

1. SUBJECT CLASSIFICATION	A. PRIMARY Serials	Y-AP10-0000-0000
	B. SECONDARY Agriculture--Water resources and management	

2. TITLE AND SUBTITLE
 Water management research in arid and sub-humid lands of less developed countries; annual progress report, 1972/1973

3. AUTHOR(S)
 (101) Utah State Univ. Dept. of Agr. and Irrigation Engineering

4. DOCUMENT DATE 1973	5. NUMBER OF PAGES 67p.	6. ARC NUMBER ARC
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7. REFERENCE ORGANIZATION NAME AND ADDRESS
 Utah State

8. SUPPLEMENTARY NOTES (*Sponsoring Organization, Publishers, Availability*)
 (Research summary)

9. ABSTRACT

10. CONTROL NUMBER PN-RAB-448	11. PRICE OF DOCUMENT
12. DESCRIPTORS Irrigation Latin America Water resources	13. PROJECT NUMBER
	14. CONTRACT NUMBER CSD-2167 Res.
	15. TYPE OF DOCUMENT

**WATER MANAGEMENT RESEARCH
IN ARID AND SUB-HUMID LANDS
OF LESS DEVELOPED COUNTRIES**

Contract AID/esd 2167

Fifth Annual Progress Report

November 1, 1972 to October 31, 1973

with a summary of the previous four years

To the United States Agency

for International Development

Prepared by

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USA

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GENERAL BACKGROUND

The increase of agricultural production of developing countries has for many years been an important objective of the United States Agency for International Development. However, effective transfer of technology from North America and elsewhere to other social and physical environments often requires considerable adaptation. AID has recognized that a key element in crop production increase is proper control of water resources at the farm level. In June, 1968 Utah State University contracted with AID to conduct research which would help to improve on-farm water management in developing countries. This contract was originally for a five-year period. Its modus operandi has been to carry out adaptive research in close collaboration with a number of government agencies and universities in Latin America.

By invitation from USAID missions, the university 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 to date 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 (especially

TABLE 1. Professional and Technical Staff Commitments To Contract November 1, 1972 to October 31, 1973

Name	Specialty	Level of effort mo. per yr.
Lloyd C. Austin	Research Engineer, Brazil	8
Jerald E. Christiansen	Civil Engineer, USU	10
David R. Daines	Lawyer, Ecuador and USU	12
Thomas W. Fullerton	Agronomist, Colombia	12
Norris Gilbert	Agronomist, Brazil	5
George H. Hargreaves	Civil Engineer, USU	9
David W. James	Soil Chemistry, USU	4
Don C. Kidman	Agronomist - Irrigation Specialist, El Salvador	12
Allen D. LeBaron	Economist, USU	4
Rex F. Nielson	Soil Chemistry, USU	1
Edwin C. Olsen	Civil Engineer, Colombia	12
Byron C. Palmer	Project Field Director, USU	10
Howard B. Peterson	Project Director, USU	4
R. Kern Stutler	Civil Engineer, El Salvador	12
Komain Unhanand	Civil Engineer - Drainage Specialist, USU	5
E. Boyd Wennergren	Economist, USU	2
Morris D. Whitaker	Economist, USU	6

Pakistan), an even broader transferability capability is emerging as the two universities interact with each other and through each other on the areas where they are directly involved. They are planning a joint traveling on-farm water management research seminar to facilitate dissemination of research results.

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.

Probably the most significant part of the report is the bibliography (Appendix IV) which lists eighty-seven publications, papers and reports which have been generated by the contract, many in collaboration with indigenous researchers. However, anyone who is anxious to get a detailed perspective of the various components of the program is encouraged to secure the reports and/or correspond with the USU researchers listed in Table 1, who, with the exception of Professors Austin and Gilbert are still on the staff of the University.

PROJECT OBJECTIVES

General Objective

As stated in the contract, "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 areas.

In the original contract there are eight specific objectives stated. Since there was some overlapping of

both objectives and activities when described under the eight headings, for the purpose of this report a consolidation has been made which should facilitate review of the program. The four consolidated objectives are:

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.
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 with Ministry of the Interior

A. **Background.** At the request of USAID/Brazil, a USU reconnaissance team made up of Professors Bruce Anderson, A. Alvin Bishop and Howard Peterson visited Brazil in February, 1969. They discussed possible areas of collaborative research with USAID and national officials. Their

report is included in the first contract Progress Report covering the period June, 1968--October, 1970. This was followed up by the visit of a research advisory team made up of Professors Anderson, Peterson and Rex Nielson in September, 1969, who were asked to assist the Ministry of the Interior's Sao Francisco Development Agency (SUVALE) in developing an irrigation research, training, and extension program. They visited four of SUVALE's established stations and three new stations yet to be developed at Pirapora, Formoso, and Sao Desiderio and made a number of recommendations on layout and development of these stations (which were subsequently quite closely following by the SUVALE administrators). See Appendix C of above listed Annual Progress Report.



Photo 1. Appearance of Research Station before commencement of construction, Pirapora, Brazil, 1969.

The report contained proposals that a two-week training session for SUVALE researchers be carried out under USU supervision and that USU send in a two man team to assist SUVALE in setting up operations at these three stations. This was agreed to by AID/Washington, USAID/Brazil and SUVALE and was accordingly carried out with the research team scheduled for a two-year period beginning April 1, 1970.



Photo 2. Brazilian researchers Drs. Toledo and Suzak examining irrigated tomato plots, Pirapora, Brazil, 1972.



Photo 3. Research Station area before clearing off vegetation, Formoso, Brazil, 1969.



Photo 4. Dr. Dorian Souza examines irrigated corn experiments at Formoso CTI, 1972.

The program was delayed at USAID's request until April 1, 1971, at which time Professor Norris Gilbert, an agronomist, and Lloyd Austin, an engineer, were assigned to Brazil to implement this phase of the report's recommendations. The formal agreement describing their responsibilities was included in the Second Annual Progress Report.

The importance of research in on-farm water management in the northeast is evident from the fact that the Brazilian government is developing nine new irrigation projects in the Sao Francisco Valley having well in excess of 600,000 hectares. At the time of the arrival of Professors Gilbert and Austin, except for some rice irrigation in the lower end of the valley, and a few farmers pumping water from the Sao Francisco River and two or three of its tributaries, there was no irrigation and for that matter, very little commercial agriculture in the Sao Francisco Valley.

SUVALE's strategy, which was developed with the assistance of USBR and United Nations technicians, was to establish in each major development region a research, training, and extension center (known locally by its acronym CTI), whose primary functions were to determine the best crops and cultural practices for the area, provide training for

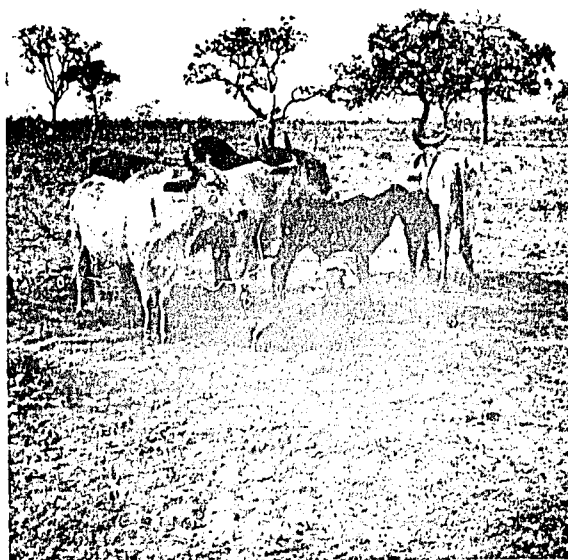
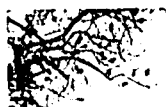


Photo 5. Sao Desiderio CTI, 1969.

farmers and irrigation system operators and administrators, and then follow up with extension assistance to the farmers.

Photos 1, 3 and 5 show the sites of the CTI's as they were in September 1969.

B. Accomplishments to Date. During the two years of Gilbert and Austin's assignment, they, in very close collaboration with SUVALE technicians, established research components at the three CTI farms. Experimental plantings under irrigated agriculture were commenced on several varieties each of 39 crops: avocado, banana, beans, black pepper, cabbage, canavalia, castor beans, cauliflower, citrus, corn, cowpea, cucumber, egg plant, figs, forage grass, grapes, green pepper, guar, guava, jilo, mango, mint, okra, onion, orange, papaya, pineapple, pomelo, potato, rice, safflower, salsa, soybeans, squash, sunflower, tangerine, tomatoes, watermelon, and wheat. Although this type of activity has many elements of site specificity, a number of lessons were learned which will have application wherever a government plans to establish research stations concurrently with new irrigation development in an undeveloped area. Results are therefore listed under two headings:

- (1) logistics of getting irrigation research stations into operation, and
- (2) results of irrigation experiments.



Photo 6. Watermelon variety trial, Sao Desiderio CTI, 1972.



Photo 7. Prof. Gilbert (L) with Brazilian technicians at sprinkler irrigated bean trials of Pirapora, 1972.

The results are summarized respectively in Appendices I and II.

A report is being prepared using this and experiences of staff in other countries which will provide some guidelines for government administrators charged with the responsibility for putting agricultural research stations into operation in new irrigation district areas.

During the 1971-72 "wet" season the value of supplemental irrigation was graphically demonstrated on the Sao Desiderio station where supplemental irrigation on one treatment of corn was compared with no irrigation. The corn receiving one irrigation during the wet season yielded a normal crop, while the rest of the corn which had to rely on natural rainfall was a total failure.

The program with SUVALE was phased out on March 31, 1973, with indigenous supervision and consulting services to the CTI's now fully operational.

Brazil Program with the Ministry of Agriculture

In July, 1973 an agreement was signed between USU, USAID/Brazil, and the Ministry of Agriculture which calls substantially for two programs. The first is new collaborative research in the northeast, preceded by an inventory of existing research activities by all agencies and a reappraisal of the Ministry's role in on-farm water management research. The second component is to improve the capability of government agencies and universities in the northeast to analyze climatological data in order to use it in calculating crop water requirements. This phase of the program is already well under way under Prof. George Hargreaves' supervision. He has collected, key punched, and analyzed rainfall data from 723 locations in the Brazilian Northeast to establish rainfall probabilities (114, 115, 116).^{*} This is of course a fundamental input to the problem of whether to irrigate and if so, how much and when.

He has met with all of the agencies collecting and utilizing this data. They, as of this writing are identifying counterparts who will be sent to USU for

^{*}Numbers in parentheses refer to the bibliography in Appendix IV.

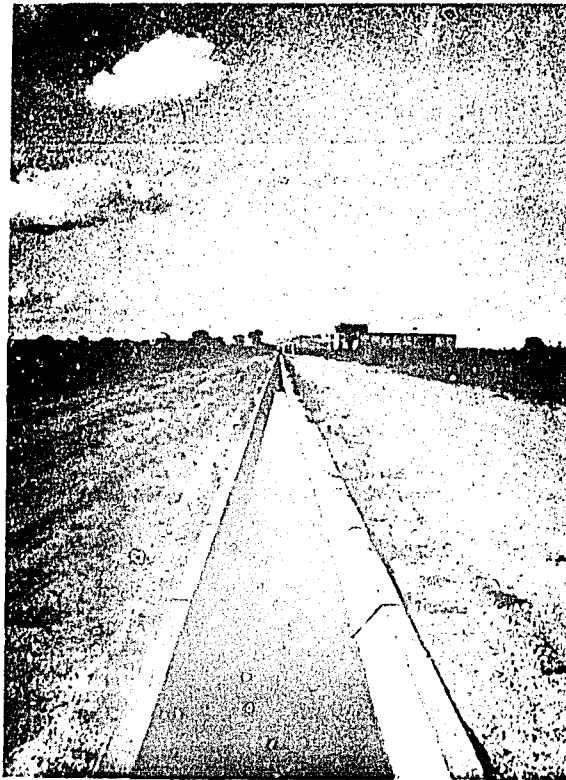


Photo 8. Main supply ditch, Sao Desiderio, 1971.

three months or more of training at no direct cost to the contract, after which they will be qualified to handle their own computerized data analysis.

Chile

A. Background. Previous progress reports have detailed the water-fertilizer and other related research done under this contract in Chile (122, 123). USU's two man team composed of Professors R. Kern Stutler and Don Carlos Kidman were withdrawn from Chile in July of 1972 at the request of USAID/Chile. Professor Stutler has been back for short visits twice to provide additional advice to SAG (Chile's extension agency in the Ministry of Agriculture).

B. Accomplishments to Date. Initially, the program in Chile was directed to the field testing of possible "drought proofing" practices. Soil maps were used to identify deep soils in which water could be stored so the pump wells, developed to produce water during drought periods could be utilized during the "off" season, thereby realizing more crop production from fewer pumps and wells.

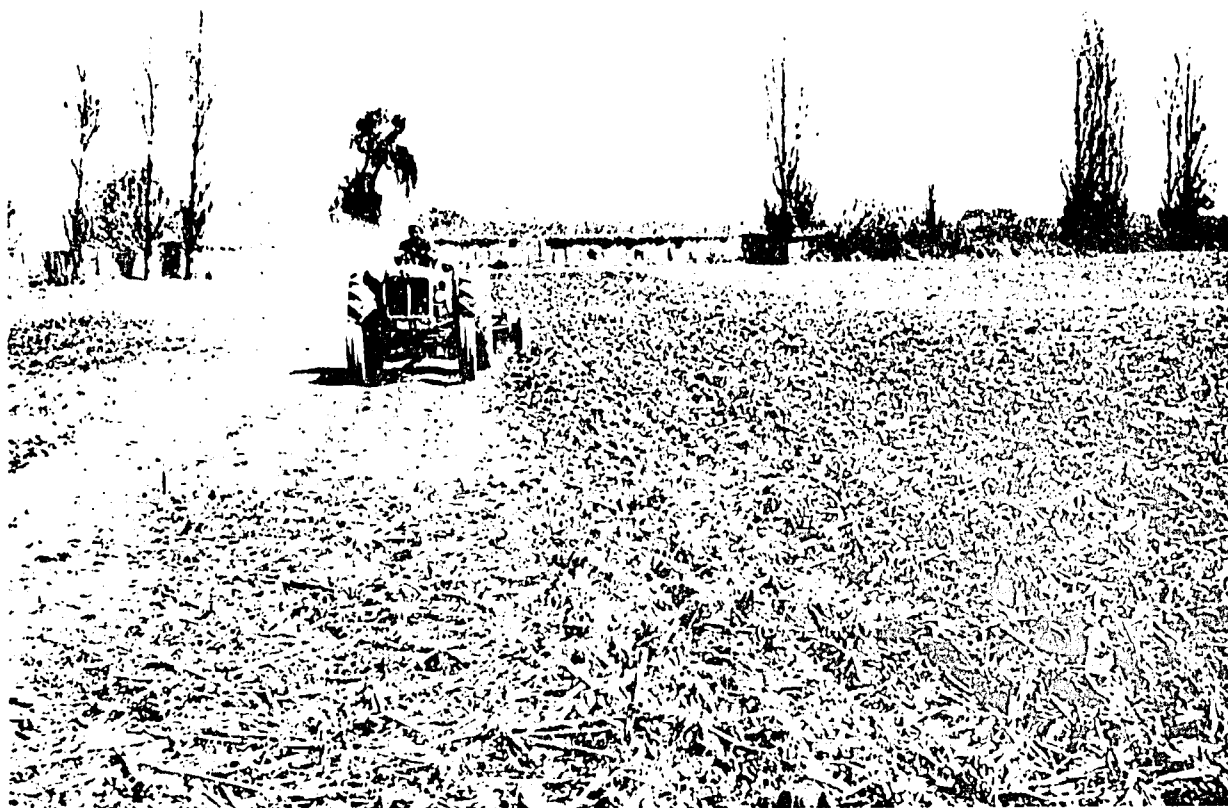


Photo 9. Tractor plowing in corn stalks in Chile to increase water infiltration rates.



Photo 10. Field day at demonstration farm, Chile. Local farmers see how to double corn yields.

This program was carried out to the point where Chilean researchers had identified several excellent field test areas. At this point a long drought came to an abrupt end and local interest turned to other priority issues so field testing of this component did not take place. In general, there are several promising areas in Chile which should be developed into "drought proofing" demonstration districts.

It was amply demonstrated through plots on eight research and demonstration farms that corn yields could be doubled without introducing any major new technology. The components required to achieve this doubling of yield are:

1. Better seedbed preparation by more careful discing and harrowing
2. Incorporation of crop residue in the soil to increase water infiltration rates
3. Furrow instead of flood irrigating
4. Increasing fertilizer application rates
5. Using locally adapted hybrid corn yields.

At the time the staff withdrew, a rather rapid transfer of technology was taking place in the Aconcagua Valley, especially on the "asentamientos" or communal farms. There is evidence that dissemination is taking place in other areas through promotion by SAG. It is hoped that the political situation will soon stabilize sufficiently for staff to return and evaluate the impact of this work, especially to determine which of the components has been most acceptable to farmers.

Colombia

A. Background. In the visit by Professors Anderson, Bishop, and Peterson, referred to earlier, the USAID/Colombia Rural Development Officer and the two concerned Colombian agricultural agencies, ICA (Colombian Agricultural Institute) and INCORA (Colombian Agrarian Reform Institute) requested that we collaborate with these two national agencies in assisting with the development of the Atlantico-3 Project in Northern Colombia in order to increase yields which after five years of project operation were still discouragingly low (about one-half of that expected).

Some 18 million dollars had been spent to reclaim what had been a multitude of swamps which were frequently flooded. Dikes, pumping plants, open and buried drains were built, and an irrigation system consisting of a reservoir, canal network, several sprinkler systems, land leveling, and other improve-



Photo 11. Chilean researcher sets a flow measuring device in head ditch.

ments installed to service about 15,200 hectares. The draining of this land also dried up an additional 30,000 hectares and created some difficult social problems as these newly dried lands became the center of dispute between old-time land owners, immigrant farmers, and several thousand fishermen who had formerly made their living fishing the marshes and swamps of the area.

In 1963 INCORA was assigned the responsibility of finding a solution to the problem. ICA was invited to establish three research stations in the region, at Santa Lucia, Malambito, and Repelon (see Figure 1) according to the criteria of principal soil types as described in a 1965 soil survey. Malambito, the second largest of the three, was created with the objective of demonstrating the capabilities of the heavy clay soils which, according to the survey occupy nearly 45 percent of the total project area. There are on this project both light and heavy tropical soils, salinity, increasing water tables and great, apparently random variables in crop yields within small fields. At the time USU sent in its Professor Fullerton to collaborate with Malambito ICA technicians, it was known that there was a problem on the heavy "Malambito" soils of low, nonuniform yields. However, this problem had until

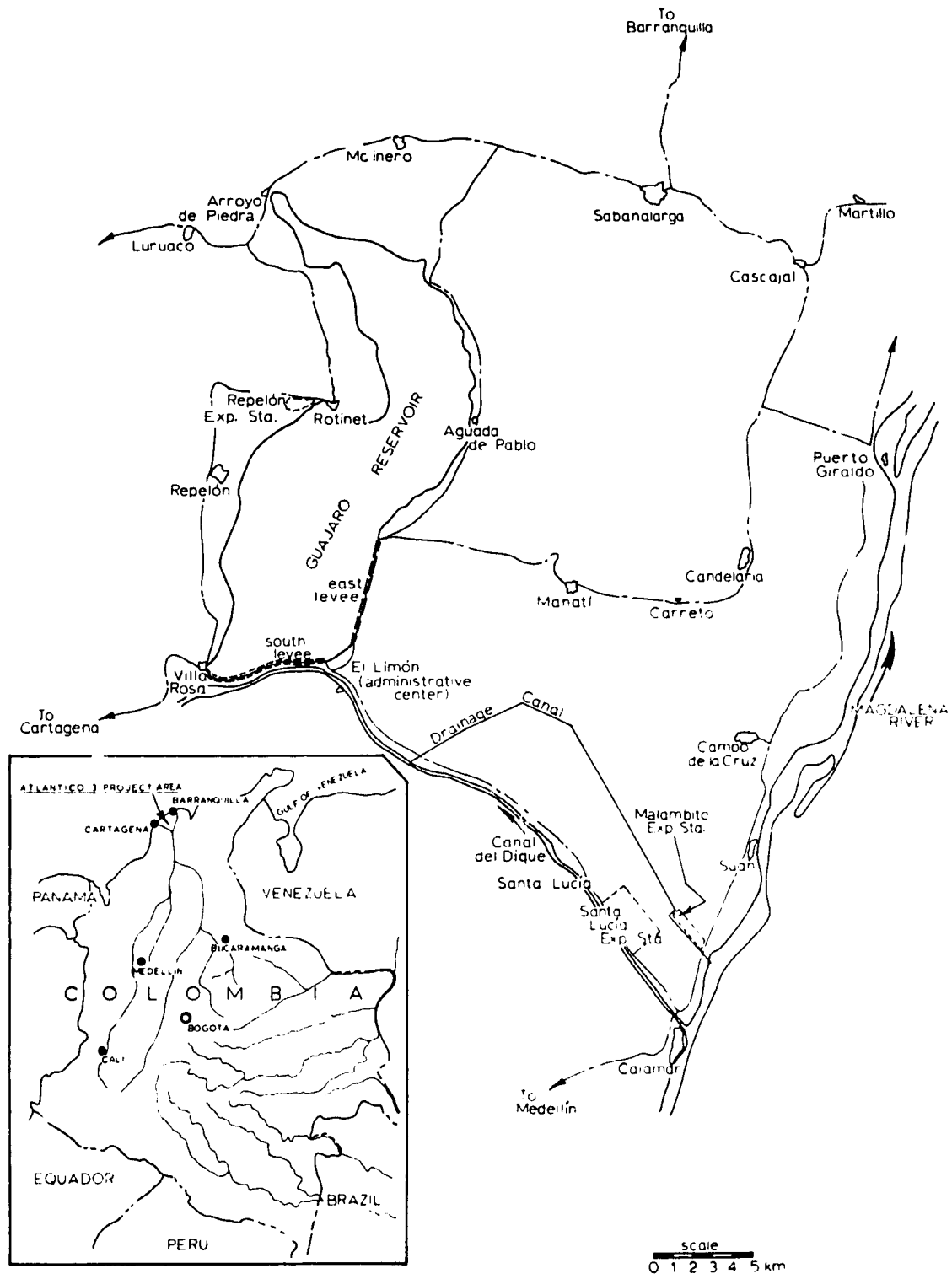


Figure 1. Map of Atlántico III project area with inset showing location in Colombia.

this time been attributed by researchers to saline, sodic, or degraded sodic conditions or to a low total nutrient status caused by excessive leaching. However, the few chemical analyses performed were not well correlated with field observations. Thus crop production was confounded by soil and crop heterogeneity. A sound basis for agronomic research at Malambito had not yet been established. All of these problems were interesting and pertinent to the objectives of the contract, so a series of activities were planned and executed from 1969 to 1973. These included:

Estimation of Evaporation and Evapotranspiration by R. Kern Stutler reported in June, 1970 (105).

A reconnaissance survey and preliminary leaching studies by Darrell G. Watts reported in January, 1971 (319).

Studies of the effects of ground water elevation of a number of alternative land use strategies using hydrologic model simulation and data analysis by hybrid computer, reported by J. Paul Riley and others in reports and theses prepared in 1970, 1971, and 1972 (314, 315, 316, 317, 318).

Field plot studies of water interacting with fertilizers and various trace elements and a number of crops from 1971 to 1973, to be reported in 1974 by Thomas Fullerton and David W. James.

Field studies of methods for determining drainage requirements and design criteria for water table control on the less saline soils and reclamation of salt affected areas. The field research was carried out in 1971-73 by Edwin C. Olsen and ICA counterparts with Jerald E. Christiansen providing advisory assistance (322).

Edaphological characterization of the soils in the Malambito Experiment Station Region. A thesis study by William L. Rubink is in preparation (132) financed by 211-d funds.

The findings of these various studies are reported under the appropriate objective heading. Under this objective, only the evaporation study and the water interaction experiments will be reported.

B. Crop Water Requirements. Stutler's study (105) analyzed pan and sheltered evaporation data from Venezuela and Colombia and provided improved equations for estimating evaporation and evapotranspiration for humid tropic areas.

His basic equation is

$$E_{vp} = K \cdot E_{vfm} \cdot C_{ef} \cdot C_{st}$$

where

E_{vp} = class A pan evaporation, mm per month

K = 1.740

E_{vfm} = sheltered evaporation, mm per month

C_m = monthly coefficient* which ranges from 0.92 to 1.05

C_{st} = station constant* which ranges from 0.87 to 1.17

C_{ef} = a coefficient based on the sheltered evaporation expressed by the following equation

$$C_{ef} = 0.71 + 0.537(110/E_{vfm}) \\ 0.365 (E_{vfm}/110) + 0.118 \\ (E_{vfm}/110)^2$$

This has had wide circulation in Colombia and among numerous developing country students and hydrometeorologists.

C. Water-Fertilizer Interaction Experiments. Specific objectives for the two-year period beginning with the arrival of Professor Fullerton in September, 1971, were to determine appropriate irrigation and other cultural practices for these soils for the following crops: corn, sorghum, cotton, upland rice, flooded rice, sesame, and soybeans. Accordingly, a number of plots were established with these crops and factorial treatments carried out using as variables the following: water, nitrogen, phosphorous and the minor elements iron, copper, manganese, and zinc.

A number of surprises lay in store for the ICA and USU researchers. The plots had so much unex-

*See Table 5 of Stutler's report for values of C_m and Table 6 for values of C_{st} .

plained variability that no yield responses to the imposed variables could be detected.

Average yields, except for flooded rice which produced 7 metric tons per hectare, were at best less than half the national average.

Most of the plots contained areas of significant size where nothing, not even native grasses or weeds, would grow.

Soybeans were, after the flooded rice, the best producers, although still not able to produce at the level of the national average.

Yields on all plots varied randomly from 0 to 75 percent of the national average. No economically acceptable yields, except for the flooded rice, were recorded.

At this point, the researchers reached the conclusion that minor element toxicity was at least partly and possibly totally responsible for the wide yield variations. It was therefore essential to study this problem before carrying out further irrigation research in this area. Activities and results of that

phase of the work are reported under the Objective 3 section.

El Salvador

A. **Background.** When USU's Professor Richard E. Griffin was sent in mid-1970 to EL Salvador to collaborate with DGORD (National Irrigation and Drainage Department) and CENTA (Agricultural Research Department) of the Ministry of Agriculture, one of the on-going activities in which USU, especially Professors Christiansen and Hargreaves, had been interested for some years was the collection and analysis of climatological data for determination of crop water requirements. Part of this activity was the installation and observation of 11 lysimeters and one evaporation pan on lands owned by CENTA and used for research and student instruction at the Santa Cruz Porrilla Experiment Station in the Zapotitan Valley and 12 lysimeters and an evaporation pan on land of the National Agricultural College of San Andres.



Photo 12. Colombian corn experiments showing random variations throughout the plots.

Objectives of this program are:

1. To determine evapotranspiration throughout the country by
 - a) Measuring evaporation from class A evaporation pans
 - b) Measuring lysimeter evapotranspiration
 - c) Comparing equations calculating evapotranspiration from climatological data with the evaporation pan and lysimeter data.

Professor Griffin assisted by training technicians in techniques of field data collection. He was replaced in 1972 by Professor Stutler who continued

the collaborative water requirements study. He and his counterpart, Nestor J. Gonzales of DGORD, issued a report (published jointly by CENTA, DGORD, USU and USAID/El Salvador) describing the lysimeter studies to October 1973 (133).

B. Accomplishments to Date. This is an on-going program designed to improve the resolution of data by providing more years of observation.

Analysis of the climatological data by the Hargreaves method (ETP) and by the Central American Hydrometeorological Project Method (ETPP), when compared with the lysimeter evapotranspiration results (ETL) yielded the following results for the period April, 1972- March, 1973.

TABLE 2: Comparison of Hargreaves' ETP and the Central American Hydrometeorological Project ETPP with Lysimeter Evapotranspiration Results

Location	ETL	ETP	ETL/ETP	ETPP	ETL/ETPP
Santa Cruz Porrilla	1631	1766	.92	1516	1.07
Escuela Nacional San Andres	1774	1453	1.22	1390	1.27



Photo 13. El Salvador extension agent students examine USBR class A evaporation pan.

Calculated evapotranspiration at Santa Cruz Porrilla was 68 percent of evaporation from the pan and 70 percent at San Andres which is somewhat lower than the world average of 80 percent.

This data is particularly useful in El Salvador, but when used cumulatively with world-wide data available at USU becomes an additional factor in understanding the relationships between climatological data, pan evaporation, lysimeter data, and irrigation requirements.

Water Interacting with Fertilizer, Row Spacing, etc. on Crop Yields

A. Background. The 1970 agreement between USU, USAID/El Salvador and the Ministry of Agriculture included as a major objective the determination of those crops and cultural practices that would best meet the needs of El Salvador in their expanding irrigated crop production program.

El Salvador has a typical tropical climate with well defined dry and wet seasons. Traditionally, farmers have grown crops only in the wet season. However, with irrigation, one and sometimes two additional crops are now possible, providing farming practices can be carefully scheduled and appropriate crop rotations selected.

During the first two years, irrigation experiments were carried out at the San Andres Experiment Station in the Avenamiento No. 1 Irrigation District in the Zapotitan Valley and have been reported in the third and fourth annual progress reports and by Griffin (124).

A second phase of this program began in 1972 when Professor Griffin returned to USU and Professors Kidman and Stutler were moved from Chile to El Salvador. Plots were laid out at the San Andres station and at the Atiocoyo Research Station in the Atiocoyo No. 2 Irrigation District.

B. Accomplishments to Date. During Phase 1 the major accomplishments were to get organized (i.e. locate and assign counterpart staff, prepare budgets, line up equipment, land, seeds, chemicals, etc.) and go through a couple of field experiment cycles. Not surprisingly, the corn, which was the main crop researched, yielded at about 180 percent of the national average. An interesting result was that yields kept increasing with increasing nitrogen rates up to 5247 kg/hectare of corn at 400 kg/ha of nitrogen. It is generally accepted that it takes about 1.2 pounds

of nitrogen to produce a bushel of corn, or that one kilo of nitrogen will produce about 47 kilos of corn. This experiment used about 3 1/2 times this much nitrogen per kilo of yield. This has been interpreted as meaning that because of the high hydraulic conductivity of these volcanic ash soils, much of the nitrogen applied is leached out unless special practices are developed (small frequent applications, careful control of water applied) to minimize this leaching. This has prompted a series of treatments currently in progress to develop fertilizer-water application practices that will maximize yields per unit of fertilizer applied.

Phase 2 began in mid-1972 and has been reported (134) under three program headings:

1. Corn and tomato production using three irrigation methods and four nitrogen levels at San Andres.

2. Corn, melon, and peanut yields with two irrigation methods, three nitrogen and three phosphorous levels at Atiocoyo.

3. Production of corn, tomatoes and beans using furrow irrigation with four nitrogen levels on demonstration plots in the Zapotitan Valley.

(1) **Findings.** At San Andres where the corn and tomatoes were irrigated by furrow, sprinklers, and a trickle system, the following results were reported. There was highly significant yield variation with nitrogen treatment in the tomato plots with yield varying from 37,500 kg/ha at the 255 kg/ha of nitrogen level downward both ways. At the 525 kg/ha level yields decreased to 33,200 kg/ha.

Sprinkler irrigation produced better results in the corn plots and furrow irrigation in the tomato plots. However, the level of significance was not high enough to be conclusive. Since the fertilizer was spread by broadcasting it is thought that this adversely affected the uptake of nitrogen in the trickle irrigation plots. An interesting statistic reported was that more tomatoes were produced per unit of water at the low nitrogen level. For example, at 75 kg/ha of nitrogen applied, 9.5 kg of tomatoes were produced per cubic meter of water whereas at 525 kg/ha of nitrogen, yield was only 7.3 kg/ha per cubic meter of water. This trend was reversed in the corn plots.

(2) **Findings at Atiocoyo.** Corn production by sprinkler irrigation was at 4200 kg/ha very significantly higher than by furrow irrigation which produced an average yield of 2600 kg/ha. There was no response to nitrogen treatments. The melons which

averaged 21,000 kg/ha did not respond to either irrigation method or nitrogen level. The peanuts yielded almost double (at 821 kg/ha) under furrow irrigation compared to sprinkler irrigation but did not respond to nitrogen variation. Results were partially

confounded by lateral movement of the water in the pervious soil.

In terms of production per cubic meter of water applied, the data in Table 3 shows crop irrigation interaction.

TABLE 3. The Production of Corn, Melon and Peanuts per Unit of Water Applied Under Furrow and Sprinkler Irrigation

Crop	Irrigation	Production kg/M ³ of water applied
Corn	Furrow	0.51
	Sprinkler	1.07
Melon	Furrow	9.53
	Sprinkler	12.25
Peanuts	Furrow	0.28
	Sprinkler	0.15

(3) **Findings on the Demonstration Plots at Zapotitan.** Three demonstration plots were set aside by the Extension Department in the Avenamiento No. 1 Irrigation District with whom Professors Kidman and Stutler collaborated.

The major objectives of this program were:

1. To demonstrate feasible yield increases for corn, tomatoes, and kidney beans using good irrigation techniques which could be implemented by the local farmers.
2. To show crop responses to the interaction of fertilizer and water.
3. To help the extension technicians develop their own capability to successfully operate demonstration farms.
4. To evaluate the effectiveness of demonstration farms as a technology transfer mechanism under new irrigation conditions in Central America.

The first objective was successful, but the second was not achieved because one plot was damaged by a high water table and another could not be irrigated for lack of available water. The third and fourth objectives will need to be evaluated for another year before results begin to become apparent.

Crop Water Requirements

A. **Background.** Determination of crop water requirements requires "due consideration" of the

type of crop grown, the soil, climate, and cultural practices used including cultivating and irrigation methods and schedules. Since 1969 a significant component of the resources of the contract have been dedicated to the determination of the effect of climate on crop water requirements. This is because equations which were developed for temperate zone-low humidity regions, have not given enough weight to the effects of humidity, extraterrestrial radiation and their interaction with temperature, wind, day length, vapor pressure, and other factors. Moreover, there was insufficient information on techniques for the maximization of use of meager and/or inaccurate climatological data. The ability to accurately predict crop evapotranspiration and evaporation is a necessary component of water management and an important asset to those who need to forecast crop water requirements, such as irrigation system designers, water resource control agencies, water users, and those engaged in the financing and marketing of farm crops. Accordingly a crop water requirements component was included in the program and the first phase in determination of potential evapotranspiration and moisture availability for most of Latin America initiated under the direction of Professors Jerald Christiansen and George Hargreaves in late 1969.

Since then data have been collected and analyzed from Bolivia, Brazil, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, and Venezuela.

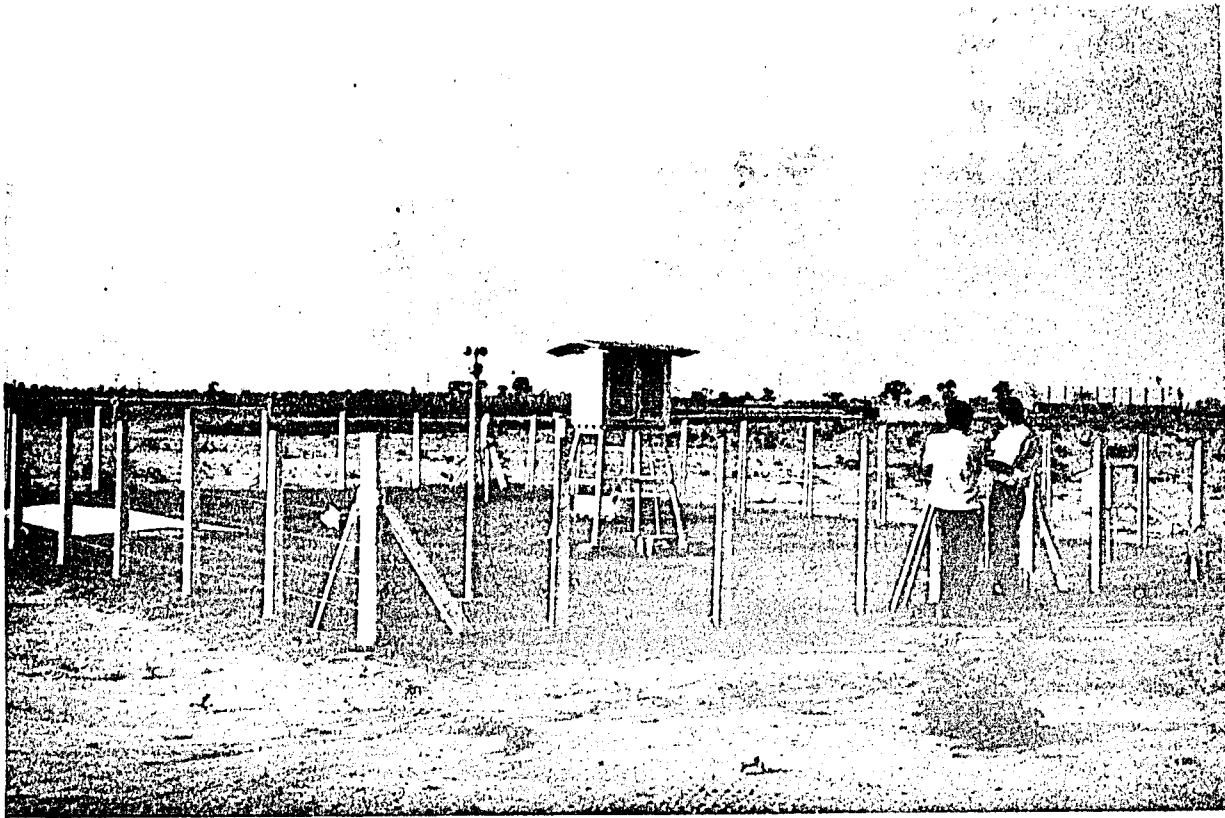


Photo 14. USU and Brazilian technicians in front of a newly installed weather station in Northeast Brazil.

This program has had three components namely:

- 1) Establishing working relationships with appropriate data collecting agencies.
- 2) Collecting and analyzing climatological, evaporation pan, and lysimeter data.
- 3) Training national counterparts in data interpretation. This has been done in four ways:

- a) National seminars
- b) One-on-one in country sessions between USU staff and host agency technicians
- c) Short courses at USU for host agency technicians
- d) Supervision at USU of foreign students working on advanced degree programs
- e) Collaborating with indigenous agencies in analyzing and publishing data. A major part of this component has been dedicated to determining the relationships between climatological factors which have influenced crop yield.

B. Accomplishments to Date. Christiansen and Hargreaves have developed several useful equations which appear in the references (103, 113, 135) whose applicability depends on the availability of various components of climatological data, location, and tradeoffs between accuracy and simplicity. Illustrative of the tradeoff situation is the following tabulation prepared by Hargreaves which shows the relationship of a number of factors as expressed by the square of the correlation coefficient (R^2) to mean lysimeter potential evapotranspiration, from data collected from, ARS and USDA studies at Coshocton, Ohio.

Element or Factor	R^2
Dew point temperature	0.88
RS (solar radiation)	0.94
RN (net radiation)	0.94
Extraterrestrial radiation	0.92
Day length	0.90
Mean temperature ($^{\circ}$ F)	0.88
Hargreaves "MF" factor	0.93
F times mean temperature	0.99
Christiansen's sunshine coefficient	0.94

Most of the equations used for potential evapotranspiration, ETP, can be written in the form

$$ETP = K \times RT \times C$$

in which K = a dimensionless constant; RT = extraterrestrial radiation; and C = a combined climatic coefficient combining corrections for temperature, relative humidity, wind, elevation and other elements.

Recently some use has been made of an equation that produces satisfactory results with a minimum of data. This equation can be written.

$$ETP = MF \times TMF \times CH$$

in which MF = a monthly factor based upon extraterrestrial radiation, day length and, for extreme

latitudes, sun angle; TMF = mean monthly temperature in degrees Fahrenheit; and CH = a correction for mean monthly relative humidity. The correction for humidity, CH, becomes 1.00 for 64 percent relative humidity or less and is therefore not required for low humidities. A correction for sunshine percentage may also be desirable in areas of quite low percentage of possible sunshine, such as in the case for Ecuador. Assuming an average correction for wind and a constant elevation, potential evapotranspiration, ETP, for arid areas becomes a function of extraterrestrial radiation multiplied by temperature in °F.

The estimation of irrigation requirements and the scheduling of irrigation can be accomplished from estimated potential evapotranspiration (ETP) by means of crop coefficients. Full crop cover and approximate average seasonal crop coefficients are reproduced in Table 4 as proposed by Christiansen and Hargreaves.

TABLE 4 Crop Coefficients, K (for use with potential evapotranspiration ETP)

Crop	Average K for full crop cover	Average seasonal K
Field and oil crops including beans, castor beans, corn, cotton, flax, peanuts, potatoes, safflower, soybeans, sorghum, sugar beets, tomatoes, and wheat	1.15	.90
Fruits, nuts and grapes		
Citrus fruits (oranges, lemons, and grapefruit)	.75	.75
Deciduous fruits (peaches, plums, and walnuts)	.90	.70
Deciduous fruits with cover crop	1.25	1.00
Grapes	.75	.60
Hay, forage, and cover crops		
Alfalfa	1.35	1.00
Short grass	1.00	1.00
Clover pasture	1.15	
Green Manure	1.10	.95
Sugar cane	1.25	1.00
Summer vegetables	1.15	.85

Objective 2

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

Accomplishments to Date. Previous years' progress reports have recorded studies in El Salvador on sprinkler irrigation operation with special reference to spacing (profile analysis) and the effect of wind on water distribution patterns (203, 204, 205, 206). Professor Griffin developed equations for using a pipe bend as a flow meter to provide an economic, readily available device (201). He also studied the feasibility of using an existing tile drainage system for irrigating land in El Salvador's Zapotitan Valley. It wasn't! (204).

Part of Dr. Miller's program in Venezuela included evaluating siphons for field irrigation research work. He concluded that with a reasonable amount of care their accuracy can be assumed at 75 percent (207). Professors Komain Unhanand and Jose F. Alfaro gave cost estimates for installing combined pipe drain-mole drain systems which showed the annual cost to be \$59/ha with main drains spaced at 30 meters and \$27/ha at 80 meter spacing (208).

In Brazil, Professor Austin, in cooperation with the USBR team assisted in the design and layout of several small individual irrigation systems using water pumped from the Sao Francisco River. These were dual purpose installations designed to meet farmer needs and to serve as demonstrations to encourage other farmers to increase production by irrigation and pumping from the river.

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

A. Background. Previous progress reports have referred to USU having developed under the leadership of Professor J. Paul Riley a hydrologic model simulating the effect that alternative land use strategies will have on the ground water table in the Atlantico-3 project.

This particular location was selected because most of the project area lies below sea level. Consequently all excess water must ultimately be pumped out. In addition, most of the area has a high water table already or a significant potential for developing it. At present the region is mostly covered except in the cultivated areas with a fairly dense natural vegetation including many types of phreatophytes, the removal of which will likely cause the water table to rise significantly.

B. Accomplishments to Date

(1) Model Simulation. Dr. Riley and his collaborators have developed and demonstrated in Colombia the computerized model and left with ICA's and INCORA's hydrologic section chiefs copies of the computer programs modified so they can be run on computers leased by these agencies.

Since the Atlantico-3 project area development program is under review, partly because of problems as explained under Objective 1, the impact of this component on production likely won't be felt until agronomists have solved the low yield problem.

The study itself will be quite useful as a component in the larger irrigation modeling program described in the proposal submitted by USU to AID to extend the contract for an additional five years.

The techniques developed have found several important applications in the United States as a result of contracts which the USU Water Research Laboratory has with the U.S. Bureau of Reclamation and the Agricultural Research Service.

(2) Leaching Results. Watt's preliminary study (319) showed that some of the north coast soils could be leached by application of as little as 500 mm of water. However, his objective was not to establish a precise relationship between the amount of water applied and the weight of salts removed from the soil. This was done by Olsen who was also interested in several other aspects of the problem. He, with the ICA counterparts, determined for the lighter soils that four 25 cm applications of water with drying intervals of between 20 and 30 days reduced total salts in the top two meters from 74 tons per hectare to 23 tons per hectare, a 70 percent reduction. Rice was planted in several of the leaching plots and it yielded 7 metric tons per hectare, thus providing a good land use while leaching is being carried out.



Photo 15. Rice growing in leaching experiment, Colombia, Atlantico-3 Project.

(3) **Drainage Experiments.** In a 400-hectare citrus orchard which is located near a major waterway (the Dique Canal built by the Spaniards to link Cartagena with the Magdalena River), a 16-hectare study area was selected, and with the collaboration of ICA and INCORA laboratories an intensive soil sampling and water level observation program developed. Twelve drain lines each 200 meters long were installed in the test area with 134 observation wells and monitored for flow and electrical conductance of the drainage water. These records provided estimates of the total amount of salt removed.

It was determined that:

1. The soils represented by those in the citrus orchard can be adequately drained and the water table maintained at a depth of 1.5 meters or more with a drain spacing of 100 meters.
2. The system removed appreciable amounts of salt from the soil even without irrigating. (Annual precipitation is about 1000 mm and falls in the seven-month period mid-April to mid-November.)
3. The principal cause of the high water table conditions was the ponding of water in depressions following rains and irrigations. The importance of good surface drainage was demonstrated.

4. The relatively high water level in the nearby Dique Canal had only a minor effect on the high ground water levels in the citrus orchard.

5. Infiltration tests in the citrus orchard indicated very large variations in the infiltration rates.

These drainage studies have two major utilization components. To Colombians they have given criteria for dewatering and leaching the Malambito type soils. A very detailed report of this work has been prepared by Olsen and Christiansen entitled "Land Drainage and Soil Reclamation Procedures in Arid and Sub-Humid Areas of Developing Countries Using, as an Example, The Atlantico-3 Project, Colombia." (322) This report would be an excellent reference for anyone working under adverse field conditions to resolve drainage and salinity problems.

Returning to the soil variability problem in Atlantico-3 described under Objective 1, efforts were made to get comprehensive soil analyses especially of the trace elements: iron, copper, manganese, and zinc. However, laboratory results of samples submitted to the two major national soils laboratories did not correlate, and hence the cause of the variable growth was not positively identified.

There were a few significant results from the plots in spite of their random variability. Yield was negatively correlated with phosphate fertilizer. There was a positive color response in corn to foliar applications of manganese, but yields did not improve. The coarser the soil texture, the lower the corn yielded.

As a consequence of these results the field and on-campus staff concluded that the most likely source of the difficulty was minor element toxicity in the soil. Whatever the problem, it has to be resolved before meaningful water-fertilizer-yield response experiments can be continued. Efforts have been made to involve the soils technicians of North Carolina State University who have been working for many years on tropical soils problems. They tried but were unsuccessful in getting clearance to go in to assist the USU team. Clearance was then sought and received to send in a USU graduate student, Mr. William Rubink, to investigate the soils problem. His thesis, which is being prepared for publication, describes his program which was carried out in early 1973. The major conclusions of his study follow.

Although this research did not provide a definitive answer to the visually most apparent problem at Malambito, a number of possibilities have been eliminated. At the same time the information presented forms a solid basis on which future agronomic investigations can be conducted.

The previous hypotheses of saline, sodic, or degraded sodic soils have been discarded. The suggested role of a possible cation imbalance is shown to be of minor importance; variations in the quantities of the four principal cations express themselves as only a small portion of the Malambito soils problem. Textural variations, although important, seem to have a result opposite to that expected: the deficiencies in plant growth are probably more closely related to the sand, rather than the clay fraction. The effects of pH are negligible, or opposite to those expected: growth seems to be slightly enhanced by small decreases in pH. Soluble salt concentrations indicate no danger to crops, however, future land leveling operations should be planned carefully to avoid subsoil exposures. The intensive measurements of soluble salt contents performed here also provide a basis for the long term evaluation of possible increasing salinity levels.

Research should now be concentrated in the realm of possible micronutrient deficiencies and toxicities, taking into account the developmental

history of the Malambito soils and utilizing all available information, e.g. aerial photographs and data obtained before the major agricultural engineering projects had begun (i.e., water quality analysis and previous soils investigations). Those crops (corn, sorghum, sesame, etc.) which have been demonstrated to be most susceptible to the problem should be eliminated from field crop experimentation except for edaphological studies. Proximate research should be devoted to those crops which show resistance to the adverse soil conditions. Until there is a technological breakthrough on this problem, research on water optimization in this region is not feasible.

The government of Colombia must now decide whether to risk more research effort on these soils, abandon hope of a commercial level of agriculture, or develop a flooded rice cropping program which would apparently be feasible. In connection with flooded rice, it is hypothesized that a primary factor in its relative success is that oxidation reduction potentials are much lower in saturated than unsaturated soils. This may be meaningful when considered with the fact that corn grown in pots at USU containing Malambito soils registered an uptake of 2400 parts per million (ppm) of iron in the roots—a staggeringly high figure. Also levels of manganese, copper, and zinc in these samples are about ten times that considered "normal," i.e. between 50 and 100 ppm. These recent results further support Rubink's suggestion that toxicity be researched.

The results, although not related to the original objectives of this component of the research are extremely interesting to Colombians. Perhaps the most significant transferrable component is to fortify the already known fact that adequate backup soils laboratory facilities are essential for all but very routine irrigation research at the farm level. This truth is apparently easy to appreciate but very difficult to implement.

In Colombia, the utilization of these results on the Atlantico-3 project will depend on the question now under review of future land use alternatives. As explained under the Objective 1 program, the high variability and low average yields over much of the project area has, as a result of Fullerton, James, and Rubink's work, raised serious questions about feasible cropping alternatives. However, as INCORA and ICA ponder this problem they now have the information to determine the effect of alternative land use programs on the ground water elevation (see Hydrologic Modeling Program previously described in the heavier soils).

About ten INCORA and ICA engineers have been closely associated with this program and are now well aware of the techniques involved in carrying out drainage and leaching studies in the field the equipment needed, manpower, requirements, plot design, and data collection and analysis.

El Salvador

Background. Previous progress reports have referred to drainage studies carried out in the period 1970-1972 by Professor Griffin collaborating with DGORD in the Zapotitan Valley. This collaboration included:

1. Determining specifications for installing flexible perforated plastic pipe drains to replace open drains.
2. Studying the feasibility of using the closed drains for subsurface irrigation. They found that it wasn't feasible primarily because of the anisotropic and heterogeneous nature of the soils with respect to hydraulic conductivity.
3. Supplying plans and specifications to DGORD for the construction of a mole plow. DGORD has had to postpone a planned mole drain developmental program because of more pressing resource needs.

Mole Drainage Research

A. Background. Mole drains, which are built by drawing a torpedo shaped plow usually of two- or three-inch diameter through the soil at a depth of from 18 to 36 inches, have been in use for many years. Their major function is to quickly dewater the ground surface so as to permit earlier cultivation and seeding, although some systems of subirrigation use the mole for water application. They also have been used for leaching (and reverse leaching) of salts from the upper two or three feet of soil profile.

Although there is a fairly extensive body of literature written on mole plow design and operation, most of it has been provided by practical field men whose observations are based on operating experience and are limited to a narrow range of field conditions.

Mole drains have, in some respects, a broader use potential in the tropics than in more temperate zones because of two factors:

1. Multiple cropping is feasible in the tropics.
2. Many tropical areas have well defined wet

seasons followed by dry seasons when little if any rain falls.

The first condition makes it important to dry out the surface as soon as possible in order to get the crop in early enough to fit it in a multiple cropping rotation. A ten-day delay in getting on land can mean the loss of a crop. The second condition makes it important under some climatic conditions to get seeds germinated early, so their roots can get down to a slowly receding water table and not be caught "high and dry." By lowering the soil moisture content from saturation to field capacity in the upper few inches, plants will get an earlier start and their roots will have a better chance to follow the moisture as it goes down in a dry land situation.

The problems which must be resolved for a successful mole drain installation are:

1. Type of plow to be used
2. Power required for various speeds and soils, plows, depths, moisture contents
3. Depth, slope, and direction of drawing mole
4. Life of drain
5. Effectiveness as a leaching device.

B. Accomplishments to Date. Six papers, reports, or theses have been prepared (301-304, 308-313) and five more are in preparation, all of which are financed at least in part by this contract.

(1) **Mole Plow Design.** The traditional single mole design has been compared with eight different double mole shapes with the objective of increasing mole channel durability. The double mole designs have indicated slightly better flow and durability after two years operation.

(2) **Optimum Soil Moisture Content.** The power requirement and structural stability of the drain are related to the soil moisture content at the time of pulling the drain. Polparsi (304) in laboratory studies at Utah State University developed a relationship between soil moisture content at the time of drawing the drain and drain discharge rate which indicates that there is a marked difference in drain capacity over a fairly narrow variation of moisture content with the best moisture content range falling between 27.5 and 29 percent. (See Figure 2.) The physical properties used in the experiments were as follows:

Soil type	Silty Clay
	(clay 54%, Silt 4%)

Void ratio	0.958
Porosity	48.9
Specific gravity	2.59
Bulk density (dry)	1.32 grams per cc

Liquid limit	44%
Plastic limit	22%
Plasticity index	22%

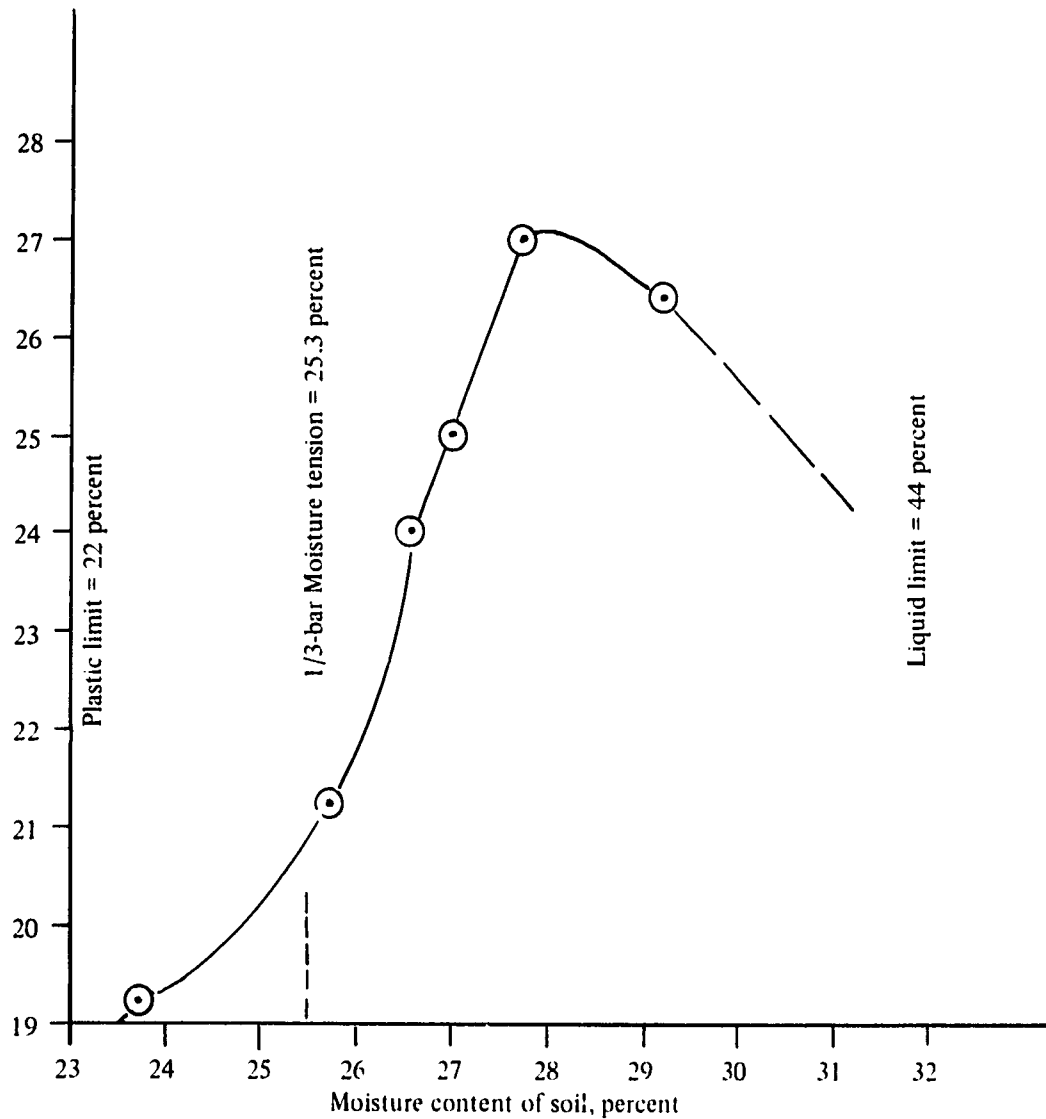


Figure 2. Discharge rates through mole channels constructed in soil under different moisture conditions.

- Note:
1. For mole channels built in the soil having moisture contents of 20.1 and 21.7 percent, the channel collapsed immediately.
 2. At a moisture content of 23.7 percent, the mole channel collapsed after only one reading was obtained.
 3. At saturation, mole channel collapsed after only two readings were obtained.

Polparsi and Unhanand also investigated the force required to draw the mole for various moisture contents and showed that the energy required at a moisture content of 25 percent was three times that required for moling the soil at 29 percent moisture content.

(3) **Combined Mole-Tile Drainage System.** A theory of a combined mole-tile drainage system based on the three dimensional equation of continuity for water movement in the soil under a transient state was developed by Kadir and Unhanand (306). Equations derived from the theory may be used to predict the height of water table at any point and any elapsed time. The equations may also be used to determine the spacing of both mole and tile drains. These have been field tested but need to be further simplified.

(4) **Removal of Salts by Mole Drains.** Unhanand (308) reported that mole drains were effective in reducing total salts in the upper soil profile and cited the fact that barley was successfully grown on a mole drained plot where previously no commercial crop could be grown. This was not a controlled experiment. Consequently it is being followed up by a controlled experiment which will shortly be reported on by a graduate student, Jose Antonio Forero, from Colombia (312) who developed an interest in the problem when he worked with a mole plow supplied to ICA's Tibaitata Research Station in 1971 by USU. At that time Professor Bertis Embry assisted their researchers to install mole drains in a corn field. Although no specific yield data was received, our observation of the crop several weeks before harvest indicated a marked variation favoring the mole plowed field when compared visually with an adjacent portion of the same field.

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

A. **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 use in the various countries and furnishes a sound basis for comparisons and selections for improved systems and strongly reinforces the best of the existing legal and administrative systems without the intervention of a "foreign expert." In order to meet this need, a 400-page Water Digest in Spanish and English has been prepared by USU's Professor David R. Daines with Dr. Gonzalo Falconi of the Ecuadorian National Hydraulics Institute (INERHI) as a co-author (421). It summarizes the water laws of Bolivia, Chile, Colombia, Ecuador, and Peru in each of the first five chapters. The sixth is a comparative study of the laws of each of these countries by subject. The thrust is on improving the expertise of the country planners by furnishing them with the information which enhances their local competence to draft suitable laws and regulations and effectively administer them.

B. **Accomplishments to Date.** Findings: The following legal and administrative inhibitors adversely affecting on-farm water use should be removed. They exist to varying degrees in all countries in the area. A water user's awareness of these factors decreases his willingness to invest in expansion of irrigation infrastructure.

1. To many economic classes of farmers, there is no "right" to use water, because they do not have access to the judicial or administrative machinery necessary to protect their right. This condition results from a lack of knowledge and a lack of financial resources to procure legal services and costs related to enforcing their rights.

2. Social pressures and customs frequently result in situations where administrators and enforcement agencies will not enforce water use rights.

3. Frequently, even where access to judicial and administrative machinery is available, the process is so slow and cumbersome that there is no effective protection against the infringement on rights. The law usually does not adequately compensate one for losses previously incurred.

4. Changes in political systems can result in loss of a previously valid right without just compensation.

5. There is a significant feeling of distrust on the part of the farmers in any legal or administrative process originating with the central governments.

6. In areas of high competition of water use, there is no substitute for continuous surveillance by a reliable and fair authority to guarantee supply in accordance with rights. It is impractical to expect

every user to provide his own continuous surveillance and to have the requisite knowledge about all the other rights from the same source to give practical protection to his rights. This element of continuous surveillance is frequently lacking.

7. The security of a right must be balanced against the need to reasonably limit the quantity and the gross abuses of an overly secure right. However, a right may be forfeited or lost for any infraction by the user of any of the rules or regulations relating to water use in most countries.

8. There are specific examples of express provisions in the laws of each country which unreasonably reduce the security of a use right.

Some inhibitors are of a more general nature in that they result in an inequitable allocation of water and result in waste. If improved allocation could be made there would be more water available for irrigation. Examples are:

1. Laws generally provide for the limitation of the quantity of a use right to the amount the user can "beneficially use." The quantifying of "beneficial use" by technical studies and determinations on a farm-by-farm basis is difficult because of inadequate finances and staffing and technical knowledge of water distribution agencies. The problem of application of water in the proper quantities and times to produce maximum yields requires considerable education of users but is partly an administrative and legal problem as well as a rather complex technical problem.

2. Commercialization or sale of water use rights is prohibited in these countries under a general policy incorporated in the laws. However, profiting from sale of water is permitted if it involves also a sale of the farm land on which the right is used. There are valid arguments in favor of and against commercialization or sale of water rights, but it appears that to allow sale of water with the property but not separate from the property is not accomplishing the goals of either free market allocation policy or the noncommercial administrative allocation of a public resource approach.

C. Dissemination and Utilization of Research Results. Comparative information and advice provided by this study to the Government of Ecuador were basic resource materials used by the drafters of the New Ecuadorian Water Code and Regulations of 1972-73. Commentaries were made to the Bolivian Ministry of Agriculture on their proposed water code. A portfolio of information was provided to

Colombian agencies at the request of USAID/Colombia.

A draft of the digest is being reviewed by top level water administration officials in each of the countries in preparation for a seminar to be held in January 1974. The Ecuadorian Water Resources Institute has requested authority to publish copies of the book before the final corrections at their expense because they consider the need for dissemination urgent. FAO has requested publication rights to research results.

Present research will be used as a base for empirical research focusing on the restraining and facilitating implications of laws and administrative structures.

Ecuadorian research involved substantial inputs from the National Hydraulic Resources Institute (INERHI) and considerable cooperation in the comparative study including Dr. Falconi's time. Daines officed there for two years. INERHI is co-sponsoring the seminar. Water distribution and administration agencies in all countries have shown great interest in utilizing the contents of the book and have continued salaries on their top level personnel while attending the seminar in all cases.

Economic Research in On-Farm Water Management

A. Background. Initial objectives of the economic component as reported in the first annual project progress report were to:

1. Establish economic bench marks
2. Evaluate price elasticity for main food crops
3. Relate domestic absorptive capacity to main food crops
4. Determine feasible water conservation, cropping, and small machinery practices
5. Forecast main crop production levels
6. Generalize direct and indirect economic impacts of viable land and water practices.

In order to accomplish these objectives, USU economists have used a variety of strategies to collect field data. Data has been collected where the collaboration of other USU field researchers and their counterparts has been feasible. Mission priorities and "low American profile" policies in some countries have precluded the gathering of data from some potentially valuable sources.

B. Accomplishments to Date. The project experience the agricultural economists have accumulated thus far has obviously shaped the program elements outlined and allows them to be presented with complete confidence. For example, they have organized, supervised, and conducted extensive rural farm surveys in Bolivia, Ecuador, and El Salvador (11 surveys) and have cooperated in national rural and urban consumption surveys in Bolivia. In the process they have completed the training of 4 M.S. students in agricultural economics (3 211-d); supported 1 undergraduate, 1 Ph.D. Three more M.S. students are nearing completion (211-d). In addition, a post-doctoral fellow was supported for 2 1/2 years.*

In addition to the project reports which have been published thus far, these surveys have also provided "data-bank" information and experience in structuring efficient field research and data gathering efforts. Table 5 is designed to give an indication of the type of farm management (input/output) and other basic economic data collected on a first hand basis.

*For the 2 1/2 years prior to July 1, 1973, the task of day-to-day supervision of such activities was largely the responsibility of Dr. Morris Whitaker.

While the overseas activities listed in Table 5 were all of a short term nature, they nevertheless required considerable campus back-up for coordination with the proper host country agencies and USOM's for planning the survey procedures and supervision. The bulk of all survey raw data also were processed in Logan, including necessary translations and preparation for theses and reports. A continuous process of additional data collection through correspondence and other methods has also been maintained. One product of this activity is a three-volume set of references to Latin American (primarily) source documents bearing on agricultural production (408, 409, 410). As part of the overall agricultural economics data collection-collation effort, Dr. Morris Whitaker (with the assistance of Dr. Boyd Wennergren) has completed a draft manuscript of a benchmark study of Bolivian agriculture. Praeger Publishing Company will probably publish this book as part of its series on the agricultural situations of various countries.

The 12-month period immediately preceding this report was devoted to two main activities: a) publication of results of earlier field research and a bibliography; b) refinement of the primary frame



Photo 16. Percy Aitken and El Salvador economist interview a farmer.

within which agricultural economics analysis will support the overseas research teams.

This latter step, while fundamental, could not really be accomplished earlier for the reasons already mentioned, also a certain amount of time must elapse before a critical mass of field experience and results are accumulated. We have now tested, in conjunction with Kidman and Stutler in El Salvador, a simple system of "economics back up" for the personnel conducting on-farm water management experiments on large experimental plots and sites overseas. Under this system the primary goal is confined to an evaluation of the effect of various irrigation methods on cropping practices under local farming conditions. Each evaluation might be composed of an initial study that could be revised from year-to-year as more accurate methods or cultural practice recommendations are made by our agronomist-engineer teams and as better cost information is available.* The actual methodology to be employed in such evaluations is flexible and would depend upon the circumstances under study.† But in any event the results would be site specific or country specific and would be most useful to national agencies that might be contemplating public investments or international financing for water resource investment. Most countries already have a certain amount of formalized economic analysis of development processes already underway, and it is most reasonable to plan to "feed" into such programs. Thus, the annual share of the overall project budget to be devoted to the economics phase can be estimated at 5 to 6 1/2 percent.

*There is an obvious need to be able to effectively estimate on-farm irrigation system costs under various site conditions, otherwise benefits and costs of technical recommendations cannot be ascertained. A plan under the supervision of a former 211-d financed engineering student, Mr. Grant Hansen, has been put into effect to conduct a pilot study in El Salvador to perfect a simplified method of helping farmers choose between alternative irrigation systems.

†A preliminary study of irrigation benefits in El Salvador is currently under review. It employs some relatively simple farm budgeting based on farmer surveys. In other cases, for example, where a whole irrigation project is studied, somewhat more detail should be developed through a linear programming model.



Photo 17. Dual purpose field in El Salvador--irrigated pasture and coconut palms.

None of the above should be read to mean that contractual obligations to emphasize regional and international transfer of on-farm irrigation and other managerial recommendations will be wholly ignored in the agricultural economics phase. We expect to lend support to the solution of the transferability question in two ways: a) create an interface between any water-soil-climate-plant growth simulation model developed (I.P. model), b) catalogue, from our own and other's farmer surveys, the most common labor and other input coefficients for crop and farm management cost and returns from countries in the regions where our experimental plots are or will be located.

The way the economics phase "fits" or is coordinated within the overall on-farm water management research effort at USU is shown in Figure 3. The field work is designed primarily to evaluate the technical information generated from USU team experimental work to provide decision information to local farmers. Information is in the form of technical Spanish and English reports, with simplified results for extension agents or farmers. This process also generates important farm input/output coefficients, many of which are suitable for data bank storage.

Table 5. Chronological Summary of the Agricultural Economics Phase of Overseas Activities

Date	Economics survey no.	Country	Purpose	Campus coordinator	Field worker	Data collection			Data dissemination	
						Field worker primary financing	Thesis program?	Thesis complete?	Project report? (ref. no.)	Journal or other article? (ref. no.)
Jul-Aug 1970	1	Bolivia	Establish system of marketing price & quantity reports	LeBaron*	Gomez	2167	No			
Jul-Sept 1970	2	Ecuador	Estimate benefits of water control investments by large rice farmers	Wennergren	White	211-d	Yes	Yes		
May 1971	3	Bolivia Ecuador Colombia	Test detailed questionnaire directed to farmer institutions	LeBaron	Aitken	2167	No			
Jul-Aug 1971	4	Ecuador	Estimate benefits of irrigation investments among classes of rice growers	Wennergren* Whitaker*	Aitken	2167	Yes	Yes		
Aug-Sept 1971	5	Ecuador	Benefits of better water management among tenure classes in an IRR project	Whitaker*	Lloyd	211-d	Yes	Yes	Yes (5)	Yes (15,16)
Jul-Oct 1971	6	El Salvador	Effect of irrigated pastures on dairy incomes	Whitaker*	Glenn	2167	No		Yes (4)	
March 1972	7	Ecuador	Observe operation of credit program for new rice coops	LeBaron	Glenn	2167	No			
August 1972	8	Bolivia	Relative benefits of shifting production areas vs. tube wells to increase sugarcane output	Wennergren	Bailey	211-d	Yes	Yes	Yes (6)	
Jul-Sept 1972	9	Bolivia	Direct national survey of rural production & consumption	LeBaron Whitaker	Whitaker Aitken	(No direct support from water management program)				
August 1973	10	El Salvador	Initial evaluation on farm irrigation system benefits		LeBaron Aitken	2167	No		In review	
Jul-Sept 1973	11	Bolivia	National I-P model of ag sector to est. potential water demand with eff. resource use	LeBaron Whitaker*	Hammond	211-d	Yes	No		
Jul-Sept 1973	12	Bolivia	National I-P model to estimate technical requirements to meet agricultural plan targets	LeBaron Whitaker*	Brown	211-d	Yes	No		

*In country with field worker part of time

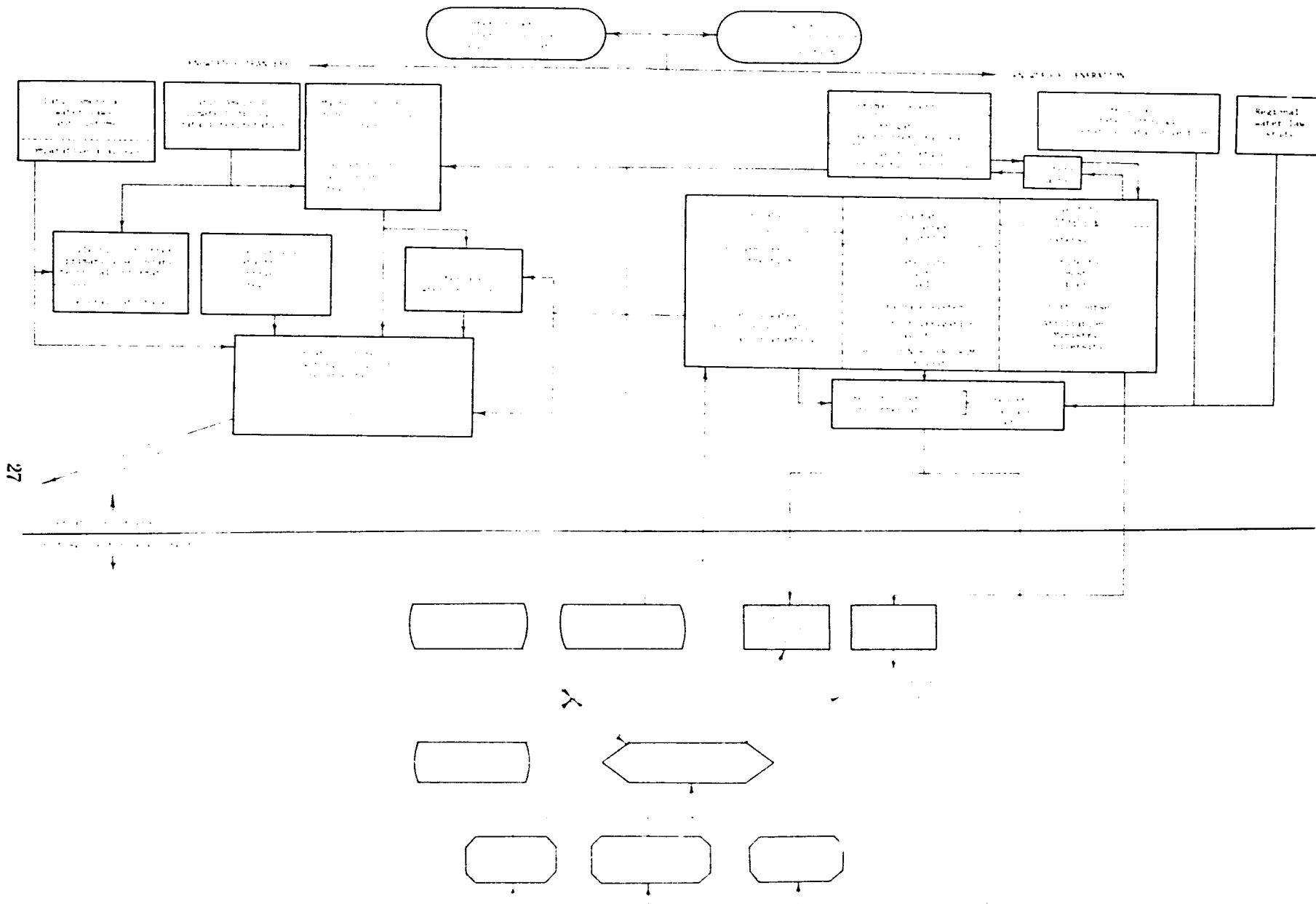


Figure 3. System Outline of On-Farm Water Management Research Program.

GENERAL OBSERVATIONS AND CONCLUSIONS

A reading of this and previous progress reports could lead a reviewer to the conclusion that there has been an element of opportunism to the selection of the field activities for this contract. This conclusion would be absolutely correct because of the existence of an important constraint—that the contractor carry out his field activities in collaboration with appropriate host country agencies and in accordance with priority issues of USAID missions. However, opportunism is not a bad strategy if the opportunities selected are contributing appropriately to the accomplishment of the contract objectives. Figure 3 has been developed to assist the reviewers to visualize the main stream interrelationships in operation.

All of the accomplishments have in general, three utilization phases:

1. Site specific applications in the area of the research
2. General application by the exercise of judgment by technicians in other areas in adapting the findings to local conditions
3. As input into further research as proposed in the document "Proposal for Extending the On-Farm Water Management Research Contract between the United States Agency for International Development and Utah State University from April, 1974 to March 31, 1977."

Research financed through this contract is establishing that in general, a doubling of yields by relatively simple adjustments to cultural practices can be anticipated on irrigated land. The impact of the water law and economic components (Objective 4) is

more diffuse, less quantifiable, but likely to provide more long term returns. A decision by a country to change its billing system to the farmer from a cost per hectare irrigated to a cost per volume of water used could materially increase the effective water supply, save on fertilizer otherwise leached out, and reverse trends in rising water tables. The implementation by a government of an effective impartial surveillance system on withdrawal from a stream in accordance with a well defined set of water rights would also greatly improve water use efficiency.

This type of research is on-going. It will result in improved yields and other benefits but will never provide ultimate answers as long as social and technological improvements are possible. There will be unforeseen spinoffs such as the identification of trace element toxicity in the soils of Northern Colombia and occasional failures to reach specific goals in specific time periods. However, in spite of these deviations, it is the contractor's opinion that this type of adaptive research is one of the best strategies AID has devised to increase food production in developing countries providing it is kept in operation long enough to reach its full potential. The past five years has achieved some worthwhile results, the most important of which may have been the increased level of competence of indigenous research agencies with whom the USU scientists have collaborated. Both they and the USU scientists are in a much better position now than they were five years ago to effectively focus available resources on the many exciting opportunities that are researchable to improve on-farm water management in developing countries.

EPILOGUE

One important aspect of the work that is difficult to convey in a progress report is an accurate reflection of what it's like to do research in a developing country. There is probably no such thing as a "typical" example of research under these conditions. However, all have a number of elements in common of which hard and often frustrating work is the most common denominator. The stereotype foreign adviser sipping tea on a veranda while he dispenses wisdom to eager, grateful, young native disciples is about as far as one could get away from the truth. A recounting of all the trials and tribulations of field researchers does not really belong in a

report of this type and would no doubt only embarrass the men who have come to accept special conditions under which they work as part of the job. For those reviewers who have an interest in getting a better feel for what it's like to really be there, we have included a copy of a letter from Dr. Fullerton to Dr. James in Appendix III. Dr. James is Dr. Fullerton's technical backup man on campus. The letter is interesting not only for its technical content but for the impression it leaves on what it means to do this kind of work. In this sense, Dr. Fullerton's letter is typical of the professionalism and dedication of the staff working in less than ideal circumstances.

APPENDIX I

Logistics of Getting Irrigation Research Stations Into Operation

The following is a summary or check list of the steps required to put a station into operation. Omission of any of these steps will delay or prohibit the successful operation of a station.

Administrative Factors

Planning

Objective Setting

Forecasting

Budgeting

Establishing Programs and Schedules

Establishing Policies and Procedures

Organizing

Developing an Organization Structure

- National Professionals

- Foreign Advisors

- Technicians

Relationships

Whether to organize vertically or horizontally - i.e. which head office departments to duplicate at the field station level and whether to have them report to the station director or to the corresponding head office department head.

Delegation

Authority vs Responsibility

Leading

Decision Making

Motivating

Communicating

Selecting, Training, Motivating People

Controlling

Establishing Performance Standards

Measuring Performance

Evaluating and Correcting Performance

This "check list" is of course not unique to the installation and operation of agricultural research stations. However, USU's experience in

working closely with government agencies in Latin America has confirmed the postulate that whenever "due consideration" was not given to all of these factors, delays, unscheduled changes and other inefficiencies inevitably resulted.

Physical Factors

As an example of some of the more important physical factors which must be properly considered in order to put a research station into operation, summarized below is a list of accomplishments through the joint efforts of USU and SUVALE in getting the Stations at Pirapora, Formoso and Sao Desiderio functional.

- Station field plot design
- Design of irrigation and drainage system
 - Pumping
 - Temporary
 - Permanent
 - Distribution system
- Construction and installation
 - Pumping and main supply pipeline
 - Land leveling
 - Gated pipe
 - Earth and concrete canals
 - Fencing and access roads
 - Construction of laboratories, offices and machine shops
 - Threshing floors
 - Surface drainage system
 - Water level observation wells
- Operation
 - Counterpart selection
 - Design and installation of irrigation interaction experiments including installation of water measurement gauges, running of furrow length and infiltration tests.
 - Seed acquisition
 - Setting up field seed storage facilities
 - Cultural practices including insect and bird control
 - Harvest
 - Analysis of results

Training of indigenous staff in

Design

Use of water and moisture measuring equipment

Meteorological observation

Insect control

Seed fumigation and storage

Soil analysis

Although in one sense, the above summary is a list of activities, each item represents an important accomplishment in which the USU team played a significant role. Agricultural crop research is dependent on the successful completion of a number of activities which must happen in proper sequence. That the SUVALE and USU technicians were able to marshal limited resources in the isolated locations of these three stations and begin to carry out meaningful research represented one of the major accomplishments of the contract.

Before the USU team left, the operation of the Pirapora CTI was well developed and was turned over to staff of the Federal University of Vicosa in Minas Gerais on contract. The Formoso and Sao Desiderio stations were still under the direct supervision of SUVALE technicians and were in the initial stages of carrying out water interaction experiments.

Irrigated crops planted included avocado, banana, beans, black pepper, cabbage, canavalia, castor beans, cauliflower, citrus, corn, cowpea, cucumber, egg plant, figs, forage grass, grapes, green pepper, guar, guava, jilo, mango, mint, okra, onion, orange, papaya, pineapple, pomelo, potato, rice, safflower, salsa, soybeans, squash, sunflower, tangerine, tomatoes, water melon and wheat. (See Appendix II for more details).

APPENDIX II

Summary of Experiments Carried Out by
Crop at Three Research Stations in North-east Brazil

- RICE - National Variety trial, 12/20/70 - 4/30/71, irrigated.
10 varieties, 4 reps, yields averaged 2150 to 4313 kg/ha.
LSD = 1425 CV = 20.35%
- CORN - National variety trial, 1970-71 rainy season, non-irrigated
25 varieties, 4 reps. Mean yields ranged from 687 to 1587
kg/ha with an experimental mean of 1081 kg/ha. CV = 36%
(among 54 National trials conducted the same season through-
out Brazil their mean yields ranged from 6691 to 634 kg/ha
with only 2 locations reporting lower yields than Pirapora.
Only one station reported a higher CV than Pirapora.
- CORN - Fertilizer x irrigation trial, 12/71 - 6/72. 4 replications,
5 treatments, yields as follows:

Fertilizer Treatments			Mean yields	Kg/ha
N	P	K	w/supplemental irrigation	without irrigation
0	0	0	297.3	25.9
1	0	0	844.6	16.1
1	1	0	676.8	61.6
1	1	1	1275.9	159.8
2	1	1	1181.2	59.2

(Note: N₁ = 300 kg/ha Ammonium sulfate
N₂ = 600 kg/ha Ammonium sulfate
P₁ = 300 kg/ha Single Superphosphate
K₁ = 100 kg/ha Potassium Chlorate)

- RICE - Variety trial, 10/71 - 2/72, 10 varieties, 5 reps, furrow irrigated.
Mean yields ranged from 764 to 2964 kg/ha with highly significant
differences among means. CV = 28%. (A duplicate experiment,
which received no supplemental irrigation yielded practically
nothing).

- SOYBEANS - Variety trial, 11/71 - 3/72, 10 varieties, 4 reps. mean yield range: 1630 - 2966 kg/ha. Differences highly significant. CV = 19%.
- ONION - Variety trial, 4/71 - 10/71, 12 varieties, 4 reps. Mean yield range: 7294 - 12604 kg/ha. Differences between means not significant. CV = 30%.
- SUNFLOWER - Variety trial, 10/71 - 2/72, 6 varieties, 4 reps. Mean yield range: 434-1525 kg/ha. Mean differences highly significant. CV = 27%.
- TOMATO - Variety trial, 4/71 - 10/71, 10 varieties, 4 reps. mean yield range: 44671 - 59007 kg/ha. Differences not significant CV = 15%.
- TOMATO - Variety trial, 9/71 - 3/72, 10 varieties, 4 reps. mean yield range: 16397 - 26990 kg/ha. Differences significant. CV - 18%.
- CASTORBEANS - Variety trial, 10/21/71 - 11/72, 12 varieties, 4 reps. Mean yield range: 357 - 729 kg/ha. Statistical analysis of data not made.

A report from the Chief of the Second Regional Agency at Pirapora dated 8/16/72 indicates that experimental plans made for the CTI for the 1972-73 crop year were interrupted by failure of the UFV/SUVALE contract to be signed and by discontinuation of the IPEACO contract, leaving the CTI without resources to conduct experimental work. He reported that by emergency measures the CTI was attempting to continue the following:

- Residual effect of green manure treatments. Begun in 12/71, corn planted in 7/72. Experiment designed by USU Team. Results not yet available.
- Castor beans - Variety trial (see above).
- Grapes - Planted 3/71, 6 varieties, 4 reps.
- Figs - Planted 8/72, 4 varieties, 6 reps.
- Citrus - 3 ha planting made in 1971 taken up due to poor transplants. Replanted.
- Banana - Variety planting made in 1971.
- Mango - Variety planting made in 1971.
- Avocado - Variety planting made in 1971.
- Tomato - Fertilizer trial, planted 5/72. 3 levels of N, P and K, 27 treatments, 2 reps.

Watermelon - Variety trial, 9 varieties, 4 reps.
 Squash - Observation planting, 5/72.
 Green pepper - Observation planting, 5/72.
 Egg plant - Observation planting, 5/72.
 Jilo - Observation planting, 5/72.
 Mint - Observation planting, 5/72.
 Cucumber - Observation planting, 5/72.
 Melon - Observation planting, 5/72.
 Okra - Observation planting, 5/72.

UFV/SUVALE Experimental Program, Pirapora

	<u>Date*</u>
1. Melon, variety x date of planting - fruit and seed production	**
2. Cucumber, variety x date of planting - fruit and seed production	**
3. Onion, variety x date of planting x fertilizer levels	3 to 5/73
4. Okra, variety x fertilizer x levels of irrigation	5 to 6/73
5. Peppers, variety x date of planting - seed production	12/7,2,5,8/73
6. Soybean, varieties	**
7. Soybean, strains (3 different experiments)	**
8. Grain sorghum, plant population x level of N x date of application	**
9. Sorghum, hybridization and line testing (5 exper.)	**
10. Cotton, effects of N, P and K on culture under irrigation	12/72
11. Lemon, variety observation	12/73
12. Pomelo, variety observation	12/73
13. Citrus, minor element studies	12/72
14. Citrus, fertilization	12/72
15. Orange, varieties	12/73
16. Citrus, comparison of 3 methods of irrigation	12/72
17. Tangerine, varieties	12/73
18. Tomato, varieties and introductions	2,4,8/73
19. Papaya, varieties	12/72
20. Cotton, varieties	12/72
21. Tomato, fertilizer x irrigation levels	1,4/73
22. Salsa, fertilizer x irrigation x 2 dates of planting	4,9/73
23. Pineapple, varieties	12/72
24. Onion, fertilizer x spacing - seed production	6/73

	<u>Date*</u>
26. Potato, irrigation x fertilizer	4/73
27. Potato, varieties x planting date	6,9/73
28. Okra, selections - observation	7/73
29. Cauliflower, varieties x fertilizers	1,4/73
30. Cabbage, varieties x fertilizers	1,4/73
31. Grape, varieties and rootstocks	7/73
32. Guava, varieties	2/73

* Date = expected date of planting

** Date = progress as of 12/72

Barreiras CTI - Experimental Plantings, 1971-72 Rainy Season

<u>Crop</u>	<u>Nature of Planting</u>
Corn	National variety trial - 26 varieties, 4 reps.
Corn	Seed increase - 2 varieties, 2 spacings
Rice	Seed increase - 31 varieties, unreplicated. . (Calculated yields up to 3320 kg/ha).
Rice	Seed increase - 2 varieties (only one produced seed)
Beans	National variety trial - 27 varieties, 6 reps. (Calculated yields of 19 varieties: 1028-1463 kg/ha).
Beans	Variety collection - 120 entries, unreplicated. (Top variety, 1857 kg/ha).
Beans	Seed increase - 2 varieties, lack of moisture, all died.
Wheat	Variety observation - 38 varieties. (up to 566 kg/ha).
Canavalia	Green manure and seed production. (Estimated green material turned under: 19,675 kg/ha).

Soil analysis made October, 1971. One to four samples from each field.

Range of results: pH - 5.7 to 6.4
 Phosphorus - 2 to 8 ppm
 Potassium - 125 to 249 ppm
 Aluminum - none
 Calcium and magnesium - 5.8 to 9.4 ppm

Precipitation during 1971-72 Rainy Season

October	114 mm	February	97 mm
November	380 mm	March	108 mm
December	158 mm	April	171 mm
January	42 mm	May	1 mm
		Season Total	1071 mm

Barreiras CTI - Experimental Plantings, 1972 Dry Season - Irrigated

<u>Crop</u>	<u>Nature of Planting</u>
Corn	National variety trial - 12 varieties, 6 reps.
Corn	Irrigation x fertilizer trial* - 3 irrigation levels, 5 fertilizer treatments, 8 replications.
Rice	Variety trial - 8 varieties, latin square.
Rice	Irrigation levels - 3 levels of water, unreplicated.
Rice	Seed increase - 3 varieties, unreplicated.
Beans	Variety trial - 24 varieties, 4 replications.
Beans	National variety trial - 24 varieties, 4 replications.
Beans	Variety collection - 160 entries, unreplicated.
Soybeans	Variety trial - 8 varieties, 5 replications.
Wheat	Variety trial - 11 varieties, 6 replications.
Wheat	Date of planting trial - 11 varieties, monthly.
Melon	Variety trial - 12 varieties, 5 replications.
Watermelon	Variety trial - 10 varieties, 5 replications.
Green pepper	Variety trial - 6 varieties (seedlings grown but never transplanted).
Cowpea	Observation planting - 20 varieties, unreplicated.
Potato	Observation planting - 5 varieties, unreplicated.
Canavalia	Green manure and seed production. (Planned but not planted: cotton, forage grasses and legumes, grapes, and citrus).

NOTE: At this writing the results of none of the above experiments have been summarized.

* Conduct of the corn irrigation x fertilizer trial was supervised by the USU Team. Brief description and mean yield data given on next page.

Calculated mean yields in kg/ha, corn irrigation x fertilizer
 experiment conducted at the Barreiras CTI,
 June - November, 1972. Variety: MAYA V.

Fertilizer, treatment			Irrigation Frequency			Mean
N	P	K	14 days	10 days	7 days	
0	- 0	- 0	1,646	1,693	1,472	1,603
150	- 0	- 0	1,589	1,794	1,695	1,694
150	- 300	- 0	2,669	2,927	2,964	2,833
150	- 300	- 150	2,445	2,845	3,023	2,722
300	- 300	- 150	2,291	2,410	2,568	2,422
Mean			2,128	2,344	2,344	2,269

Notes on Experimental Design and Conduct:

Experimental design: Split plot, with irrigation as whole plots and fertilizer as sub-plots; 8 replications (originally designed with 2 varieties and 4 replications).

Plot size: six rows spaced 1 m apart, 9 m long. Harvested area of plot: 4 rows 8 m long, 32 m²,

Fertilizer, including one half of N, hand broadcast and disked in before planting. Remaining N hand-spread between rows and covered, 45 days after planting date.

Planted with tractor mounted planter, 4 replications on June 22, 4 replications on June 28.

Barreiras CTI - Experimental Work Planned
for 1972-73 Rainy Season

<u>Crop</u>	<u>Nature of Planting</u>
Rice	Variety trial - 8 varieties
Rice	Variety trial - 10 varieties
Rice	Seed increase - 24 varieties
Beans	Variety trial
Beans	Variety collection - 153 varieties and strains
Soybeans	Observation and seed increase - 14 varieties
Wheat	Variety trial - 11 varieties
Wheat	Date of planting trial - 11 varieties, monthly
Melon	Variety trial - 12 varieties
Melon	Seed increase - 12 varieties
Forage grass	Introductions - 51 entries, including 22 species
Forage legume	Introductions - 46 species and varieties
Cowpea	Variety collection - 9 varieties
Black pepper	Observation planting
Citrus	Variety observation - 11 orange, 3 tangerine, 3 lime, 3 lemon
Corn	Study of the residual effect of P_2O_5 - to be conducted in field where the corn irrigation x fertilizer trial was conducted during the 1972 dry season.

NOTE: The black pepper and citrus plantings were never made due to lack of propagating material. The other plantings listed were made and now in progress.

APPENDIX III

Dr. D. W. James
Department of Soils and Biometeorology
College of Agriculture
Utah State University
Logan, Utah 84322
USA

Dear Dave:

Sorry it has taken so long to get this to you, but I have been involved in both harvest and establishment of tests for the coming dry season and haven't been able to work on the Colombian report. I have most of the crops data analyzed and have started weaving it into the progress report we sent in a year ago. As suggested when you called, I'm including most of the data here and will try to give you an idea of how I will try to write the report (sequence, etc.). I am also including the objectives of the field tests and comments on what led into each particular test. Unfortunately, there is not much to interpret from the data presented. I think from our discussions and what you have seen of the work in Colombia over the past two years that you will be able to see how the project developed. I hope there is enough for a brief summary in the over-all USU WG-69 report.

Here goes:

For an introduction I will review the WG-69 on-farm water management objectives and then state that the Malambito work was initiated to complement the drainage and reclamation research already in progress in Sta. Lucia in late 1971. Malambito was chosen because of the heavy soils which are more common throughout the project than the lighter ones of the Sta. Lucia experiment station. Our particular objectives in Malambito were to study water-fertilizer interactions, including population, variety, etc., eventually arriving at irrigation requirements for a crop of economic importance to the district. Consumptive use, development and interpretation of retention curves, prevention of salinization and surface drainage were to have been principal considerations while arriving at these requirements. My own thinking at the time we started was that the crop we selected in achieving these aims was not too important but rather that it would be a useful research tool in demonstrating to the ICA counterparts how to correctly go about obtaining the kind of information we were after (that is good responses to water, nitrogen, etc.) in order that they could go through the process themselves with any crop they desired after the USU group had left. Again, we did want to concentrate on a crop of economic significance in the Atlantico-3 district.

At this point I may have something to say about location and climate, although not much as this information is documented in a variety of reports on Atlantico-3. I will briefly describe what we know about soils (the general soils maps of INCORA) and that we went into our first experiments without benefit of soil analyses from the actual test site (it usually takes several weeks to get soil analyses results in Colombia).

The dry season was starting at that time and we wanted to take advantage of it for irrigation work. Since the parcels (farms) neighboring Malambito were being seeded with sesame and all of the materials were immediately available (seed, herbicide, etc.), we decided to start with this crop. We expected to learn

something about water needs and about nitrogen limits for sesame in considering it as a possibility for the crop we were to emphasize in reaching our objectives, as well as generally becoming acquainted with the area and the problems we would face. The INCORA soil maps showed the heavy soils as being high in potassium and medium to low in phosphorous; thus, we included phosphorous/non-phosphorous treatments in that first test. The most notable observations about the test were:

The extreme sesame variability within small areas (ranging from stunted to normal growth).

Chlorosis of all plants during vegetative growth resembling Mn deficiencies (which Sam Portch later supported through tissue analyses).

Significantly less growth and seed production where P had been applied.

Extremely reduced root systems (leading us to consider the possibility of a hardpan).

Lack of a response to water or N.

The results of this work led us into a second experiment which involved application of several trace elements including Mn produced an immediate color response (green instead of chlorosis) but did not appear to overcome stunting. Data from both of these tests are presented in the progress report of last year.

About the time our sesame results were coming in, we received our first soil analyses data back from ICA (which didn't tell us anything except that phosphorous was high). This was also the time of your first visit. We were fairly certain that our original objectives could not be met unless we could find a plant well adapted to the soils of the area or determine why our crop stands were so variable and be able to take corrective measures. This was when we decided to try and get Bill Rubink on the soils and at the same time look at all of the available crops in relation to both soil and water aspects.

With this background in mind, the following are results developed since the progress report was turned in last year.

SESAME

We were aware that stunting was not the result of salinity. If you will recall, we were wondering about the possibility of degraded sodic spots (as reported by Tahal) and had noted that most of our pH readings fell around 6.0 or below. We wanted to go a step further with sesame and Mn treatments in an attempt to correct stunting. A third test was established with lime treatments of 1, 3, 5 and 7 metric tons/ha applied and incorporated on September 6, 1972 and a control. Sub-plots were 25 kg/ha of soil applied $MnSO_4$ and a control. The manganese was applied on November 28, 1972 followed by seeding on November 30th with China Rojo variety of sesame. Our objectives were:

- (1) To determine if soil-applied manganese would correct stunting and chlorosis.

- (2) To determine if applications of lime would aggravate the Mn-like symptoms.
- (3) To measure the response, if any, to the lime treatments by sesame.

The deficiency symptoms (chlorosis) appeared within two weeks after germination in both the controls and soil-applied Mn treatments. Lime at all rates appeared to have no effect either on plant color or stunting. We applied foliar-Mn solutions (2 kg/ha) in some parts of the experiment and immediately observed the development of a dark green color. No improvement in stunting was detected as a result of the foliar treatments. We experienced a severe drought in late 1972 and the winter and spring of 1973. During most of this period the irrigation system serving Malambito was non-functioning. The sesame test was so extremely variable and dry that we ploughed it under in late February without trying to measure yields. We decided at that time that our soil problem involved more than just low Mn content. We felt that lime may not have been present long enough to affect the soil reaction.

SOYBEANS

We were encouraged by two earlier soybean tests in that both were characterized by very uniform stands. One of these prior tests was almost lost from lack of water and yielded poorly. The other was inadvertently killed when atrazine was mistaken for sevin and applied for insect control. While we had observed uniform growth, we did not have yield data to support the contention that soybeans were better adapted to the heavy soils than other crops common in the district. On March 26, 1973 two soybean varieties were seeded where lime had been applied for the sesame test just described. Main plots were the lime treatments with varieties as the sub-plots. We wanted to learn;

- (1) If we could produce a uniform stand of soya in an area of known soil variability (sesame in the same plots had been extremely variable).
- (2) If we could obtain normal soybean yields on the heavy soils.
- (3) The difference, if any, between the two varieties in adaptability or yield.
- (4) If there would be a response (positive or negative) to the lime treatments.

No differences could be observed where $MnSO_4$ had been applied as reflected by color or height and these treatments were not considered in analyzing the yield data.

The soybeans were generally very uniform in appearance. Slight depressions in plant height were observed, however, in areas where stunting had been noted for sesame. Although above-ground growth could be classified as normal, root systems were found shallow in these areas (approximately 5 to 6 inches in depth). Heavy rains in May and June resulted in lodging which occurred first in portions of the plots where root systems were reduced. Irrigation was required more frequently

than once per week in order to maintain development of the stand. Wilting generally started to occur within three or four days after water had been applied in areas of the test where root systems were shallow.

The soybeans were harvested the first week in July. No statistical differences were found between lime treatments or varieties. Measurements of soil pH taken shortly after harvest were approximately the same for each lime treatment. Yields of 2,735 and 2,745 kg/ha were recorded for ICA-Lili and Mandarin, respectively (a normal yield would be around 2,200 kg/ha).

We concluded that soybean production under irrigation frequencies utilized during the test would be difficult on a commercial basis. We do think, however, that a greater probability for obtaining normal yields exists for this crop than others commonly produced in the Atlantico-3 district on heavy soils such as those found in Malambito.

CORN

A previous corn test in Malambito was characterized by a high percentage of plants which lacked ears. A large number of plants which developed ears failed to produce grain. Either of these characteristics can indicate boron deficiency. A deficiency of this element has been reported in citrus near Malambito. Abnormalities in cotton produced in the vicinity of Malambito have also suggested low levels of soil boron to visiting experts. We initiated a paired-comparison field test with H207 corn to determine if a 4 kg/ha soil-applied boron treatment would result in normal ear and grain development. The test was seeded on September 27, 1972. Eight replications were included.

Corn plants were found highly erratic in growth within one month after germination. No relation could be seen between the boron treatments and growth variability. Only a few plants of the entire test had survived at harvest time (most plots had no surviving corn plants). For this reason we were unable to obtain growth or yield data. We couldn't conclude that boron applications would not improve corn production as a result of this test. It does appear, however, that if boron is a problem in corn production in Malambito, then it is a secondary one.

Potassium is generally considered high in the soils where we did our work (you can refer to the soils analyses in the first report we did). The work done for us by North Carolina State, however, indicated that potassium would stimulate plant growth (you have this correspondence in your files - Sam Portch, Arvell Hunter). With a limited amount of the heavy soil and additions of potassium solutions, they were able to measure a positive growth response with sorghum. Their analyses of the soil indicated a very low Mn content. Mn solutions also brought about a positive growth response in comparison to the checks. Hunter attributed these positive responses to:

- (1) Adjustment of the Mg/K ratio.
- (2) Meeting the sorghum's requirement for Mn.

This information was the basis for a corn test we seeded last April 2, 1973.

Potassium treatments were 0, 50, 100, 200, 400 and 800 kg/ha of K_2O as mainplots. A 1 kg/ha foliar application of $MnSO_4$ applied on two dates (April 28th and May 8th) was randomized within each mainplot with a control plot. We replicated the treatments three times.

In each of our corn tests we have noted symptoms highly similar to those usually associated with copper or calcium deficiency. These include failure of the upper leaves to unroll, followed by elongation of the stem which eventually breaks through these leaves. Still later, the upper stem becomes discolored and deteriorates. This is the disorder that Alfredo Pelaez is trying to associate with a disease factor. We haven't worried much about it in the past since we could never relate it to stunting or poorly developed root systems. This past spring it showed up very strongly in a sorghum field near Malambito as well as in our corn test (again we couldn't relate it to stunting in either of the fields). ICA and INCORA both became very excited about this phenomena and we were feeling pressure to try something. We reasoned that calcium wouldn't be the problem on a mineral soil but that copper might be worth a try (even though Sam Portch had been telling us that copper was very high in these soils). On May 14th we split our Mn plots with a control and a foliar application of $CuSO_4$ at 0.75 kg/ha as a sub-subplot treatment.

On May 28, 1973 we measured corn height and the percentage of plants demonstrating the symptoms described. The plots were harvested on August 3rd. Unfortunately, the third replication was harvested for us at night a few days before ours took place. The yield data I am including was based on two replications only and could represent a Type II error in saying that no differences exist. I have the information to calculate % blank stalks and % barren ears and will do so at the first opportunity.

We found no significant differences between potassium treatments (although I thought I could see differences in the field between the controls and plots where potassium had been applied). As you pointed out during your visit, we didn't incorporate the potassium treatments well and may not have really tested corn response to this material. The attached table summarizes manganese and copper effects on plant height, the percentage of plants showing the disorder and yields. Generally, applications of Mn and Cu were damaging to the corn according to the measurements we made. I first thought this could have resulted from applying solutions that were too concentrated (even though recommended for these deficiencies). After seeing the data you developed based on DPTA extractions, however, I'm wondering if these applications didn't just compound a soils problem -- your idea that a super abundance of trace elements are present at or near inhibitory levels.

Concerning a conclusion on this one--none of the treatments resulted in uniform stands or normal yields. Let me know if you think these data support your idea of extremely high trace element levels in the soil. I probably won't mention the North Carolina State data in the final report other than the fact that it raised some possibilities with K and Mn.

COTTON

When we first learned that the water table in Malambito was within a couple of meters of the soil surface, we decided to stay away from the deeper rooted crops such as corn, sorghum and cotton for our irrigation work. We got into

corn after we ran into the trace element thing with sesame (because corn has been studied so much in this regard). We later got into sorghum at INCORA's request when we did the subsoiler study. INCORA was also after us to work on cotton and tomatoes. I'm sure that water-logging is a common problem in the project. We wanted to do some surface drainage work and decided on cotton because it is probably the most important crop in the district and (mainly) to be able to say to INCORA that we were working on it (in other words not ignoring their requests).

Our objectives:

- (1) To see how well cotton was adapted to the heavy soil (would we have stunting, etc.).
- (2) To determine if surface drainage would result in increased cotton yields.
- (3) To gain more information about responses to nitrogen on these soils.
- (4) To learn if boron would improve cotton production.

The test was a split-split-plot design. Deltapine 16 variety cotton was seeded on beds 18" high and compared with cotton seeded on flat areas for mainplots. The bedded plots were drained by adjusting the slope of a series of small, interconnecting canals. Subplots consisted of a control and nitrogen applied at levels of 50, 100 and 150 kg/ha. A boron application (3 kg/ha--actual) and a control were included as the split-split-plot treatments. Four replications were utilized. The experiment was seeded on September 12, 1972. The plots were harvested on January 24th and February 15th of 1973.

No significant differences were found between the surface-drained and non-drained treatments or between nitrogen treatments. Boron applications resulted in a significant decrease in seed cotton yield in the non-drained areas but not within the drained areas (see table). Construction of the beds in the surface-drained plots may have created a more loosely packed soil than in the non-drained plots permitting better distribution of the boron. Uneven growth was observed in all areas of the experiment although cotton appeared better adapted than corn, sorghum or sesame to the heavy soils.

Our conclusions were as follows:

- (1) We really didn't test the benefits of surface drainage. We experienced abnormally low rainfall during the test. INCORA irrigation pumping systems were damaged during most of this period so that application of excess water by sprinklers was impossible. Bedding and surface drainage seemed to emphasize the drought although this wasn't reflected by yields. We still think that surface drainage would be advantageous in a normal rainfall period for cotton and other crops.
- (2) Boron did not improve yields. We may have had poor incorporation or applied too much of this material, however, which would account for the decreased yield obtained in the non-drained plots.

- (3) Nitrogen needs to be further studied with cotton under normal soil moisture in this area.

MULTICROP

I won't go into much detail about the multicrop test since you were the one that planned it. This was during your first visit to Atlantico-3 when we were wondering about sodic spots as well as degraded sodic areas with low pH. We did have a limited knowledge of soil analyses from Malambito at that time.

The test involved lime (5000 kg/ha), gypsum (4000 kg/ha) and a check. These treatments were randomized strips 45 meters long by 3 meters in width. They were incorporated with a disc-check plots received machinery work equal to the other two treatments. There were four replications. Crops utilized were corn, cotton, rice, sesame, sorghum, soybeans and tomatoes randomized in 2 meter strips at right angles to the lime, gypsum and control treatments. Within the 45 meter strips we were able to duplicate the crop units three times. We obtained no germination from the soybean or tomato seed (germination tests later showed that it was not viable seed). During the later part of the test we received no rain. The irrigation system was not operating during the second month of the test. While rice appeared to be the most uniform and vigorous of any of the crops planted, it was lost during the second month of the experiment due to dry conditions. Measurements of mean plant height (cm) and plant weight (g) were taken for each of the crops from each of the three units and averaged. We felt that we would lose the experiment from lack of water we attempted to wait for yield data. The data for each crop was analyzed individually as a randomized complete block design (see table).

Lime and gypsum were incorporated on August 22, 1972. Planting and harvest followed on November 14th and January 15th, respectively. Soil samples taken late in December indicate that these treatments had not affected pH at that time (although I still need to examine these data more closely). With the exception of sorghum, no statistical increases or decreases for any of the crops were found between the control, lime or gypsum treatments as reflected by plant height or weight. Sorghum height was significantly greater in plots where lime had been applied as compared to the mean of the control plots. Since no other responses of this nature were encountered, I'm not sure how reliable it is. How well does this fit with the slight calcium imbalance Bill Rubink found?

Concerning conclusions, the only thing we can say here was that rice, cotton, sorghum, corn and sesame (in that order) appeared decreasingly less adapted to the test area soil. Also that the lime and gypsum treatments probably were not in the soil long enough to affect pH (especially under the dry conditions we experienced). Except for rice, all of the crops were extremely variable in height and weight for one portion of the test regardless of treatment.

RICE

At this point you can see that this past year was a bad one--several tests which we lost altogether or results with no significance or negative responses (which may be good information but are not much fun to write up). However, in every sad tale there should be a little sunshine, which is what rice came to represent for us in Malambito--it was the only crop we worked with that seemed completely vigorous and normal.

We felt that rice was the logical crop to work with as soon as we started (heavy soils, drained swamp, etc.). We avoided it, however, since ICA (Colombia) has had a very good rice program and were not interested in expanding it any further. This was especially true in Atlantico 3 where the original philosophy was to cover their investment through high money-yield horticultural crops. They also have many shallow water tables and salinized areas and have felt that rice would compound this problem.

We initiated a small rice test on October 2, 1972 using CICA-4 variety which can be seeded either as an upland or inundated rice. We decided to look at it as an upland type (using sprinkler irrigation) because of the high water tables with the following objectives:

- (1) To determine if we could produce uniform stands (in other words, how well was it adapted to Malambito soils -- we planted in low spots, etc.)
- (2) To obtain yield information under sprinkler irrigation.
- (3) To establish nitrogen limits for future tests.

The experiment was a Latin square design which compared a control and nitrogen treatments of 50, 100 and 150 kg/ha. Half of each nitrogen treatment was applied at seeding and half November 22.

Following germination and throughout the test the rice was very uniform and appeared to respond well to the nitrogen levels (height, color). About two months after seeding we began to get nightly visits from cattle, which gradually developed a taste for lush, green rice plants. We were having our fences cut each night by a campesino so that he could short cut across Malambito on his \$5.00 (U.S.) burrow. During the last month the plots were three weeks without water and appeared to be lost. When water became available we inundated the area and the rice recovered. In spite of all of this mistreatment, up to 3,000 kg/ha were harvested from some of the plots (about normal). No statistical analyses was run for obvious reasons. At this point we decided that rice could represent the only alternative for having a normal agricultural situation (relative to other crops) in the Malambito area of the district-- at least until soils or other problems could be determined and solved. Rice also fit well with our needs for field experimentation (short root systems, response to nitrogen, etc.).

We initiated a second rice test on April 26, 1973 for the following purposes:

- (1) To obtain yield information for both sprinkler irrigated and inundated rice. We wanted precise water measurements along with a minimum and a maximum yield to provide a basis for further study in establishing optimum production with least possible water use in maintaining a constant downward of water.
- (2) To study the interaction of nitrogen and water between the two methods of irrigation.
- (3) To determine the influence of population densities as related to the above factors.

Irrigation treatments were mainplots. Both treatments received equal amounts of sprinkler irrigation until May 30th. The plots were sprinkled when tensiometers installed at 15 cm depth read 50 centibars of tension. Sprinkler irrigated plots were maintained on this schedule until shortly before harvest. Paddy rice treatments were inundated to a depth of 15 cm each day that water was available. While it was not possible to maintain the 15 cm depth at all times, soil moisture in these plots was continually at saturation. A total depth of more than 4 meters of water was applied in the inundated plots as compared to about 500 mm in the sprinkler irrigated plots (be careful of these figures as they disregard rainfall and what the inundated plots received prior to inundation--I'll calculate the totals when I have more time). Eleven observation wells were installed in each of the three replications at three meter intervals from the center of the sprinkler irrigated plots to the center of the inundated plots. Water table depths were recorded periodically from July 13th through August 16th. Since there would have been a great deal of lateral movement of ground water from the plots, they do not indicate water table levels under inundated rice conditions (or sprinkler irrigated) but do reflect that a downward movement might be maintained under these conditions.

Nitrogen treatments included a control and 75, 150 and 225 kg/ha of N. Population densities resulting from seeding rates of 60, 100 and 140 kg/ha were randomized within each N treatment for sub-subplots.

Measurements taken were yield, plant height, weed control (one of the important disadvantages of upland rice is weed competition), % lodging (heavy winds and rain knocked down a lot of our inundated rice about two weeks before harvest) and root depths (still not analyzed--taken shortly after harvest).

As expected, much more rice was obtained from the inundated plots although yields from these two treatments were not found significantly different (see table). Yields from both treatments were normal. ICA recommendations call for a commercial yield of 6,200 kg/ha with this variety. Upland yields are usually considered normal when they are 50% of the inundated yields. The 75 kg/ha nitrogen treatment resulted in more rice being produced than in plots where 150 or 225 kg/ha had been applied. This same general trend was followed under both the sprinkler irrigated and inundated methods. (As best we can learn, commercial fertilizer has never been used in the field where this work was done).

Almost no lodging occurred in the sprinkler irrigated plots as compared to a mean of 48% in the high nitrogen plots under inundation. This data is somewhat substantiated by measurements of plant heights as a response to nitrogen and water treatments. No grain losses were incurred as a result of lodging under the system of harvesting what we used. With a less efficient method (combine) it should still be possible to attain 6,200 kg/ha rice yields as called for by ICA.

We applied preforan (a pre-emergence herbicide) to all plots immediately after seeding. With the exception of one weed (Euphorbia heterophylla L.), good control was accomplished (we hand weeded to remove this particular species). During the last month of the test sprinkler irrigated plots were invaded by a morning glory (Ipomoea sp.) which would interfere with combine harvesting and could reduce yields. Essentially no weeds were present in the inundated plots.

I'll have to get you the population data later (although slightly less yield was obtained with a seeding rate of 140 r 60 kg/ha). Also I will be forwarding an analysis on root depths.

We had one surprise during this test. We found that the upland rice was influenced by the "parches" although this didn't seem to affect yield. We have good data demonstrating a significant correlation between plant height of rice and distance from the soil surface to a more dense layer. You can judge for yourself the value of the means of the water table depths as they fluctuated during the experiment.

Our conclusions are that rice (probably inundated rice) can be produced normally on the heavy soils. The data also defines some base lines for determining optimum yields with minimum water use for future research.

SOILS

In writing the terminal report I will include the same table I sent in a year ago regarding soils. I will point to Bill's work and what has developed since then. Briefly, the stunting that we found with all crops but rice is not due to salinity, alkalinity, water-lodging, degraded sodic spots, excessive leaching in low spots or soil compaction. As I interpret what you have told me thus far, the following ideas have developed:

- (1) A superabundance of trace elements; all present at near-toxic levels. I am interested in the last soils we collected to learn what happens to these nutrients with depth.
- (2) High quantities of phosphorous which interacts and possibly ties up other nutrients at the root surface (ex. Fe).
- (3) Negative correlations between iron and phosphorous and corn weights have been identified. These are not the problem in themselves but are being released from parent material at proportional rates to the release of a third mineral (ex. nickel) which is toxic to the crops we have studied. This would be related to a particular soil fraction which Bill associated with stunting in the thesis (did you get the contradiction on this point straightened out with him?)

Any or all of these ideas fit with our results in the field. For example, inundated rice is grown under anerobic soil conditions which could cause a change in the chemistry of the proposed toxic element. Also root inhibition seems to be an effect of whatever the problem is. Under inundation, a large extensive root system might not be necessary for normal growth and yield.

I'll probably not have too much to say about soils but leave this part up to you. In summary, it's regretful that we didn't start out with rice instead of ending with it. I think the district could become prosperous with a switch to this crop. If you can pin-point the soils problem (whether or not it can be solved) it would almost certainly have a large influence on the Atlantico Project.

Once again, pardon me for getting this to you so late and in such a dis-organized form. I'm hopeful that the final report will come more logically and complete.

Sincerely,

Tom Fullerton
El Salvador

P.S. I am also forwarding copies of the calculations we did in Barranquilla.

cc: Byron Palmer

Table _____. Cotton yields as influenced by boron treatments within non-drained and surface-drained areas.

<u>Boron treatments</u>	<u>Cotton yields (kg/ha)</u>	
	<u>non-drained</u>	<u>surface-drained</u>
control	1546 a ¹	1319 a
boron (3 kg/ha)	1361 b	1347 a

¹ Means followed by different letters are significantly different at the 5% level of probability according to Duncan's multiple range test. Compare in columns only.

Table _____. Plant heights, percentage of plants displaying "disorder" symptoms and yields of H207 corn as influenced by manganese and copper treatments.

	<u>Manganese treatments</u>		<u>Copper treatments</u>	
	<u>control</u>	<u>MnSO₄ (kg/ha)</u>	<u>control</u>	<u>CuSO₄ (.75 kg/ha)</u>
Plant height (cm)	175 a ¹	159 b	166 a	168 a
% Plants showing Disorder symptoms	9 b	30 a	16 b	22 a
Yields (kg/ha)	1944 a	1707 a	1947 a	1704 b

¹ Means followed by different letters are significantly different at the 5% level of probability according to Duncan's Multiple range test.

Table _____. Average height and fresh weight per plant of corn, cotton, sesame and sorghum according to lime and gypsum treatments.

Crop	Height (cm)			Weight (g/plant)		
	Control	lime (5000 kg/ha)	gypsum (4000 kg/ha)	Control	lime (5000 kg/ha)	gypsum (4000 kg/ha)
Corn	140	126	125	171	153	154
Cotton	59	53	51	45	40	38
Sesame	96	103	97	82	77	75
Sorghum	76 b ¹	86 a	82 ab	100	104	88

¹Means followed by different letters are significantly different at the 5% level of probability according to Duncan's multiple range test.

Lime and gypsum applied and incorporated on August 22, 1972.

Seeded November 14, 1972
Harvested January 15, 1973.

Table _____. CICA-4 rice. Yield, percent lodging, plant height and percent weed control as influenced by different irrigation methods.

	<u>% Weed Control</u>	<u>Plant Height (cm)</u>	<u>Percent Lodging</u>	<u>Yield (kg/ha)</u>
Sprinkler Irrigated	72 b ¹	67 b	0.5 a	3951 a
Inundated	98 a	94 a	28.0 a	7302 a

¹Means follow _____ test.

Table _____. CICA-4 rice. Yields, percent lodging, plant height and weed control as influenced by nitrogen treatments under different irrigation methods.

		Nitrogen treatments (kg/ha)			
		Control	75	150	225
Yield (kg/ha)	Sprinkler irrigated	4126	4135	4228	3313
	Inundated	7798	8200	6255	6955
	Average	5962ab ¹	6168a	5242bc	5134
Percent Lodging	Sprinkler irrigated	0 a	2 a	0 a	0 a
	Inundated	7 c	22 bc	35 ab	48 a
	Average	4 b	12 ab	18 a	24 a
Plant Height (cm)	Sprinkler irrigated	66 a	66 a	69 a	67 a
	Inundated	87 c	93 b	99 a	98 a
	Average	77 c	80 b	84 a	83 a
Percent Weed Control	Sprinkler irrigated	79	64	74	71
	Inundated	97	97	98	99
	Average	88	81	86	85

¹Means followed etc--test. Comparison can be made only on a horizontal plane.

²0 = complete weed cover; 100 = no weeds present or 100% control.

APPENDIX IV

Publications, Papers and Reports Prepared and Planned

The following list describes manuscripts, publications and reports prepared and being planned using resources provided by this contract. Those listed in the 100 series relate to objective one, 200 to objective two, etc. In most of the references cited other resources have been involved through data collection, assisting in the field research, actual publication of a report etc. In order to assist reviewers of this report in understanding the linkages generated at the reporting level, the following coding which appears at the end of each reference is provided.

- (A) Data collected, report written and published using contract resources primarily.
- (B) Report in Thesis form only. Student supervision by professional staff associated with the contract. Copies available on request.
- (C) Report published using contract resources in which local water involved agencies collaborated.
- (D) Report published by another agency. Data generated and analyzed.

* Publications not yet published

Objective 1 - Publications, Papers, Reports and Manuscripts

101. Analysis of Colombian Precipitation to Estimate Irrigation Requirements. 1971. M. S. Thesis, Hardee, J. E. (B)
102. Investigaciones Sobre Evapotranspiración y Requerimientos de Irrigación. (23 page report with 13 maps). 1970. Instituto Geographico Nacional (El Salvador C.A.) (D)
103. Irrigation Requirements in Latin American Countries. Second World Congress of Engineers and Architects, Tel Aviv, Israel. December, 1970. (Published in ITCC Review, Vol. 1, No. 2, April 1972, pp. 40-50), Christiansen, J. E. and Hargreaves, G. H. (C)
104. Analysis of Venezuelan Data to Compare Computed Evaporation, Potential Evapotranspiration and Evapotranspiration Deficit. 1970. M.S. Thesis, USU, Rujirakul, S. (B)
105. Estimation of Evaporation and Evapotranspiration in Colombia. 1970. M.S. Thesis, USU, Stutler, R. K. (B)
106. Analysis of Chilean Meteorological Data to Estimate Evapotranspiration and Irrigation Requirements. 1972. M.S. Thesis, USU, Tosso, J. (B)
107. Estimation of Irrigation Requirements for Venezuela. 1972. M.S. Thesis, USU, Rondon, F. F. (B)
108. The Relationship Between the Climate and Dry Farmed Wheat in Iran. 1972. M.S. Thesis, USU, Mirnezami, H. (B)
109. Pan Evaporation and Evapotranspiration in Iran. M.S. Thesis, USU, Khosravi, A. R. (B)
110. The following three reports were prepared by Professor George H. Hargreaves and published by UNDP - World Meteorological Organization - Proyecto Hidrometeorologico Centroamericano.
 - a. Necesidades y Requerimientos para Irrigación, Arenal y Vecindades, Costa Rica. Published by PHCA (D)
 - b. Necesidades y Requerimientos para Irrigación, Comayagua y Vecindades, Honduras. Published by PHCA (D)
 - c. Deficiencias de Agua en Centro America y Panama. In Press by PHCA, December, 1972. (D)
111. Irrigation Requirements and Climatic Evaluation for Venezuela. 1971. Christiansen, J. E. and Hargreaves, G. H. (C)
112. Requerimientos para el Riego de la Caña de Azucar, Santa Cruz, Bolivia. 1971. Hargreaves, G. H. (D)

113. Irrigation Analysis for Selected Crops, Santa Cruz, Bolivia. 1972. (Also available in Spanish). Bolivian Utah State/USAID Study Team (D)
114. Monthly Precipitation Probabilities for the States of Maranhao, Ceara and Piaui in Northeast Brazil. 1973. Hargreaves, G.H. (A)
115. Moisture Adequacies and Deficits for Agricultural Production in Ceara and Piaui, Brazil. 1973. Hargreaves, G. H. (A)
116. Monthly Precipitation Probabilities for Northeast Brazil. 1973. Hargreaves, G. H. (A)
117. Requerimientos Hidricos de la Region Sud Oriental de la Republica Dominicana. Hargreaves, G. H. and Alfaro, J. F.; paper presented at the Symposium on Tropical Savannah Soils, Santa Domingo, Dominican Republic, Jan. 22-26, 1973 (C)
118. Irrigation Requirements and Ground Water Development. Paper prepared for presentation at the National Ground Water Symposium, Sao Carlos, Sao Paulo, Brazil, No. 27 - Dec. 1972. Hargreaves, G. H. (C)
119. Groundwater Extraction and the Water Balance.* Hargreaves, G. H. (A)
120. Irrigation Requirements for Grasses Including Turf. Hargreaves, G.H.* (A)
121. Irrigation of Community Gardens in Panama. 1973. Christiansen, J.E. (A)
122. On-Farm Water Management Research in the Aconcagua Valley, Chile. Third Annual Report, 1971-72. Kidman, D. C., Stutler, R. K. James, D. W. (C)
123. Interim Report of Water - Soil - Crop Interaction Experiments in Chile. 1970-71. Kidman, D. C., and Stutler, R. K. (C)
124. Irrigated Corn Production Studies in the Zapotitan Valley, El Salvador. 1972. Griffin, R. E. (C)
125. Corn Studies in Los Llanos, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Martinez, E., Bustillos, A., Gonzales, A., and Guilarte, T. (D)
126. Irrigation-Fertility Studies with Caraota. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Martinez, E., Cheves, E., Bustillos, A., and Guilarte, T. (D)
127. Efectos de Diferentes Niveles de Riego y Fertilidad y Cultivo del Arroz. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., and Bustillos, A. (D)

128. Investigations of Sugar Cane Growth in Las Majaguas, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R.W., Bustillos, A., and Guilarte, A. (D)
129. Summary of Cambur Study; The First Nine Months. 1970. Prepared in Spanish and English by Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Martinez, E., Gonzales, A., and Guilarte, T. (D)
130. Irrigation-Fertility Studies with Cambur. 1972. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Martinez, E., Gonzales, A., Guilarte, T., and Chavez, E. (D)
131. Research Activities in Water Use and Soils in Los Llanos, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W. (D)
132. An Intensive Edaphological Characterization of the Soils of Malambito Experimental Station and its Implications in Future Agricultural Research. 1973. Rubink, W. L. (B)
133. Evapotranspiración Por Medio de los Lisímetros y su Relación con la Evaporación en Santa Cruz Porrillo y San Andres - Informe Anual. 1973. Stutler, R. K. and Gonzales, M. J. (D)
134. Investigacion del Manejo de Aqua de Riegos a Nivel de Parcela Informe Preliminar, 1972-1973. 1973. Stutler, R. K., Kidman, D. C. and Gonzales, N. J. (D)
135. The Estimation of Potential and Crop Evapotranspiration. 1973. American Society of Agricultural Engineers. Hargreaves, G. H. (D)
136. The Evaluation of Water Deficiencies. Paper presented at Irrigation and Drainage Division Specialty Conference, ASCE, Spokane, Washington, September 26-28, 1972. Hargreaves, G. H. (A)
137. Development of a Procedure for Determining Spacial and Time Variations of Precipitation in Venezuela. May 1971. M.S. Thesis, USU, Ramirez, L. E. (B)
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202. Sub-Irrigation in the Zapotitan Valley, El Salvador. 1971. Griffin, R. E. (C)
203. Sprinkler System Distribution Evaluation Using the Superimposed Method. 1971. Griffin, R. E. (C)
204. A Study of Wind Velocity Profile at Santa Cruz Experiment Station, Venezuela. 1970. M.S. Thesis, Gutierrez, O. (B)
205. Sprinkler Profile Analysis to Predict Field Performance. 1971. Published by American Society of Agricultural Engineers, St. Joseph, Michigan. Keller, J., Moynahan, M. D., and Ptacek, R. L. (D)
206. The Use of Sprinkler Profiles to Predict Field Performance. 1972. M.S. Thesis, Moynahan, M. D. (B)
207. Irrigation with Siphon Tubes. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Guilarte, T., and Chavez, E. (D)
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314. A Hybrid Computer Model of a Hydrologic System within the Atlantico-3
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315. Combined Surface Water - Ground Water Analysis of Hydrological Systems
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402. Economic Aspects of Irrigation from Ground Water. 1972. Presented at the Brazilian National Ground Water Symposium, University of Sao Paulo, Dec. 1972. Hargreaves, G. H. (C)
403. Relative Rates of Return to Controlled Irrigation Among Classes of Summer Paddy in the Guayas Basin in Ecuador. May, 1972. Department of Agricultural Economics, USU. M.S. Thesis, Aitken, P. (B) and (C)
404. Impact on Rural Incomes and Improved Water Management in Milagro County, Ecuador. May, 1972. Department of Agricultural Economics, USU. M.S. Thesis, Lloyd, P. (B) and (C)
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