (inches) at Spray Time	Application Rate (lbs./A)	Yields (maunds/A)
Flamprep-methyl post	2-3	2.97	27.5
Flamprep-methyl	2-3	4.45	32.3
Chlorotoluron post	2-3	2.23	37.8
Chlorotoluran	2-3	2.67	37.4
Lenuron pre	pre-emergence	0.89	19.3
Lenuron pre	pre-emergence	1.34	20.6
Lenuron post	2-3	0.71	17.8
Lenuron post	2-3	1.16	36.7
Decamba post	2-3	0.25	25.8
Decamba	2-3	0.37	30.1
Methabenythioyuron	2-3	2.14	29.2
Methabenythioyuron	2-3	1.60	34.9
Methabenythioyuron	2-3	2.14	29.2
Methabenythioyuron	2-3	2.67	32.6
Flamprep-methyl pre + Chloroloturan post[3]	pre-emergence 6-8	(2.97 ((2.14	34.9
Flamprep-methyl pre + Chloroloturan post[3]	pre-emergence 6-8	(4.45 ((2.67	33.7
Flamprep-methyl pre + Chloroloturan post[3]	pre-emergence 6-8	(2.97 ((2.67	33.8
Normal Weed Control	2-4	Hoeing Once	31.0
No Weed Control	(Check)	-	27.1

L.S.D. (.05) = 5.6 md/a
L.S.D. (.01) = 7.5 md/a
C.U. = 11.4%

was no substantial increase with higher rate (32.3 maunds/A). Linuron application reduced yields by 32-41%. It was most probably due to its phytotoxic effects. Decamba treatments yielded 25.82 and 30.10 maunds/A with an application of 0.25 and 0.37 lbs. material/A, respectively. Among all the methabenythioyuron application rates a maximum yield of 34.94 maunds/A was received with 1.60 Kg/A which was 29% more as compared to weedy check treatment. Normal weed control yielded 31.05 maunds/A which was not too bad if labor is available. But as far as observations in the field were concerned, most of the weeds, quite adjacent to wheat plants were still standing after the hoeing operation. This also resulted in seed multiplication and continued infestation.

Yields: Tubewell-56

The effect of chemical and traditional weed control methods on wheat yield is described in Table 4.

Chemical weed control always gave higher yields as compared to local weed control methods. Most were significantly higher. A maximum yield of 33.09 maunds/A was received from a chemical treatment of flamprop-methyl at the rate of 2.97 lbs/A (pre-emergence) and methabenythiayuron at the rate of 2.14 lbs/A (post emergence). A yield of 18.24 maunds/A was obtained from normal weed control treatments. Under single chemical treatments methabenythioyuron at the rate of 2.14 lbs/A was observed to be the best, yielding 31.76 maunds/A, 74.12% more than normal weed control. Pre-emergence application of Linuron observed phytotoxic to wheat plants. Wheat plants showed symptoms as thin stem, pale-yellow color, and stunted growth. Under these treatments, seed germination was poor. However, plants recovered after the second irrigation. Higher doses of Decamba (0.37 lbs/A) gave 70% more yield than check treatments.

Costs and Returns: Phularwan Farm

The herbicide costs ranged from 6 to 96 Rs/A (Table 6) at both locations. Among all the herbicides, flamprop-methyl was found to be the most costly. On the other hand, if combined costs of flamprop-methyl and chlorotoluron were added up, it exceeded Rs. 165/A. However, single treatments which were commonly recommended should be considered. The returns above the treatment costs are presented in Table 6. Gross returns varied from 806 to 1705 Rs/A, with chlorotoluron at the lower rate giving the highest and the linuron treatment (0.71 kg/A) the lowest. Similarly, net return followed the same trend. Return received from chlorotoluron treatment compared with normal weed control benefited Rs. 311. Methabenythioyuron was the other second herbicide which returned 280 and 144 Rs/A at 1.60 and 2.67 Kg material/A, respectively. Linuron produced negative returns due to its toxicity to the wheat crop.

Table 4. The effect of chemical and traditional weed control methods on wheat yield at Tubewell-56

Treatment	Application Rate (lbs/A)	Yield (maunds/A)
Flamprep-methyl post	2.97	27.5
Flamprep-methyl	4.45	26.6
Chlorotoluron post	2.23	23.7
Chlorotoluran	2.67	18.9
Lenuron pre	0.89	26.7
Lenuron pre	1.34	24.0
Lenuron post	0.71	19.1
Lenuron post	1.16	26.8
Decamba post	0.25	23.3
Decamba	0.37	25.5
Methabenythioyuron	2.14	21.9
Methabenythioyuron	1.60	22.8
Methabenythioyuron	2.14	31.8
Methabenythioyuron	2.67	26.5
Flamprep-methyl pre + Chloroloturan post[3]	(2.97 ((2.14	33.1
Flamprep-methyl pre + Chloroloturan post[3]	(4.45 ((2.67	29.1
Flamprep-methyl pre + Chloroloturan post[3]	(2.97 ((2.67	26.5
Normal Weed Control	Once	18.2
No Weed Control	-	15.0

L.S.D. (.05) = 5.4 md/a
L.S.D. (.01) = 7.3 md/a
C.U. = 13.9%

Table 5. The cost of material and labor for each weed control treatment at Phularwan Farm and Tubewell-56

Treatment	Application Rate	Chemical Cost	Sprayer Cost (hired)	Labor Cost	Total
	---lb/A---	---------------------	---------Rs./A---------	---------------------	
Flamprep-methyl post	2.97	64	10	20	94
Flamprep-methyl	4.45	96	10	20	126
Chlorotoluron post	2.23	58	10	20	88
Chlorotoluran	2.67	69	10	20	99
Lenuron pre	0.89	19	10	20	49
Lenuron pre	1.34	29	10	20	59
Lenuron post	0.71	15	10	20	45
Lenuron post	1.16	25	10	20	55
Decamba post	0.25	6	10	20	36
Decamba	0.37	9	10	20	39
Methabenythioyuron	2.14	58	10	20	88
Methabenythioyuron	1.60	44	10	20	74
Methabenythioyuron	2.14	58	10	20	88
Methabenythioyuron	2.67	73	10	20	103
Flamprep-methyl pre	2.97	64			
+			20	40	168
Chloroloturan post[3]	2.14	44			
Flamprep-methyl pre	4.45	96			
+			20	40	225
Chloroloturan post[3]	2.67	69			
Flamprep-methyl pre	2.97	64			
+			20	40	163
Chloroloturan post[3]	2.67	69			
Normal Weed Control	-	-	-	96	96
No Weed Control	(check)	-	-	-	-

Table 6. Comparison of costs and returns of the chemical and conventional methods of weed control at Phularwan Farm. Weed control costs only are considered.

Treatment (lb/A)	Rate (lbs/A)	Treatment Cost	Gross Return	Net Return	Return Compared to Normal Weed Control	Return Compared to No Weed Control
		Rs/A				
Flamprep-methyl post	2.97	94	1241	1147	(-)159	(-) 77
Flamprep-methyl	4.45	126	1460	1334	(+) 28	(+)110
Chlorotoluron post	2.23	88	1705	1617	(+)311	(+)393
Chlorotoluran	2.67	99	1688	1589	(+)283	(+)365
Lenuron pre	0.89	49	870	821	(-)485	(-)403
Lenuron pre	1.34	59	930	871	(-)435	(-)353
Lenuron post	0.71	45	806	761	(-)545	(-)463
Lenuron post	1.16	55	1659	1604	(+)298	(+)380
Decamba post	0.25	36	1166	1130	(-)176	(-) 94
Decamba	0.37	39	1359	1320	(+) 14	(+) 96
Methabenythioyuron	2.14	88	1319	1231	(-) 75	(+) 7
Methabenythioyuron	1.60	74	1578	1504	(+)198	(+)280
Methabenythioyuron	2.14	88	1319	1231	(-) 75	(+) 7
Methabenythioyuron	2.67	103	1471	1368	(+) 62	(+)144
Flamprep-methyl pre + Chloroloturan post[3]	2.97 2.14	168	1578	1410	(+)104	(+)186
Flamprep-methyl pre + Chloroloturan post[3]	4.45 2.67	225	1520	1295	(-) 11	(+) 71
Flamprep-methyl pre + Chloroloturan post[3]	2.97 2.67	163	1526	1363	(+) 57	(+)139
Normal Weed Control	-	96	1402	1306	-	(+) 82
No Weed Control	(check)	-	1224	1224	(-) 82	-

Costs and Returns: Tubewell-56

The cost of each treatment varies with each chemical and manual weed control method (Table 7). Application of two herbicides (pre- and post-emergence) incurred maximum costs (Rs. 225/A). Hoeing once with khurpa cost Rs. 96 per acre, which was more than chemical (lower dose) application costs. The minimum cost (Rs. 39/A) incurred with decamba application while comparing return on chemical with normal weed control, a return of Rs. 618, Rs. 419, Rs. 287, and Rs. 256 was obtained for methabenythioyuron, flamprop-methyl, decamba, and chlorotoluron with lower rates, respectively. A combined treatment of the first two at lower rates gave a return of Rs. 599/A compared with normal weed control but other such treatments with higher rates of methabenuthioyuron did not exhibit better results. Similarly, when the various weed control methods were compared with no weed control, a return of Rs. 669, Rs. 650, Rs. 470, Rs. 338, and Rs. 307 was received for methabenythioyuron, flamprop-methyl + methabenythiayuron, flamprep-methyl, decamba and chlorotoluron, respectively. Linuron also resulted in a reliable net return but because of its phytotoxic effects it is difficult to recommend this herbicide for farmers fields.

Summary: Phularwan Farm

Weed control demonstrations were conducted using different herbicides with varying rates as single treatments, in combination, pre-emergence and post-emergence application. Excellent weed control was achieved with chlorotoluron 60 WP and methabenythioyuron 70% WP. Chlorotoluron gave 82% and, methabenythioyuron controlled 90% weeds with lower rates of application. Decamba's control was 38% and flamprop-methyl eradicated 18% weeds as compared to check at lower herbicidal doses.

The highest yield of 37.75 maunds/A was obtained with chlorotoluron at an application rate of 2.23 Kg material/A. This is not statistically different from other chloroloturan's. The second highest yield was received with methabenythioron at the rate of 1.60 Kg material/A. Combination of flamprop-methyl and chlorotoluron gave an average yield of 34.37 and 34.15 maunds/A which were much less as compared to chlorotoluro along, when total chemical costs were compared. Linuron used as pre-emergence and post-emergence showed 26% and 34% decrease in yield as compared to no weed control treatment.

These results revealed that chlorotoluron WP at the rate of 2.23 Kg/A as single treatment is the best weed control chemical. Methabenyathioyuron WP is another herbicide with better weed control efficiency. Linuron causes toxicity to plants at both application times. Perhaps its further lower application rates might be suitable for reliable weed control

Table 7. Comparison of costs and returns of the chemical and conventional methods of weed control at Tubewell-56. Costs of weed control only are considered.

Treatment	Rate (lbs/A)	Treatment Cost	Gross Return	Net Return	Return Compared to Normal Weed Control	Return Compared to Normal Weed Control
		Rs/A				
Flamprep-methyl post	2.97	94	1241	1147	419	470
Flamprep-methyl	4.45	126	1201	1075	347	398
Chlorotoluron post	2.23	88	1072	984	256	307
Chlorotoluran	2.67	99	853	754	26	77
Lenuron pre	0.89	49	1207	1158	430	481
Lenuron pre	1.34	59	1086	1027	299	350
Lenuron post	0.71	45	864	819	91	142
Lenuron post	1.16	55	1213	1158	430	481
Decamba post	0.25	36	1051	1015	287	338
Decamba	0.37	39	1152	1113	385	436
Methabenythioyuron	2.14	88	988	900	172	223
Methabenythioyuron	1.60	74	1028	954	226	277
Methabenythioyuron	2.14	88	1434	1346	618	669
Methabenythioyuron	2.67	103	1195	1092	364	415
Flamprep-methyl pre + Chloroloturan post[3]	2.97 / 2.14	168	1495	1327	599	650
Flamprep-methyl pre + Chloroloturan post[3]	4.45 / 2.67	225	1316	1091	363	414
Flamprep-methyl pre + Chloroloturan post[3]	2.97 / 2.67	163	1195	1032	304	355
Normal Weed Control	Once	96	824	728	-	51
No Weed Control	-	-	677	677	(-)51	-

Summary: Tubewell-56

Chemical and traditional weed control methods were compared on a field demonstration. Five different herbicides were also compared with one another in relation to their efficacy on weed control in wheat. A weed control of 97%, 89%, 74%, 61%, and 21% was recorded with methabenythiayuron WP, Decamba, and normal weed control, respectively. Similarly, an increase in wheat yield of 81%, 74%, 40%, and 30% was obtained with flamprop-methyl + methabenythioyuron, methabenythioyuron, decamba and chlorotoluron than normal weeding, respectively.

Application of lenuron as pre- and post-emergence did not give statistically different results. This herbicide was also found phytotoxic to wheat plants.

The total cost incurred by different herbicides (lower rates) was less than the traditional weed control method. Return compared with normal weed control was Rs. 618, Rs. 599, Rs. 419, and Rs. 385 with methabenythioyuron, flamprop-methyl + methabenythioyuron, flamprep-methyl and decamba, respectively. Single post-emergence spray of chlorotoluron or methabenythioyuron observed the best chemical weed control measure in wheat. Lenuron application at 2-4 wheat leaf stage was found useful rather at pre-emergence stages.

CONCLUSIONS

Several herbicides were investigated for their potential use on weed control in wheat. Very good yield increases were obtained from several of the materials. The return over treatment costs, compared to no weed control, were as high as Rs. 669/A under heavy weed infestations. Compared to the normal weed control practice that is followed by only a small percentage of the farmer, the return was as high as Rs. 618/A. These results show that weed control with chemical herbicides is very profitable. Additional effort should be extended to insure that more chemical herbicides are cleared and approved for use by the farmers. Farmer education will have to be imparted before most farmers can use herbicides. This is a large undertaking but the potential rewards of increased production are great and undoubtedly worthwhile.

APPENDIX 26

ECONOMIC ANALYSIS OF THE RESPONSE OF WHEAT TO WATER, NITROGEN AND PHOSPHORUS

Bashir Sadir, John Reuss and Mohammed Iqbal[1]

I. INTRODUCTION

While many water x fertilizer interactions experiments have been conducted in Pakistan, most experimental designs do not allow for the evaluation of the response surface over a complete range of three factors. The work reported here represents an attempt to evaluate the response of wheat over a wide range of rates of the three factors; water, nitrogen and phosphorus, in a manner amenable to a rigorous economic analysis.

Another unusual feature of this experiment is the method used to determine water applications to the individual irrigation treatments. Common methods used are either to apply water according to a fixed irrigation schedule or to determine soil water deficits through direct analysis. The first method usually does not adequately track plant water requirements, while the second is generally not applicable in a farm context, particularly in Pakistan. In this experiment soil water deficits were estimated using historical potential evapotranspiration (E_{tp}) rates, modified by appropriate crop coefficients, to determine actual evapotranspiration (E_{ta}). A fixed percentage of the E_{ta} was supplied by irrigation after correcting for rainfall.

II. EXPERIMENTAL PROCEDURE

The design utilized was an incomplete factorial with five levels of each factor as shown in Table II.1. The levels of nitrogen and phosphorus are in kg/ha of N and P_2O_5, applied prior to planting. The levels of water are more complex, and represent the percentage of soil water deficit that was to be replaced. As the emphasis of our analysis is on the aggregate usage, only a brief description of the method of determining irrigation time and amount will be included. First a 7.5 cm application was given to all treatments about 3 weeks after emergence. The daily theoretical water use was calculated for the season based on historical potential

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Table II.1 Design levels of water nitrogen and phosphorus used in the incomplete factorial.

Level	Water %E_{ta}	Nitrogen kg N/ha	Phosphorus kg P_2O_5/ha
1	40	0	0
2	70	56	45
3	100	112	90
4	130	168	135
5	160	224	180

Table II.2 Treatment combinations showing levels of each factor used for each of the 35 treatments.

	Factor					Factor			
Treatment	Plot	Water	N	P	Treatment	Plot	Water	N	P
1	1A	1	1	1	19	7A	5	1	1
2	1B	1	1	3	20	7B	5	1	3
3	1B	1	1	5	21	7C	5	1	5
4	2A	1	3	1	22	8A	5	3	1
5	2B	1	3	3	23	8B	5	3	3
6	2C	1	3	5	24	8C	5	3	5
7	3A	1	5	1	25	9A	5	5	1
8	3B	1	5	3	26	9B	5	5	3
9	3C	1	5	5	27	9C	5	5	5
10	4A	3	1	1	28	10A	2	2	2
11	4B	3	1	3	29	10B	2	2	4
12	4C	3	1	5	30	11A	4	2	2
13	5A	3	3	1	31	11B	4	2	4
14	5B	3	3	3	32	12A	2	2	2
15	5C	3	3	5	33	12B	2	2	4
16	6A	3	5	1	34	13A	4	4	2
17	6B	3	5	3	35	13B	4	4	4
18	6C	3	5	5					

evapotranspiration rates and appropriate crop coefficients. This use was then accumulated over time and soil moisture deficit calculated by subtracting current rainfall. This deficit was then multiplied by the percentage appropriate to the treatment (Table II.1) to calculate the amount of application needed. When this amount exceeded the amount to be applied at a single application (7.5 cm), irrigation was applied.

Treatment number and the associated levels of each factor are shown in Table II.2. In this design the three dimensional "treatment space" is covered by a total of 35 treatments rather than the 125 that would have been required for a complete factorial with 5 levels and 3 factors (5^3). The "spatial" arrangement of the treatments is shown in Fig. II.1.

The field layout consisted of 13 main plots representing the 13 combinations of water and nitrogen, with each main plot split with phosphorus levels. Note that this sults in each main plot of treatments 1-27 being split into 3 subplots while treatments 28-35 are split into two subplots. The 13 main plots were laid out in a randomized block design with three replications and the subplots were randomly located within the main plots. Main plots were 3.66 x 29.26 m. Subplots were 3.66 x 9.75 m for treatments 1-27 and 3.66 x 14.63 m for treatments 28-35. Trials were conducted in the Mona Reclamation Experimental Project (MREP) area near Tubewell Mn 11. Water table depths ranged from 2.75 to 3.25 m over the cropping season. The variety used was Vacora.

Statistical Analysis

Treatments 1-27 comprise a 3^3 factorial with N and W as the main plots which were split with levels of phosphorus. Thus, these treatments can be subjected to the usual analysis of variance with three levels of two factorial (W and N) in main plots, each split with three levels of the third factor (P). Treatments 28-35 can be analyzed separately as a 2^3 factorial, with main plots of 2 factors each at two levels, each main plot being split with two levels of the third factor.

While these analyses are useful in themselves, the most useful feature of the trials is that they can easily be analyzed by multiple regression techniques to establish a response surface. These response surfaces are very useful in determining the most desirable combination of inputs from an economic standpoint.

Empirical regression models that mathematically describe a yield response surface in terms of the independent variables (water, nitrogen and phosphorus), are fit to the data using multiple regression techniques. The mathematical model that best fits the data is then used to determine the economic optimum combinations of inputs as described below. Goodness of fit is evaluated using the R^2 statistic and the

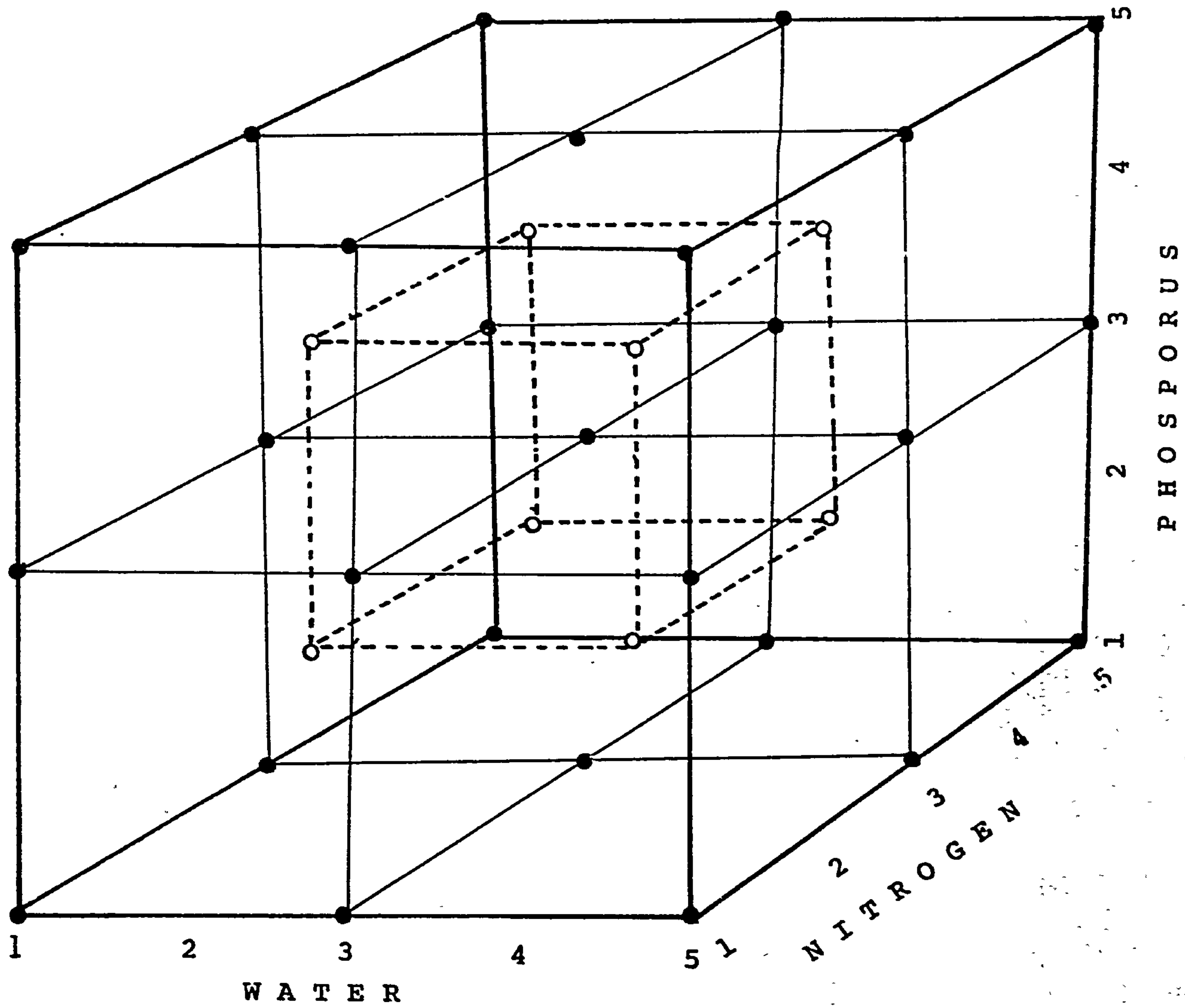


Figure II.1. Diagrom showing the relationship among treatment levels. The 27 black circles comprise a 3^3 factorial while the open circles comprise a 2^2 factorial.

standard errors of estimate. Models testnd for use with these data are shown in Table II.3.

Economic Analysis

Crop response to inputs such as water and fertilizer usually follow a pattern of diminishing returns such that successive increments of an input result in progressively smaller increments of output. As excessive levels of inputs are applied, a maximum output (yield) level may be exceeded and additional increments of the input may actually decrease output.

In a diminishing returns situation economic theory indicates that the optimum point of production occurs when the price received for a unit of output, times the output resulting from a small increment of input (marginal value product), is

Table II.3 Statistical regression models tested for fit on 1977-78 Mona wheat data.

1. $Y = b_0 + b_1N + b_2N^2 + b_3W + b_4W^2 + b_5P + b_6P^2 +$

$b_7NW + b_8NP + b_9WP$

2. $Y = b_0 + b_1N^{3/4} + b_2N^{3/2} + b_3W^{3/4} + b_4W^{3/2} + b_5P^{3/4}$

$+ b_6P^{3/2} + b_7N^{3/4}W^{3/4} + b_8N^{3/4}P^{3/4} + b_9W^{3/4}P^{3/4}$

3. $Y = b_0 + b_1N + b_2N^{1/2} + b_3W + b_4W^{1/2} + b_5P + b_6P^{1/2}$

$+ b_7NW + b_8NP + b_9WP$

4. $Y = b_0N^{b_1}W^{b_2}P^{b_3}$

Where N = Nitrogen, kg N/ha

W = Water applied, cm

P = Phosphorus, kg P_2O_5/ha

just equal to the cost of the increment of input. Mathematically this is expressed as,

$$P_Y \frac{dY}{dX} = C_X \qquad \text{(II.1)}$$

where

P_Y = price received;

$\frac{dY}{dX}$ = change in yield per unit of input X; and

C_X = cost of a unit of X

Where more than 1 input is involved the optimum combination of inputs must satisfy the relationship of II.1 above for all three inputs so that,

$$P_Y \frac{\partial Y}{\partial X_1} = C_{X_1} \qquad \text{(II.2a)}$$

$$P_Y \frac{\partial Y}{\partial X_2} = C_{X_2} \qquad \text{(b)}$$

$$P_Y = \frac{\partial Y}{\partial X} = C_{X_3} \qquad \text{(c)}$$

The method of solution of these equations depends on the model chosen and will be discussed in section III below.

III. RESULTS AND DISCUSSION

Water Application

The scheme of determining irrigation application described above does not result in exact application of the design percentage of E_{ta} - Rain. This arises due to the termination of irrigation when the crop is judged to have reached physiological maturity. At this point some treatments will have recently been irrigated, while others are relatively dry. The total amounts applied and the percentage achieved are shown in Table III.1. Total in season application varied from 7.62 cm to 54.58 cm. Rainfall was 8.61 cm and the pre-irrigation was 10 cm so that total water supply varied from

Table III.1 Irrigation water applied for each of the five treatment levels.

Irrigation Level	Percent Design %	E_{ta} - Rain Achieved* %	In Season Application cm	Total Supply** cm
1	40	41	7.62	26.23
2	70	82	23.90	42.51
3	100	100	30.81	49.42
4	130	139	46.23	64.84
5	160	160	54.58	73.19

* Percent of level 3.

** Includes 8.61 cm rainfall and 10 cm preirrigation.

Table III.2 Analysis of variance for treatments 1-27.

Source	df	Mean Square	F
Replications	2	18465	2123.11***
Nitrogen	2	46471083	90.46***
Water	2	1980080	8.87**
N x W	4	194254	
Error a	16	21888	
Phosphorus	2	123806	5.29**
P x N	4	27897	1.19
P x W	4	66171	2.83(10%)
P x N x W	8	54746	2.34*
Error b	36	23471	
Pooled error	52	22946	

Standard deviation 151.48 kg/ha

26.23 to 73.19 cm. This appears to give a satisfactory range of water application for economic evaluation of the water-fertilizer interaction.

Analysis of Variance

The analysis of variance for treatments 1-27 are shown in Table III.2 while the means for the principle significant effects are shown in III.3. By far the most important effect was that of nitrogen, with main effect mean yields of 1786, 3635, and 4322 kg/ha for the 0, 112, and 224 kg N/ha application, respectively. The next most important was water, with means of 2936, 3308, and 3419 kg/ha for the application of 26.23, 49.42, and 73.19 cm of water, respectively. A relatively small N x W interaction occurred due to a slightly higher N response at the two highest water levels as compared to the low water level, but major N responses occurred at all three water levels. A small main effect due to the application of phosphorus was noted with mean yields of 3175, 3260, and 3309 kg/ha for the 0, 89.6, and 179.2 kg P_2O_5/ha treatments, respectively.

The AOV and main effects for treatments 28-35 are shown in Table III.4. The general pattern is similar to that found for treatments 1-27; but significance levels are lower, due to both reduced degrees of freedom and reduced ranges of treatment levels. The F value for the main effect of P was higher than that for water but the water effect is greater in terms of kg/ha response. This difference in F value arises from the split plot design and the resultant lower variance for sub-plots.

Regression Analysis

The first step in the regression analysis is to select the general form of the regression model. Fit parameters for the four models shown in Section II are given in Table III.5. Selection among models 1, 2, and 3 is relatively straightforward as the error degrees of freedom are the same in all cases and the independent variable is not transformed for the regression analysis. Model 3 is obviously superior among these three. However, in the case of model 4, the regression analysis is actually performed on the logarithms of both dependent and independent variables, so that the R^2 values are not strictly comparable. A standard error of estimate (SEE) that is not affected by the transformation can be obtained by taking the sum of squares of (Predicted - Observed) and dividing by the error degrees of freedom. The SEE obtained in this way is shown in Table III.5, and as this is substantially larger than the SEE value for model 4, model 4 was selected as the general form for use in the economic analysis. However, only a very small phosphorus response was obtained (Tables III.3 and III.4) and from an examination of the "F" values associated with the dropping of individual terms

Table III.3 Principal significant effects, treatments 1-27.

Water cm	Nitrogen, kg/ha			Main effect (water)
	0	112	224	
26.23	1656	3238	3913	2936
49.42	1793	3800	4572	3388
73.19	1908	3867	4482	3419
Main effect (N)	1786	3635	4322	3248

Phosphorus kg P_2O_5/ha	Yield kg/ha
0	3175
89.6	3260
179.2	3309

Table III.4 Main effects and analysis of variance for treatments 28-25.

Source	df	Mean Square	F
Replication	2	6296	
Nitrogen	1	1284081	30.64**
Water	1	246844	5.89(10%)
N x W	2	46387	1.11 -
Error a	6	41906	
Phosphorus	1	131206	6.51*
P x N	2	19462	-
P x W	2	41265	2.05
P x N x W	1	69868	3.46(10%)
Error b	8	20164	

Main effects

Nitrogen (kg/ha)	Yield (kg/ha)
56	3290
168	3752
Water (cm)	
42.51	3419
64.84	3672
Phosphorus (kg P_2O_5/ha)	
89.6	3447
179.2	3592

Table III.5 Standard Errors of Estimate (SEE) and R^2 values for models 1-4, (Section II), as applied to Mona wheat data.

Model	df (error MS)	R^2	SEE
1	25	.949	263.3
2	25	.9643	220.3
3	25	.9714	197.2
4	31	.9782	226.0

it became obvious that it was unnecessary to retain all of the four terms associated with P in model 3. By successively dropping or including individual terms in the regression and examining the individual fit parameters, it was determined that the phosphorus effect could be best described by including one simple N x P term. This modification substantially reduced the complexity of the subsequent calculations, and was, therefore, adopted. The final model selected, which we will designate as model 3A, is therefore:

$$Y = b_0 + b_1N + b_2N^{1/2} + b_3W + b_4W^{1/2} + b_5NW + b_6NP \qquad \text{(III.1)}$$

The values of the coefficients and the fit parameters for Eq. III.1 were as follows:

b_0 = 777.67

b_1 = -3.1766

b_2 = 177.69 $\qquad R^2$ = .9702

b_3 = -42.531 $\qquad$ SEE = 190.3

b_4 = 678.50

b_5 = .024225

b_6 = .005145

It is often times useful to examine two dimensional response surfaces in the form of isoquant diagrams. Equation III.1 actually contains 3 independent variables: nitrogen, water, and phosphorus. The phosphorus response, however, is very small so we shall examine the form of the N and W response at the 89.6 kg P_2O_5/ha level of P. At any given level of P, Eq. III.1 can be written as:

$$Y = b_0 + b_1'N + b_2N^{1/2} + b_3W + b_4W^{1/2} + b_5NW \qquad \text{(III.2)}$$

where $b_1' = b_1 + b_6P$.

An isoquant diagram with independent variables N and W, is shown in Fig. III.1. This is prepared from Eq. III.2 with P held constant at 89.6 kg P_2O_5/ha. It is essentially a "contour map" of the yield as a function of the two inputs. Calculations for such diagrams are rather lengthy, but they can readily by accomplished using an electronic computer. The horizontal axis shows the N inputs, while the vertical axis shows the aggregate water input including rainfall and pre-irrigation. The curved lines are "isoquants" or lines of constant yield. The yield level associated with each isoquant are shown in the Table of "keys to isoquant numbers". For instance, the line consisting of the numeral 6 represents a yield of 3800 kg/ha. If 66 cm of water are supplied, this yield could be attained by application of about 130 kg N/ha. However, one could also attain this yield by supplying only 24 cm of water if 240 kg N/ha are supplied, or by using one of the other combinations as represented by the 3800 kg output line.

The most striking feature of Fig. III.1 is that at low N levels, yields are very insensitive to the amount of water supplied. Only at high N levels is any response to water evident, but even at low water levels there is a large response to nitrogen. We also find that there is little or no evidence of reduced yields at high N levels. This indicates that lodging was not sufficient to reduce yields in this trial, probably because the variety (Yacora) is not highly susceptible to lodging.

Economic Analysis

Because response to phosphorus is very limited and can be expressed by a single term in the model, it is appropriate to first examine the economics of P applications. The marginal value product, M_p, of any input is given by the partial first derivative with respect to that input times the price received for output. The first derivative with respect to P is simply:

$$\frac{\partial Y}{\partial P} = b_6 N \qquad \text{(III.3)}$$

The marginal value product is then given by:

$$M_p = (b_6 N)\ P_Y \qquad \text{(III.4)}$$

In our system we have taken the price of wheat as Rs 1.09 per kg, b_6 is equal to .005145 and N is the rate of nitrogen. If no N is applied there will be no phosphorus response. From Eq. III.3 it is obvious that the maximum response to P will be at the highest rate of N and we can calculate that with a 224 kg/ha application of ' the marginal value product of P will be Rs 1.15/kg. Stated another way, for each kg of P_2O_5 applied, the value of the grain produced will be Rs 1.15. As P_2O_5 costs about Rs 4.5 per kilogram, it is obvious that application of phosphorus would not have given an economic return at this location, and that it is not possible to

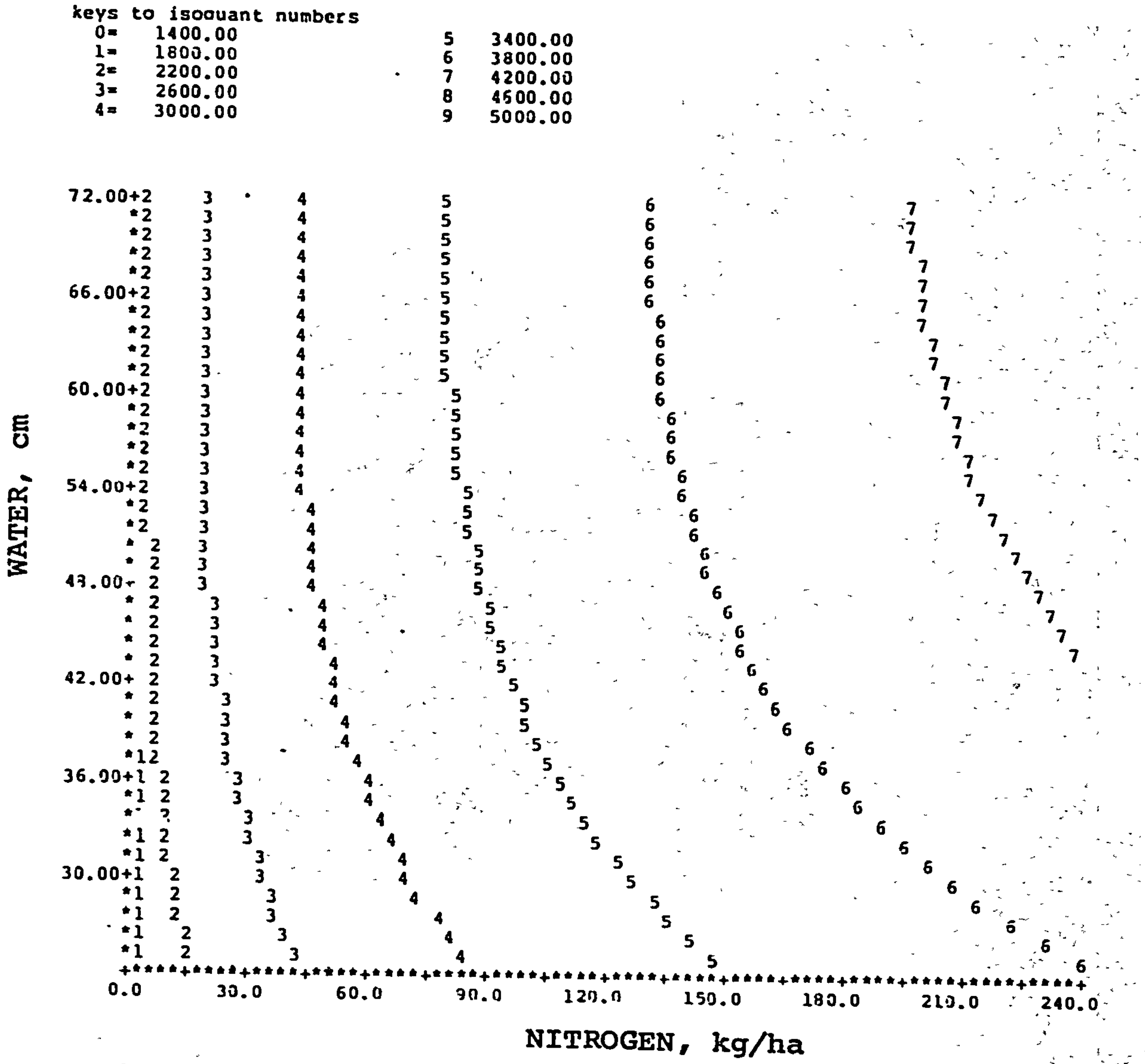


Figure III.1. Yield isoquants as a function of water and nitrogen inputs at the 89.6 kg P_2O_5/ha phosphorus rate.

calculate an optimum rate of P application. We can calculate optimum N and W applications for any P rate between zero and 180 kg P_2O_5 per hectare, but we must recognize that the phosphorus is not providing an economic return.

We noted above that many combinations of N and W may give the same yield. The most economical combination of nitrogen and water depends on the relative cost of the two inputs. We find the cost of N to the farmer to be about Rs 3.3 per kg including interest and application cost, but water costs are highly variable. As an example, if water costs are Rs 2.5 ha/cm and the farmer applies 66 cm of water and 130 kg N the total cost of N and water to produce 3800 kg/ha is Rs 594. If he chose to produce 3800 kg/ha by applying 24 cm of water and 240 kg N as the total cost for water and nitrogen would be Rs. 852. However, if water costs Rs 15/ha cm, the combination of 66 cm water and 130 kg N would cost Rs 1419, while the 240 kg N and 24 cm program would only cost Rs1115.2. We must, therefore, consider the problem of choosing the optimum combinations for any particular cost of inputs and price of outputs.

For this purpose, we substitute the partial first derivative of Eq. III.4 into Eq. II.2a and II.2b:

$$P_Y \ (b_1' + 1/2 b_2 N^{-1/2} + b_5 W) = C_N \qquad \text{(III.5a)}$$

$$P_Y \ (b_3 + 1/2 b_4 W^{-1/2} + b_5 N) = C_W \qquad \text{(III.5b)}$$

where C_N and C_W are the costs of N and water, respectively. Solutions of these two equations for N and W will give the optimum rates of these inputs.

In some cases, the operator may not have the resources to apply the optimum rates, so he may wish to be content with lower inputs. He would then wish to know the combination that would give the maximum return on money invested in these two inputs. This optimum combination will occur at lower levels of the inputs but at the same ratio of costs for the two inputs. The return per unit investment will be greater than 1.0 and will be the same for the two inputs, i.e. the benefit/cost ratio R will be equal. To describe this situation mathematically, we multiply the costs in equation II.2a and II.2b by the benefit/cost ratio R.

$$P_Y \ \frac{\partial Y}{\partial X_1} = R \ C_{X_1} \qquad \text{(III.6a)}$$

$$P_Y \ \frac{Y}{X_2} = R \ C_{X_2} \qquad \text{(III.6b)}$$

Equations II.5a and II.5b, now become:

$$P_y\ (b_1' + 1/2b_2N^{-1/2} + b_5W) = RC_N \qquad \text{(III.7a)}$$

$$P_Y\ (b_3 + 1/2b_4W^{-1/2} + b_5N) = RC_W \qquad \text{(III/7b)}$$

In the construction of a graph such as that in Fig. II.1, the value of W is fixed for each line of the graph. It is then possible to solve the above two equations in the unknowns N and R. Again, for the model used here it is not feasible to obtain an analytical solution, but iterative solutions can be obtained using a computer. When these solutions are plotted on a graph such as that in Fig. II.1, a line is obtained for each cost of water considered. Mathematically, these are known as lines of steepest ascent.

The properties of these lines of interest to us is that the optimum combinations of N and W inputs lie along these lines as shown by the asterisks (*) in Figs. III.2 and III.3. Reading from the top, down the four lines lie on the optimum N and P combination for water costs of Rs 2.5, 5.0, 10.0 and 15.0 Rs per hectare cm, respectively. It is not surprising that the optimum water application decreases as water costs increases. Therefore, if the farmer wishes to attain a given yield, as water costs increase, he should decrease the water application and increase the nitrogen. This is plainly shown by the intersections of the lines of steepest ascent with the yield isoquants on Figs. III.2 and III.3.

It is important to remember that the cost of water may not be what the farmer pays for it, but may represent opportunity cost, i.e., the value of that water for production of more acres, either of wheat or some other crop. This is especially important in Pakistan where the actual cost to the farmer of canal water or water from a public tubewell may be low, but uncropped land may be available so that cropped acres may be increased if water applications are reduced.

Another useful parameter is the benefit/cost ratio R of each increment of input added. As noted above, in the classical economic sense at the optimum combination, the return to the last increment of inputs will just pay the cost of the increment. However, if capital for inputs is limiting, the operator may wish to produce at a lower level of intensity, perhaps requiring a return of 1.5 or 2 times the amount invested on the margin. On Figs. III.2 and III.3, some of the asteriks on the lines of steepest ascent have been replaced by numerals. These numbers indicate the approximate return that can be expected from an increment of either water or nitrogen at that point. For instance, the number 2 occurs

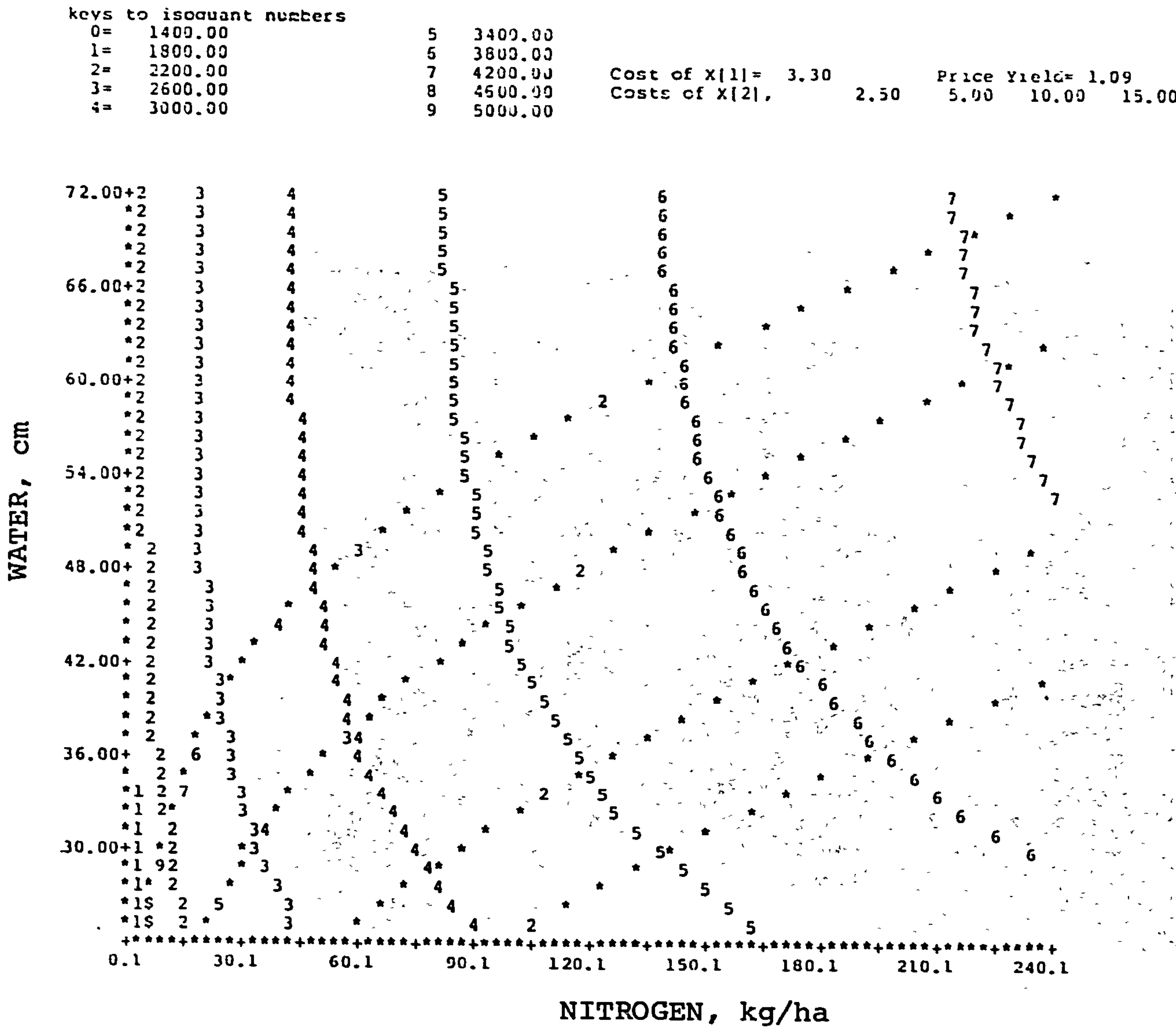


Figure III.2. Yield isoquants with lines of steepest ascent showing optimum combinations of water and nitrogen for producing a given yield. Reading from top down the lines of steepest ascent represent water costs of Rs 2.5, 5, 10 and 15 per ha.cm, respectively. P rate is zero.

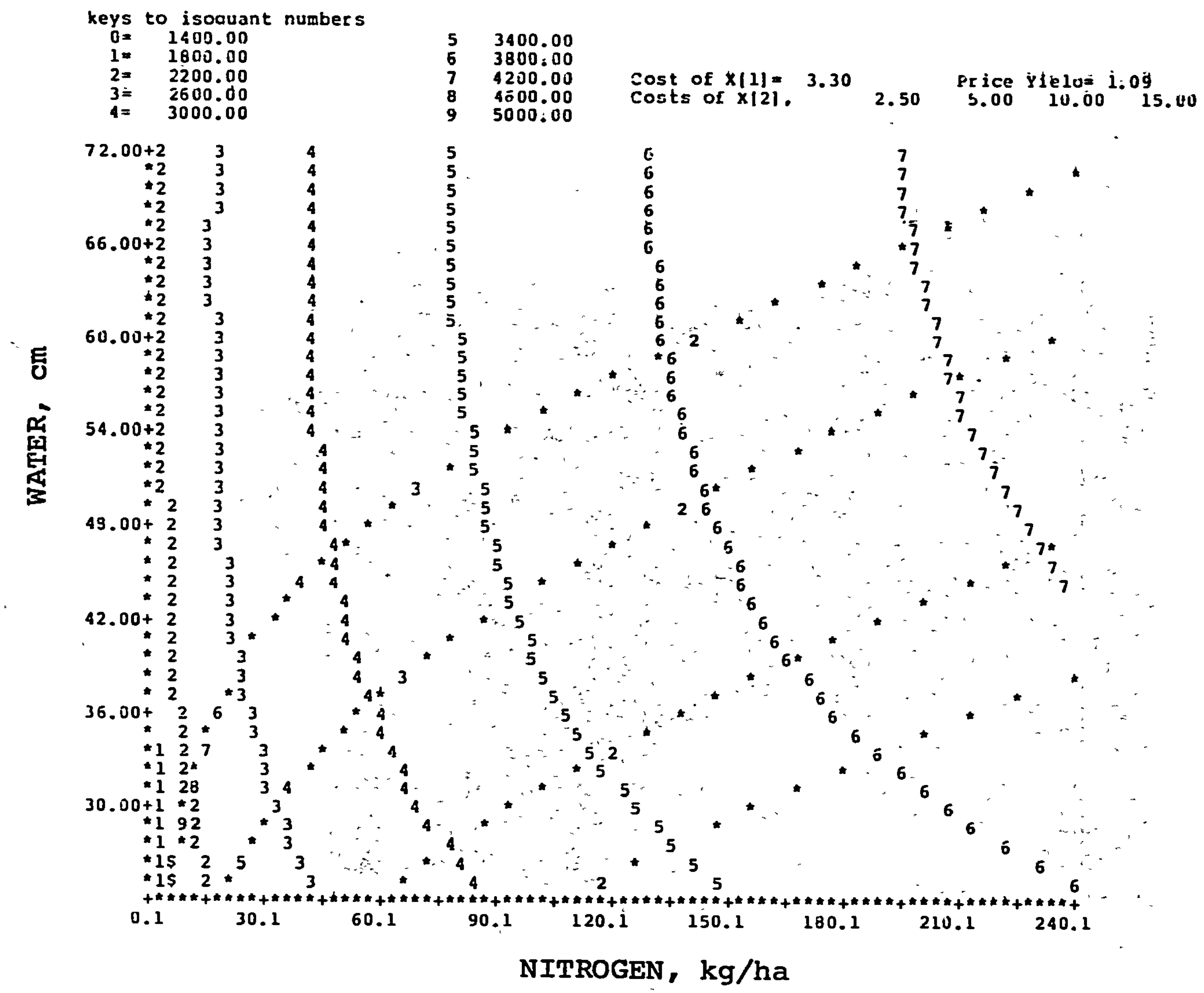


Figure III.3. Yield isoquants with lines of steepest ascent showing optimum combinations of water and nitrogen for producing a given yield. Reading from top down the lines of steepest ascent represent water costs of Rs 2.5, 5, 10 and 15 per ha.cm, respectively. P rate is 89.6 kg P_2O_5/ha.

on all of the lines in the range of 120 to 135 kg N/ha. This would indicate that nitrogen application in this range would still return about two rupees for each rupee spent on fertilizer.

The optimum N and water rates required for a given B/C ratio of the last increment applied are shown more precisely in Table III.6 for the no phosphorus situation. All combinations of N and W occurring on any of the four lines of steepest ascent gave a marginal B/C ratio greater than 1.0. The marginal return of 2 Rs for each rupee investment for the optimum combination, occurs at 130 kg N/ha and 59.5 cm when water costs Rs 2.5/ha.cm; and at 106 kg N/ha and 25 cm water when water costs Rs 15/ha.cm. Thus, as water becomes more expensive the optimum water level for a given marginal return drops very rapidly, while the optimum N level changes only slightly. The important factor here is that nitrogen fertilizer rates should be only slightly reduced if water is scarce and/or expensive.

It is also important to remember that the returns indicated in Figs. III.2 and III.3 and in Table III.6 are marginal returns, i.e., return from the last increment, and not total returns from the nitrogen and water program.

For example, at 48.4 cm of water and 112 kg N/ha, the yield is 3600 kg/ha, worth Rs 3923. At zero N and 24 cm water the yield is 1525 kg/ha, worth Rs 1662. The difference is Rs 2271, achieved at a cost of Rs 644, assuming water at Rs 5/ha.cm and N at Rs 3.30/kg. The overall return from N and additional water was Rs 3.53 for every rupee invested, while the marginal return (for the last increment) was 2.0. If only the additional water were added the yield would have been 1885 kg worth Rs 2059. The increase of Rs 397 would have cost Rs 122 or a return of 3.25 per rupee invested. If the additional N were added without increased water (i.e., 24 cm water and 122 kg N/ha) the expected yield is 3171 kg, worth Rs 3456. The increase in income would be 1794, achieved at a cost of Rs 403, or a total return of Rs 3.53 for each rupee invested in N. Note that the return of Rs 2271 from both N and water is slightly greater than the total of 397 + 1794 = 2191, for utilizing the inputs separately.

Table III.6 Calculated yield and optimum nitrogen and water inputs at various costs of water, and benefit cost ratios of the final increment, assuming no phosphorus applied.

B/C		Cost of Water		Rs/ha.cm	
		2.5	5.0	10.0	5.0
1.0	N (kg/ha)	*	*	*	*
	W (cm)				
	Y (kg/ha)				
1.5	N	217	198	176	165
	W	69.4	57.8	42.5	32.9
	Y	4214	4070	3820	3603
2.0	N	130	122	112	106
	W	59.5	48.4	34.0	25
	Y	3727	3600	3348	3118
2.5	N	89	84	78	75
	W	54.1	42.6	28.5	20.4
	Y	3420	3285	3008	27.6
3.0	N	65	61	58	*
	W	50.3	38.3	24.4	
	Y	3198	3048	2739	
3.5	N	50.0	47.2	*	*
	W	47.2	34.9		
	Y	3026	2857		
4.0	N	39.1	37	*	*
	W	44.7	32.0		
	Y	2887	2698		

* Only solutions within the range of 0-240 kg N/ha and 24-72 cm water are reported.

APPENDIX 27

WATERCOURSE IMPROVEMENT: METHODS, COSTS AND LOSS RATES AT TUBEWELL 78 WATERCOURSE[1]

Mohammad Akram and W. D. Kemper[2]

ABSTRACT

The test watercourse sections at Tubewell 78 have provided data essential to the Pilot Watercourse Studies in the Mona Project area and the watercourse improvement component of the Punjab Agriculture Department's Water Management Development Program.

These included (1) a determination that pakka lined watercourses (costing over Rs. 25/acre foot) cannot generally be justified on a benefit/cost basis for branch channels, but may be justified for some main channels (Eckert, Dimick and Clyma, 1975); (2) that Pakistani masonry and concrete is commonly porous and requires a good coat of plaster to achieve the desired reductions in water loss; (3) that losses from watercourses in a sandy loam soil can be reduced to 20 to 35 percent of their present value by a thorough job of bank reconstruction and compaction, or core compaction; (4) that farmers can reduce their water losses by 50 percent by reconstructing and doing a medium to poor job of packing the new banks by expending less than 0.5 man hours per foot of watercourse and that the water saved has a lower cost than other sources of water in Pakistan; (5) that farmer participation in planning and constructing the improvements is helpful to gaining their support of a continued maintenance and cleaning program; and (6) the warabundi system of orderly scheduling of water does avoid appreciable operational loss and should not be discarded as long as the irrigation systems are susceptible to these operational losses.

1/Based on studies conducted by the Mona Reclamation Experimental Project, the Colorado State University Water Management Research Team and cooperating farmers. Studies were supported by USAID/Pakistan Agreement No. 204-75 and by USAID/Washington Research Contract No. AID/ta-C-1100.

2/Junior Agricultural Engineer, MREP, and Field Party Chief, CSU Water Management Research Project. See acknowledgments for other participants.

Background and Layout

Beginning in 1973 a series of test sections were constructed on the watercourse serving Tubewell 78. The test sections were constructed primarily to evaluate methods for reducing the loss of water from these watercourses which was high, averaging up around 10 to 15 percent of the water per 1000 feet.

The basic plan of the improvements designed by Mian Ashraf, Gilbert Corey and Wayne Clyma was to provide the best watercourse for the mainline channel and to improve branches and sections of branches with less costly lining which had more possibility of failing. A map of the watercourse command area showing the main channel and branches A through U is shown in Figure 1. The types of improvement installed are shown in Figure 2, and the costs of the sections are shown in Table 1.

Measurements

Loss measurements were taken using the surface recession method. For most of these measurements the sections chosen were approximately 220' long and a compacted earthen bank was formed at each end of the test section. After the section had been filled with water to slightly above the normal operating level, a ruler was fixed vertically in each section and the rate at which the level of water in the watercourse receded was recorded. This recession rate is combined with the width of the watercourse surface at the measurement time to compute the rate of water loss.

Concrete and Masonry Improvements

The data (Table 2) show the losses of water through the walls and bottom of the portion of the main channel which had plastered walls 13-1/2" thick were less than 0.01 cusecs per 1000 feet. This is practically negligible loss. However, there were surprisingly large losses in many of the other pakka (concrete or masonry) lined test sectons. Some of the largest rates of loss were found in the trapezoidal concrete sections. In the sections constructed of 1:2:4 mixtures of cement, sand and gravel and in the 1:4:8 sections the average rate of loss was over 0.40 cusecs per 1000 feet. This is near the average rate of loss encountered in unimproved unlined watercourses. Inspection of these sections indicated that when the

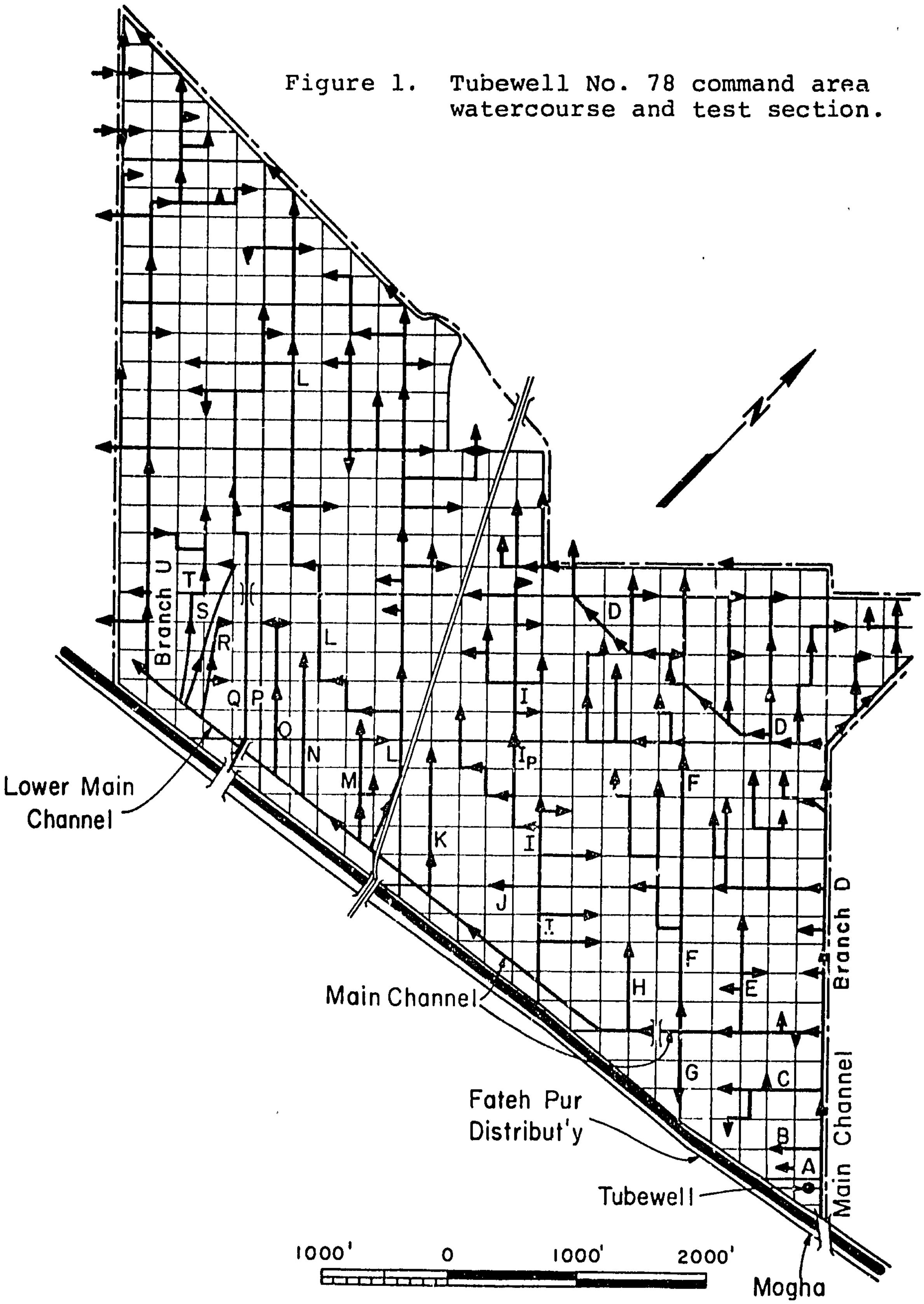
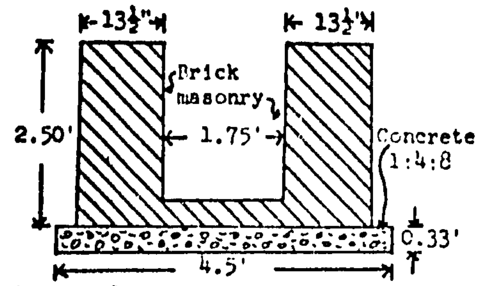
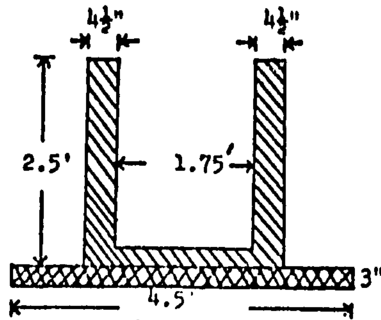


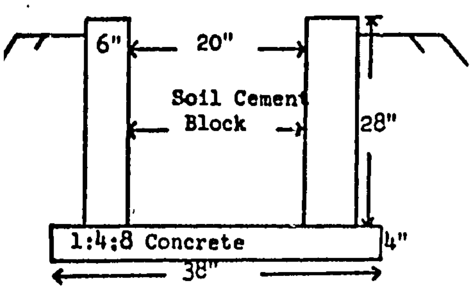
Figure 1. Tubewell No. 78 command area watercourse and test section.



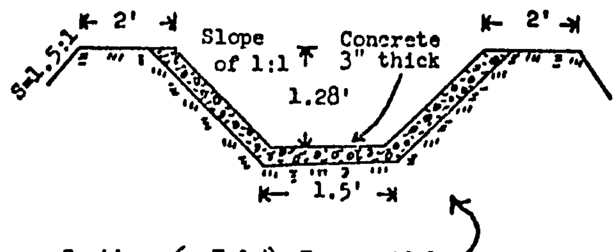
Section 1. Rectangular-Main Channel



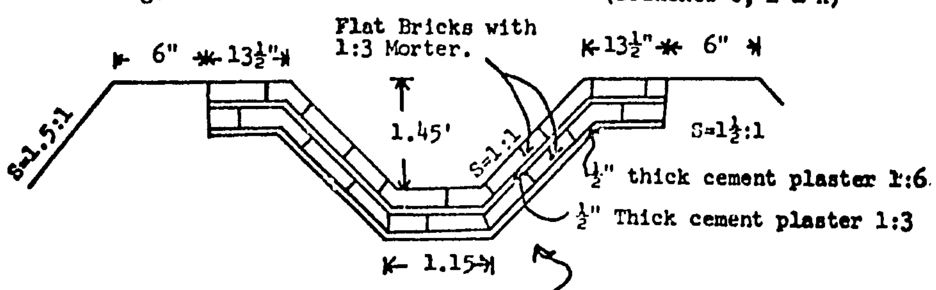
Section 3 & 4. Rectangular Branch U.



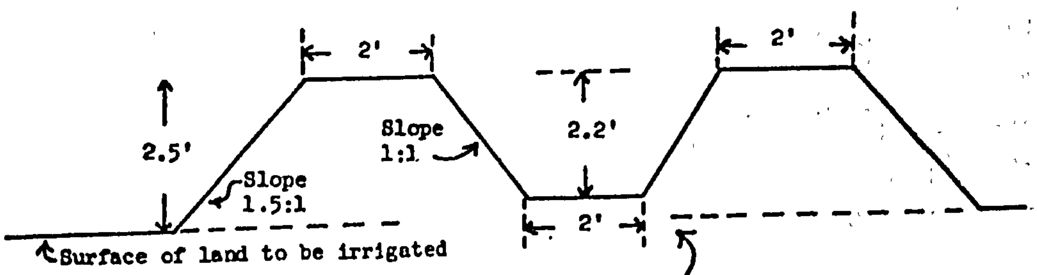
Section 5. Rectangular used in Banni Village



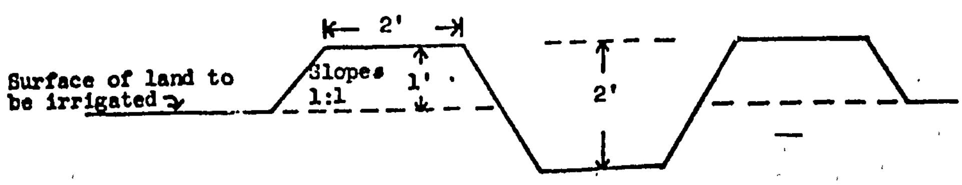
Sections 6, 7 & 8. Trapezoidal (Branches C, E & K)



Section 9. Trapezoidal Brick (Branch F)



Section 10. Trapezoidal Earthen Improved (Branch D) Built by contractors.



Section 11. Trapezoidal Earthen Improved, Renovated by farmers (branch I).

Figure 2.

Table 1. Cost and Details of Construction of Watercourse Serving TW No. MN-78.

Section	Description	Length	*Cost/1000 ft	Type/Design
1.	Main Channel	5280	41,480	Rectangular Section. Brick Masonry. 13-1/2" Thick wall.
2.	Main Channel Watercourse	2240	55,810	Rectangular Section. Brick Masonry. 9" Thick Wall.
3.	Branch "U"	1000	26,930	Rectangular Section. Brick Masonry. 4-1/2" Thick wall.
4.	Branch "U"	1000	26,930	Rectangular Section. Brick Masonry. 4-1/2" Thick wall. 3" Thick C.C. 1:4:8 Foundation.
5.	Banni Village	220	18,000 20,000 (Plastered)	Rectangular Section. Base of 1:4:8 concrete. Walls of 6x4x12" soil cement block.
6.	Branch "C"	769	35,150	Trapezoidal Section. Cement Concrete 3" Thick (1:3:6).
7.	Branch "E"	642	36,240	Trapezoidal Section. Cement Concrete 3" Thick (1:2:4).
8.	Branch "K"	908	36,260	Trapezoidal Section. Cement Concrete 3" Thick (1:4:8).
9.	Branch "F"	3248	55,210	Trapezoidal Section with 2 Brick Layers.
10.	Branch "D"	4600	10,920	Trapezoidal Section. Earthen Improved. Built by Contractors.
11.	Branch "I"	2200	2,000	Trapezoidal Earthen Improved. Built by Farmers.

*Cost includes construction of check structures and outlets.

Table 2. Rates of Loss from Pakka Sections at Tubewell 78 Watercourse

Description of Section	Replication	Rates of Loss in cusecs per 1000 ft. Before plastering or repair	After plastering or repair	Cost of repair or plastering (Rs./1000 ft.)
Rectangular section, plastered brick walls 12-1/2" thick (main channel)	1 2	0.009 0.007		
Trapezoidal section, concrete 1:3:6 walls 3" thick (Branch "C")	1 2	0.040 0.059		1290
Trapezoidal Section, concrete 1:2:4 walls 3" thick (Branch "E")	1 2	0.414 0.354	.014	1290
Trapezoidal Section, Concrete 1:4:8, walls 3" thick (Branch "K")	1 2	0.341 0.750	.022	1290
Trapezoidal Section, Double thick brick walls (Branch "F")	1 2	0.103 0.197	.012	1290
Rectangular section, plastered brick walls 9" thick (Lower main channel)	1 2	0.348 0.595	.005** .013	218
Rectangular section, plastered brick walls 4-1/2" thick (Branch "U")	1 2	0.057 0.104	.038**	50
Rectangular section, plastered soil cement block walls 6" thick ("I")	1 2*	0.004 0.002		
Rectangular section, unplastered soil cement block 6" thick ("I")	1 2	0.082 0.087	0.048+ 0.036+	160
Rectangular section, plastered brick walls 9" thick (Branch "F")	1	0.30	0.04***	286
Rectangular section brick walls 9" thick (Branch "F")	1 2	0.56 0.96	.01	1800

* Plaster containing Pakka Kaum (Sodium silicate)

** Repair of old plastering job where poorly mixed plaster (sand) had eroded away

*** Rain, beginning when this plaster repair had not had time to set caused some washout of the plaster at the repair points.

+ "Pointing", or filling of obvious holes in joints between blocks 6 months after construction.

sections were constructed the concrete was not completely tamped and the occasional holes occurring in the concrete frequently extended all the way through the three inches of concrete and passed water rapidly to the outside of the concrete section. The fact that this was a matter of quality control during the time of tamping rather than the amount of cement in the mix is shown by the rate of loss in branch "C" in which the mix was 1:3:6 and the rate of loss was only 1/10 as much as in the other concrete trapezoidal sections. Section "C" was one of the first constructed and there was closer supervision of the contractor's employees which apparently resulted in the better quality of the concrete mixing and tamping.

The other test section showing the highest rate of loss was the rectangular cross section of the main watercourse where brick wall linings are 9" thick and plastered on the inside. This was surprising because this section should have had loss rates nearly as low as those with the 13-1/2" wall thickness. Inspection showed that a poor job of plastering had been done toward the bottom of the walls and that the plaster had either eroded or broken away from the walls in many places where the walls joined the floor and for 2 or 3" above that line. This indicated that there had been considerable sediment in the bottom of this watercourse at the time of plastering and that the masons had allowed this sediment to mix with their plaster. There was also a crack in the base of this watercourse in the first section measured which was near the end before it joins Branch U. This crack occurred in the section where fill in the channel of the original earthen watercourse was necessary to bring the bed up to grade and apparently this fill was not adequately compacted before the concrete bottom of this watercourse was installed.

Going from this section of 9" thick walls with loss rates averaging more than 0.4 cusecs per 1000 feet, to the immediately following section in Branch U which has walls 4-1/4" thick and a loss rate averaging only 0.08 cusecs per 1000 feet, it is again apparent that the loss rates are more highly dependent on quality control than on thickness of the brick wall.

Repair and Plastering

At the lower end of branch "F" there is a section which has a rectangular cross-section and has walls 9" thick, built of brick, one section of which is not plastered and one section of which was plastered, but erosion of the plaster indicates that the plaster was poorly mixed. The rates of loss from these sections were measured and found to average about 0.8 cusecs per 1000 feet.

It seemed apparent thar both the brick and cement sections should receive a coat of plaster to reduce their permeabilities to acceptable levels. The effectiveness of a good plaster job was further pointed out by comparison of the sections of watercourse constructed of soil cement blocks. When these were not plastered the rate of loss was slightly less than 0.1 cusecs per 1000 feet where common plaster was used and where this plaster had been treated with sodium silicate (locally known as pakka-kaum) the loss was 0.002 cusecs per 1000 feet. Since plastering of sections can cost up to Rs. 2 per lineal foot of watercourse the question raised was whether a careful pointing of joints between the soil cement bricks could reduce the rate of loss since pointing could be done at lower cost. The data in Table 2 show that an improved pointing of the joints did reduce the rate of loss from an average of about 0.08 to about 0.04 cusecs per 1000 feet.

On the basis of these indications of the effectiveness of a good plaster job for reducing the loss rates, the sections on which cost and loss data are shown in the last two columns of Table 2 were plastered, or the existing plastering job was repaired as indicated in the footnote to that table.

Since other studies have shown that the bottoms of watercourses are sealed by sediment from the canal water, only the sides of these watercourses were plastered, or repaired.

The plastering of unplastered sections stopped an average of 94% of the leakage at costs of Rs 1.3 to Rs 1.9 per foot of watercourse (Table 2), saving an average of 0.34 cusecs of water per thousand feet of watercourse plastered.

If water flows in such a watercourse for 50 days a year, the savings would be 34 acre feet of water per year which is a good investment of 1300 to 1800 Rs and indicates that a good plaster job to seal the masonry or cement walls should always be a part of pakka watercourse construction.

Unimproved and Earthen Improved Branches

Branch D (Contractor constructed)

This branch was designed as indicated in Figure 2 so the bed of the watercourse was generally about at the ground surface and all the water could be drawn out of the watercourse at any point, thereby eliminating "dead storage" in the channel. The specifications called for compacted earth. However, soil sampling following construction showed there were many sections of this branch which were compacted only on the surface, after all the fill soil (3 to 4 feet high in some places) had been placed in the banks. There was concern that these uncompacted sections would give way when the channel was filled with water. The branch was divided into seven sections between the six drop structures on this watercourse. Nine sizeable leaks through the banks began as the sections were filled. Seven of these were stopped by trampling the banks above the leaks in time to prevent major damage although banks subsided from 2 to 8" in the process. Two of the leaks developed into major washouts before they were detected. These washouts were quickly repaired and measurements of the rate of fall of the water surface began within an hour of the time that the sections were filled.

Despite the poorly compacted condition of the banks the loss rates in the six sections measured were fairly low as indicated in Table 3 except for the subsection between drop structures 5 and 6. In this section compaction was particularly poor and several seeps along its sides were apparent. In the rest of the sections the loss rate averaged about 0.07 cusecs per thousand feet. The average loss along the total 4,000 foot length of this channel was about 0.10 cusecs per 1,000 feet. When this branch watercourse is carrying 4.6 cusecs at the top end, for which it was designed, the total loss in 4,000 feet would be about 0.4 cusecs or 9 percent. This is considerably lower than the average losses measured in the old large unimproved earthen watercourses in this area, despite the fact that this newly constructed watercourse was poorly compacted.

After twenty months the rate of loss in this watercourse was measured again. One hour after filling the watercourse the rate of loss was 0.13 cusecs per 1,000 feet in each of the first two sections. This indicated approximately 70 percent increase in the permeability of the banks during that twenty months.

Table 3. Characteristics of 6 sections of Branch D of the Watercourse Serving TW 78 at Mona*

Sections between drops #	Water Surface Fall Rate (Ft/sec) At Operating Level**	Cusecs Loss per 1000 feet	% of Flow Lost per 1000 feet
Start-1	$.014 \times 10^{-3}$	0.08	1.7
1-2***	.012 "	0.07	1.5
3-4	.015 "	0.08	1.8
4-5	.011 "	0.06	1.3
5-6	.041 "	0.23	5.0
6 to end	.017 "	0.09	2.0
Start-1	.022 "	0.13	2.8
1-2	.022 "	0.13	2.8

* Texture of the soils ranges from loam to sandy loam

** This was an average depth of about 1.9 ft. In these basins, formed between the drop structures, water was 3 to 6" deeper at the top than at the bottom ends. At this average depth the width of the water surface averaged about 5.6'.

*** Section between drop structures 2 and 3 is very short and was not measured.

Branch 1 (Unimproved and Earthen improved)

Effects of Water Level in Watercourse on Loss Rates

Comparing the loss rates in the Old Sod Bank Section (Kemper et. al. (1975)) and in the straight channel sections and junction sections (which were also unimproved) Table 4, it is apparent that lowering the level of water in the watercourse sharply reduces the rate of loss. Reducing the water level by 0.2' resulted in an average reduction of loss to one-third of the loss occurring at full supply level. Close inspection of these banks showed many insect and rodent holes near the upper portion of the bank and when the water level in the watercourse was lowered below the openings of these holes on the inside banks of the watercourse, the rates of water loss were sharply reduced. Further reduction of level of water in the watercourse and a continued exponential decrease in loss rates indicate that practically negligible amounts of water are lost from the bottom sections of these watercourses. However, the upper portions of the banks commonly have permeabilities from 5 to 10 times the permeability of cropped soils in adjacent fields.

Loss Rates at Junctions Compared to Straight Sections

In this unimproved branch watercourse about 45 percent of the loss was occurring in the junction sections, (those obviously widened sections of watercourse with deteriorated banks which are within 20 to 30 feet of the point where sub branches leave the main branch) (Kemper and Akram, 1975, and Table 4 comparing the straight and junction sections). Estimates of losses on other watercourses also indicate that roughly half of the loss is in the vicinity of degraded junctions. At these junctions weekly borrowing of soil to build dams, and erosion of this soil downstream during the process of dam construction and dam removal lowers the level of the soil in adjacent fields, if the farmers owning those fields permit (or endure) the borrowing. When the farmers owning those fields strongly object to this borrowing of soil and destruction of their crops, the man building the dams takes soil from the inside of the watercourse, and from the banks themselves, resulting in a broadening of the watercourse and the banks become thinner. The banks also tend to become taller as borrowing from inside and outside the watercourse reduces the ground and bed levels. The result is thin, tall banks at most of these junctions, which are extremely leaky.

This condition can be improved by bringing soil from the fields into these junction areas, building the banks back to proper cross section and providing excess soil at these junctions for the weekly dam building. A solution to this problem requiring more initial expense, but having a high benefit/cost ratio is to install concrete control structures

Table 4. Losses measured in earthen test sections on Branch I

Treatment or condition	Loss Rates Cusecs/1000 ft
Unimproved old sod banks of full supply level	0.75
Same section as above with level 0.2' lower than FSL	0.25
Straight Channel sections at "Full Supply Level"**	0.06
" " " " " " "	0.56
" " " " " " "	0.40
" " " " " " "	0.25
Sections, level 0.2' lower than FSL	0.01
" " " " " "	0.28
" " " " " "	0.32
" " " " " "	0.08
Junction Sections* at full supply level	0.70
" " " " " "	2.15
" " " " " "	1.25
Junction Sections*, level 2.5" lower than FSL	0.05
" " " " " " "	0.74
" " " " " " "	0.68
Newly constructed by farmers without compaction	0.38
" " " " " "	0.44
Same as above, but banks carefully compacted	0.10
" " " " " " "	0.16
Leaky section (a) after first filling	0.61
" " (b) " " "	0.44
" " (c) " " "	0.66
Leaky section (a) after second filling+	0.11
" " (b) " " "	0.37
" " (c) " " "	0.50

\+ Compacted cores were formed in the banks of section (a) between the first and second filling.

** That surface water level which occurs when full supply of water is running in the channel.

* Generally included the widened sections which were within 30 ft. of the junction point.

at each of these junctions which will eliminate the need for borrowing appreciable amounts of soil.

Role of Bank Compaction in Reducing Water Loss

When the banks are carefully compacted, as indicated in Table 4, rates of water loss were reduced to only 26 to 35 percent of those occurring in sections which were not compacted. The core compaction technique discussed by Kemper and Akram (1975) with results indicated at the bottom of Table 4, reduced the loss rate to only about 20 percent of that occurring before a compacted earthen core was formed in the bank. This core was compacted while water was flowing in the watercourse by trimming away the freeboard down to within one inch of the water level, compacting a 3" wide core in the center of the banks to a depth of about 8" below the water level (see Kemper and Akram 1975 for further details). The low loss persisted for about 11 months and then a sudden surge of rodent activity in that section increased the loss again. However, rodent activity generally appears to be lower in packed than in unpacked banks. Core compaction of this type requires about one hour to do ten feet.

Operational Losses in Branch I before Improvement

Measuring all the water entering the watercourse and all the water going into the field from the watercourse during the complete irrigation turn of Branch I it was found (Kemper et al., 1975) that only 43 percent of the water entering this branched reached the fields.[3] This compared with steady state measurements at this and other times which indicated an average of 60 percent of the water entering this branch was reaching the field. The difference has been called "operational loss" and is that portion of the water which is used in rapid initial wetting of watercourse banks, filling of watercourses, occasional dam ruptures, etc., during which times, steady state measurements are generally not taken. The drastic increase of operational losses which occurs when farmers in different branches of a watercourse trade water indicate that the warabundi system does help reduce these operational losses compared to what they would be if a "demand system" were installed and water was delivered randomly with time to farmers within the command area.

Effect of Farmer Reconstruction of Water Losses

On the basis of the lower loss rates measured in the newly constructed test sections with compacted banks, the farmers were asked to reconstruct and compact the banks of

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[3]A substantial portion of the loss occurred as a result of filling another branch watercourse as one farmer allowed another farmer on the other branch to use his water.

their watercourse. They did this (i.e. see Kemper, Clyma and Ashraf 1975, or Chandawana, 1976). The compaction of this whole branch was supervised by an extension field assistant and was not as complete as on the test sections. However, the farmers were able to reduce their loss rate to less than half of what it had been previously and to increase deliveries to their fields by almost 50 percent. This was done at a labor cost of about one man hour per two feet of watercourse reconstructed. Concrete control structures were also installed in these sections and the total cost of the improvement averaged about Rs. 2.2/foot. However, it will require about 300 man hours of labor per year to clean and maintain this 2,500 foot branch.

The benefit/cost ratio was greater than 3 and this cooperative study with the farmers provided the essential information used in planning the Pilot Watercourse improvement program initiated on the watercourse at Tubewell 56L.

ACKNOWLEDGMENTS

Appreciation is expressed to the following for their contribution to this study.

Mian Moh'd Ashraf, Project Director at the Mona Reclamation Project (1968-1975) and Gilbert Corey, CSU Party Chief, planned and initiated the improvement studies at Tubewell 78.

Abdul Hamid, Executive Engineer, MREP, supervised the contractors who constructed most of the test sections.

Wayne Clyma, Agricultural Engineer, CSU Field Party, helped design the test sections and initiate the project.

Bashir Ahmad, Mohammad Afzal and Moh'd Iqbal, Jr. Agr. Engineers, MREP, helped evaluate water losses.

Iqbal Hussain, sub-engineer, supervised the masons in the plastering of old test sections and construction of the soil cement sections.

Moh'd Munir Chaudhry, Project Director, MREP (1975-present) supported and gave guidance to this study.

The efforts of Mohsin Wahla in convincing the farmers they should cooperate by reconstructing Branch I and the leadership displayed by Moh'd Khan Chandawana in that reconstruction were vital to the introduction of the "farmer component" into this study.

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