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Contract AID/ta-c-1103

Annual Progress Report

November 1, 1973 to October 31, 1974

To the United States Agency

for International Development

Prepared by

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USA

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INTRODUCTION

The geography of hunger throughout the world closely approximates the geography of drought and serious water deficiencies. Improved knowledge of the probabilities and degrees of seriousness of water shortages combined with techniques for more efficient water use and management offer significant possibilities for improved planning and production. The needs are greatest in the less developed countries and particularly in the homelands of the nearly half a billion people who suffer from some form of hunger.

For many years the United States of America has recognized the need to increase production in developing countries. In 1968 Utah State University (USU) contracted with AID to conduct research in the area of soil and water. The general purpose of the project was to solve some of the food and nutrition problems of the world through increased agricultural production. Primary emphasis has been placed on problems of on-farm water management and related problems as a means of improving the quality of life for the poorest farmers. Emphasis has been placed on adaptive research and utilization of information.

This contract recognizes that proper control of water resources at the farm level is a key element in increasing crop production. However, effective transfer of technology from North America and elsewhere to different social and physical environments requires considerable adaptation. This is being accomplished in various ways, probably the most important of which is adaptive research carried out within the developing countries by their technicians working in cooperation with USU technicians. Adaptive research is carried out in close collaboration with a number of government agencies and universities in Latin America.

By invitation from USAID missions, USU has integrated its contract objectives with host country agency needs to produce a spectrum of water management research activities designed primarily to:

1. Transfer and adapt techniques used in developed areas to developing country situations.
2. Strengthen the capabilities of indigenous research agencies to effectively carry out their own programs.

Although much of the research has been carried out in Latin America, most of what has been learned has wider application. Through a similar contract which AID has with Colorado State University, whose major off-campus effort has been focused on water management in the Near East South Asia region, an even broader transferability capability is emerging as the two universities interact.

An important feature of the contract has been to relate the specific contract objectives to the objectives of the USAID missions of the countries where the field research is conducted and with objectives and priorities of the host countries.

The program is in the sixth year and tangible evidence of accomplishments are now becoming more evident, much of the knowledge gained is being published and otherwise dispersed through seminars, field days, etc., for utilization.

A significant part of this report (Appendix A) contains abstracts of the publications, reports, papers, etc. generated by the contract, many in collaboration with indigenous researchers.

Major progress on the Water Law studies became evident this year with the completion of the digest, its publication and the conducting of a water law seminar in Ecuador. Success in the research on drainage and salinity is also more noticeable than in previous reports.

Anyone desiring more information about the detailed studies are invited to contact the specialists on the project listed in Table 1.

PROJECT OBJECTIVES

General Objective

The general objective of this research is to increase food production in the arid and sub-humid lands of the less developed countries through the improvement of water management practices and the integration of these with other good management practices in the semi-arid lands of the Latin American region but will be applicable in principle to similar conditions in other regions. This improvement of water management practices is necessary to obtain maximum economic returns from limited water resources and such inputs as improved seeds, increased use of fertilizers and pesticides, and supporting institutional structure.

Specific Objectives

The specific research studies have been selected to meet the high priority needs of the Latin American area but with intended application and adaptation to other developing countries.

1. Development of farming practices including methods, timing, and amounts of water applied to the

TABLE 1. Professional and Technical Staff Commitments to Contract, November 1, 1973 to October 31, 1974.

Name	Specialty	Level of effort mo. per yr.
Percy G. Aitken	Research Technician, USU	1.2
Bruce Anderson	Professor of Irrigation, USU	.9
Craig Anderson	Research Associate, Ecuador and USU	1
Charles M. Burt	Research Engineer, El Salvador	2
J. E. Christiansen	Drainage Engineer, USU	9
David R. Daines	Lawyer, USU	11
Thomas M. Fullerton	Agronomist, El Salvador	12
Grant R. Hansen	Research Engineer, El Salvador	3
George Hargreaves	Research Engineer, USU and Brazil	9
David W. James	Soil Fertility, USU	2.5
Don C. Kidman	Agronomist-Irrigation Specialist, Brazil	12
Allen LeBaron	Resource Economist, USU	1.4
Edwin C. Olsen	Civil & Irrigation Engineer, Colombia and USU	12
Byron C. Palmer	Project Field Director, USU	8.5
H. B. Peterson	Project Director, USU	5.7
R. Kern Stutler	Irrigation Engineer, El Salvador	12
Komain Unhanand	Civil Engineer-Drainage Specialist, USU	4.9

land which optimize the use of water from rain and irrigation within the constraints of climate, soils, markets, infrastructure and interaction with other agricultural practices.

2. Development and adaptation of efficient water control and delivery systems especially for on-farm use.

3. Development of strategies for minimizing the deleterious effects on crops of excess surface and subsurface water, poor water quality and excessive concentrations of soil salinity, exchangeable sodium and other toxic elements.

4. Identification of institutional and policy factors (legal, social, economic, manpower, credit, etc.) that influence the efficient distribution, management and utilization of water at the farm level and the development of strategies for replacing inhibiting factors with facilitating factors.

REVIEW OF PROGRAM BY OBJECTIVE

Objective 1

Development of farming practices including methods, timing and amounts of water applied to the land which optimize the use of water from rain and irrigation within the constraints of climate, soils, markets, infrastructure and interaction with other agricultural practices.

Brazil Component

Background

The cooperative research with SUVALE of the Ministry of Interior has been completed with the results reported last year. A new agreement has been completed. In compliance with this agreement between USU, the government of Brazil and USAID, Professor Palmer reviewed the water management research in Northeast Brazil. He prepared a report which contained an evaluation of the current status and made recommendations for establishing a central research facility. The report was presented to EMBRAPA (Empresa Brasileira de Pesquisa Agropecuaria) in June 1974. As a result of this study and the identification of the research needs, USU assigned Professor Don Kidman to the project with headquarters at Petrolina where he is now beginning field studies in cooperation with technicians from EMBRAPA. There has not been time for any substantive results to come from the new venture.

In the program agreement there were provisions for Professor Hargreaves to spend as much as six months in Brazil to work on data there. This he has done, and as a result he completed several reports and conducted training sessions.

Accomplishments to Date

Professor Hargreaves collected and analyzed climatic and other data in order to evaluate the effects of climate on agricultural production and to quantify the needs and requirements for irrigation. From this effort came such reports as: "Potential Evapotranspiration and Irrigation Requirements for Northeast Brazil", "Climatic Zoning for Agricultural Production in Northeast Brazil", and "Precipitation and Agricultural Production in Northeast Brazil".

Dissemination and Utilization of Research

During March Professor Hargreaves participated in a seminar for the semi-arid Northeast sponsored by SUDENE. He presented a half day program on climatic zoning for agricultural production and participated in work groups for the purpose of presenting proposals for future water resource development programs in Northeast Brazil. The seminar was attended by about 200 Brazilian technicians.

USU organized and then conducted (July 10-26) a Water Use Management Research Seminar. Training was provided for 27 participants principally from EMBRAPA and SUDENE in Brazil. Technicians from EMBRAPA, SUDENE and the Oregon, Wisconsin and Cornell Teams assisted with the instruction.

Colombia Component

Background

Utah State University activities in the Atlantico-3 Irrigation District of the Colombian Land Reform Institute (INCORA) were initiated in January 1971. Dr. Olsen directed projects in drainage and reclamation of salinized areas (Objective 3) on light soils of a citrus grove located near Santa Lucia. Research activities in crop management on heavy soils of the Malambito Agricultural Experiment Station were established in October 1971. This section summarizes the work carried out on the Malambito Station.

The heavy soils of the Malambito Farm are representative of more than 40% of the irrigation district. Original aims of the project included the development of consumptive use data and the determination of yield functions of soil moisture and fertility for crops of economic importance to the district. However, field experiments with traditional crops of the zone were found highly erratic due to the presence of stunted and chlorotic plants randomly interspersed with areas of plants which appeared normal. The root depth for all crops studied was limited to the first few inches of the soil profile for both stunted and normal plants. Problems experienced through research efforts were identical to those of producers of the region utilizing the same crops on similar soils.

Variability within experimental stands obscured the effects of irrigation or fertilizer treatments and seemed related to soil differences more than any other factor. It was concluded that valid irrigation information could not be developed unless the source of irregular crop growth could be determined and corrected or alternative crops, well adapted to conditions of the area, could be found. The objectives of the project were modified to include these considerations. Mr. William Rubink, candidate for the M.S. degree in soils at USU was subsequently assigned to the project for a period of three months in order to carry out intensive sampling of the heavy soils for both chemical and physical analyses. Numerous samples were forwarded to Colombian laboratories and to the Department of Soil Science and Biometeorology, USU. Six different crops were evaluated under a variety of treatments in one or more of fourteen field tests.

Accomplishments to Date

Considerable progress has been achieved in the development of extensive water delivery structures and drainage systems in the Santa Lucia region of the Atlantico-3 Irrigation District. In addition to water control facilities, modern farm machinery and agricul-

tural chemicals are among the management tools commonly utilized by area producers. More important, both farmers and INCORA agronomists have accumulated several years of valuable experience in crop production since district activities were initiated. In contrast to these advances, however, crop yields continue at levels far below those required for obtaining normal agricultural profits.

Average commercial yields over a five-year period for the Santa Lucia region and the Atlantico-3 District as a whole are presented in Table 2. Low yields had casually been attributed to factors such as salinity or alkalinity, but no information was available to verify or reject various contention of this nature for the heavy soils of the Malambito Farm. Crop management recommendations were static over a period of years in spite of low production.

TABLE 2. Expected yields, average experimental and commercial yields, and estimates of production required to return investment in kilograms per hectare.

Crop	Expected yields	Experimental yields Malambito 1971-1973	Production required to return investment[1]	Commercial yields[2] 1968-1972	
				Sta. Lucia region	Atlantico -3
Corn	4000	1475	1464	--	--
Cotton	1600	1393	710	1088	1335
Upland rice	3100	3951	--	--	--
Inundated rice	6200	7302	2583	--	--
Sesame	800	569	305	137	220
Sorghum	4000	2445	1470	973	1678
Soybeans	2200	1722	975	30	956

[1] Estimates of production required to cover investment were based on 1970-72 cost data obtained from the INCORA Office of Statistics, Atlantico-3. The estimate for inundated rice was based on 1970 date of the Boliver #1 district and does not include fixed costs.

[2] Weighted means representing two to five seasons of production. Growing seasons where complete crop loss was experienced were not utilized in calculating averages.

The Water Management Research Program in Malambito was conducted in collaboration with investigators of the Colombian Agricultural Institute (ICA). Principal accomplishments of the program are as follows:

1. Intensive sampling and analysis of heavy soil of the Malambito Experiment Station by Mr. William Rubink failed to substantiate the presence of saline, sodic, or highly acidic soils as a basis for low yields and irregular crop growth. The data developed did suggest an imbalance of several cations.

2. Variable crop growth was related to excessive soil phosphorous and heavy metal toxicity. DTPA-extractable Fe, Cu and Zn were analyzed in quantities ten times greater than usually considered normal for agricultural soils. Productive soils generally contain from 0.01% to 0.1% total phosphorous. In contrast measurements of this nutrient ranged from 0.6% to 1.6% for the heavy soils of Malambito. Economically feasible measures are not available for the reclamation of soils affected in this manner.

3. Field tests with corn, cotton, sesame and sorghum indicated that these crops were poorly adapted to study site conditions (Table 2). Soybeans appeared much better adapted to the heavy soils but required frequent irrigation due to shallow root penetration. Irregular vegetative growth was also noted for upland rice. However, vigorous, uniform stands of rice were produced where irrigation by inundation was utilized. An equivalent of more than 8000 kg/ha of grain was harvested for certain treatments. Extensive testing of inundated rice with emphasis on irrigation efficiency and drainage control was recommended.

4. Colombian counterparts affiliated with the Water Management Research Program in Malambito were provided the opportunity to gain both investigative and practical experience in water and crop management.

Agronomic yields have been consistantly low over a period of years in the sector of the district where studies were conducted. Although a continued and expanded research effort remains as the most promising approach for increasing yields for a wide range of crops, immediate solutions are still lacking. Investments in irrigation and drainage facilities to date have been of little consequence in creating a profitable agricultural situation.

Photo 1. Plant growth disorders in heavy soils at Malambito was attributed to excessive amounts of phosphorus and heavy metal elements from indigenous sources. In spot shown not even weed species survived. Corn died in seedling stage. The dead plants shown were transplants that succumbed.

Dissemination and Utilization of Research

Host agencies, ICA, INCORA and USAID/ Colombia were informed regularly of project activities through meetings in Bogota or by visits to the Atlantico-3 Irrigation District. INCORA personnel located in the district were frequent observers of the research plots in Malambito, especially when rice or soybean studies were in progress.

The Atlantico-3 Project was the site of a CIDIAT short course in irrigation district management. Most of the students were INCORA employees assigned to Atlantico-3 or other districts in Colombia. USU personnel with ICA counterparts presented lectures concerned with research results developed through the Water Management Program. Participants were given a tour of the research plots in Malambito and in the citrus grove near Santa Lucia.

Also, in June 1973 ICA directors in Tibaitata met to develop a research strategy for the Atlantico-3 Irrigation District. A seminar for the purpose of reviewing USU activities in Malambito was presented. Those in attendance included the director of the Department of Agronomy as well as chairmen of the

Programs of Water and Soil Resources, Corn and Sorghum, Soils and Plant Pathology. A representative of the Plant Physiology Program was also in attendance. Plans were established for a continuation of the project in Malambito following the termination of tours of duty by USU staff. Collaborative research efforts were organized with members of the Departments of Agricultural Engineering and Agronomy.

Dr. David James and USU field staff met in Tibaitata with representatives of the Departments of Agricultural Engineering and Agronomy in September 1973. Dr. James reviewed the results of the studies conducted on Malambito soils. Areas of concentration for continuing research in Malambito were recommended.

Research results are being disseminated through final written reports on the project which has been terminated.

El Salvador Component

Background

In El Salvador, as well as in most of Central America and much of Latin America, there are well defined wet and dry seasons of approximately 6 months of duration each. The typical practice is to obtain one or in some cases two crops during the rainy season with little or no production during the dry season. There is a small amount of traditional irrigation in the country, but it is limited mostly to pasture and some small areas of vegetables. The Government of El Salvador is stressing irrigation with the Zapotitan Irrigation District completed, and the Atiocoyo-Nueva Concepcion District, scheduled for construction in November 1974.

Irrigation experiments have been carried out since the beginning of the program in 1970 at various locations in El Salvador. These have been continued during the year reported at San Andres (Zapotitan District) and Atiocoyo. USU personnel have worked with two agencies of the Ministry of Agriculture and Livestock: the National Agricultural Technology Center (CENTA) and the General Directorate of Irrigation and Drainage (DGORD).

Accomplishments to Date

Evapotranspiration

At the time the water management activities were initiated in El Salvador, lysimeters were installed at Santa Cruz Porrillo (representing the coastal zone) and San Andres (representing the interior valleys) to measure evapotranspiration from a complete grass cover. Evaporation from a USWB Class A Pan is also measured, and climatological data are available for the two sites. This is an on-going program designed to improve the reliability of the data by providing more years of observation. For the period, March 1973 - March 1974, the following results were obtained:

Location	Mean Evapotranspiration mm/day	Mean Pan Evaporation mm/day	Ratio of Evapotranspiration to Evaporation
San Andres	5.13	6.96	0.74
Sta. Cruz Porrillo	4.85	5.75	0.84

Crop Response to Irrigation and Fertility

Previous results have been reported in a series of publications. Present results are detailed in "On Farm Water Management Research in El Salvador, Progress Report 1973-1974" and in a Master of Science thesis by Don C. Kidman entitled: "Residual Nitrogen as it Affects Soil Fertility under Irrigation Agriculture in a Tropical Wet-Dry Climate". The results from two locations are included here.

San Andres. At San Andres where corn and tomatoes were irrigated by furrow, sprinkler and drip systems, the drip irrigated tomato plots currently yielded 32 metric tons/ha as compared with 26 and 27 tons/ha for the sprinkler and furrow irrigated plots, respectively. Under all irrigation methods this year there was an increase in yield with the application of 100 kg N/ha over the check plots, and under drip irrigation an additional response to 200 kg N/ha. In the case of corn there was no difference in yield among irrigation methods. All fertilized plots yielded more corn than the check plots, and maximum yields were obtained where 200 kg N/ha were utilized.

Yield averages in metric tons per hectare for the two year period by irrigation method are as follows:

	Furrow	Sprinkler	Drip
Corn	2.1	2.1	2.3
Tomato	33.4	29.6	33.6

The data indicate that soil moisture can be controlled using any of the three methods. A farmer's selection of method will depend on the available water supply and equipment. Sprinkler irrigation on tomatoes tended to reduce yields because of more disease damage.

Crop yield response to nitrogen and soil moisture was studied using grain sorghum during the rainy season (July-November). Applications of 100 and 200 kg N/ha resulted in yields of 3.8 mt/ha and 4.6

mt/ha, respectively. The hybrid corn variety H-3 was planted on the same area during the dry season to evaluate the response to applied and residual nitrogen at 4 levels of soil moisture. Table 3 gives corn yield results in metric tons per hectare by nitrogen treatment and soil moisture level (M-1 is the wettest level and M-4 the driest). Corn response from split plots to both current and residual nitrogen was defined at differing levels of soil moisture. The data represent the first year of a three year study.

TABLE 3. The effect of different amounts of water and nitrogen fertilizer on corn yields in metric tons per hectare.

Soil moisture level	Depth of water applied	Corn yields for different nitrogen rates (kg/ha) applied during previous season				
		0	100	200	400	mean
	cm	metric tons per hectare				
M-1	60.2	1.7	1.8	2.8	3.2	2.4
M-2	41.3	1.2	1.6	1.9	2.1	1.7
M-3	29.8	1.0	1.7	1.6	2.0	1.5
M-4	18.4	0.8	0.8	1.0	1.4	1.0
mean		1.2	1.4	1.8	2.2	
Soil moisture level	**Depth of water applied**	**Corn yields for different nitrogen rates (kg/ha) applied during current season**				
		0	100	200	400	mean
	cm	metric tons per hectare				
M-1	60.2	1.8	4.7	5.0	5.2	4.1
M-2	41.3	1.1	3.7	3.9	4.1	3.2
M-3	29.8	1.1	2.6	3.1	2.6	2.6
M-4	18.4	0.7	1.4	1.2	1.4	1.2
mean		1.2	3.1	3.3	3.3	2.7

In the Zapotitan Valley near San Andres, Kidman made a study to determine a method for evaluating residual soil nitrogen. Yields were measured from corn during the rainy season following a dry season experiment where the variables were irrigation method, crop and rate of application of N fertilizer. Results indicate the following: (1) soil NO_3-N alone was an efficient indicator of residual soil N; (2) there was a linear increase of soil NO_3-N with N applied four months previously to the dry season crops; (3) soil sampled to the 30 cm depth was sufficient to estimate availability of the residual N; (4) corn yields increased linearly with the increase of soil NO_3-N; (5) the measurement of residual soil NO_3-N can be used as a soil test index and in connection with N prediction equations for estimating fertilizer N requirements.

Atiocoyo. At Atiocoyo research was conducted to evaluate supplemental irrigation during the rainy season and to evaluate the residual fertilizers from three crops irrigated during the preceding dry season using two methods, furrow and sprinkler. In general yields were found higher on the areas where water was applied by sprinkler during the previous dry season, and yields tended to increase with greater increments of N for the preceding crop. Because of

frequent and abundant rainfall there was no opportunity to apply supplemental water.

Corn, beans and soybeans were grown under two methods of irrigation, furrow and sprinkler, with different rates of nitrogen fertilizer applied to the corn and beans. Various treatments of inoculant and inoculant plus nitrogen were included for soybeans.

Corn irrigated by furrows yielded more than sprinkler plots (2.4 mt/ha vs 1.9 mt/ha). The highest yield for both methods was measured where 200 kg/ha of N had been applied.

Beans showed no response to nitrogen fertilizer. The average yield under furrow irrigation was 1.6 mt/ha compared with 1.2 mt/ha under sprinkler irrigation.

Soybeans responded well to seed inoculation and yielded better under furrow than sprinkler irrigation. Nitrogen fertilizer applied in addition to the inoculant failed to increase yields. Plots with only inoculated seed produced 2.6 mt/ha. This is considered an exceptional yield for the variety Lucerna and suggests a potential for soybean production in the new irrigation district during the dry season.

This year saw the initiation of an experiment to evaluate year round pangola grass pasture production through irrigation and nitrogen fertilizer applications. Results indicated that commercial production can be doubled by extending the growing season to 12 months per year by means of irrigation. Four levels of nitrogen fertilizer were also studied. The highest of these (total annual application of 500 kg N/ha) almost doubled production of dry matter over the control plots (30.8 mt/ha vs 17.5 mt/ha).

Dissemination and Utilization of Research

The Water Management Research Program in El Salvador has been in progress for four years. Data accumulated to date serves as a basis for planning of continuing research activities. Results are disseminated annually through written reports submitted to USAID/El Salvador, CENTA and DGRD in both Spanish and English. Salvadoreans and USAID personnel located in El Salvador are also made aware of day to day progress through seminars, lectures and field days conducted by the USU staff.

Photo 2. Dr. Fullerton (left) and Eng. Stutler evaluating growth of sorghum during the wet season in El Salvador. Field plots are part of a continuous experiment involving irrigation, natural precipitation, current fertilizer nitrogen, and residual fertilizer nitrogen, as related to crop growth. The goal is to develop crops response functions to soil water and nitrogen on a year-round basis.

In March an international short course in irrigation district management was sponsored in San Salvador by CIDIAT. Participants from four Central American countries and Panama were in attendance. The USU staff presented lectures on on-farm water management during one morning session of the course. Participants were given a tour of the research plots in San Andres during the afternoon. Irrigation methods as well as a variety of research techniques and instruments were demonstrated. During April a seminar concerned with USU activities in El Salvador and other Latin American countries was presented for the USAID staff and other persons affiliated with agriculture.

In May the staff participated in a seminar designed to summarize agricultural activities by USAID contract personnel in El Salvador for newly arrived Ambassador James Campbell. In June the DGRD extension agents were given a tour of the research plots in Atiocoyo. Emphasis was placed on how information being developed would be useful to their programs.

An October meeting followed by dinner was sponsored by USU at the Camino Real Hotel in San Salvador. The purpose of the meeting was to review and discuss Water Management Program activities over the past year. Persons attending included the directors of DGRD, CENTA and USAID/ Agriculture. Also present were the sub-director of DGRD, the Director of Atiocoyo Irrigation District and the chairman of the Agricultural Engineering Department (CENTA).

Current Status of On-Going Work

A detailed report for the 1973-1974 work period is currently in preparation. On-going research is, for the most part, a continuation of the studies described in the report.

Measurements of consumptive water use for pangola grass are still in progress in San Andres and in Santa Cruz Porrillo. Actual evapotranspiration will be compared with predictions based on climatic data and with Class A Pan evaporation.

An intensive water/nitrogen interaction test with corn and sorghum was described above. Data for the first year has been compiled. Sorghum was planted in the plots in July (wet season) in order to obtain further information regarding both current and residual nitrogen in addition to supplemental, wet season irrigation. All phases of this program, planned for a period of three years, are proceeding as originally scheduled.

Corn was planted in the same plots used for the irrigation methods study already discussed for the purpose of measuring responses to residual nitrogen. The plots are currently being harvested. Sprinkler and furrow irrigation were evaluated through corn, bean and soybean production in Atiocoyo during the dry season of 1973-74. Wet season plantings of corn and rice have been established to reflect residual nitrogen effects.

A rice test involving a continuous water variable and six nitrogen levels was initiated in early June. Harvest of this experiment is in progress. The test will be duplicated again in Atiocoyo during the irrigation season.

A large percentage of the Atiocoyo district will be utilized for the production of beef and milk. A pangola pasture test involving an evaluation of irrigation methods and nitrogen levels has been in progress over the past eighteen months. The test will be terminated in November, 1974. However, excellent results to date have stimulated the design of a more intensive forage study which will be established in December. The experiment will involve water variables and amounts and frequencies of nitrogen application.

Objective 2

Development and adaptation of efficient water control and delivery systems especially on the farm.

Background

Much of the research dealing with this objective is intermixed with that of other objectives such as Objective 1. The efficiency studies on sprinkler and drip systems is reported in terms of the effect on crop production. The work on mole drain sytems is closely related to Objective 3.

Mole drains, constructed by pulling a bullet-shaped object through the soil, have been used for drainage of heavy soils in which tile drains are economically unjustified due to the required close shaping. Because of the short life of mole drains, the combined mole-tile drain system, which takes advantage of the low cost of mole drains and the long life of tile drains, was developed.

Many agricultural lands have heavy soils and are often aggravated by extremely wet and dry climatic conditions. In these areas effective drainage is important for it may mean the failure or success of seed germination. Furthermore, effective drainage accelerates the drying of land surface to permit early land preparation for planting. Harvesting is also facilitated and the time can be scheduled more definitely.

The research on mole drains under the On-Farm Water Management Research contract was initiated in 1970 aiming initially at the development of a double mole plow which was expected to produce more durable mole channels than those constructed with a single mole plow.

The activities programmed are as follows:

1. Design and fabrication of mole plows.
2. Research in power requirements for the construction of mole drains.
3. Investigation on performance and durability of mole drains.
4. Research on salt removal by mole drains.
5. Field tests and research in Latin American countries.
6. Research on the combined mole-tile drain system.
7. Preparation of a manual on the design and construction of mole drain systems.

Accomplishments to Date

Design and Fabrication of Mole Plows

Double mole plows which are believed to be capable of producing more durable mole channels were developed and tested. The design was also based on the criterion that the plow be pulled with a medium size tractor which is normally available on farms. Two single mole plows and eight double mole plows have been designed, fabricated, and tested in the field.

Power Requirement

The research on this topic was conducted in two steps. First, the investigation was done by using small models, approximately one-fifth the size of the prototype. Then, the prototypes were designed using the information from the model studies. The prototypes were later fabricated and tested in the field.

Model test results using soil from the USU Drainage Farm indicated that there is a narrow range of soil moisture content (i.e. between 25-29 percent by weight) in which a smooth and stable mole channel could be produced. It was found that the power requirement increases rapidly when the soil is only slightly too dry.

In order to be able to predict the power requirement for mole drain construction, theoretical equations based on mechanical properties of soil were developed. The verification by model and field experiments indicated satisfactory agreement between the results obtained from the equations and experiments.

In 1974 a model study was conducted to investigate the possibility of reducing the power requirement by vibrating the plow while being pulled. The result of the study is being analyzed and will be presented in an M.S. thesis.

Performance and Durability of Mole Drains

At the beginning model studies were used to investigate the hydraulic roughness of mole channels and to compare the durability of single mole channels with double mole channels. Later the two types of mole drains were constructed at the spacings of 6, 12, and 24 ft. in the field to study their durability. No evidence was observed which indicated that the single mole drains were more durable than the double mole drains. It was found that both types of mole drains performed equally well in the second year as they did in the first year. Both types of mole drains still produced water during the third summer following the installation.

A theory of the combined system was developed. The equations derived could be used in the design of the system and for predicting the performance of a proposed system. Two technical papers on the theory, the performance, and evaluation of the combined system were written and had been accepted for publication in national and international journals. The field performance of a combined mole-tile drain system and the durability of the two types of mole drains in the system were investigated in 1972, 1973, and 1974. The results indicated that the water table in the combined system receded almost twice as fast as that in the tile drain system (without mole drains).

Salt Removal by Mole Drains

It was found during the first year of field experiment that the salinity of the soil, as measured by the electrical conductivity of the soil saturation extract, reduced much more in the moled area than in the unmoled area. In order to obtain reliable data, a systematic experiment was conducted to investigate the effectiveness of mole drains for leaching in the summer of 1973. The results have been analyzed in 1974 and presented in a thesis, "Effectiveness of Mole Drains in Leaching Heavy Soils".

Field Tests and Research in Latin American Countries

Field tests were conducted in El Salvador and Colombia. Single and double mole plows using USU designs were fabricated in the two countries. It is expected that more extensive field experiments will take place after foreign graduate students who worked on mole drain research at USU return to their homelands.

Dissemination and Utilization of Research

Since the beginning of the present research program in 1970, the research data obtained have been used in producing seven M.S. theses with another M.S. thesis to be completed in December, 1974. One technical paper was prepared and presented at an international symposium. Two technical papers using the experimental data have been accepted for publication in national and international journals.

The theses were written by graduate students from Turkey, Iran, Iraq, Republic of China, Colombia and Thailand. Many of these students have expressed their intention of continuing the research on mole drains after returning to their homelands. They believe that this type of drainage system could be the most suitable for the local conditions.

A preliminary field study in Tibaitata, Bogota, Colombia, demonstrated larger corn plants grown in the moled area than those in the unmoled field.

The work has received attention from people both locally and abroad. Requests for information regarding research findings and publications were received from Ireland, UAR, Brazil and Thailand. Local Utah farmers have been interested in the project and have offered the use of their land for experiments. Others have requested advice when installing mole drains using USU designed mole plows.

Photo 3. **Ing. Agr. Roberto Gonzales (INCORA), Dr. Olsen (USU), and Ing. Hugo Garcia (ICA) evaluating the performance of a sprinkler irrigation system.**

Objective 3

Development of strategies for minimizing the deleterious effects on crops of excess surface and subsurface water, poor water quality and excessive concentrations of soil salinity, exchangeable sodium and other toxic elements.

Colombia Component

Background

Previous annual progress reports have referred to the drainage and leaching experiments carried out in the period 1971-1973 by Professor Olsen in collaboration with ICA and INCORA in the Atlantico-3 Project of the north coast of Colombia. The results indicated that the major contributing factor to the high water table and the saline soil conditions in the 16-hectare study area was the lack of surface drainage in a region of intense seasonal rainfall. The water table was lowered and the saline conditions were reduced with the installation of a subsurface drainage system, but the study showed that the adverse conditions would not have been so severe if good surface drainage had been provided in the affected area when the land was initially prepared for cultivation.

Leaching studies were implemented on extremely salinized soils where no natural vegetation would grow. The results indicated that the salt affected soils in the study area can be reclaimed from the barren conditions using the soil and water management practices required for inundated rice culture (provided that adequate subsurface drainage is available); and that 8 metric tons per hectare of paddy rice can be obtained during the reclamation process, which insures an income from the affected area during the reclamation process.

Photo 4. **Ing. Hugo Restreppo (center) the ICA counterpart of Dr. Olsen in Colombia, and two field workers preparing a rice paddy for the leaching experiment.**

Dissemination and Utilization of Research

The results obtained from both of the above studies are typical of what might be accomplished in other areas of Latin America having similar conditions of climate and soils where high water tables and saline soils are present.

In the final report, "Land Drainage and Soil Reclamation Procedures In Arid and Sub-Humid Areas of Developing Countries, Using, as an Example, the Atlantico-3 Project, Colombia," Olsen and Christiansen enumerate several points relating how to apply the research results to the overall Atlantico-3 project. They also give a discussion on the transferability of the results to other areas. Their report is the unattached Appendix B.

For INCORA and ICA to fully realize the benefits to be gained from the research already conducted, and to determine whether or not this zone can produce citrus economically, Olsen and Christiansen also note in their final report that further research should be conducted by ICA. They identify eleven problems needing research and provide an outline of how to proceed with the research for the more complex studies.

Current Status of On-Going Work

The contract with Colombia was terminated in January, 1974. Prior to the departure of Professor Olsen, recommendations were given to his ICA counterpart regarding obtaining additional field data and the establishment of additional studies. These recommendations were again delineated in the final report under the topic, Suggestions for Further Research.

Peru Component

Background

The AID mission in Peru has agreed to provide technical assistance to the Ministry of Agriculture (MOA) for the solution of specific problem areas considered to be of high priority to the Government of Peru.

One of these priority areas pertain to the development of a Pilot Overhead Sprinkler Irrigation Project in the valley of La Joya with an investment of thirty million dollars to provide water to some 1400 hectares of land. The first stage of this project is to leach the salt deposits from the soil profile of this arid region, utilizing the sprinkler irrigation system.

Accomplishments to Date

Utah State University provided the services of Dr. Olsen for three months as a specialist in Agricultural and Irrigation Engineering to assist the Land Reclamation Office (SUDRET) of the MOA in a series of studies related to the leaching of salt deposits in soils using sprinklers. Dr. Olsen was selected because of his experience gained from USU AID-sponsored On Farm Water Management Research in Latin America, and because of his fluency in the Spanish language.

Dr. Olsen reviewed all available soil maps, topographic information, meterological data, the results of laboratory soil analysis, and site research as related to the La Joya Irrigation Project. Several days were spent with his Peruvian counterpart in the project area determining first hand what the problem consisted of, and consulting with the project engineers.

A leaching program was developed that was compatible with the soil conditions, the sprinkler system as designed by the project engineers, and the schedule of water delivery to the new colonists being settled in the area. Alfalfa was planned as the initial crop for the new areas being developed, so a series of test strips of this crop were incorporated into the leaching program to determine the effectiveness of the leaching operation and at what stage of the soil reclamation process the alfalfa could be planted by the settlers.

The infrastructure for the delivery of water to the farm irrigation systems was not complete, so Dr. Olsen also spent some time with his counterpart visiting other projects in Peru where drainage and salinity problems exist.

One week was spent traveling with the USAID/Peru Food and Agriculture Officer in the Chimbote area to the north of Lima where the Santa, Lacramarca, Nepena, Casma, Sechin, Culebras, and Huarmey Valleys were visited and small irrigation projects studied. It was determined that some valleys have chronic water shortages in comparison to the arable land. Other valleys were found to have generally plentiful water supplies with misuse of the water, which leads to drainage problems in the lower part of the valley. Both conditions would be improved by more efficient use of the irrigation water. Recommendations were made for increasing the efficiency of water use in the different valleys.

A seminar was given by Dr. Olsen to personnel of the MOA at which the problems encountered in the soils of the La Joya Project were discussed and the planned Sprinkler Leaching Program was pre-

sented. A joint paper was prepared by Dr. Olsen and his counterpart, Ing. Agr. Luis Manrique C., which discussed the soil problems associated with the La Joya Project and the method of reclaiming them by leaching with sprinklers for presentation at the First National Convention of Agricultural Engineers in Lima, June 25-28, 1974.

A report, "Sprinkler Leaching Program for Very Saline Desert Soils in the La Joya Irrigation Project, Peru", in cooperation with USAID/Peru and SUDRET, DIPRECO, Ministerio de Agricultura, Lima, Peru, June 1974, was prepared by Dr. Olsen. Copies are available in both Spanish and English.

Water Quality Component

Background

During a short-term assignment to Guatemala in 1972, Christiansen and Olsen encountered a situation when visiting the La Fragua Irrigation Project where certain well waters used for irrigation had created a sodic soil condition resulting in very low infiltration rates. The use of these waters had been discontinued after the expense of drilling the wells and installing deep-well turbine pumps and motors. Complete analyses of the waters had been made, and they were reported by a consulting engineering firm to be very acceptable water for irrigation according to standards in common use.

In their Guatemala report Christiansen and Olsen proposed a set of criteria for rating the quality of irrigation water that considers more of the factors which they feel are generally responsible for degrading water for agricultural purposes.

Accomplishments to Date

Christiansen and Olsen have recently expanded the idea of a rating system they proposed for establishing the acceptability of a given water for irrigation purposes. A computer program has been devised which will accept the chemical analysis of the water as reported by a laboratory and classify the water in each of seven categories in six levels of acceptability. Using the computer as a tool, classifications have been made on over 140 surface and well waters (many having analyses for each month of the year) from California, Colorado, Utah, Bolivia, Colombia, and Guatemala. Examples were selected which illustrate both excellent waters as well as extremely hazardous waters in each of the categories considered. The rating system as originally proposed has been altered slightly as a result of the computer exercise to make the ratings in each category more consistent with each other. The revised rating system is given in Table 4.

TABLE 4. Suggested Classification for Irrigation Water, Maximum Values.

Classification	EC mmhos	Na^+ %	SAR	Na_2CO_3 meq/l	Cl^- meq/l	ES meq/l	Boron ppm
1	0.5	40	3	0.5	3	4	0.5
2	1.0	60	6	1.0	6	8	1.0
3	2.0	70	9	2.0	10	16	2.0
4	3.0	80	12	3.0	15	24	3.0
5	4.0	90	15	4.0	20	32	4.0

Note:
EC = electrical conductivity of the water,
Na^+ = sodium ion percentage of the total cations in the water,
SAR = sodium adsorption ratio,
Na_2CO_3 = residual sodium carbonate,
Cl^- = chloride ion present,
ES = effective salinity as defined by Doneen, and
Boron = boron present.

In this classification system a water rated number one in all categories would be considered excellent for agricultural use, and one that exceeded the limits for Class 5 (which would be rated 6) would generally not be usable for irrigation. Intermediate values are relative to these extremes. Waters are

classified with respect to each factor, and no attempt is, or should be made to combine the ratings into a single index. A water might be rated number 1 for all factors except boron which might be number 6. Due consideration must be given to conditions of drainage, soil type, and the crop to be grown before any judgment is made regarding the acceptability of any given water after the classification is made and the hazardous factors are recognized.

Two reports are being developed which will present the classification system, illustrate its use, give examples of water analyses, and present the computer program for making the classifications.

Drainage Manual Component

Background

There are many technical treatises on drainage theory which include derivations of numerous mathematical equations related to the size, depth, and spacing of drains, but there is very little material available which discusses philosophically the causes of drainage and salinity problems in irrigated areas, how to detect the symptoms of the initial development of poor drainage conditions, means of avoiding or eliminating the occurrence of high water table and/or salinity conditions prior to the necessity arising for the installation of a drainage system, and finally if the construction of a network of drains is deemed essential, how to proceed with the initial investigations, field work, and construction of the system.

This paucity of the philosophy of agricultural land drainage in irrigation areas in the hands of implementing agencies and technicians has become very apparent in the experience of Utah State University scientists throughout the less developed world. It has become especially apparent that the agencies and persons responsible for decision making and the allocation of project funds (not necessarily technicians) do not really understand the needs for a consideration of existing or anticipated problems of drainage and salinity in the early stages of the development of an irrigation project. For these reasons Drs. Christiansen and Olsen have been requested to prepare a drainage manual.

Accomplishments to Date

A preliminary 64 page manual was reproduced by Christiansen and Olsen in April, 1974, entitled, "Drainage and Salinity Problems in Irrigated Areas, How to Avoid or Minimize Them." This has been reviewed and suggestions for improvement are being incorporated into the revision. Drs. Ronald C. Reeve, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland; and Lyman S. Willardson, Professor of Irrigation Engineering, Utah State University have joined as authors. This edition is currently about half completed.

Dissemination and Utilization of Research

It is anticipated that this drainage manual will be finally translated into Spanish for distribution to the responsible funding and project implementation agencies throughout Latin America. (The English version will have additional distribution). This should cause the anticipation of and earlier funding for the avoidance or control of drainage and salinity problems before the problems reach the stage of reducing crop yields or, in the extreme, of putting valuable developed agricultural land out of production.

Objective 4

Identification of institutional and policy factors (legal, social, economic, manpower, credit, etc.) that influence the efficient distribution, management and utilization of water at the farm level, and the development of strategies for replacing inhibiting factors with facilitating factors.

Water Law Component

Background

Legal and institutional restraints and facilitators play a significant role in rational use of water on the farm. Identification of these factors and removal of restraints are vital to a complete program dealing with on-farm water management. Published and disseminated research clearly defining the present status of water laws and administration in a given region demonstrates alternatives actually in force in the various countries and furnishes a sound basis for comparisons and selection for improved legal systems without the intervention of a "foreign expert." The collection, documentation and dissemination of this critical information is the principal goal of this component.

Accomplishments to Date

USU has accumulated an in-house micro-fiche library of global water laws. Later it collected the detailed water laws and regulations for the Andean countries of Bolivia, Chile, Colombia, Ecuador and Peru. Professor Daines then prepared drafts of a book entitled "Water Legislation in the Andean Pact Countries, Resume and Comparison" coauthored by Gonzalo Falconi H., legal advisor of the Ecuadorian Water Resources Institute, with English and Spanish versions.

The materials collected provided the information base from which the Ecuadorian Water Code of 1972 and Regulations of 1973 were prepared. Professor Daines also provided consultations to the governments of Colombia and Bolivia on contemplated water code changes in those countries.

Planning and organization was completed for a Water Law Seminar for the dual purpose of disseminating the information contained in the book referred to above and also verifying the accuracy of its contents before final publication.

Water Law Seminar

Professor Daines organized and directed the first Andean Water Law Seminar held in Quito, Ecuador, from January 12 to January 19, 1974. An abstract of the printed proceedings published in Spanish is included in this report. The seminar was attended by high level water administrators and legislation drafters from the Andean countries of Bolivia, Chile, Colombia, Ecuador and Peru. A Spanish draft of the book, "Water Legislation in the Andean Pact Countries", formed the basic documentation through which alternatives to water law problems were presented to the participants. Their suggestions were also received for incorporation into the final draft of the book. Significant recommendations came from the group. AID observers reported that the Seminar was very successful.

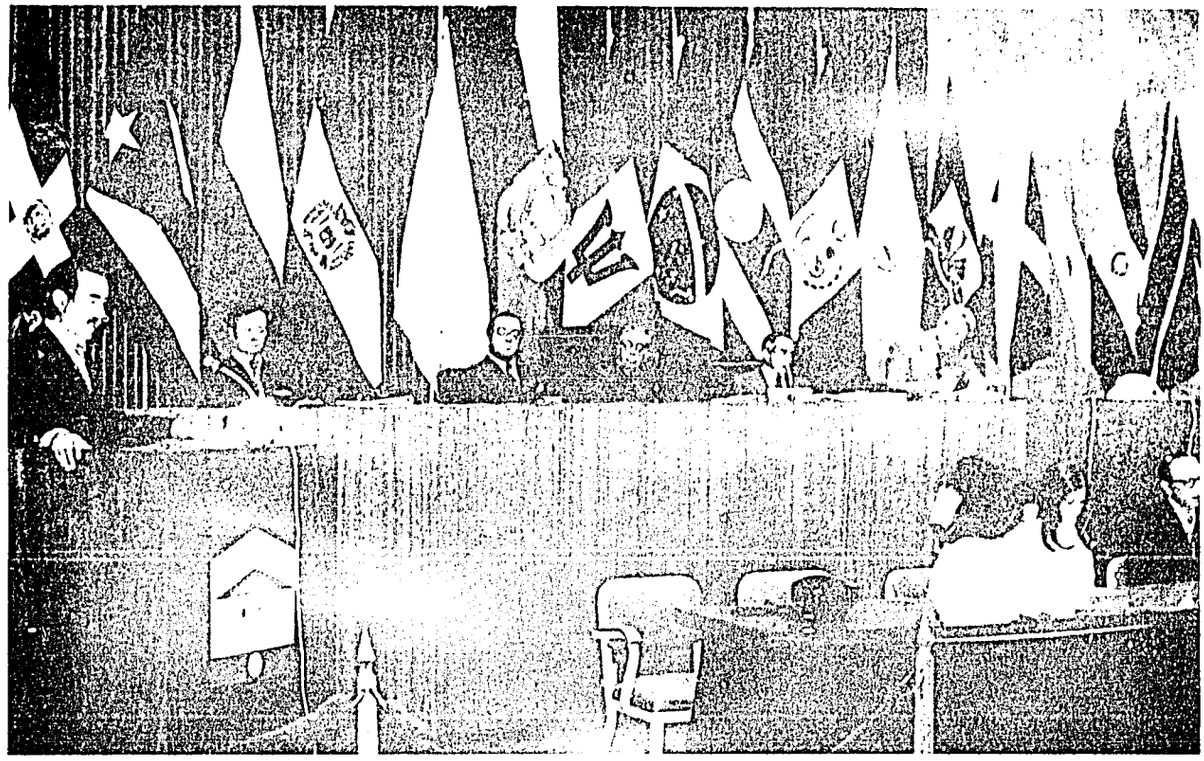

Photo 5. The book "Water Legislation in the Andean Pact Countries" was the subject of this Andean Water Law Seminar held in Quito, Ecuador in January 1974 and attended by water administrators and legislation drafters from Bolivia, Chile, Colombia, Ecuador, and Peru.

Publication of Water Law Digest

The seminar inputs were integrated into the Spanish and English drafts of the digest, "Water Legislation in the Andean Pact Countries." The final publication of 2,000 copies both in Spanish and English is completed. The distribution of the book to significant users is not yet completed. A copy of the book in English is the separate unattached Appendix C to this report and an abstract is contained in the attached Appendix A.

Andean Irrigation Institutional Research Project

A significant results analysis of the research in the book and the Seminar demonstrated that important indicators of institutional and legal facilitators and inhibitors could best be illuminated by empirical research into the interaction between irrigation water users and the various types of cooperatives and government bodies that act as agencies for distributing water to the irrigation user. There has been practically no reported descriptive or analytical

research on this subject. During the year a detailed "Work Plan" for research in the Andean Countries and a "Questionnaire" for the first phase of the work plan have been developed. The approval of USAID/ Ecuador has been obtained to commence the research program in Ecuador, and a strategy exists for extending the study to Chile, with financial support from Resources for the Future, and to Bolivia. Efforts are continuing to obtain approval for this research in Peru and Colombia when conditions stabilize in those countries. A full time researcher, Mr. Craig Anderson, is working on this program now and will be headquartered in Quito, Ecuador, beginning in January, 1975.

International Conference on Global Water Law Systems

Dr. Daines of USU is cooperating with Colorado State University in the planning and direction of an "International Conference on Global Water Law Systems" to be held in Valencia, Spain, in September, 1975. He is on the Conference committee, participated in planning meetings held in Spain and is preparing a conference presentation. This program is part of an on-going cooperative effort on broadening the documentation of alternatives to a world wide basis.

Miscellaneous

Professor Daines presented a paper at a Resources for the Future Conference in Santiago, Chile, in June of 1974, and has made preliminary plans for the collection of materials to expand the coverage of the book referred to above to include the Central American countries.

Economics Component

Background

The initial objectives of the economic phase have been modified and refined through experience in the field and in response to AID/TAB review. At present three main courses of action are being followed. 1) Establish economic bench marks through collection of data from various Latin American countries as part of field research or in other ways. 2) Economic assessment of specific on-farm water management practices or potential irrigation benefits. 3) Support the design and execution of proposed field research of the Water Law Phase.

Farm budgets from several Latin American countries (with and without irrigation) covering a variety of crops have been collected during the course of 11 rural surveys executed since 1970. Recent budgets have been obtained from other investigators and agencies. In addition a substantial library of technical, statistical and planning documents has been acquired through correspondence or by gift from Latin American contacts. This material is an important foundation of an economics data bank associated with contractual obligations to emphasize regional and international transfer of on-farm irrigation and other cultural practice recommendations.

The rural surveys mentioned have provided data for a number of working papers and publications, the titles of which have appeared in earlier annual reports. In general it has been found that investments in supplemental water supplies yield net benefits higher than those from other modern inputs. Rural income distribution can be made more equal with better technology. The challenge is to adapt what is technically possible to small farmer capabilities.

Accomplishments to Date

There are no population or agricultural census statistics for Bolivia. As a consequence, many important parameters, necessary in agricultural planning, are simply "best estimates". As part of the crop and food bench mark statistics activity, urban income elasticities have been estimated for over 40 major food groups, utilizing data from a large household consumption survey conducted in La Paz by Michigan State University. As shown in Table 5, the results obtained vary considerably from the values currently in use as estimated by FAO. The results are fairly consistent with similar estimates made in Peru by a USDA study.

TABLE 5. Some Comparisons of Elasticity of Demand for Food According to Various Sources.

	FAO/Bolivia	Lima ERS/USDA	LaPaz USU
Wheat	.6	.42	.36
Rice	--		.32
Corn	.5		.80
Potatoes	.2	.48	.37
Sugar	.5	.49	.26
Fats and oils	.9	.76	.66
Beef	--	.89	.51
Mutton	--		.94
Pulses	.5	.43	1.10
Fresh Fruits	.6	1.52	1.13

La Paz families appear to treat red meats as well as cereals, potatoes and sugar as somewhat inferior foods. This means they have relatively little difficulty in obtaining such products. Even fresh fruits are treated as necessities rather than as a luxury.

Colleagues in the Department of Marketing and Transportation Administration, Michigan State University, have provided a computer tape of all the raw survey data obtained in an extensive marketing study in La Paz in the late 1960's.

A preliminary analysis of potential benefits of surface irrigation to production of basic food crops as well as for horticultural items has been compiled for two irrigation districts in El Salvador (Table 6). In one district, Zapotitan, only supplemental dry season water supplies are considered. Nevertheless benefits are quite high even on beans. This is an important result because, in general, irrigation development to be viable, must "pay" on even the lowest valued crops.

Development of irrigation in the other district, Atiocoyo, would provide a supply of dry season water for the first time. The average cost per hectare of on-farm development would be more expensive, but the returns are not unattractive because a crop of both beans and corn can be obtained during the dry season.

Irrigated pastures are being developed by a number of ranchers in El Salvador and the summarized estimates in Table 6 suggest why. When allowance is made for the reduced need for labor and attendant legal and institutional constraints, returns from pastures may appear fully competitive with food crops.

TABLE 6. Preliminary Estimates of Benefits from On-Farm Investments in Irrigation Systems in Two Areas of El Salvador – (Dry Season)

Crop	Annual Net Returns to Management and Capital Improvements (R)			Estimated Required On-Farm Investment for Irrigation Water Managements or Improvements (Surface) (C_o)	Internal Rate of Return Estimated for 8 Year Investment Horizon
	Current	Improved	Difference		
	---------- (¢/ha.)----------			¢/ha.	%
Zapotitan					
Tomato[a]					
Cucumber	¢987.80	¢2,334.04	¢1,346.24	¢ 215	626
Corn	-3.13	187.67	190.8	215	100
Beans	203.63	369.68	166.05	215	76
Pasture	789	858[b]	78	215	24
Atiocoyo					
Onions	70 est.	¢1,313,39	¢1,243.39	¢ 515	241
Corn	70 est.	177.47	107.47	515	13
Beans	70 est.	994.33	924.33	515	179
Pasture[c]	70 est.	431	361	515	64
				(1,330)[d]	(11)

[a]Land allocated .6 to tomatoes and .4 to cucumbers. Tomatoes 50% non-marketable, cucumbers 25% non-marketable, under current practices; 20% and 10% non-marketable under improved practices.

[b]Estimated increase due to better management of 10%.

[c]5-year time horizon.

[d]Cost of sprinkler system on rough lands.

Extension agents and other MAG personnel contributed about 2 man-weeks toward collecting and refining survey and experimental data.

A linear programming analysis of the main agricultural regions of Bolivia indicates that present activity levels generally are very similar to those that are generated by a profit maximizing solution within the model. In Santa Cruz Department this conclusion does not hold. The marginal value product of labor is much higher there than elsewhere. A greater labor mobility would increase total output from the agricultural sector. Insufficient quantities of data were available to make a firm conclusion about achieving greater irrigation water use efficiency. However, there is some indication that agricultural sector revenues in each administrative unit would increase if small, additional amounts were spent to clean and maintain present irrigation systems.

In another linear programming analysis of the agricultural sector in Bolivia, the question has been asked, "What is the least expensive way to achieve certain food demand targets in the year 1985?" New land can be developed more cheaply than to rely solely on high-cost technology and more credit. More land of all qualities should be brought into production in nearly every zone of the country. Coffee, cocoa leaf, rice, quinoa, barley, tobacco, cotton and pineapple all exhibit sensitivity to changes in production coefficients and are most sensitive to agricultural policy that effects prices and inputs. Milk cows, sugar cane, sheep and corn silage are the least sensitive.

Once new technologies, including irrigation and fertilizer are in place, rice, cotton, peanuts, potatoes and wheat can all be produced at lower out-of-pocket resource costs than at present. These are important crops and an irrigation/fertilization policy should be investigated. Other crops may do quite well with traditional technology. Labor should shift from the altiplano to the oriente. Capital is very competitive as a substitute for labor, especially in the new commercial agricultural areas.

A production function analysis of on-farm survey data obtained from rice growers in the Guayas Basin of Ecuador supports the land reform policy of that country. As unproductive or grazing land moves into the hands of small farmers (where it is augmented by irrigation and leveling investments) the value of the land increases substantially. Land is the main recipient (factor) as far as division of total monetary returns is concerned. Capital gets far less; but these farmers use few modern inputs except some credit. More capital needs to be employed on dry farms. Irrigation provides benefits, but it is expensive in relation to the total increase in output achieved, the pumps used are too small. In cases where farmers own 10-20 hectares and continue to farm with traditional methods, output per hectare drops considerably. This is only one of several indications that not enough labor is available on campesino rice farms during critical cultivation periods.

Regional Workshop

AID has identified "On-Farm Water Management" as one of the key problems that must be solved in order to achieve more food production and a better life for the small farmer. Better water management on the farmer's field relates directly to the availability of food that people eat, thereby affecting their health, nutrition, and productive human energy. Consistent with this, FAO and AID jointly sponsored a Workshop on Irrigation and Drainage Planning at the Farm Level in April 1974. The workshop entitled, "Seminario de Riego y Drenaje a Nivel Parcelario para los Paises Centroamericanos y Panama," was composed of three days of technical sessions in San Jose; two days in the field discussing problems and seeing results accomplished at the Fabio Baudrit Experiment Farm (Universidad de Costa Rica), the Itiquis Irrigation Project, and the Instituto Interamericano de Ciencias Agricolas (Centro Tropical de Ensenanza, CATIE); and a final day of technical sessions devoted to country reports in San Jose. The working language of all sessions was Spanish.

AID sponsored Water Management Research scientists in the area were used along with FAO field personnel to carry the major assignments in the technical program. As participants in the workshop, two senior officers in charge of, or directly related with, water development plans and management were invited from Guatemala, Honduras, Costa Rica, Nicaragua, El Salvador and Panama. One delegate each from the Dominican Republic, Mexico and Colombia were invited as observers.

The agenda included the following major topics:

The role of effective irrigation water management in Central America.
Surface irrigation methods and practice.
Drainage as a means of water control at the field level.
Drainage methods and practice.
Crop water requirements.
Water conveyance and distributions systems – Technical aspects.
Management of irrigation schemes.
Country reports.
Recommendations.

USU sent Professors Alfaro, Hargreaves, Olsen, and Stutler as lecturers and discussion leaders. Professor Stutler discussed methods and practices of surface irrigation, Dr. Olsen discussed drainage as a means of water control, Professor Hargreaves presented a discussion on crop water requirements, and Dr. Alfaro presented the topic of sprinkler irrigation.

Photo 6. Participants from Central America and Panama observing the use of siphon tubes for better water control in furrow irrigation.

The workshop was viewed as an excellent means of utilizing the products of the AID-sponsored On-Farm Water Management Research. The USU/AID scientists who participated all have an intimate knowledge of the conditions prevailing in Central America through working in their respective fields on the very problems under consideration, and thus could relate very well with the needs of the participants. All of the Utah State University scientists are fluent in Spanish, so all points of interest and controversy were lively discussed after each technical presentation.

Particularly rewarding was the final day devoted to the Country Reports. The reports were invariably oriented to the problems each country was facing in light of the material presented previously in the workshop. Lengthy discussion followed each report in which there was considerable sharing of experience between the participants and the AID-FAO technicians. None of these impromptu discussions could have been really effective if it had been necessary to translate all of the proceedings into Spanish and English.

Photo 7. The use of locally manufactured flexible tubing to improve water distribution to irrigation furrows being demonstrated to interested participants in the Workshop in Costa Rica.

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74-148 Hargreaves, George H. Climatic Zoning for Agricultural Production in Northeast Brazil.

74-149 Hargreaves, George H. Moisture Availability and Crop Production.

74-151 Kidman, Don Carlos. Residual Nitrogen as it Affects Soil Fertility Under Irrigated Agriculture in a Tropical Wet-Dry Climate. M.S. Thesis.

74-152 Olsen, Edwin C., III. Sprinkler Leaching Program for Very Saline Desert Soils in the LaJoya Irrigation Project, Peru.

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APPENDIX A

ABSTRACTS

ABSTRACTS

INVESTIGACIONES SOBRE EVAPOTRANSPIRACION Y REQUERIMENTOS DE IRRIGACION

by G. H. Hargreaves and J. E. Christiansen

Methods are given for calculation of irrigation requirements for crops and a comparison made between dependable precipitation and potential evapotranspiration. Data are analyzed for 13 locations. The paper is accompanied by 13 map sheets showing moisture excesses and deficits for each month of the year and an annual average summary. The study represents a joint effort by Instituto Geografico Nacional (El Salvador), Utah State University, Interamerican Geodetic Survey, Agency for International Development and Centro Interamericano de Desarrollo Integral de Aguas y Tierras. [70-D102 (16 pages)]

PAN EVAPORATION AND EVAPOTRANSPIRATION IN IRAN

by Abdol Reza Khosravi, Master of Science Utah State University, 1972

Monthly climatological data, including Class A pan evaporation, for 6 stations in Iran, with a total of 132 months of data, was analyzed to develop a formula for estimating pan evaporation where evaporation measurements are not made.

Using computed pan evaporation and coefficients previously prepared by Christiansen, a formula was developed to estimate potential evaporation. This formula was used to compute potential evapotranspiration for 24 stations in Iran with 2615 months of climatic data. These values were then compared with values computed by four other formulas.

Measured evapotranspiration of one station in Iran with two years of data for seven crops was compared with measured pan evaporation and computed evapotranspiration. [70-B103 (174 pages)]

ANALYSIS OF VENEZUELAN DATA TO COMPARE COMPUTED EVAPORATION, POTENTIAL EVAPOTRANSPIRATION, AND EVAPOTRANSPIRATION DEFICIT

by Supojana Rujirakul, Master of Science Utah State University, 1970

The monthly climatological and evaporation data for six years of record at twenty stations in Venezuela were analyzed in this study.

Pan evaporation was computed using Christiansen's formulas. One based on theoretical radiation and the other based on measured radiation. Potential evapotranspiration was computed from Jensen's, Linacre's, and Christiansen's formulas. Also, the evapotranspiration deficit was computed and the results of the computation were discussed.

All of the formulas of this study gave reasonable values, but Christiansen's formulas, which take into consideration more of the climatic factors, are believed to be the most reliable. [70-B104 (118 pages)]

ESTIMATION OF EVAPORATION AND EVAPOTRANSPIRATION IN COLOMBIA

by R. Kern Stutler, Master of Science Utah State University, 1970

A formula for estimating class A pan evaporation from sheltered evaporation was developed using data from ten climatological stations in Venezuela. The formula is of the form:

$$Ev = K\, E_{vf}\, C_{ef}$$

where

- Ev = pan evaporation,
- K = a constant,
- E_{vf} = sheltered evaporation,
- C_{ef} = a coefficient based on the amount of Fuess or sheltered evaporation.

Using this formula the pan evaporation was estimated for 17 stations in Venezuela and 20 stations in Colombia where measured sheltered evaporation data were available. Using Christiansen's formula the potential evapotranspiration was also estimated from the pan evaporation and compared to that estimated by Christiansen's formula using climatic data.

Using the Christiansen-Pardo formula, sheltered evaporation was estimated for 26 stations in Colombia. From this estimated sheltered evaporation the pan evaporation was estimated using the new formula and compared with the pan evaporation estimated by the Christiansen formula for climatic data. [70-B105 (103 pages)]

IRRIGATION REQUIREMENTS IN LATIN AMERICAN COUNTRIES

by J. E. Christiansen and G. H. Hargreaves

This paper is a review of procedures for the analysis of climatic data for Latin American countries to determine the need for irrigation and irrigation requirements in several Central and South American countries. Technical terms are defined and formulas for estimating potential evapotranspiration, dependable precipitation and potential irrigation requirement are presented. Examples of the available data and computer printouts of the analyses are presented. [70-C106 (10 pages)]

IRRIGATION REQUIREMENTS FROM EVAPORATION

by J. E. Christiansen and G. H. Hargreaves

Pan evaporation, as measured with a Class A pan under standardized conditions is a reliable index of climate as it pertains to evapotranspiration. Pan evaporation is now being measured in many places in the world, but when it is not available it may be estimated from many formulas, some of which are included here. Potential evapotranspiration can be estimated from pan evaporation or computed directly from radiation and climatic data. Actual evapotranspiration varies with crops, and many factors besides climate, but can be best

estimated from potential evapotranspiration or directly from pan evaporation.

Three formulas are presented for estimating Class A pan evaporation and four for estimating potential evapotranspiration. These formulas may be applied in either English or metric units. Coefficients are presented from which actual evapotranspiration may be estimated from either measured or estimated pan evaporation, or from estimated potential evapotranspiration.

Irrigation water requirements depend basically upon the evapotranspiration, but also upon many other factors including precipitation and irrigation application efficiency. As water resources become more limiting, the need for better estimates of evapotranspiration will increase. [70-C107 (28 pages)]

A STUDY OF WIND VELOCITY PROFILE AT SANTA CRUZ EXPERIMENT STATION, VENEZUELA

by Omar Gutierrez, Master of Science
Utah State University, 1970

Data from five years of daily records of wind velocity at heights .6, 2, and 10 meters above the ground taken at Santa Cruz Experiment Station, Venezuelan Ministry of Public Works, were used to study the characteristics of wind profile with respect to height above the ground level in the lower 10 meters of the atmosphere.

The information was used to compare formulas for wind velocity profile found in the literature, and formulas developed at Utah State University with actual data. The formulas that best fit the Santa Cruz Experiment Station data are Christiansen-Hargreaves', Power-law and Stutler-Hardee's. All of these formulas were either developed at, or modified at, Utah State University

The other formulas ranked in the following order: Geigher's as modified by Gutierrez, Logarithmic, and Sutton's.

A simple and practical relation was proposed to correct Geigher's formula. Computer programs were developed to process the information. [70-B201 (53 pages)]

MOLE DRAINAGE CONSTRUCTION, OPTIMUM SOIL MOISTURE CONTENT AND CORRESPONDING POWER REQUIREMENT

by Kitcha Polparsi, Master of Science
Utah State University, 1970

Modeling was used to determine the relationship between the most efficient form of mole channel and the moisture content of the soil at the time of construction, and to find the corresponding power requirement to operate a mole plow. The mole plow consisted of a 19/32-inch diameter steel torpedo attached to a steel blade 3/16-inch thick which was pushed through a clay soil contained in a 10 x 18 x 11 inch Plexiglas box. The relative efficiency of the mole channel was determined by visual inspection and by the discharge rate through the mole channel under a constant head loss. Visual inspection showed that smooth, well-formed mole channels could be obtained when constructed in soils having a moisture content higher than the plastic limit of the soil. Measurement of the discharge rate agreed with the visual inspection.

The equation was developed for determination of the power required to operate a mole plow in terms of the soil properties and the dimensions of the plow. The theoretical force required to operate the mole plow was found to be approximately 25 to 35 percent larger than that obtained experimentally.

Both theoretical and experimental resisting forces indicated that the variation of the force with moisture content was small in the range of excessively dry and wet soil. The variation was large in the range of moisture content suitable for mole channel construction. [70-B301 (100 pages)]

DURABILITY OF DOUBLE MOLE DRAINS

by Anan Sukwiwat, Master of Science
Utah State University, 1970

The purpose of this study is to compare the durability of mole channels constructed with a conventional mole plow and a modified or double mole plow by means of a model. The conventional mole plow consists of a single torpedo which makes a single mole channel while being pulled through the soil. The modified or double mole plow has two torpedoes which leaves two mole channels in the soil. The two types of mole plow utilize the same blade thickness of 1/4 inch and torpedo diameter of 3/4 inch.

The experiment was conducted by constructing mole channels by the two types of mole plow. The water was then applied to the surface at a certain rate and the ability of the mole channel in discharging the water was measured after certain depths of water had been applied. Four different rates of application were used.

The result of the study indicated that the mole channel constructed with the modified plow yielded better durability than ones constructed with the conventional mole plow. The per cent deterioration of the conventional mole channel did not change when the rate of application of water was increased from 1/2 to 1 inch per hour. For the double channel the per cent deterioration increased appreciably with an increase in rate of application of water. [70-B302 (66 pages)]

COMBINED SURFACE WATER-GROUNDWATER ANALYSIS OF HYDROLOGICAL SYSTEMS WITH THE AID OF THE HYBRID COMPUTER

by W. James Morris, Neil W. Morgan, Bi Huei Wang and J. Paul Riley

The solution of the partial and total differential equations for an integrated surface water-groundwater system with the aid of the hybrid computer is described.

A versatile computing technique has been developed to make a rapid and accurate study of the groundwater response due to varying inputs (deep percolation) or outputs (evapotranspiration) from the groundwater system. Areal variations in input parameters such as vegetation, crop patterns, hydrological parameters, and boundary conditions are represented by a grid network. The technique, developed for the analysis of a surface water-groundwater system in Colombia, South America provides the water resources engineer with valuable information in appraising various development alternatives under conditions of irrigated agriculture. [70-C303 (27 pages)]

IRRIGATION REQUIREMENTS AND CLIMATIC EVALUATIONS FOR VENEZUELA

by Jerald E. Christiansen and George H. Hargreaves

Data are presented from 148 precipitation stations including 55 which had Class A pan evaporation, and 7 which had complete climatic data. From these data, general relations were developed between climatic parameters, elevation, evaporation, and potential evapotranspiration, ETP. ETP values were estimated for all parts of the country and summarized by states. The dependable precipitation, PD, i.e. that occurring with a probability of 75 per cent of the time for each month, was computed by the Gamma distribution theory. The ratio PD/ETP, called the moisture availability index, MAI, was computed for all stations. These indices indicate that there is a need for irrigation during approximately six months of the year from November through April in most parts of Venezuela. [71-A107 (130 pages)]

ANALYSIS OF COLOMBIAN PRECIPITATION TO ESTIMATE IRRIGATION REQUIREMENTS

by James E. Hardee, Master of Science Utah State University, 1971

Monthly and annual distributions of precipitation were analyzed for a 103-year record station. A gamma probability distribution with maximum likelihood estimates of the parameters gave the best fit.

For 97 stations throughout Colombia a computer program was written to calculate 13 probability levels of precipitation using the gamma distribution. Potential evapotranspiration was calculated from climatic data at 43 of these stations using the Christiansen and Hargreaves formula. The difference between potential evapotranspiration and five probability levels of precipitation were calculated as an index of irrigation requirements. [71-B108 (63 pages)]

DEVELOPMENT OF A PROCEDURE FOR ESTIMATING SPACIAL AND TIME VARIATIONS OF PRECIPITATION IN VENEZUELA

by Luis E. Ramirez, Master of Science Utah State University, 1971

An analysis of the influence of the length of the record in the reliability of mean values of precipitation was made for the Caracas-Cagigal Station in Venezuela. Ten series of values were obtained for 10, 15, 20, 25, 30, and 35-year periods, extracted for sliding intervals for the overall record of 75 years. The reliability of mean values computed from Figure 3 was quite low for 10, 15, and 20-year periods. The long term record means had higher reliability, increasing with the number of years in the record, but the differences are not important in terms of accuracy.

Precipitation values for .5, .10, .20, .30, .40, .50, .60, .70, .80, .90, and .95 equal or less probability levels were computed based on an incomplete gamma distribution for 126 stations distributed throughout Venezuela.

Computer programs were used to process the data. [71-B109 (94 pages)]

REQUIREMENTS FOR IRRIGATION OF SUGAR CANE, SANTA CRUZ, BOLIVIA

by George H. Hargreaves

A study was made of the needs and requirements for irrigation in order to define the feasibility of a proposal to irrigate a large area of sugar cane from groundwater. The study covers a portion of the Department of Santa Cruz and includes information on soils, climate, precipitation, water supply, irrigation requirements and suggested methods for increasing the production of cane. Two sprinkler irrigation designs are compared and a proposal is made that consideration be given to use of deficit irrigation in order to obtain maximum benefits from limited expenditures for equipment. [71-A110 (25 pages) (In Spanish and English)]

EFFECTS OF THE SHAPE AND SPEED ON SOIL RESISTANCE OF THE MOLE PLOW

by Rustu Kasap, Master of Science Utah State University, 1971

The purpose of this study is to investigate the effects of shape and speed of the mole plow on soil resistance by means of a model. Two sets of mole plows were used in these experiments. The first set consisted of five different shapes of mole plows where one has only a blade and the other four have similar blades with torpedoes having different front angles. The second set was similar to the first set except the sides of each plow in the set were made thinner than the front edge to eliminate the friction resistance of the soil on the surface.

An equation for determination of the soil resistance on the plow was developed and expressed as a function of the mole plow shape, speed of the mole plow through the soil, and the physical properties of the soil.

The equation was verified by experiments for the case of a very slowly moving plow with a blunt leading edge. It was found that the theoretical resistance computed from the equation for a very slowly moving plow with a blunt front agreed satisfactorily with the experimental results.

The studies also indicated that by modifying the shape of the mole plow to minimize the frictional resistance on the surface, the power required to operate the plow may be reduced as much as 30 - 40 percent. Such modification can be done by reducing the thickness of the blade and, perhaps, reducing the diameter of the torpedoes of the portion behind the front edge. [71-B305 (76 pages)]

RECLAMATION STUDIES ON THE LIGHT AND MEDIUM TEXTURED SOILS OF PROJECT ATLANTICO - 3 COLOMBIA

by Darrell G. Watts

Project Atlantico-3 in the northern coastal area of Colombia has the potential for producing a number of high value crops both for export and internal consumption. In some areas patches of saline soil considerably reduce the productivity. The basic purposes of the work were to gain a greater insight into the nature of salinity problem on the light and medium textured soils and to obtain quantitative data needed in planning larger scale reclamation studies.

A series of leaching trials was installed on a saline area of the Santa Lucia Experiment Station. Leaching by both flooding and sprinkling was attempted. However, the sprinkler trials were abandoned because of very low infiltration rates which caused runoff of the applied water.

Salinity levels were reduced appreciably in the flooded plots by passing approximately 500 mm of water through the soil profile. However, additional leaching is required to obtain an acceptable salt level in the top meter of soil. Wide scale leaching by sprinkling the saline areas will be feasible only if steps can be taken to increase the basic infiltration rate through tillage treatments and by maintaining a vegetative cover. It is not known whether soil amendments will be of value in solving the infiltration problem because it was not possible to make an adequate assessment of the sodium status of the soil which was studied.

The construction of additional subsurface drains at spacings closer than the present design of 400 meters will be required if successful leaching operations are to be conducted. In the absence of closely spaced drains much of the saline water from the leaching plots flowed laterally through the soil and was either transpired or evaporated from the soil in adjacent areas. Very little if any of the leaching effluent reached the drainage canals to be transported from the area.

Two types of field studies are suggested as the next steps in solving the problem:

1. A further determination of the characteristics of the saline areas with particular reference to factors causing the low infiltration rates.
2. A reclamation experiment including different treatments to increase the infiltration rate, thereby permitting a more rapid entry of leaching water. Leaching should be attempted with very low application rate sprinklers. The experimental area should be drained by subsurface tile lines placed at various spacings. [71-A308 (73 pages) (English and Spanish versions)]

HYBRID COMPUTER SIMULATION OF GROUNDWATER REGIMES

by Bi-Huei Wang and J. Paul Riley

A computer model is described which simulates the response of the groundwater table to various rates of input and abstraction. The model consists of two linked submodels each of which simulates the surface and the groundwater system, respectively. The surface submodel consists of mathematical expressions for the various processes of evapotranspiration, surface runoff, infiltration, and percolation which are functions of the soil characteristics, crop-pattern, and topography. Basic input data are precipitation, temperature, and irrigation and drainage rates. The groundwater submodel simulates the fluctuation of the groundwater table as a function of effective percolation and aquifer characteristics and is described by a two-dimensional second order partial differential equation of parabolic type with Dirichlet type boundary conditions. The partial differential equation describing the groundwater system is solved by the numerical alternating direction method. The application of the general model to a particular area is described. A grid is superimposed upon the study area and at each grid point the effective percolation rate to (or withdrawal from) the groundwater table is simulated. Calibration is accomplished by using a period of reliable data to identify the model parameters. Groundwater responses under various agricultural management alternatives of cropping and irrigation are predicted. [71-C309 (30 pages)]

WATER DEFICIENCIES IN CENTRAL AMERICA AND PANAMA

by George H. Hargreaves

This study was prepared for the United Nations World Meteorological Organization and the WMO-UNDP Proyecto Hidrometeorologica Centroamericano (PHCA). It is based upon long time mean climatic records for 10 locations in Guatemala and 11 in El Salvador and upon climatic data for 1970 from 99 stations in the six republics. Potential evapotranspiration, the 75 percent probability of precipitation occurrence and moisture adequacies or deficits are estimated by months for the long records. Potential evapotranspiration and actual excesses or deficits are given for 1970. For one station in Nicaragua an 8 year period is analyzed. Two methods of calculating potential evapotranspiration are compared.

This study is available in Spanish from Proyecto Hidrometeorologico Centroamericano, Colonial Los Robles No. 3, Casa No. 160 de la Casa Modelo, 2 Cuadros al Sur, Managua, Nicaragua, C.A. Apartado Postal 4328. [72-C117 (86 pages)]

IRRIGATION REQUIREMENTS AND WATER BALANCE, ARENAL PROPOSED PROJECT, COSTA RICA

by George H. Hargreaves

The study was prepared for the United Nations World Meteorologic Organization, WMO; the WMO-UNDP Proyecto Hidrometeorologico Centroamericano, PHCA; and the Instituto Costarricense de Electricidad, ICE. The primary purpose is to determine the area of agricultural crop land that can be irrigated in Guanacaste from the waters to be made available by the proposed hydroelectric project (now under construction, 1974). A description is given of the soils of the area, the climate, irrigation requirements and a water balance study of the Arenal Watershed. It is concluded that not more than 30 to 40 thousand hectares are suitable for development to irrigated agriculture and that the available water supply, after project construction, will be fairly adequate.

The study is available in Spanish from Proyecto Hidrometeorologico Centroamericano, Apartado Postal 4328, Managua, Nicaragua, C.A. [72-C118 (23 pages)]

NEEDS AND REQUIREMENTS FOR IRRIGATION, COMAYAGUA AND VICINITY, HONDURAS

by George H. Hargreaves

A study was made for the United Nations World Meteorologic Organization; the WMO-UNDP Proyecto Hidrometeorologico Centroamericano, PHCA; and the Direcion General de Irrigacion, Ministerio de Recursos Naturales, Republica de Honduras of the irrigation requirements of the Comayagua valley. Soils, crop and economic information relative to the existing irrigation project were not made available. Available climatic data were used to complete a moisture availability analyses and to estimate irrigation requirements for individual crops.

Copies of the study are available in Spanish from Proyecto Hidrometeorologico Centroamericano (PHCA), Apartado Postal 4328, Managua, Nicaragua, C. A. [72-C119 (18 pages)]

IRRIGATION ANALYSIS FOR SELECTED CROPS, SANTA CRUZ, BOLIVIA

by Bolivian-Utah State/USAID Study Team

The area selected for intensive study comprises the portion of the eastern plains near Santa Cruz which is now served by all-weather roads and for which good infrastructure for development is available. The study was made jointly by the Bolivian Ministry of Agriculture, Agricultural Bank, Ministry of Public Works, USAID, and Utah State University in order to assist in defining priorities for agricultural credit programs. The primary purpose was economic analyses of various crops and cropping systems including dry farming and several types or methods of irrigation.

The subject matter covered includes land systems, soil surveys present resources and development, irrigation requirements, water supply, irrigation systems and costs, crop yields, production costs and profits, market analysis and long range development. The study contains much basic data, pictures and colored maps as well as ample appendices showing cost details.

The report is available in both English and Spanish from Office of International Programs, Utah State University, Logan, Utah. [72-A120 (185 pages)]

THE RELATIONSHIP BETWEEN THE CLIMATE AND DRY FARMED WHEAT IN IRAN

by Hossein Mirnezami, Master of Science
Utah State University, 1972

In Iran 75 percent of the population is engaged in agriculture. The major portion of farms depend upon rainfall. Wheat is a crop of major importance. Data are available giving yields of dry farmed wheat on eight experiment stations and controlled experiments on surrounding farms covering periods ranging from 1 to 9 years. A statistical analysis shows the relationships between a moisture availability index, moisture deficits and dependable precipitation and the yield of dry farmed wheat. The effect of various fertilizer treatments at different moisture levels is analyzed.

Annual and growing season values of the moisture availability index, MAI, [which depends upon the 75 percent probability of precipitation, PD 75, and the potential evapotranspiration ETP, (MAI = PD 75/ETP)] were found to correlate well with yields. The use of fertilizer was economical at the higher moisture levels. The limiting factor of moisture availability is proposed as a reference for future government investment. [72-B124 (187 pages)]

ESTIMATION OF IRRIGATION REQUIREMENT FOR VENEZUELA

by Freddy F. Rondon, Master of Science
Utah State University, 1972

Christiansen's formula was used to compute evaporation and potential evapotranspiration using 1013 months of data from 19 stations in Venezuela.

Thirteen probability levels of precipitation were determined for each station.

Potential irrigation requirements for 16 stations were computed based on gamma distribution of 5 probability levels subtracted from the potential evapotranspiration.

A formula for computing precipitation at any level of probability was developed based on gamma distribution and average monthly value of the years of record available. [72-B125 (113 pages)]

ANALYSIS OF CHILEAN METEOROLOGICAL DATA TO ESTIMATE EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENTS

by Juan Tosso, Master of Science
Utah State University, 1972

A formula for estimating Class A pan evaporation was developed using data from six ENDESA meteorological stations and eight Meteorological Institute stations. The formula is of the form

$$E_v = K\ RMM\ C_c$$

where

E_v = pan evaporation
K = a constant
RMM = extraterrestrial radiation
C_c = climatic coefficients

An evapotranspiration equation was developed using Class A pan evaporation as a base. Using this equation, and the gamma distribution that calculated the dependable precipitation at five probability levels, the irrigation requirements for twelve stations were calculated.

An equation that estimated dependable precipitation at 75 percent probability level was developed using the gamma distribution as a base.

Equations to estimate crop coefficients were developed using measured evapotranspiration and climatic data. [72-B126 (110 pages)]

THE EVALUATION OF WATER DEFICIENCIES

by George H. Hargreaves

The terms actual evapotranspiration, potential evapotranspiration, dependable precipitation, moisture availability index, adequacy percentage and moisture deficit are defined. A general relationship between moisture availability and yield is described. Equations are presented for estimating potential evapotranspiration and dependable precipitation (the 75 percent probability of precipitation occurrence). A classification of moisture deficiencies is presented. The paper summarizes current methodology in use at Utah State University for analyzing moisture deficiencies. [72-C128 (17 pages)]

IRRIGATION REQUIREMENTS AND GROUND WATER DEVELOPMENT

by George H. Hargreaves

A brief summary of ground water conditions in the Brazilian Northeast is given. Methods for calculating irrigation requirements, a moisture availability index and their use in water balance studies are described. Climatic data including precipitation from 23 locations are presented and analyzed.

Paper was presented and reproduced at the National Ground Water Symposium, Sao Carlos, Sao Paulo, Brazil, November 27 - December 1, 1972. [72-C129 (26 pages)]

IRRIGATION AND DRAINAGE BY MOLE SYSTEMS-PROGRESS REPORT

by Komain Unhanand

The research reported includes the work on the design and fabrication of single and double mole plows, field studies on the effectiveness and durability of mole channels, removal of salts by mole drains, power to pull mole plows, laboratory studies on optimum moisture content in soil for moling and the corresponding power requirement, durability of a double mole drain, effect of shape and speed of mole plow on soil resistance. Equations for determination of soil resistance on mole plows are derived. [72-A311 (52 pages)]

IMPACT ON RURAL INCOMES OF IMPROVED WATER MANAGEMENT PRACTICES IN MILAGRO COUNTY, ECUADOR

by Phillip H. Lloyd, Master of Arts
Utah State University, 1972

Farm budgets based on survey data are used to calculate the net revenue for average irrigated and unirrigated farms for four tenure classes on the Milagro irrigation project, Ecuador. Differences in net revenues between irrigated and unirrigated farms within each tenure class are assumed to be the return to investment in irrigation capital, assuming homogeneity of all other production factors.

The internal rate of return is calculated on investment in irrigation capital assuming returns to such an investment are the difference in net revenues between irrigated and unirrigated farms. Investment in such capital is found to be highly profitable assuming the opportunity cost of capital is 12 percent. However, small size farms (minifundios) are relatively more profitable than larger farms.

Also, the pure economic profit (rent) accruing to each hectar of land is determined. This is done by finding the water tariff that causes the internal rate of return to fall to 12 percent and subtracting the current water tariff per hectar (S/.200) from the maximum tariff. The difference is rent per hectar, which is greater for small farms than larger ones. However, when total land area by tenure class is considered, larger farms capture the greatest share of the economic rent from the project. [72-B408 (122 pages)]

ECONOMIC ASPECTS OF IRRIGATION FROM GROUND WATER

by George H. Hargreaves

Some typical examples of economic analysis of ground water development are given. The advantages of pumping ground water to improve drainage, where feasible, are described. A typical well and sprinkler irrigation system design are presented in order to compare costs and benefits from three types of production. There are: without irrigation or fertilization, with irrigation but without fertilization and with both irrigation and fertilization. Internal rates of return are shown for cotton, soy beans, pasture, wheat, sugar cane and various double cropping combinations. Conditions in the Sao Francisco Basin of Brazil are described briefly in a very general manner.

Paper presented and reproduced at the National Ground Water Symposium, Sao Carlos, Sao Paulo, Brazil, Nov. 27-Dec. 1, 1972. [72-C410 (21 pages)]

PRACTICAL DEVELOPMENT STRATEGY AND TECHNICAL RESEARCH ACTIVITY

by A. LeBaron and P. Aitken

This paper discusses some research aims and methods associating it to an example in the field. It illustrates certain elements of an evolving philosophy about operating in less-developed countries.

It discusses the limitations of the technicians (local and foreign) to deal with peasants and farmers in the less-developed countries as well as the peasants' attitudes after their experiences with the technicians.

The foreign technician's advantage of not being subject to local prejudices and value systems, which are task limiting, is analyzed.

Also a short analysis is made of the political advantages of short-run (immediate) and long-run (mediate) measures in their role of influencing the masses towards change. [72-D413]

REQUERIMENTOS HIDRICOS DE LA REGION SUDORIENTAL DE LA REPUBLICA DOMINICANA

by George H. Hargreaves and J. F. Alfaro

The Southeastern region of the Dominican Republic comprises roughly two thirds of the national territory. This region has a large agricultural potential. The climate of the area is evaluated in order to determine the needs and requirements for irrigation. Various methods for calculating potential evapotranspiration are evaluated. Crop coefficients are given for estimating crop water requirements. Climatic data and an analysis of available moisture are presented for nine locations.

Paper presented at the Symposium on Tropical Savannah Soils, Santo Domingo, Dominican Republic, 22-26 of February, 1973. [73-C131 (25 pages)]

GROUNDWATER EXTRACTION AND THE WATER BALANCE

by George H. Hargreaves

Groundwater extraction and net use are related to groundwater depletion and the water balance. Potential evapotranspiration, actual crop or vegetative evapotranspiration, dependability of precipitation, moisture deficits and a moisture availability index are defined.

A method is presented for estimating potential evapotranspiration and crop evapotranspiration from a minimum of climatic data. For arid areas the only weather measurement required is temperature. Crop factors are presented for a wide variety of crops. A water balance study for an essentially closed basin in Nicaragua is described and used to illustrate the relationships proposed.

The economics of using groundwater extraction to prevent or alleviate drainage problems is discussed. Irrigation requirements are related to the economics of pumping water for irrigation. [73-C132 (23 pages)]

IRRIGATION OF COMMUNITY GARDENS IN PANAMA

by Jerald E. Christiansen

In order to improve the nutrition of the people living in small communities in Panama, USAID/Panama and Ministerio de Salud proposed a project to provide for community gardens in rural areas. The study evaluated the need for irrigation of such gardens and the alternative means of providing irrigation. The most feasible method of irrigation was found to be by means of semi-portable sprinkler systems. Problems associated with the development of a large number of such irrigated gardens are numerous and will require the assistance of a technical expert in irrigation system design and operation. [73-A133 (43 pages)]

AN INTENSIVE EDAPHOLOGICAL CHARACTERIZATION OF THE SOILS OF MALAMBITO EXPERIMENTAL STATION AND ITS IMPLICATIONS IN FUTURE AGRICULTURAL RESEARCH

by William L. Rubink, Master of Science
Utah State University, 1973

Malambito Experiment Station, in the Atlantico III project area, Department of Atlantico, Colombia, had almost no quantitative edaphological data on which to base agricultural research. Unexplainably low general yields as well as problem areas of deficient plant growth only confounded the results of field plot experiments. Intensive soil sampling and subsequent measurements of pH, EC_e of the saturation extract, and the four major cations disproved the previous suggestions that the crop growth problems were related to saline, sodic, or degraded sodic soil conditions. The Ca/Mg + K = Na ratio, although significant when correlated with plant height, was sufficient explanation for only a small portion of the Malambito problem. The heavy soil texture (50 percent clay) was also shown to be of minor importance in the overall problem. Although no definitive answer was given to explain the variations in plant growth, a basis for further research was provided, including estimates of soluble plus exchangeable cations and their field variability, pH, organic carbon, EC_e and CEC. Future studies in the areas of micronutrient deficiencies and toxicities and possible resistant crops were advocated.

Recent research based on the results of this theses has now implicated heavy metal toxicity as a probable cause for the growth deficiencies and low yields at Malambito. [73-B135 (81 pages)]

EVAPOTRANSPIRACION POR MEDIO DE LOS LISIMETROS Y SU RELACION CON LA EVAPORACION EN SANTA CRUZ PORRILLO Y SAN ANDRES

by R. K. Stutler and N. J. Gonzales

Evapotranspiration from a complete vegetative cover using pangola grass was measured using a battery of 12 buried lysimeters at two locations in El Salvador. Evaporation from a USWB class A pan was also measured at each location. Periods reported were May 1972 to May 1973 for San Andres and April 1972 to April 1973 for Santa Cruz Porrillo.

Average daily evapotranspiration at San Andres was 4.86 mm/day and daily class A pan evaporation was 6.93 mm/day, giving a ratio of 0.68.

At Santa Cruz Porrillo the average daily evapotranspiration was 4.47 mm/day and the pan evaporation was 6.61 mm/day for a ratio of 0.70.

Based on average temperatures and relative humidities, also included in the report, evapotranspiration using Hargreaves' formula was calculated and compared with that measured by the lysimeters. [73-E136 (14 pages)]

MONTHLY PRECIPITATION PROBABILITIES FOR NORTHEAST BRAZIL

by George H. Hargreaves

Monthly precipitation probabilities at various levels of occurrence are calculated at 723 locations in Northeast Brazil. The analysis is of long term precipitation data. Many of the records exceed 50 years and some are longer than 100 years. The methodology used consists of the gamma distribution procedure. This publication provides a source of basic data for further studies and publications. The 75 percent probability of occurrence is used in the computation of moisture availability indices for climatic zoning for agricultural production. [73-A139 (423 pages)]

MANEJO INTEGRAL DEL AGUA EN LA PRODUCCION AGRICOLA

by Komain Unhanand and Jose E. Alfaro

Factors affecting water management for agricultural production are identified and discussed. Special emphasis is made on methods of drainage of heavy soils and their costs. Results of an experiment on the combined mole-tile drain systems in heavy soils are presented together with the cost analysis. Presented at the Symposium on Savannah Soils in the Tropics, Santa Domingo, Dominican Republic, 1973 [73-C207 (26 pages)]

IRRIGATION PROJECTS IN GUATEMALA OBSERVATIONS AND RECOMMENDATIONS

by E. C. Olsen and J. E. Christiansen

Four irrigation projects (La Blanca, Monjas, Atescatempa, and Cabanas-Antombran-Reforma) are described. Factors are noted that pertain primarily to the suitability of the project area for irrigated agriculture. Especially noted are features that may result in a drainage and/or salinity problem at some later date.

A discussion is presented on groundwater observation wells, which are of primary importance in determining what is happening to the groundwater levels as the result of rainfall and introduced irrigation. Since the quality of irrigation water with respect to the salinity and sodium hazard is also of great importance to our understanding of irrigation and drainage problems, a discussion of this subject is included. A suggested table for rating the quality of irrigation water is presented.

Comments are given on the establishment of good engineering procedures for data collection and presentation. Recommendations are also given on increasing the competence of engineering and technical personnel.

The use of pilot projects and research and demonstration stations are discussed with regard to the solution of

special problems prior to the construction of large projects. The importance of properly managing and maintaining established irrigation and drainage systems for successful results is emphasized. [73-A312 (53 pages)]

LAND DRAINAGE AND SOIL RECLAMATION PROCEDURES IN ARID AND SUB-HUMID AREAS OF DEVELOPING COUNTRIES, USING AS AN EXAMPLE THE ATLANTICO-3 PROJECT, COLOMBIA

by J. E. Christiansen and E. C. Olsen

Studies were implemented in Stage I of the South Sector of the Atlantico-3 Project near Barranquilla, Colombia, where high water table conditions and the resulting increase of soil salinity were beginning to have adverse effects on parts of a 300 hectare citrus plantation. The principal objectives of the research were to determine the drainage requirements and design criteria for water table control on the less saline soils, and to reclaim and improve salt affected areas.

The principal source of the high water table in the citrus zone was determined to be from rainfall during the intense rainy season collecting in surface depressions resulting from the uneven topography. Water table control was achieved with a buried tile drainage system in combination with a well developed surface drainage system. In the early stages of a project, surface drainage should be provided to delay or avoid the development of a high water table condition and the necessity of a more expensive tile drainage system. Two drainage functions were developed as an aid in the design of drainage systems in regions of similar circumstances.

A leaching study is described which demonstrated that the highly salinized soils, which were out of production, can be reclaimed for crop use if adequate drainage is first provided for the area to be reclaimed. A minimal amount of leaching and no special soil amendments were required. Paddy rice was grown on these soils during the reclamation process. Yields of 8 metric tons per hectare were achieved.

The results accomplished in this study through better water management, including surface and subsurface drainage combined with adequate leaching, are typical of what might be accomplished in other areas throughout Latin America where high water tables and saline soils are present. [~~73-A313~~ 74 A312 (164 pages)]

A THEORY OF THE COMBINED MOLE-TILE DRAIN SYSTEM

by Tariq Naji Kadir, Master of Science
Utah State University, 1973

A theory is presented to describe the stages of flow of water in the soil in a combined mole-tile drain system.

Based on the theory and along with some assumptions to simplify the complexity of the mathematical calculations involved, two general equations are derived for the spacing of the tile drains and the mole drains, respectively. Six different boundary conditions are considered, and the solutions for each presented. Some of the theoretical equations are compared with field data. A method is presented whereby the equations can be corrected for convergence of flow at the drains.

Finally, a procedure is presented whereby the theoretical equations could be used in designing a combined mole-tile drain system. [73-B315 (96 pages)]

THE EFFECT OF INCREASED WATER SUPPLY ON NET RETURNS TO DAIRY FARMERS IN SONSONATE, EL SALVADOR

by M. Whitaker, A. LeBaron,
B. Wennergren and G. Glenn

The difference in annual net returns with adequate and inadequate water supplies (farms that are otherwise as nearly alike as possible) range from ¢5.01 to ¢461.13 and average ¢186.53 per manzana. Dairy farms are more labor intensive than might be suspected.

As a means of supplying additional irrigation water, pumps appear more attractive than a proposed surface irrigation project. But, another alternative would be to structure and improve management and institutions that control distribution and use of water. [73-A415 (90 pages)]

RELATIVE PROFITABILITY OF IMPROVED ON-FARM WATER MANAGEMENT PRACTICES AMONG TENURE CLASSES IN MILAGRO COUNTY, ECUADOR

by A. LeBaron, M. Whitaker,
P. Lloyd and B. Wennergren

Under existing Ecuadorian law the 7,000 hectare Milagro project must be amortized through water fees levied on users. Calculations of the average per hectare rates of return for four tenure classes range from 44% for the minifundios down to 24% for the latifundios.

If changes in yields, prices, and costs are simulated, the rates of return remain above 12% even under the most pessimistic simulated conditions.

This study also suggests that irrigation is the most important modern input; the marginal cost of introducing an entire technology package is sometimes greater than the marginal benefits. [73-A416 (117 pages)]

PRODUCCION Y DESARROLLO AGRICOLA LATINO AMERICANO, CATALOGO DE INSTITUCIONES NACIONALES DE INVESTIGACION Y LISTA DE INVESTIGADORES AMERICANOS

by A. LeBaron, P. Aitken,
R. Johnson, and A. Ely

During 1971, a large number of Latin American research organizations were contacted by the Utah State University, Economic Research Center, to discover those most interested in agricultural development and agricultural production. Responses covered a wide range of research interests, and we have chosen to include as much as possible - from animal pathology to international trade.

Other international listings of research organizations are available (primarily those of OECD), nevertheless, in

some respects, the present tabulation is more complete for intended purposes. In addition, the second section contains a substantial list of United States university professors who have conducted or directed research activities in Latin America. [73-A417 (87 pages)]

BIBLIOGRAFIA LATINO AMERICANA EN PRODUCCION Y DESARROLLO AGRICOLA VOLUMEN I: INSUMOS Y PRODUCCION AGRICULTURA Y GANADERIA VOLUMEN II: PLANIFICACION AGRICOLA GENERAL, ESTUDIOS ESTADISTICOS Y DEL MEDIO

by A. LeBaron, S. Daines, P. Aitken, R. Johnson and A. Ely

This bibliography is designed to emphasize Latin American sources of information on subjects within the general framework of agricultural production and development.

Volume I

Emphasis is on physical factors and relationships that affect agricultural production (water, soil, fertilizers, varieties, management of land and livestock, disease, machinery, and labor. Economic studies of crop and livestock production or production functions are included). Excluded are such topics as agricultural credit and capital. References to certain crop/livestock planning or program statements are included, otherwise, general or nonspecific crop and livestock studies are cited in Volume II. [73-A418 (272 pages)]

Volume II

The range of topics and types of publications useful for agricultural development research could be expanded far beyond those chosen here. General economic policies are ignored except as they are implied in published national plans and multisector studies. Literature on land tenure is avoided, although some demographic and social entries are included. International trade studies are included because many exports are of primary products. [73-A419 (222 pages)]

IRRIGATION WATER MANAGEMENT IN ECUADOR

by D. Craig Anderson, Master of Arts
Utah State University, 1973

The following thesis describes and analyzes irrigation water management in Ecuador.

One of the primary thesis objectives is to discuss the different private and public administered entities which have irrigation water delivery programs and describe the function and role of each as water management institutions.

Secondly, the thesis investigates and analyzes non-technical variables which influence the actual distribution of irrigation water by those institutions, and the use of water on the farm unit.

The thesis concludes that there are definite recognizable social, political, economic and natural physical factors in Ecuador which are directly associated with programs of irrigation water delivery and use. These non-technical factors play significant roles in determining the success or failure of such programs. They are therefore important variables for development in general.

This thesis is also designed to introduce technical assistance people to these non-technical factors in Ecuador which are so highly relevant to development programs, specifically to irrigation water management and use. [73-B421 (135 pages)]

IRRIGATION AND NON-IRRIGATION ALTERNATIVES FOR REDUCING SUGAR CANE TRANSPORTATION COSTS IN SANTA CRUZ, BOLIVIA

by Lee M. Bailey, Master of Science
Utah State University, 1973

A series of dry years plus substitution of cotton production have displaced and reduced sugar cane production in the Santa Cruz area of Bolivia. Distances between mills and new producing areas have doubled transportation costs. Could anything be gained by rationalizing transportation, shifting mill sites on productive areas?

The annual savings in transport costs exceed the necessary amortized investment costs in only three of the alternatives studied. The best alternative would be to establish zones of influence for each mill while maintaining the evolved production areas. The next best alternative is to close one mill and increase the capacities of the remaining two. The third best alternative is to relocate cane production from the northern to the southern region and utilize irrigation. [73-B422 (Also Spanish version)]

WATER LEGISLATION IN THE ANDEAN PACT COUNTRIES-SUMMARY AND COMPARISON

by David Rainey Daines, J.D. and
Dr. Gonzalo Falconi H.

This work contains a summary statement of the laws and regulations relating to water rights and administration of those countries comprising the Andean Pact including Bolivia, Chile, Colombia, Ecuador and Peru. The subject matter and its organization is best explained by the title headings as follows:

Introduction; Legislation; Organization for Water Administration; Ownership and Control; Right to Use Water; Obligatory Water Use, Priorities Between Use Rights; Rights-of-Way Related to Water Use; Harmful Effects; Financing Works and Administration; Legislation on Uses Other than Irrigation; Subterranean Waters; and Penalties and Sanctions. [73-A423 (English version - 268 pages) (Spanish version - 312 pages)]

ON-FARM WATER MANAGEMENT RESEARCH IN CHILE: EFFICIENT USE OF SOIL MOISTURE AND NITROGEN FOR INCREASED CROP PRODUCTION

by Don C. Kidman, R. Kern Stutler and
David W. James

A project involving research and demonstration on modern concepts of irrigation management was conducted in the Aconcagua Province of Chile during three seasons 1969-1972. The test crop was corn. Experimental variables were soil moisture, nitrogen fertilizer, hybrid corn variety

and plant production. In general it was demonstrated that there was a need to coordinate and improve crop and soil water management with all farming practices. This would be required before any serious attempts could be made to establish modern irrigation technology in the area. Some of the factors involved were seedbed preparation, early season soil moisture control, adequate crop stand establishment, weed control, and use of an irrigation method that would avoid drought and loss of yield potential throughout the growing season.

Surveys of commercial corn fields indicated that plant densities in the range of 20,000 to 30,000 plants per hectare were most common. In controlled tests, highest yields were obtained with 60,000 to 65,000 plants per hectare.

Results from the corn variety indicate the need for development of corn hybrids that will be tailored to conditions of intensive irrigation agriculture and also to the long and favorable growing season common to this area of Chile.

Two kinds of responses to fertilizer nitrogen were obtained. The first indicated a zero response and reflected a history in some fields of relatively heavy annual fertilizer applications. Yield levels where these observations were made (under conditions of intensive irrigation management) were in the neighborhood of 120 quintales per hectare (190 bushels per acre). The second kind of response was a large yield increase from the application of 100 to 200 kilograms of nitrogen per acre. On commercial farms with zero fertilizer nitrogen, yield averages ranged from 44 to 64 quintales per hectare. With 200 kilograms of nitrogen, yields averaged up to 88 to 91 quintales per hectare. These results were obtained on farms where the best possible soil and irrigation management was not necessarily practiced.

Characteristic of some soils, not previously recognized, was that poor soil structure was causing a severe limitation on irrigation water intake rate. This problem, not related to salted soil conditions, resulted in serious limitations on soil moisture management and on corn yield potential. An experiment demonstrated that proper utilization of crop residues, heretofore burned or eliminated in other ways, can assist in overcoming this problem.

It was concluded that Chile has the resources which, if properly utilized, could lead to an intensive irrigation agriculture and a large expansion in the production of food and fiber. A modest estimate of what might be possible is that corn yields could increase an average of 150% over current levels using resources farmers now have at their disposal. Although corn was the only test crop, similar responses would be anticipated in most of the irrigated crops grown in the area. [74-A145 (34 pages)]

CLIMATIC ZONING FOR AGRICULTURAL PRODUCTION IN NORTHEAST BRAZIL

by George H. Hargreaves

The climate of Northeast Brazil is outstanding in the degree to which it is erratic and unpredictable. In order to relate precipitation to potential crop production both amounts and distribution (probability of occurrence) are compared with water requirements for a satisfactory level of agricultural crop production. A brief summary is given of previous studies on rainfall probabilities of occurrence, potential evapotranspiration, moisture deficits and moisture availability indices. A proposed classification of climate is used in order to zone the Northeast into 4 zones. These are: very arid, arid, semi-arid and wet-dry. The zones are shown on a map of the Northeast. [74-A148 (5 pages)]

MOISTURE AVAILABILITY AND CROP PRODUCTION

by George H. Hargreaves

Definitions are given for actual evapotranspiration, potential evapotranspiration, dependable precipitation, moisture availability index and moisture deficit. A method is given for standardizing yields and for relating crop growth and production to the level of moisture adequacy. A generalized production function equation is proposed and graphed together with its first derivative. The first derivative can be used as part of an economic model. Methods for estimating potential and crop evapotranspiration are presented. A classification of moisture adequacies or deficits is proposed.

ASAE paper No. 74-4010 was presented at the 1974 Annual Meeting, American Society of Agricultural Engineers at Oklahoma State University, Stillwater, Oklahoma, June 23-26, 1974. [74-C149 (12 pages)]

RESIDUAL NITROGEN AS IT AFFECTS SOIL FERTILITY UNDER IRRIGATED AGRICULTURE IN A TROPICAL WET-DRY CLIMATE

by Don Carlos Kidman, Master of Science
Utah State University, 1975

In the Zapotitan Valley near San Andres, El Salvador, Central America, an experiment was conducted to determine the availability of residual soil N to corn grown during the rainy season. This was an extension of an experiment conducted during the preceding dry season. The variables of the dry season experiment were irrigation method, crop, and rate of fertilizer N application. Soil NO_3-N and NH_4-N in ppm was determined by soil sample analysis to a soil depth of 120 cm by 30 cm depth increment. The samples were taken at the end of the dry season experiment and again at harvest time of the wet season experiment. Yields were measured from corn grown during the rainy season. The results indicate the following: (1) soil NO_3-N alone was an efficient indicator of residual soil N; (2) there was a linear increase of soil NO_3-N with N applied four months previously to the dry season crops; (3) soil sampled to the 30 cm depth was sufficient to estimate availability of the residual N; (4) corn yields increased linearly with the increase of soil NO_3-N; (5) the measurement of residual soil NO_3-N can be used as a soil test index and in connection with N prediction equations for estimating fertilizer N requirements. The measurements of soil NO_3-N can, therefore, increase the efficiency of fertilizer use in a wet-dry tropical climate. [74-B151 (60 pages)]

SPRINKLER LEACHING PROGRAM FOR VERY SALINE DESERT SOILS IN THE LAJOYA IRRIGATION PROJECT, PERU

by Edwin C. Olsen III

A leaching program using sprinkler irrigation has been developed for the Moro-Moro soil series in the LaJoya Irrigation Project, Arequipa. Soils of the Moro-Moro Series are characterized by their high salinity and by the presence of lenses of saline crusts in the top meter of the soil profile.

Before initiating the leaching program, it was planned to pre-irrigate the soil to field capacity and leave it in this condition for one week in order to initially dissolve the salts and to facilitate the leaching process. Additional applications of 25 cm each at intervals of 3 - 4 days were then to be applied in the leaching operation until an acceptable level of salinity was reached as indicated by soil tests. It was anticipated that an additional 50 cm would be sufficient.

In order to show physiologically the effect of the leaching process on plant development, a strip of alfalfa was to be planted after the pre-irrigation but before the first 25 cm application of leaching water. Additional strips of alfalfa were to be planted after each successive 25 cm application of leaching water.

After the soils have been adequately leached and all of the area is cultivated with alfalfa, a program of sprinkler irrigation is presented which will deliver the consumptive needs of the alfalfa plus an additional leaching requirement on a six day frequency of irrigation. The leaching requirement is important for maintaining a favorable salt balance in the root zone after the initial leaching process. [74-A152 (26 pages)]

IRRIGATED CORN PRODUCTION IN CHILE: INCREASING YIELDS THROUGH INTENSIVE IRRIGATION MANAGEMENT

by R. Kern Stutler, Don C. Kidman, Juan Tosso, and Norbert Fritsch

About 31% of the agricultural land (excluding pasture) is irrigated in Chile. The limiting factor in the northern areas of Chile is available water, but improved water management practices could increase the irrigated area as well as the yield per unit area. The available moisture in Chile increases from north to south.

About 7.4% of the irrigated land is devoted to corn which yields on the average 33 quintales per hectare. It is shown that yields can be increased to over 120 quintales per hectare with improved water management practices. The physical principles and irrigation methods involved are discussed in detail.

Where the amount of moisture that is possible to store in the root zone is limited by low infiltration rates, methods of incorporating the crop residue into the soil to increase the rate of water intake are discussed. Where this condition prevailed yields were increased 38% by this practice.

Land management practices including plowing, irrigation, seed-bed preparation, planting, and cultivation are discussed from the point of view of better methods and the best sequence to increase production.

The effect of the amount of timing of fertilizer applications on yield is discussed and illustrated. Cost and returns are shown for different applications of nitrogen. A discussion of the corn varieties available in Chile and how the yield can vary with plant density is also presented. Suggestions are made as to possible planting sequences for different varieties.

By adapting the practices discussed, corn yields in Chile can be increased at least 150% with the resources currently available to the farmers. Specific recommendations are given regarding irrigation, land management, fertilizer, variety, and density of planting. [74-A153 (48 pages) (An Extension Bulletin)]

DRAINAGE AND SALINITY PROBLEMS IN IRRIGATED AREAS, HOW TO AVOID OR MINIMIZE THEM

by J. E. Christiansen and Edwin C. Olsen III

The necessity for drainage in irrigated areas is discussed. Basic considerations are listed for two conditions: existing irrigation projects where drainage has not been adequate, and proposed projects where the land is not presently irrigated.

A discussion is presented on the requirements for and methods of obtaining data from field studies and observations. Topographic, water table, water quality, soil physical characteristics, soil salinity, reclamation, and water management conditions are considered.

The advantages and disadvantages of different methods of achieving adequate drainage are presented. The effectiveness and economy of pumping where feasible, and the importance of good surface drainage are emphasized.

The philosophy and methods of reclaiming saline and/or sodic soils are presented, and the concept of a "salt balance" is discussed.

Points to consider for the anticipation of future drainage problems during the initial investigations and planning of proposed irrigation projects are presented.

The paper concludes with a large glossary of terms commonly found in drainage, salinity, and reclamation literature to further develop a better understanding of the topic. [74-D301 (64 pages)]

A FIELD EVALUATION OF COMBINED MOLE-TILE DRAIN SYSTEMS IN HEAVY SOILS

by Kovit Thuamsangiem, Master of Science Utah State University, 1974

An investigation was conducted to evaluate the field performance and to study the cost analysis of the combined mole-tile drain systems in heavy soils by comparison with a similar tile drain system. The field performance studies included the recession rates of water table in the system, the deterioration of mole drains in the combined systems during the period of two years. The economic analysis was made by comparing the cost of the combined systems with that of an equivalent tile drain system. The results of the experiments indicate that the combined systems were more effective than the tile drain system in lowering the water table. The difference in the effectiveness between the combined systems using the single and double mole drains was not distinctly apparent. There was no conclusive indication of the deterioration of the mole channels during the period of two years. Also, the construction cost of a combined system is always lower than that of an equivalent tile drain system. [74-B303 (88 pages)]

MOISTURE ADEQUACIES FOR AGRICULTURE IN THE SOUTHEAST

by George H. Hargreaves

The adequacy of precipitation for dependably supplying moisture needs for agricultural production in the 13

southeastern states is analyzed by climatic divisions and for one station within each state. Data are presented giving mean monthly temperature (MEAN TEMP), mean relative humidity in percent (MEAN R.H.), mean precipitation for each month (MEAN PREC), the 75 percent probability of precipitation occurrence (PREC DEP, used in equations as PD), the calculated potential evapotranspiration (POT ET or ETP), montly moisture deficits (ETDF) and an index of moisture availability or adequacy (MAI). A classification of moisture adequacies is proposed based upon values of MAI and their approximate relationship to crop production. For one station daily values of potential evapotranspiration are presented. The computer programs for both monthly and daily analyses are given. Further correlation of moisture indices with crop yields and with the economic appraisal of irrigation is recommended. Economic studies are suggested relative to providing supplemental irrigation during months having a probability of severe moisture deficiency.

Paper presented at ASCE, Irrigation and Drainage Specialty Conference, Biloxi, Mississippi, August 14 to 16, 1974. [74-C304 (6 pages)]

TRENDS IN IRRIGATION AND DRAINAGE RESEARCH

by Robert W. Hill and George H. Hargreaves

A continued rapid rate of increase in agricultural production is required in order for the United States to maintain a strong world economic position. Most non-irrigated agricultural areas suffer from water shortages. Increased emphasis on irrigation is considered essential to major increases in agricultural production. This paper summarizes the irrigation research funding by the Office of Water Resources Research and by the Agricultural Research Service as well as the relative emphasis given to various irrigation related subjects in the publications of ASAE and ASCE.

Research in progress reflects not only the needs within the United States but of the developing countries as well. A history of trends in irrigation research is given for recent years and recommendations are made for desirable future irrigation and drainage research programs and activities. Activities carried out by Utah State University designed to assist the Latin American developing nations are briefly described.

Paper presented at ASCE, Irrigation and Drainage Specialty Conference, Biloxi, Mississippi, August 14 to 16, 1974. [74-C305 (14 pages)]

RICE AS AN ALTERNATIVE CROP IN THE SANTA LUCIA REGION OF ATLANTICO #3, IRRIGATION DISTRICT OF COLOMBIA

by T. M. Fullerton, Hugo Garcia S., Luis Molina M. and D. W. James

Irrigation and soil fertility field trials involving maize, cotton, sesame, soybeans, and rice were made on the flood plain of the Magdalena River, Colombia. Growth disorders in most crops limited production to uneconomical levels. These disorders were attributed to excessive amounts of phosphorus, iron, copper, zinc, and possibly cobalt and nickel in the soil. These elements were of geologic origin and no soil amendments were found that ameliorated the effects. However, paddy rice performed exceptionally well and at this time represents the most logical crop to produce while dealing with, otherwise, unfavorable soil conditions. The district involved had been previously drained and had irrigation water delivery facilities installed. The overall results dramatize the need to evaluate land production capabilities before committing resources to development of irrigation.

(Paper presented to ICA - Revista, Bogota, Colombia for publication) [74-C316]

EXCESSIVE INDIGENOUS PHOSPHORUS AND HEAVY METAL ELEMENTS IN SOILS OF A NORTHERN COLOMBIA IRRIGATION DISTRICT

by D. W. James, T. M. Fullerton, W. L. Rubink and Hugo Garcia S.

Irrigation and soil fertility field trials involving maize, cotton, sesame, soybeans, and upland rice were made on the flood plain of the Magdalena River, Colombia. Crop growth was very erratic and average yields were low. In localized areas, plants were stunted and chlorotic. Negative growth responses were measured to soil-applied phosphorus fertilizer and foliar applied minor elements. Soils analyses with DTPA indicated extractable Fe, Cu, Zn, Ni, and Co were very high. Available P as well as total P were also very high. It was concluded that heavy metals and phosphorus were present in excessive amounts. A soil pH of 6.3-6.7 indicates that there is little possibility of correcting the toxicity problems by liming.

(Not yet published. To be presented at Annual Meetings American Society of Agronomy, Nov. 1974) [74-C317]

EFFECTIVENESS OF MOLE DRAINS IN LEACHING HEAVY SOILS

by Jose Antonio Forero, Master of Science Utah State University, 1975

A field experiment was conducted to determine the effects of leaching by mole drains, 3 inches in diameter, installed 18 inches deep at the spacings of 6, 12, and 24 feet. The water was applied periodically by sprinklers at a rate slightly less than the basic intake rate to avoid ponding. Soil samples, taken before and after leaching from the same location in the experimental area, were analyzed to determine the EC of the saturation extract and the reduction in salt concentration of the soil after leaching. Results of the experiment indicate that, within the limits of the three spacings tested, the combination of mole drains and low application rate of irrigation water leaches the salts more effectively than using the low application rate alone. However, because the initial salt concentration was different from plot to plot, no conclusive result could be drawn as to which mole spacing is most effective in leaching. [74-B318]

PERFORMANCE AND EVALUATION OF COMBINED MOLE-TILE DRAIN SYSTEMS IN HEAVY SOILS

by Komain Unhanand and Kovit Thuamsangiem

A field experiment was conducted to investigate the performance and cost of the combined mole-tile drain systems in heavy soils in comparison with a similar tile drain system. Three experimental plots consisted of a tile-drained plot, a combined (single mole) drained plot and a combined (double mole) drained plot. They were constructed with a tile drain spacing of 37 meters (120 ft.) and a mole drain

spacing of 1.83 meters (6 ft.). The experimental results show that the combined systems were more effective than the drain system in lowering the water table. The difference in the effectiveness of the single mole drains and double mole drains was not distinctly apparent. No deterioration of the mole drains during the period of two years tested was detected. The cost analysis indicated that the annual cost of the combined systems is always less than that of an equivalent tile drain system even if the mole drains in the combined system have to be redrawn every year. [74-C319]

A THEORY OF THE COMBINED MOLE-TILE DRAIN SYSTEM

by Komain Unhanand and Tariq N. Kadir

A theory of water movement in the combined mole-tile drain system, based on the Transient State condition, was developed. Two general equations were derived to describe the height of water table at any location in the system at any elapsed time after the drainage process begins. One of the equations is applicable for the stage where the water table is above the mole drains while the other equation is for the stage where table falls below the mole drains. The two general equations were simplified for the point located at mid-point between the tile drains and mole drains in the system. In the derivation, assumptions regarding the flow condition of ground water and shape of the water table profile at certain boundaries were made. Field experiments were then conducted and the test data were used in verifying the equation for the first stage. A reasonably good agreement between the theoretical analysis and field data was obtained for this type of research. [74-C320]

WATER MANAGEMENT RESEARCH INSTITUTIONAL AND LEGAL FACTORS IN THE ANDEAN REGION

by David R. Daines

This paper consists of 13 pages and was presented at a Resources for the Future sponsored meeting on Water Management Research in Santiago, Chile from June 3 to 7, 1974.

The first part is a broad general description of water management research in Latin America carried out by Utah State University under the water management contract with AID/Washington. Some specific legal and institutional inhibitors found in the Andean area were discussed under the following headings; lack of institutional integrity and user confidence; "Beneficial Use Limitations" technical, administrative and legal problems in enforcement, and sale of water use rights. [74-D402]

ECONOMIC ANALYSIS OF ALTERNATE IRRIGATION METHODS IN EL SALVADOR

by Grant R. Hansen

Land leveling designs and earthwork volumes were calculated using topographic grid surveys of 10 sites in the Zapotitan and Atiocoyo-Nueva Concepcion irrigation districts in El Salvador.

Typical irrigation system designs for a 50 ha. farm were presented for both sprinkler and surface methods including land leveling requirements, canals, structures, etc. Costs of land leveling required for surface irrigation were based on design results of the ten surveyed sites for various slope and earthwork volume combinations.

Comparative costs for the two methods were given for each of the slope and earthwork volume combinations and criteria suggested for selecting the proper irrigation method.

Appendix includes a computer program for land leveling design and a chart for land leveling earthwork volume estimates in metric units. [74-A405 (16 pages)]

PROCEEDINGS OF ANDEAN GROUP WATER LAW SEMINAR

by David R. Daines and Gonzalo Falconi H.

This is a publication of a Water Law Seminar held in Quito, Ecuador from January 12 to 19, 1974 and consists of 92 pages.

The basic seminar documentation was a draft of the book "Water Legislation in the Andean Pact Countries. Resume and Comparison." This book is abstracted separately and is not contained in these proceedings.

The proceedings contain photos, names and addresses of participants and officers of the Seminar; an agenda; the full text of speeches given at opening and closing sessions and special presentations given during the seminar.

The recommendations and conclusions of the participants is the fifth chapter and a partial bibliography on water laws in Andean countries completes the "proceedings." [74-E430 (Publication in Spanish only)]