ON-FARM WATER MANAGEMENT RESEARCH IN CHILE:

EFFICIENT USE OF SOIL MOISTURE AND

NITROGEN FOR INCREASED CROP PRODUCTION

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INTRODUCTION

Water application to arid land can increase crop production many-fold. Equally important is the fact that a careful integration of other plant growth factors--soil chemical and physical properties, crop variety or genetics, and crop pest control--can often increase crop production an equivalent amount more than the increase attributed to irrigation. This integration of crop growth and water management factors is the essence of modern intensive irrigation agriculture.

The maximum benefits available from irrigation are yet to be realized even in areas of the world now practicing the most advanced technology. This is primarily because irrigation principles are not generally understood and therefore not practiced. In developing countries, particularly, there is a great potential for increasing food supplies through adaptation of the concepts involved in intensive irrigation management.

The agricultural economy of Chile depends heavily on irrigation. Irrigation water is limited and land and water resources must be utilized efficiently. To this end a water management research agreement was joined between the United States Agency for International Development (AID), Instituto Nacional de Investigaciones Agropecuarias (INIA) and Servicio Agricola y Granadero (SAG) in Chile, and Utah State University to evaluate ways and means for adapting the concepts of intensive irrigation management to Chile's irrigated land.

The center selected for this work was Los Andes, a city situated in the Aconcagua valley about 60 kilometers north of Santiago.

Irrigation was introduced into the Province of Aconcagua about 100 years ago. It developed gradually and at the present time involves about 36,600 hectares of land. As such, Aconcagua represents an important segment of Chile's agricultural production. Irrigated crops produced include grain corn and forage (for dairy and beef feed), hemp, fruit and nut crops, and vegetables.

On initiating the research, corn was selected as the indicator crop because it is economically important to the area and also because it is well adapted to soil moisture-soil fertility interaction studies. The research program covered three full crop years and involved several facets of irrigation technology.

RESEARCH IN ACONCAGUA

Objectives

The long-term objective was to develop crop response functions to soil moisture and fertility. Such functions have many useful applications. First, they will provide the basis for prediction of optimum combinations of soil moisture and fertility for maximum crop production under a given set of climatic and soil conditions. Secondly, they can be used in connection with consumptive use data, as the basis for frequency of irrigation and irrigation system design criteria. The latter application is important in the design of on-farm water distribution systems and larger water storage and delivery systems.

The research was aimed toward a long range objective which, at the outset, was not necessarily considered to be attainable within the expected lifetime of the project. Short-term objectives were outlined to guide year-to-year activities.

Chile, typical of many developing countries, has yet to explore its real potential in the area of irrigation agriculture. Therefore, short-term objectives for the Aconcagua research project were aimed first toward an analysis of the growth limiting factors in irrigated crop production in the area to determine the yield potential at the site.

An additional short-term objective was to delineate the boundary conditions and establish a basis on which future experiments could be designed which would be aimed specifically at generating the response functions.

Another important short-term objective was extension-oriented. As crop production management practices were evaluated, results were relayed to commercial growers so that they could learn and profit from the new information.

Connected with all the objectives was the intent to train professional agriculturists in Chile, both research and extension, in the techniques of field research and demonstration.

MATERIALS AND METHODS

The soil parent material in the Aconcagua Valley includes both igneous and sedimentary rocks. The soils are relatively young; the weathering intensity is low. Soil texture is predominantly sandy loam to silt loam, but significant amounts of both coarser and finer textures occur. The soils are variable in depth and are generally well drained.

The valley enjoys a growing season of about 210 days--September 15 to April 15. The average daily maximum temperature during the warmest part of the year is about 30°C. The average annual precipitation is near 200 mm, almost all of which falls during the winter months. Irrigation water is derived from snow melt in the high Andes.

Most of the research was done at two experimental sites, fundo El Castillo and fundo Condoroma. Experiments were designed to study interaction between crop growth factors. The experimental variables included various combinations of irrigation rate or frequency, nitrogen fertilizer, corn hybrid variety, and plant population density. The treatments were always replicated in randomized complete blocks. Where irrigation was a variable, other treatments were arranged as split plots within the irrigation whole plot.

Crop yields were expressed in terms of quintales per hectare (qq/ha) of shelled corn at the standard 15 percent moisture content. Yield estimates were based on all the ears harvested from 32 linear meters of row within each rectangular plot. Due regard was given to border effects on the ends and sides of the plots. Phosphorus as treble superphosphate was applied uniformly as required. Nitrogen fertilizer (specific amounts indicated in the results) in the form of urea was applied broadcast and incorporated with a disc plow. Soil moisture was measured with tensiometers and electrical resistance (gypsum) blocks. Where pertinent, irrigation water was measured on and off the plots using weirs. Irrigation water was applied in furrows using siphon tubes at the furrow heads.

The types of experiments and the controlled factors in each of three seasons were as follows:

1969-70:	Pilot trials - 2 sites, 4 rates of N, 3 irrigation frequencies, 2 varieties
1970-71:	2 sites - 5 rates of N, 2 irrigation frequencies, 2 plant populations using hybrid MA-7 from INIA.
1971-72(a):	1 site - 5 nitrogen rates, 5 plant populations, 2 corn varieties (T - 133 and MA - 7).
1971-72(b):	1 site - 3 levels of crop residue incorporation, 2 levels of gypsum.

In addition to the foregoing, crop management demonstrations were conducted on a total of 15 private and cooperative farms during 1970-71 and 1971-72. These involved mostly single replications of several nitrogen fertilizer rates and plant populations. Average results from these demonstrations are given for general comparison with the research plot results.

The experimental results are presented in chronological order together with additional procedural information as needed to clarify the data.

RESULTS AND DISCUSSION

Pilot Trial Results in 1969-70

Although this report is limited essentially to the experiments conducted in 1970-71 and 1971-72, the results of the pilot trials in 1969-70 are summarized here because of the importance of the initial experiences in guiding all subsequent efforts. The early experiences and information not only served as a basis for designing experiments, but provided the basis for initiating an extension program. The most prominent features of the initial results were as follows:

1. Seedbed preparation had to be modified to provide a surface soil mulch in order to conserve soil moisture, improve seed germination and seedling establishment, and to allow for better weed control. The traditional method of seedbed preparation consisted of disc plowing in the spring followed by one operation of a disc harrow. Under these conditions the soil was very cloddy, and it lost moisture rapidly. Seed germination and seedling establishment were very poor. The relatively thin stand of corn that often resulted made weed control extremely difficult.

2. In general, the irrigation technique common to the area had to be improved in order to insure adequate soil moisture throughout the root zone during the growing season. The traditional method of water application was flood

irrigation. The water was applied rapidly for short intervals, allowing little if any time for wetting the subsoil, especially at the lower ends of the fields.

3. In the field experiment shelled corn yield increased with irrigation frequency and added nitrogen fertilizer, but because of the nature of the experimental design (incomplete factorial), the interaction between moisture and nitrogen was not defined. Corn yield was highest with the highest plant population used (60,000 versus 90,000 plants per hectare), and of the two commercial hybrid corn varieties, Tracy - 133 outyielded Tracy - 99.

<u>1970-71</u>

As indicated previously, irrigation treatments in this season were arranged by two irrigation frequencies. The first was designed to avoid any moisture stress in the crop; water was applied when tensiometers placed at 45 cm depth averaged .6 atm. In the second irrigation treatment, water was applied when the corn showed wilting through most of the day.

The shelled corn yield results are given in Table 1 in terms of the simple averages of the respective treatments. Table 2 contains the analysis of variance for data in Table 1. As indicated in Table 2, the design was a split-split plot where nitrogen rates were sub-plots of water treatments and plant populations were sub-plots of the nitrogen treatments.

Significant increases in yield resulted from the high water treatment and significant decreases in yield resulted from the high plant density. No significant response to fertilizer nitrogen occurred at either site.

The only interaction that was statistically significant was the nitrogen by moisture effect at Condproma (Table 2). Table 1 does not display it, but this effect was attributed to the fact that the yield trends within the two irrigation levels in going from treatment N-0 to N-300, alternately diverged, then converged. This erratic behavior undoubtedly

Table 1. Yield of Shelled Corn (qq/ha) for Two Sites in 1970-71: Average Results for Fertilizer, Irrigation and Plant Population Treatments

Treatment		El Castillo	Condoroma
Nitrogen -	0	121.3	74.2
	100	114.3	76.2
	200	116.9	75.3
	300	114.1	83.5
	400	115.7	76.4
Moisture	high	122.1	93.2
	low	110.8	61.0
Population	60,000	118.8	85.8
	90,000	114.1	68.4
Overall mean		116.4	77.1

Table 2. Analysis of Variance for 1970-71 Results

Source of Variation	El Castillo		Condoroma	
	df	MS	df	MS
Replication	5	24.32	3	11.97
Moisture	1	293.75**	1	88.45**
Error (a)	5	9.31	3	1.62
Fertilizer - N	4	16.00	4	.91
N x M	4	19.24	4	2.18*
Error (b)	20	55.71	16	.56
Population	1	50.38**	1	25.90**
P x N	4	2.72	4	.50
P x M	1	0.0	1	.10
Error (c)	74	1.68	42	.28
Total	119	---	79	---

*Significant at 5% level.
**Significant at 1% level.

gave rise to the statistical significance but it was interpreted merely as an artifact of the experiment arising from the problems of soil moisture control that were experienced at this site.

The average yield (Table 1) for each site shows that there was about 50% more yield at El Castillo than at Condoroma. This striking difference was attributed to the difficulty encountered at the latter site in getting the irrigation water to penetrate the soil. At Condoroma it was observed after the first irrigation that water infiltration was not sufficient to affect the tensiometers even after 18 hours of continuous irrigation. This problem necessitated a change in procedure for determining irrigation frequency at that site. Irrigation was applied to the high moisture plots when the plants in these plots wilted at midday rather than when the tensiometers registered slight moisture stress as originally planned. Accordingly, drouth stress retarded corn yield despite the efforts to control it. This problem was not encountered at El Castillo.

The contrast between water intake rates by the soils at the two sites may be seen in the data of Table 3. This table shows that the irrigation frequency for Condoroma was essentially double that for El Castillo, but that the total seasonal water intake was about 20 cm less at Condoroma.

The fact that there was no response to nitrogen fertilizer at either of the two experimental sites was unexpected. It was apparent, from the lack of response in connection with the rather respectable yield levels obtained, that the residual carryover of nitrogen in the soil from previous seasons was large enough to satisfy the needs of the corn.

The failure to obtain a well defined corn yield interaction between soil moisture and nitrogen resulted from two causes. First, nitrogen was not deficient, and second, the soil moisture was not excessive in any part of the experiments. Plant growth stresses induced by out-of-balance growth factors are required if the interactions between growth factors are to

Table 3. Irrigation Frequency and Total Net Water Application at Two Sites, 1970-71

	El Castillo		Condoroma	
	High Rate	Low Rate	High Rate	Low Rate
Total number of irrigations	8	4	14	8
Season net water application in cm	92.1	68.8	75.4	48.8

Table 4. 1971-72 Preseason Extractable Soil Nitrogen (ppm) by Depth and Field Location. Data shown are replication averages

Depths	Replication				Average
	1	2	3	4	
1	6.6	13.0	11.2	13.8	11.15
2	5.0	7.6	12.2	11.4	9.05
3	4.4	6.4	8.4	9.4	7.15
4	4.0	7.6	7.2	7.4	6.55
Total	20.0	34.6	39.0	42.0	33.90

be manifest. The long range objectives of this series of experiments require that the interaction in crop yield between soil moisture and soil fertility be fully defined. It is obvious that one prerequisite for the long range objectives is adequate control of the experimental medium.

The results indicated a decrease in yield with an increase in population density. This is opposite to those obtained the previous year when variety Tracy - 133 was used. It is apparent that under the conditions of the 1970-71 growing season, the optimum stand density was somewhere below 90,000 plants per hectare for variety MA-7. The contrasting results for the two years emphasize the need to thoroughly evaluate corn varieties in order to be able to provide complete characterization of the soil moisture and fertility needs of the corn.

1971-72

Since fundo El Castillo was not available in 1971-72, all the research was done at fundo Condoroma. The design of two separate experiments took cognizance of the water infiltration problems encountered there the previous season. One of the projects was aimed specifically at water penetration as a limiting factor in irrigated crop production on these soils.

Experiment 1: Nitrogen x Variety x Population

Residual Soil Nitrogen

For purposes of site characterization, soil samples were taken before the experiment was established. Average analytical results for the soil were as follows: pH, 7.1; electrical conductivity of the saturation extract on successive 30 cm depths to 120 cm were .84, .77, .65, and .62 mmhos/cm, respectively. These data indicated that the soil was not salt-affected. The organic matter of the top 30 cm amounted to 2.0 percent.

Extractable mineral nitrogen (nitrate plus ammonium) was determined in the pre-season soil samples. Soil test results are given in Table 4 by depth and field location. Table 4 shows the distribution of soil residual nitrogen both vertically and horizontally in the field. It will be noted that soil nitrogen increased from the upper to the lower end of the field (replication 1 through 4) and that it decreased from the top to the bottom of the soil column. Since the sampling was made before the experiment was established at the higher residual nitrate readings toward the bottom of the field are probably due to an accumulation from erosion.

Crop Yield

In order to minimize the problem of water intake rate in this experiment, the site was surveyed and the rows oriented to allow minimum, although not uniform, slope in the direction of water flow.

During the entire growing season the N-0 plot was visibly different from the other nitrogen treatments, displaying nitrogen deficiency symptoms. By mid-summer some of the N-100 treatments appeared nitrogen deficient, too. The average results from varieties and nitrogen are presented graphically in Figure 1. The figure illustrates the superiority of variety T-133 over MA-7. Average overall yields were: T-133, 67.75 quintales per hectare and MA-7, 58.57 quintales per hectare. Figure 1 also demonstrates that the fertilizer response in the two varieties was very similar. Yield increased from 56.69 (T-133) and 41.08 (MA-7) at treatment N-0 to 79.29 (T-133) and 72.61 (MA-7) quintales per hectare at N-300. Yield decreased in both varieties at the N-400 rate to approximately the same level as was measured at the N-200 rate.

Statistical analyses of the data shown in Figure 1 are summarized in Table 5. This table indicates that fertilizer rate and variety effects were highly significant. Table 5

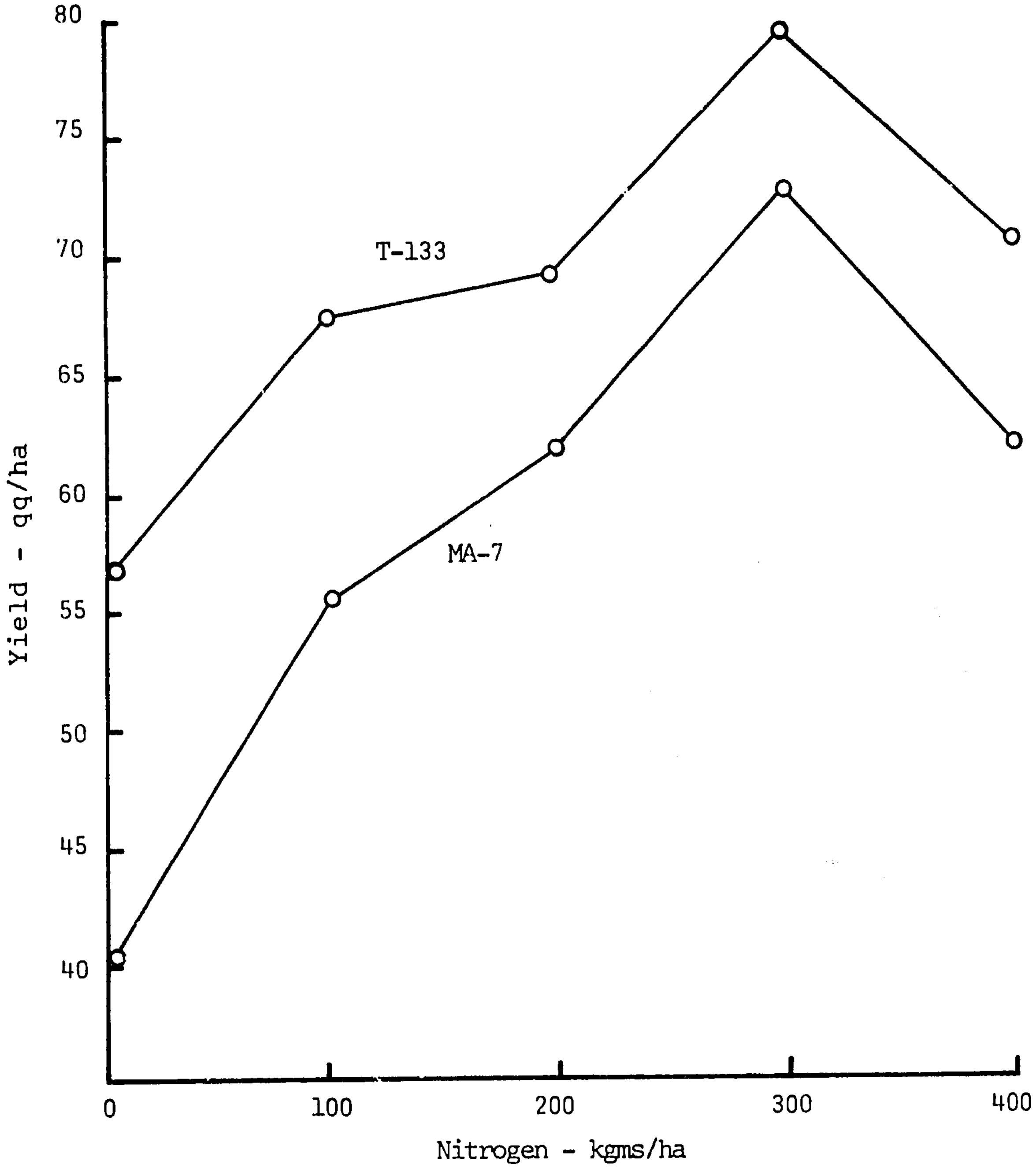

Figure 1. Yield of Corn as Influenced by Nitrogen Rates and Varieties. (Each point is the mean of twenty observations---four replications and five populations.)

Table 5. Analysis of Variance for 1971-72 Corn Yield

Source of Variation	df	MS
Total	199	----
Replication (R)	3	1,244.71
Nitrogen (N)	4	4,450.16**
Population (P)	4	404.32
N x P	16	248.33
Error (a)	48	496.69
Variety (V)	1	4,211.32**
V x N	4	61.04
V x P	4	20.91
V x P x N	16	53.70*
Error (b)	99	29.04

*Significant at 5% level.

**Significant at 1% level.

Coefficient of variation:

N + P = 35%, Variety = 9%

$LSD_{(01)}$(yield) = 42.23 qq/ha

$LSD_{(01)}$(variety) = 10.01 qq/ha

also shows that there was no effect from population density, but it was apparent from the results that 65,000 plants per hectare was optimum for both varieties. The only significant interaction among the results was the three-way V x P x N effect (Table 5).

<u>Field Slope vs. Yield</u>

It became apparent during the growing season that soil moisture varied among plots despite the fact that water was applied uniformly. This difference was attributed to the variation in slope in the field. After the crop was harvested the field was surveyed and percentage slope was obtained from each whole plot. The survey results are given in Table 6. Values for slope percentage (parallel to the furrows) are given. Table 6 shows that slope varied from 1.05% to 0% in the experimental area. The field slope at right angles to the furrows (not shown in the table) varied from 1.2% to 1.7%.

It was observed during crop growth that corn growing in the flatter plots was, in general, more vigorous than corn growing in other areas. In order to evaluate this effect, yield data were averaged across varieties and populations and then averaged among nitrogen rates and slope categories. The results of this comparison are given in Table 7. Correlation and regression analyses were done on these data and the results are given in Figure 2. Figure 2 shows that the yield decreased with increasing slope and increased among slope groups with nitrogen rates. Average yields varied from about 94 quintales per hectare at zero slope and N-400 to about 36 quintales per hectare at 1% slope and N-0. The differences in corn performance as related to field slope were interpreted entirely in terms of moisture availability. That is, moisture penetration increased as the field slope approached zero.

Table 6. Slope Percentages for Each Whole Plot. (Data are presented in the same relative position as they occurred in the field. Direction of irrigation flow was from left to right. The highest elevation was in the upper left hand corner and the lowest was in the lower right hand corner.)

Replication	Plot No.	Plot Number 1	2	3	4	5	Mean
	1	1.00	.45	.90	.90	.85	.82
	2	1.05	.65	.65	.95	.85	.83
	3	1.00	.55	.90	.60	.90	.79
	4	.85	.40	1.10	.40	1.00	.75
	5	.85	.65	.80	.40	.70	.68
	Mean	.95	.54	.87	.65	.86	.77
2	1	.95	.50	.55	.85	.35	.64
	2	.95	.60	.75	.65	.40	.67
	3	.90	.90	.55	.70	.40	.69
	4	.85	1.00	.60	.75	.20	.68
	5	.65	1.05	.85	.60	.20	.67
	Mean	.86	.81	.66	.71	.31	.67
3	1	1.05	.85	.65	.30	.55	.68
	2	.95	.85	.65	.25	.35	.61
	3	.90	.70	.70	.30	.15	.55
	4	.90	.55	.70	.40	.00	.51
	5	.75	.60	.65	.35	.00	.47
	Mean	.91	.71	.67	.32	.21	.56
4	1	.90	.55	.45	.30	.10	.48
	2	1.05	.60	.40	.25	.10	.48
	3	1.00	.65	.60	.10	.00	.47
	4	.85	.65	.65	.10	.10	.47
	5	.90	.45	.50	.30	.00	.43
	Mean	.94	.58	.52	.21	.06	.46

Table 7. Relationship Between Corn Yield, Slope of the Land, and Nitrogen Fertilizer Rate

Slope Percent	Nitrogen Rate - kgms/ha 0	100	200	300	400	Average
	Corn Yield - qq/ha (see Table 1)					
.0	54.30	76.82	-	-	93.63	74.93
.1	-*	75.34	81.88	92.25	-	82.49
.2	48.36	-	-	84.72	-	66.54
.3	56.26	68.61	78.07	92.33	-	73.82
.4	58.42	65.32	71.70	82.40	66.04	68.78
.5	53.64	71.11	-	68.90	62.73	64.10
.6	50.67	70.74	69.12	73.99	64.50	65.80
.7	42.71	57.71	73.94	78.72	68.32	64.28
.8	45.57	55.17	58.85	56.11	61.71	55.48
.9	34.86	52.09	51.50	72.26	42.65	50.67
1.0	36.42	55.53	52.63	-	81.98	56.64

*Where no data are shown, no slope-N combinations existed. All datum points are means of from two to ten observations per cell.

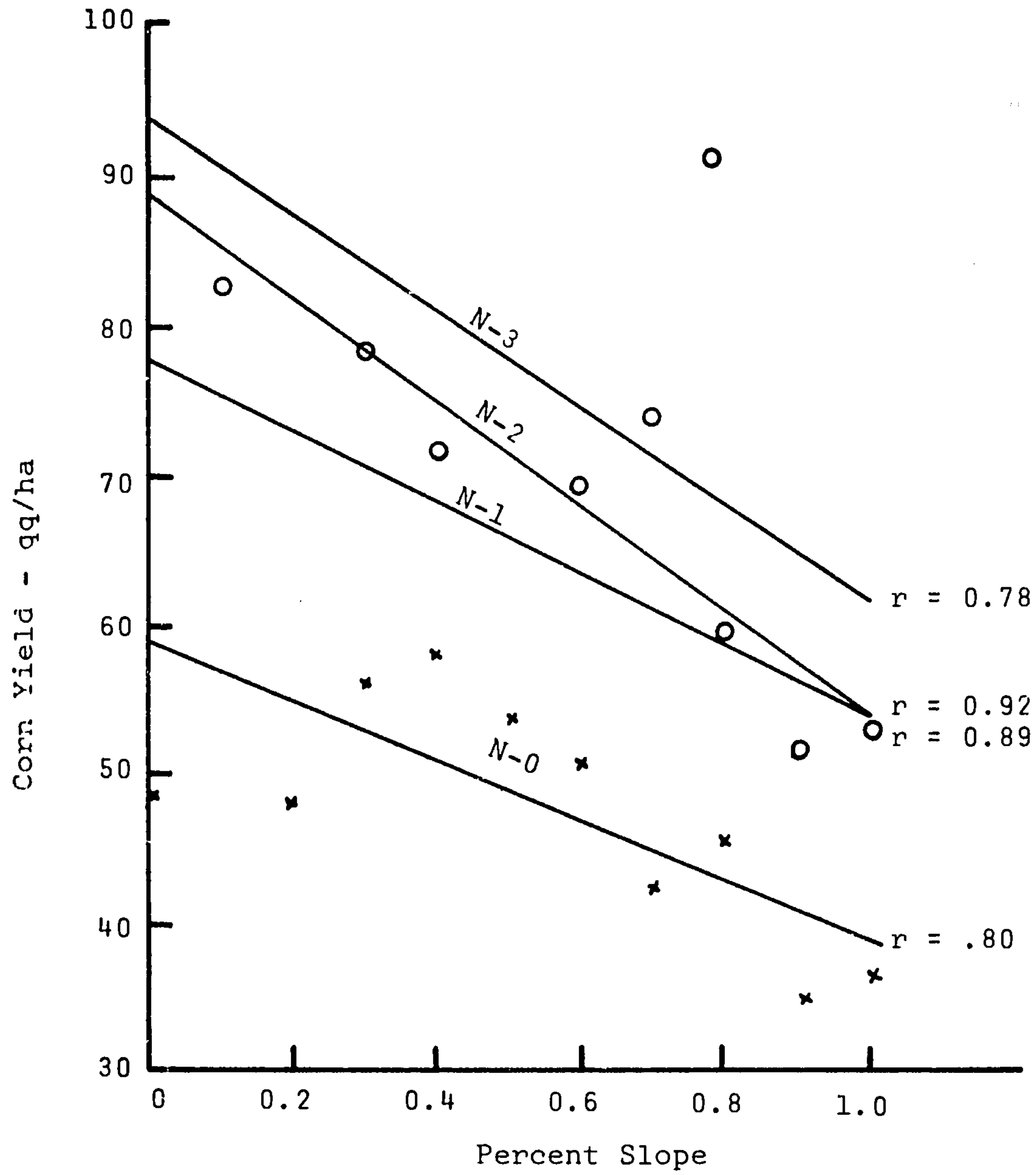

Figure 2. Yield of Corn as Influenced by Slope of Plots and Nitrogen Rate. (Points are shown only for N-0 and N-200 plots. Other points were not included because of overlap. Regression line for N-400 lies across the N-100 and N-300 lines and is not shown. The number of plots in each point (replications plus populations plus varieties) ranged from 2 to as high as 10. The regression lines were calculated using only the mean of all points in each N rate and slope group.

It is apparent from the results of this experiment that limitations imposed on the crop by soil moisture stress prevented a full expression of the controlled variables (i.e., N, V, and P). The average yields from this experiment were considerably below the demonstrated potential for this area as discussed elsewhere in this report. If soil moisture had not been limiting, differences between varieties probably would have been accentuated. In addition, competition from increased growth vigor would have resulted in a more clear definition of the plant population effects.

The pattern of response to nitrogen fertilizer would have been quite different if moisture penetration, and therefore effective rooting depth, had been better. The results of soil analysis at the beginning of the season (Table 4) indicate that appreciable amounts of nitrogen were carried over in the soil from previous seasons. Poor water infiltration limited most root expansion, which positionally limited the nitrogen availability. In addition, the pre-irrigation was done after plow-down of the fertilizer treatments, which may have leached some of the nitrogen from near the surface to depths beyond the limited root zone, where it was positionally unavailable to the crop. Certainly 300 kgm of nitrogen per hectare is excessive as an optimum rate (Figure 1), and these data should not be construed to indicate that this much nitrogen is required by corn.

The decrease in yield from N-300 to N-400 (Figure 1) is questionable behavior for corn, all other things being adequate and equal. This phenomenon is interpreted as being an example of the soil moisture-soil fertility interaction. Treatment N-400 probably induced very succulent and rapid growth early in the season. This would lead to greater drouth susceptibility, which would occur cyclically between irrigations. As will be pointed out later, water intake rate decreased as the season progressed. Therefore drouth stress was most pronounced during the time of maximum moisture demand by the crop.

Irrigation Frequency and Depth

Irrigation dates and the depth of application for each replication block are shown in Table 8. Uniform water application to all of the blocks was achieved by keeping the irrigation frequency and time the same. Any differences in net water application among replications thus reflect the differences in the average infiltration rate over the whole block. The yield results already discussed correspond to the net water application results.

The depth of water applied was inversely related to the average slope of the whole block. Block 1, for example, with the highest average slope (0.77%) had the least total depth of water application (46.27 cm). Compare this to Block 4 which had the least average slope (0.46%) and the greatest net water application (59.04 cm). These water application depths do not include the pre-planting irrigation which was estimated to be 12 cm over the entire field.

Since the furrow length was very short, the water generally reached the end of the block within 30 minutes. There was thus essentially no difference in opportunity time for infiltration over the whole block. The increase in infiltration with decreasing slope was apparently the result of decreased velocity which required a larger cross section in the furrow and greater wetted perimeter. Thus, there was a larger area of water-soil interface and greater opportunity for infiltration to occur.

Table 9 gives the evaporation pan data for the periods between irrigations, as well as the average net water application for the same periods. In practice, pan evaporation usually exceeds actual crop evapotranspiration. It is generally observed that the potential evapotranspiration (PET) is about 80 percent of Class A pan evaporation. By applying a seasonal crop coefficient for corn of 0.9 to PET, actual evapotranspiration is calculated to be 59.5 cm, as compared to the net water application of 53.3 cm. This suggests that the crop was extracting slightly more water from the soil than was being replaced by irrigation.

Table 8. Net Water Applied as Related to Date of Irrigation and Replication Block

Irrigation Date	Water Applied - cm Block				
	1	2	3	4	Average
Nov 23 - 26	12.83	12.70	9.59	12.28	11.85
Dec 13 - 16	8.70	9.66	8.35	10.74	9.36
Jan 3 - 6	6.91	9.16	7.47	8.52	8.01
Jan 17 - 20	5.04	6.14	7.07	8.62	6.72
Jan 25 - 28	4.35	7.80	6.44	5.50	6.02
Feb 7-10	4.70	5.34	6.39	6.19	5.66
Feb 22 - 25	3.72	4.86	7.11	7.19	5.72
Total	46.27	55.66	59.04	59.04	53.34

Table 9. Evaporation from the "Class A" pan in Relation to the Net Water Application

Period	Evaporation cm	Net Water Applied cm
Nov 3 - Nov 26	17.05	11.85
Nov 27 - Dec 16	14.01	10.21
Dec 17 - Jan 6	16.29	8.01
Jan 7 - Jan 20	10.24	6.71
Jan 21 - Jan 28	6.00	6.02
Jan 29 - Feb 10	9.72	5.66
Feb 11 - Feb 25	9.34	5.72
Total	82.65	53.34

Experiment 2: Water Infiltration

Soil Amendment to Improve Structure

Experience gained previously on many soils in the Aconcagua valley, especially those at Condoroma, indicated a serious problem related to irrigation water intake rate in the area. One solution was obvious at the outset. It is a general habit in this area to remove crop residues either by pasturing, burning, mechanical removal, or a combination of these practices. It appeared that proper utilization of the crop residues would improve the soil moisture situation through facilitating soil structural development and channels for moisture flow. There was also some speculation that sodium was part of the problem and that gypsum would be a necessary soil amendment.

To this end a field that had produced corn for grain the previous season was prepared as follows: four treatments were organized into a randomized complete block design in eight replications. Treatment 1 was the control and consisted of complete removal of all the corn litter. Treatment 2 was the incorporation of the indigenous corn residue. Treatment 3 was the incorporation of approximately double the indigenous corn residue level, or 110 quintales per hectare of the air-dry material. Treatment 4 was the same as treatment 1 (all litter removed) except that gypsum was applied at the rate of 40 quintales per hectare.

Following application of the treatments the soils were disc plowed, irrigated, and plowed again for thorough incorporation. Phosphorus at the rate of about 30 kg of P and nitrogen fertilizer at the rate of about 200 kg of N per hectare were applied uniformly before plowing. Seed bed preparation and planting methods were standard.

All eight replications of a given treatment were irrigated simultaneously. Attempts were made to apply enough water at all times to avoid drouth stress. Drouth did occur, however. During the growing season differences in crop moisture status developed that were associated with the treatments. These differences were also registered in Bouyoucos soil moisture blocks (which were installed at depths of 30, 60, and 90 cm at the approximate centers of each plot) and also on tensiometers which were installed at 40 cm depths in the four central replications.

Crop Yield

The yield results by treatment and replication are given in Table 10. The Least Squares Deviation (LSD) for these data, also shown in Table 10, indicates that there was a significant difference in yield due to the effects of Treatment 3, which was the double rate of crop residue incorporation. The yields from Treatments 2 and 4 were essentially the same as that from the control. These results indicate that the addition of substantial amounts of gypsum had no effect on soil moisture availability. Actually, no effect from gypsum could have been anticipated based on the soil analytical results because these data showed that sodium was minimal in the soil.

The yield from residue 2 represents an increase of 15.4 qq/ha of shelled corn, or 38 percent more than the control plot. This increase in yield reflects the increased water availability which resulted from the improvement in soil moisture infiltration. This result shows that the problem of low moisture availability under irrigation can be overcome, at least in part, by managing the soils and crops specifically to alleviate it. The problem needs further analysis, but it is evident that crop residue incorporation, including that of corn, wheat and many other crops grown in the area, should become a standard practice. The added management costs with this practice would be insignificant compared to the benefits that would accrue.

Table 10. Corn Yields, qq/ha from Water Infiltration Experiment

Replication Blocks	Treatment 1 Control	2 Residue 1	3 Residue 2	4 Gypsum	Average
A	47.53	40.24	69.94	44.29	50.50
B	36.97	48.91	61.52	55.50	50.72
C	58.18	48.20	78.44	26.44	52.81
D	70.72	29.08	71.51	78.14	62.36
E	21.53	48.02	30.66	22.05	30.56
F	13.19	24.50	32.22	18.70	22.15
G	31.98	46.97	38.95	41.37	39.82
H	40.34	46.26	60.55	30.56	44.43
Totals	320.44	332.18	443.79	317.05	
Average	40.06	41.52	55.47	39.63	44.17

$LSD_{(05)}$ = 13.7 qq/ha

Table 11. Net Water Application Depth to Treatments by Replication Blocks in Infiltration Experiment

Replication Block	Treatment 1	2	3	4
A	33.0	29.2	33.5	41.6
B	45.6	52.1	48.9	47.2
C	45.5	47.4	53.0	47.4
D	48.8	41.3	57.9	62.2
E	36.6	40.9	36.8	33.1
F	33.9	41.7	43.5	42.1
G	55.7	58.8	51.6	51.9
H	40.5	43.2	36.5	37.7

It is likely that a permanent adoption of this practice would have accumulative effects, not only from the direct residue carryover but also because as root and top growth are increased by improved soil conditions, so that more residue would be available for incorporation in subsequent seasons.

Soil Moisture Conditions

The net amount of water applied by treatments is given in Table 11. The irrigation schedule is that given in Table 8.

No appreciable differences in water applied are indicated by the data; there seems to have been no treatment effect on net water application. This result is not in line with the yield results just discussed, or more particularly, with observed differences in crop appearances among treatments during the growing season.

With the exception of one replication block, there were obvious differences in corn appearance among treatments. The control plots showed clear signs of moisture stress in the plants and retarded crop development. In general, the plots receiving the double crop residue treatment showed the greatest plant development and least signs of moisture stress, although at times there were slight signs of wilting in these plots (photograph of plots is shown in Figure 3).

The observations during the growing season and yield results indicated a difference in available moisture related to treatments, even though a difference in water applied was not measured. This can be explained at least in part by the following:

1. The first irrigation was applied uniformly over the field and was not measured on the individual blocks. At this time the crop residue on treatments two and three was at or near the surface where it had maximum effect in holding the soil open for greater moisture penetration. This effect was in fact observed during the first irrigation

Figure 3. Crop Residue Treatment Plots

in terms of the rate of advance of the water across the plots. This allowed the root zone in these treatments to be more nearly filled to field capacity. As indicated previously, following the first irrigation, the field was replowed and the residue was incorporated to such a depth that its influence on infiltration may have been reduced.

2. Following planting, the inflow of water was measured through a submerged orifice and then delivered in unlined earth canals along the upper end of the furrows in each block. Then water was distributed to the individual furrows by means of siphon tubes. The outflow from the plots was collected in a small ditch at the lower end of the block and measured at the end of this ditch. Because of this arrangement, the water losses due to seepage in the canals were measured as water applied to the plot. This over-estimation of net water application to the plot was greatest for treatment number 4 which was the first to receive water during each irrigation cycle. At this time the seepage loss was greatest, the canals being relatively dry after periods of from three to ten days without water. Evidently, the means used for measuring net water application was too gross to be able to distinguish effects from the treatments.

Considering the 10 cm depth of water applied in the pre-plant irrigation, the average total net water applied was 54.47 cm. This compares with 78.11 cm of evaporation from the evaporation pan which was located well within an alfalfa field. If this applied water is taken as a measure of consumptive use, then the ratio of consumptive use to pan evaporation for the period November 3 to February 17 would be approximately 0.7 (as compared with a ratio of about 0.9 that was predicted based on other local results). This would indicate that all the water transpired by the crop was not being replaced by irrigation, and that the soil in the root zone was gradually drying out during the growing season. This premise is supported by the soil moisture block data summarized in Table 12. These are the average conductivity readings for the eight replications. While some of the blocks at the 30 cm depth responded to the irrigation, the blocks at 60 and 90 cm depths became progressively drier with time.

The water holding capacity of the 120 cm root zone was estimated to be 25 cm of water. If irrigation was applied when 40 percent of this had been removed, the net application would have been 10 cm and the average frequency 2 weeks (providing the irrigation time could be long enough to apply the 10 cm depth each time). In this experiment, a nine-hour irrigation period applied an average of about 5 cm of water. Where a seven-day interval was possible, approximately the same amount of water was replaced as was evaporated from the pan.

A reliable estimate of consumptive use could not be made from this study because soil moisture availability limited crop growth and development. In the results given above (Experiment 1) the overall average yield for variety T-133 was 67.76 qq/ha with a total of 66.34 cm of water applied. In this experiment the overall average depth applied was 54.47 cm of water and yield averaged 44.16 qq/ha.

From soil bulk density samplings of the plots at the end of the season, no differences were observed in the soil density values with and without tractor wheel traffic in the row. There were no differences of bulk density in treatments or replication blocks.

Demonstrations on Commercial Farms

There were a total of 18 such demonstrations established in the two seasons, but for various reasons (bird damage to the maturing corn, faulty irrigation, poor stand establishment initially, etc.), measurable data were taken from only 13 of the trials. The average corn yields, as influenced by nitrogen fertilization, are shown in Table 13. The area average yield of corn as taken from the yield performance

Table 12. Average of Bouyoucos Soil Moisture Block Readings in Terms of Relative Conductivity by Treatment and Depth in Relation to Irrigation Dates

Reading Dates	Treatment 1			Treatment 2			Treatment 3			Treatment 4			Dates of Irrigations*
	Depth in Centimeters												
	30	60	90	30	60	90	30	60	90	30	60	90	
Dec 22	164	95	155	56	31	157	13	85	180	118	67	133	Dec 1-6
Dec 28	21	69	108	28	24	106	105	73	111	14	45	96	Dec 20-23
Jan 4-7	8	11	37	5	8	11	45	15	9	26	17	13	Jan 5-7
Jan 12	10	4	12	6	4	6	5	10	6	4	7	7	
Jan 18	7	7	8	4	5	4	3	7	4	66	5	5	Jan 17-20
Jan 21	22	7	8	53	5	3	33	8	3	23	7	5	
Jan 24	9	6	4	32	5	3	10	8	3	5	5	5	Jan 24-27
Jan 28	11	7	7	56	5	3	30	10	3	20	7	5	Feb 7-9
Feb 18	44	6	6	74	9	3	43	6	3	51	5	4	Feb 14-17

*Irrigations were applied to the treatments in the following order: 4, 1, 2, 3.

Note. - High electrical conductivity indicates high moisture content and vice versa.

Table 13. Corn Yield Results from Commercial Farms in Two Seasons as Related to Nitrogen Fertilization

		N Rate - kgm/ha			
	Number of Sites	0 qq/ha	100 qq/ha	200 qq/ha	300 qq/ha
1970-71	8	43.79	74.71	88.36	-
1971-72	5	64.52	82.75	91.18	93.00

record of the SAG area office in San Felipe is about 45 qq/ha. Thus the average yields from both years at the 200 kilo nitrogen rate (Table 13) represent about 100 percent increase over the area average yield of corn.

The results from irrigation frequencies were not as conclusive, since the farm managers tended to move away from the "traditional" method and to copy the times and rates of water application on the demonstration part of the field.

In the experiments at El Castillo and Condoroma, top corn yields were taken from plots having plant densities of 60,000 to 90,000 plants per hectare. Since the average corn populations in the area range between 20,000 and 30,000 plants per hectare, it is apparent that this factor of corn production should improve corn yields in the area. Results from the demonstrations indicated that 60,000 to 65,000 plants was a reasonable plant density to strive for with good water management.

GENERAL DISCUSSION

In appraising the results of this research program, it is believed that the short-term objectives have been well satisfied. First of all it has been proven that corn yield potential in the Aconcagua valley, on a per-hectare basis, is much higher than current production levels. Secondly, it has been shown that by adopting progressive measures of land and water management, farmers in the area can increase yields at least 150 percent with resources they currently have at their disposal. Actually, there is no indication in the data of the true upper limits of yield under the very favorable climatic conditions prevailing in the Aconcagua valley.

The progressive measures we refer to may be categorized into two groups, based on whether a capital outlay is required at the outset. The items that require no capital outlay are (a) adequate seedbed preparation (good land preparation will conserve soil moisture and will assure rapid and uniform seedling establishment), (b) timely and thorough irrigations, and (c) incorporation of crop residues for favorable soil structure development.

Proper recharging of the soil moisture reservoir will reduce the total number of irrigations (and attendant costs for labor) and will reduce the yield losses associated with moisture stress. Much remains to be done on irrigation scheduling to completely overcome soil moisture as a limiting factor--both in terms of too little water and too much--but in the meantime growers can correlate wilting symptoms of corn with the feel of moist soil in the hand and so irrigate to maintain soil moisture above symptom-causing levels.

The problem of limited water infiltration was brought to light in this research. Proper management of crop residues is undoubtedly one of the keys to the solution of this problem. The geographic extent of the water intake problem was not clearly defined. Much work remains to be done to classify the soils so affected, to establish optimum rates of residue incorporation, and to evaluate the long-term effects of residue management on resultant increased dry matter production and overall changes in soil physical and chemical properties.

The second category of management factors, items that require capital outlay, has to do with fertilizers and other agricultural chemicals. The results given here demonstrate that nitrogen was limiting to the yield of corn. But although nitrogen fertilizer will increase the gross costs of production, the dramatic fertilizer responses will sharply reduce unit costs. No nitrogen responses were obtained in two experiments. This result simply indicated that soil nitrogen carryover from previous liberal fertilization had eliminated nitrogen as a growth limiting factor. The two null responses were the exception and not the rule in Aconcagua. The twelve demonstrations on commercial fields all indicated the need for considerable amounts of fertilizer nitrogen.

Much remains to be done to refine soil nitrogen management. The establishment of a well-calibrated soil test for nitrogen availability would be a worthwhile intermediate objective as th. work is continued toward the long-range goal. Soil test nitrogen was referred to in the results. Since annual precipiation is very limited, leaching does not occur over the winter. Testing for mineral nitrogen in the root zone needs to be carefully evaluated. Soil testing for nitrogen availability will have the added benefit of eliminating risks and lower net returns involved with over-fertilization.

Although other fertilizer elements and chemicals have received no attention in this work, these factors will naturally come into the picture as nitrogen and soil moisture problems are overcome.

The third short-range objective, that of training the professional agriculturists in the design, execution, and analysis of field research and demonstrations, was also satisfied. This kind of result is less tangible than the production research. The real test of how well this objective was achieved will be in how rapidly the proven management practices are adopted. There is good evidence that this has already begun. If the program is continued, these efforts will be reflected in sharp increases in average yields throughout the province. In the meantime, other crops and other provinces will become involved in the total effort.

SUMMARY AND CONCLUSIONS

A project involving research and demonstration on modern concepts of irrigation management was conducted in the Aconcagua Province of Chile during three growing seasons, 1969 to 1972. The test crop was corn. Variables were soil moisture, nitrogen fertilizer, hybrid variety, and plant density. One other variable that was used in the last season was incorporation of soil amendments to evaluate effects on the soil moisture intake rate.

Observations and results made in the initial season emphasized the need to coordinate and improve crop and soil water management in a number of farming practices. This was required before any serious attempt could be made to establish modern irrigation technology in the area. Some of the factors involved were seed bed preparation, early season soil moisture control, adequate stand establishment, weed control, and use of an irrigation method that would avoid drouth and loss of yield potential throughout the growing season.

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

As would be expected, the corn hybrids varied markedly depending on the special traits they were bred for. Results from the variety tests, taken together, indicated the need for development of corn hybrids that will be tailored to conditions of intensive irrigation agriculture and also to the long and favorable growing season common to this area of Chile.

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

An important characteristic of some of the soils in Aconcagua not previously recognized was that poor soil structure was causing a severe limitation on irrigation water intake rate in some fields. This problem resulted in serious limitations on soil moisture management and on corn yield potential. An experiment demonstrated that proper utilization of crop residues, heretofore burned or eliminated in other ways, may assist in the solution to this problem.

Based on the results of this project, sophisticated experiments can now be conducted in Aconcagua which can lead to the development of prediction equations of crop yield as a function of soil moisture and fertility. The attainment of this objective will be required in order to attain maximum irrigated crop yield with the available resources.

Chile has both human and natural resources which, if properly organized and utilized, can lead to an intensive irrigated agriculture and a large expansion of their production of food and fiber. A modest estimate of what might be possible is that corn yield could increase an average of 150% over current levels using resources producers now have at their disposal. Although corn was the only test crop, similar responses could be anticipated in most of the irrigated crops grown in the area.