WATER-USE PRODUCTION FUNCTIONS OF SELECTED AGRONOMIC CROPS IN NORTHWESTERN NEW MEXICO, PHASE I

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Corrections for Report No. 137: Water-Use Production Functions of Selected Agronomic Crops in Northwestern New Mexico, Phase I.

Page	Location	Correction
3	line 13 from top	(_Ephedra_ _viridis_)
21	under figure	$r^2 = .96$
28	under figure	physiological maturity
54	line 5 from top	high-nitrogen plot
70	line 2 from bottom	Equation 14
93	Equation 9	0. instead of p.
93	Equation 27	In denominator needs a + between Δ and γ

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This report represents one year of data and the conclusions reached are based upon that limited data base. Additional years of research are being conducted and the initial conclusions may be changed based on information from the increased data base.

ABSTRACT

Efficient irrigation requires a knowledge of the consumptive use requirement of the crop plant. In northwestern New Mexico consumptive use of water, as influenced by level of nitrogen fertilization, of spring barley, pinto beans, and field corn was investigated for the 1980 growing season. Potential evapotranspiration was calculated using several methods, and crop coefficients developed. Crop yield has been demonstrated to be significantly and highly correlated to seasonal evapotranspiration. Crop coefficients greater than unity were routinely achieved at the higher yield levels during periods of peak evapotranspiration. As the level of nitrogen fertility increased from 10 to 200 kilograms per hectare the maturation period of the crop is lengthened and its rate of growth increased. The level of nitrogen fertility however does not appear to affect the water use efficiency of the developing crop. Both linear and curvilinear water production functions were produced with the form of the function varying upon the crop. Further research will allow a refining of the investigative technique and replication of the experimental methods in different seasons.

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INTRODUCTION

Agriculturally usable water is currently the limiting factor to potential crop production in the state of New Mexico. In northwestern New Mexico water resources may currently be over-allocated if the peak demands of a plethora of federal, state, municipal, and private interests are to be met. Since the supply of water is not likely to increase by any significant amount, more efficient means of using the available water will have to be developed.

In crop production the efficient allocation of water resources and the application of these resources by irrigation require that the amount of water necessary to produce a given level of yield be known. In most cases water applied in excess of crop evapotranspiration requirements is detrimental to the management of water and agricultural resources. Excessive water application results in the loss of water available to downstream users, the decrease in water quality due to retention of nitrate salts and other agricultural chemicals, the leaching of applied fertilizers from the root zone, and the unnecessary input of energy resources for water delivery and application.

OBJECTIVES

The objectives are as follows for the 1979-80 project year:

1. Develop the water production function which is the

relationship between crop yield and seasonal evapotranspiration for spring barley (Hordeum vulgare), and pinto bean (Phaseolus vulgaris).

2. Determine how the level of nitrogen fertility in the field affects the water production function for these two crops.
3. Measure the driving climatological variables used in the Blaney-Criddle, Priestly-Taylor, Jensen-Haise, and Penman equations to estimate consumptive use. The measured evapotranspiration amounts will be used to improve the estimates of the crop coefficients in these formulae.

MATERIALS AND METHODS

The Site

The study site is on the San Juan Agricultural Experiment Station (N.M.S.U.) located 11 kilometers southwest of the city of Farmington, New Mexico. This site is leased from and is surrounded by the lands of the Navajo Indian Irrigation Project. The elevation of the site is 1719 meters above sea level. An official U. S. Weather Bureau climatological station is located on the grounds of the experiment station. The weather station is .9 kilometers from the sprinkler-line-source plots and .3 kilometers from the drainage-type volumetric lysimeters. The prevailing wind direction is from the west.

The climatological data obtained includes daily maximum and minimum temperature and humidity. Psychrometric readings are taken at frequent intervals to insure proper calibration of the hydrothermograph. The climatological data also include 24 hour solar radiation measured by a star pyranometer and an integrator, 24 hour total wind accumulation measured at a height of 2 meters using a cup anometer, evaporation from a U. S. Weather Bureau Class A Evaporation Pan, and precipitation using a standard eight-inch rain gauge.

Soil

The experimental plots were established in an area never before in cultivation. The land was plowed to a depth of 46 centimeters, disked, fertilized, and harrowed. The original vegetation was Indian rice grass (*Elyonurus barbiculmis* Hack.), snakeweed (*Gutierrezia lucida*), cactus (*Opuntia* species), and morman tea (*Ephedraviridis*).

The soil type is Nagessi sandy loam (69-79 percent sand, 9-17 percent silt, and 12-18 percent clay) with a 1 percent slope (anonymous, 1970). The soil classification is a Typic Calciorthid, coarse loamy mixed, mesic family. The depth of this soil is limited by a highly calcareous layer which becomes massive and essentially impenetratable to plant roots at a depth of .8 to 1.5 meters. Field capacity of the soil was determined to be approximately 18-21 percent by volume in the upper meter of profile.

At planting the upper 50 centimeters of soil contained 7.3 kilograms of nitrate nitrogen, 50 kilograms of P_20_5, and 147 kilograms of K_20 per hectare.

Sprinkler-line-source Plots

Objectives one and two were achieved using sprinkler-line-source plots and drainage-type lysimeters. The sprinkler-line-source plots were established in the manner described below.

Figure 1 diagrams the basic plot design. This design was developed by Hanks et al. (1976). The design utilizes as the irrigation source a single sprinkler line passing through the center of the plot. The sprinklers are spaced at intervals of 6.1 meters with each sprinkler having a water distribution pattern with a diameter of 15 meters at a pressure of 3 bars. Each sprinkler discharges approximately .5 liters per second. The overlapping sprinkler patterns create a plot 24.3 meters by 30.3 meters (80 x 100 feet) in which is provided an equal application of water at points equidistant from the sprinkler-line source. As distance from the sprinkler-line source increases a decrease in the application rate occurs. A border area 15 meters in length on each end of the 24.3 x 30.3 meter plot also exists as a result of providing the necessary overlap of sprinkler distribution pattern within the actual plot area. The plot is further divided into two sections, one section on each side of the sprinkler-line source. The western section of each plot was identified as "section 1"; the eastern section as "section 2."

Each section is divided into subplots. Each subplot is .91 meters (3 feet) wide and 24.3 meters (80 feet) in length. The 24.3 meter length is parallel to the sprinkler-line source while the .91 meter width is at right angles to it. The subplot which receives the highest water application rate and which is centered under the sprinkler line, will be shared between the two sections.

Due to leakage of the sprinkler-line source at the joints data collected from this subplot is not used in determining the water

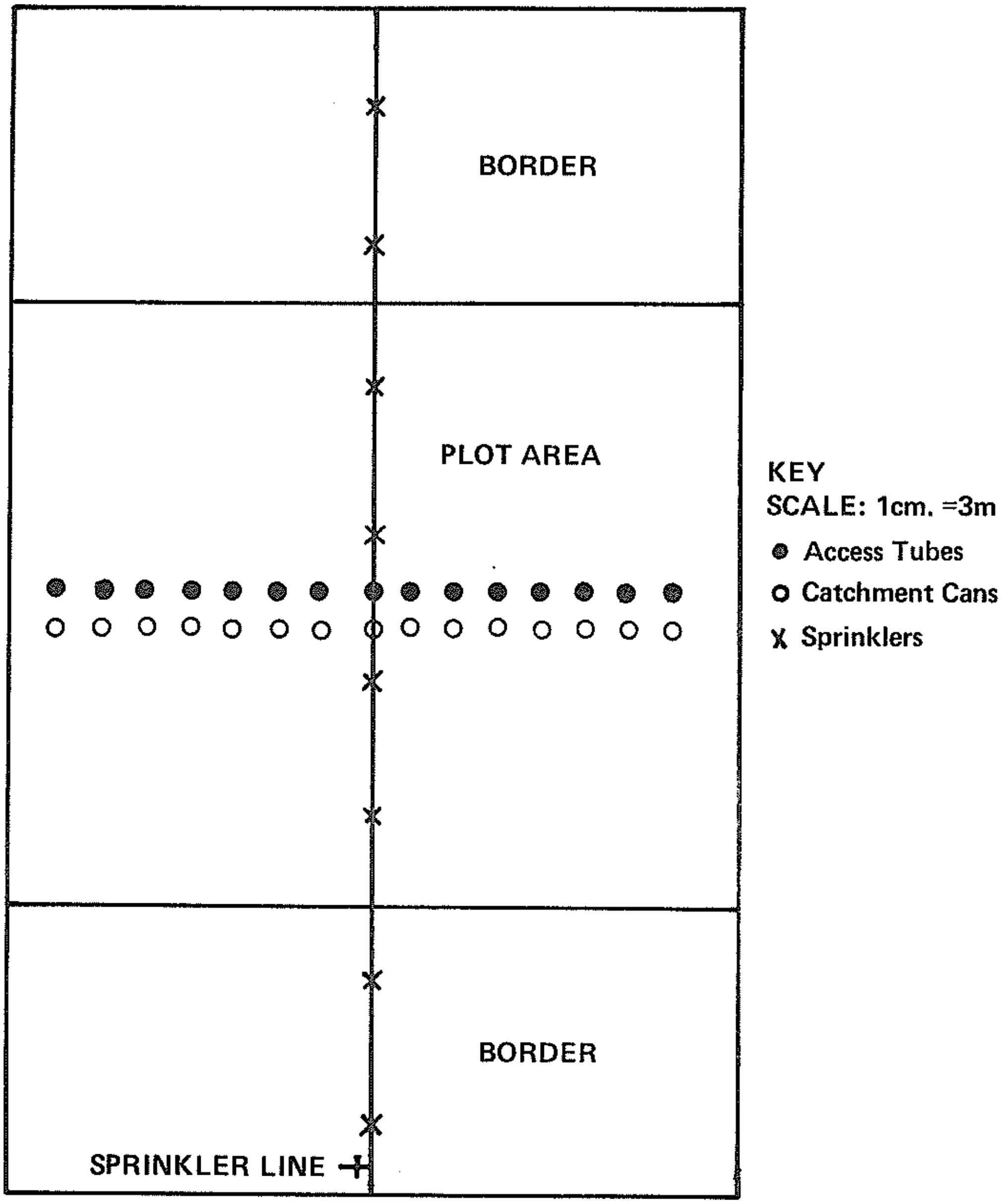


Figure 1. The design of the sprinkler-line-source field plot.

production functions. Thus the fact that the central subplot is evenly divided between the two sections does not complicate reporting of results. Two subplots are located immediately adjacent to the center subplot, one on each side. This pattern of subplot assignment continues until a distance of 13.2 meters is reached on each side of the sprinkler-line source. The water application rate is virtually zero at a distance of 15 meters from the sprinkler-line source.

Each subplot is further divided into three equal parts along the 24.3 meter length to allow three yield replications in each subplot on each side of the sprinkler-line source.

The total water applied at each irrigation of the plot is measured volumetrically by catchment cans in every other subplot beginning at the subplot situated under the sprinkler line. These catchment cans are attached to metal poles and can be raised as the crop grows. Aluminum access tubes 5 centimeters in diameter and 1.5 meters in length are buried adjacent to each catchment can and a neutron scattering device (Troxler Electronic Lab. Model 2601) is used to measure the soil moisture status through the rhizosphere at time intervals of one to two weeks.

Three plots each differing in the amount of applied nitrogen were established for the spring barley and for the pinto beans. Nitrogen levels were selected based on previous fertility tests of Gregory (1976, 1979).

Spring Barley

The cultivated variety of spring barley which was grown was "Steptoe." The applied nitrogen levels in the barley plots were

0, 95, and 196 kilograms per hectare (kg/ha). All green leaf tissue was removed at weekly intervals from two random samples of three plants each, in the highest, middle, and lowest yielding subplots of each plot. Tissue removed included the entire blade as well as the portion of the sheath that could be easily torn from the culm. Leaves were removed from all tillers as well as the main culm. These samples were dried in an oven at 80 degrees centigrade for 24 hours to determine dry weight. All reported grain weights for barley are adjusted to 14 percent moisture. The grain was harvested using a small self-cleaning combine.

Physiological maturity was determined by weekly sampling of 2 spikes from each of 3 plants, in two random samples. Dry weight of these samples was determined in the same manner as the green leaf tissue. The time at which the heads ceased increasing in dry weight was the point of physiological maturity.

Green leaf area index (GLAI) was calculated in the same manner as Legg et al. (1979) except no adjustment was made for stems, heads, and awns. Growing degree days (GDD) are calculated using the following formula:

$$\text{GDD} = \frac{(\text{daily temp. max.} + \text{daily temp. min.})}{2} - 5 \qquad (1)$$

The temperatures are reported in degrees centigrade. The maximum and minimum temperature limits are placed at 30 and 5 degrees centigrade, respectively. Daily temperature values beyond these limits are given the limit value when GDD are calculated.

Potential evaporation (PET) is determined by using the formulae in Appendix C.

Pinto Beans

The cultivated variety of pinto beans used in the investigation was "Womack." The applied nitrogen fertility levels in the pinto bean plots were 40, 124, and 162 kg/ha. Time did not permit collection of the developmental stages of the pinto bean plants.

The pinto beans were harvested by hand. The whole plant was harvested, allowed to air dry for one month in an empty greenhouse, and then threshed using a stationary thresher. Seed as well as total plant weight was recorded. All reported grain weights for the pinto beans are adjusted to 15.5 percent moisture.

Growing degree days are calculated using the following formula:

$$\text{GDD} = \frac{(\text{daily temp. max.} + \text{daily temp. min.})}{2} - 10 \qquad (2)$$

All temperatures are in degrees centigrade. The temperature limits are placed at 30 and 10 as the maximum and minimum values, respectively. Daily temperature values above or below these limits are given the limit value when GDD are calculated.

Corn

"Pioneer 3195" was the cultivated variety of corn grown. Corn was grown only in the lysimeters.

All reported corn yields are adjusted to 15.5 percent moisture. Growing degree days are calculated using the following formula:

$$\text{GDD} = \frac{(\text{daily temp. max.} + \text{daily temp. min.})}{2} - 10 \qquad (3)$$

All temperatures are in degrees centigrade. The temperature limits are placed at 30 and 10 as the minimum and maximum values, respectively. Daily temperature values above or below these limits are given the limit value when GDD are calculated.

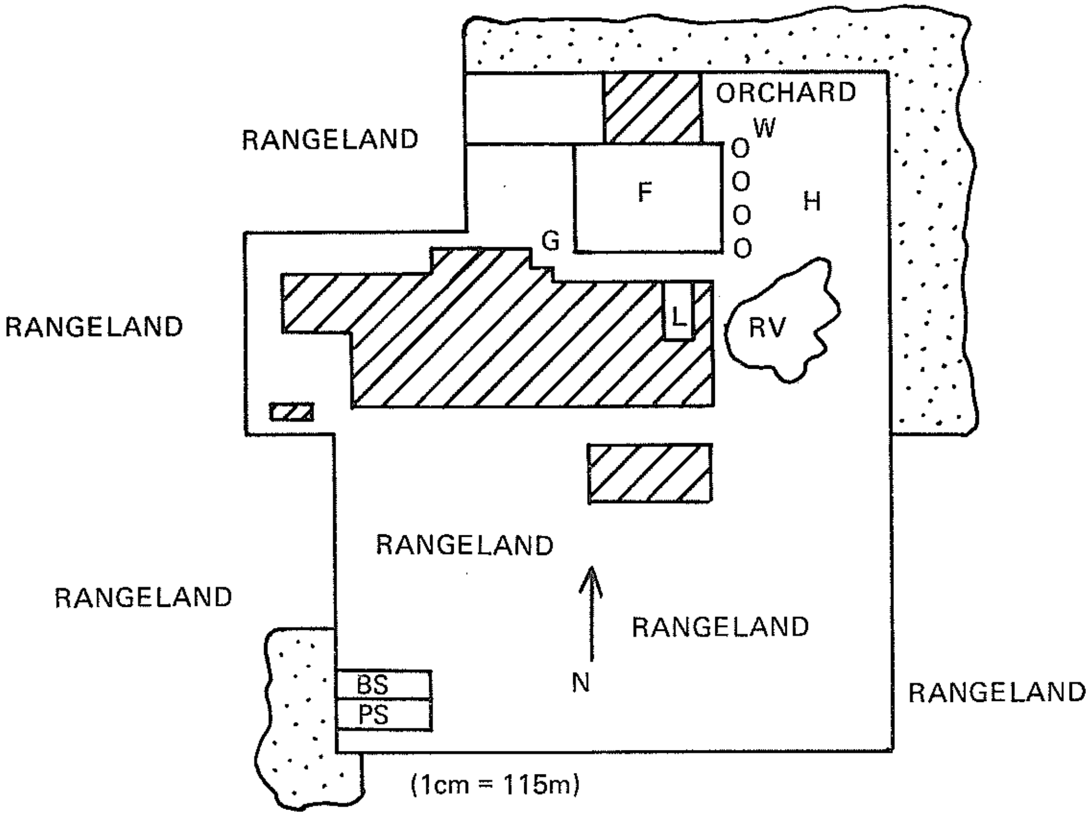
Lysimeter Design

Figure 2 is a map of the entire San Juan Agricultural Experiment Station and the surrounding lands of the Navajo Indian Irrigation Project. Lysimeters were installed at the site shown in Figure 2. The lysimeters are 1.8 by 1.8 meters wide and 1.2 meters deep. The plans for their construction are presented in Figure 3. A hole was hand dug. Plywood 1.9 centimeters thick was then used to line the hole. Five layers of 4 mil plastic were used to line the frame forming a water tight container. Suction candles and drainage pipe 1.3 centimeters in diameter were installed on the bottom. The soil was replaced in the hole according to the order in which it was removed.

Crops were placed in the lysimeters as follows:

crop	lysimeter number	applied nitrogen
spring barley	one and two	196 kg/ha
pinto beans	three and four	168 kg/ha
grain corn	five and six	112 kg/ha

The lysimeters containing beans, barley, or corn were surrounded by similar crops with at least 150 meters on alfalfa cover to the west (prevailing wind direction) and 40 meters to the east. Each lysimeter contains two access tubes for neutron probe measurements of soil moisture content and depletion. Measurements of water



SYMBOL	LOCATION NAME
BS	barley sprinkler line source
F	fallow field
G	gulley
H	headquarters
L	lysimeters
NIIP	Navajo Indian Irrigation Project
O	Russian Olive hedge
PS	pinto sprinkler line source
RV	reservoir
W	weather station
▨	crops (alfalfa, corn, beans, small grains vegetables, others)
░	NIIP cropland

Figure 2. Map of the San Juan Agricultural Experiment Station and surrounding lands.

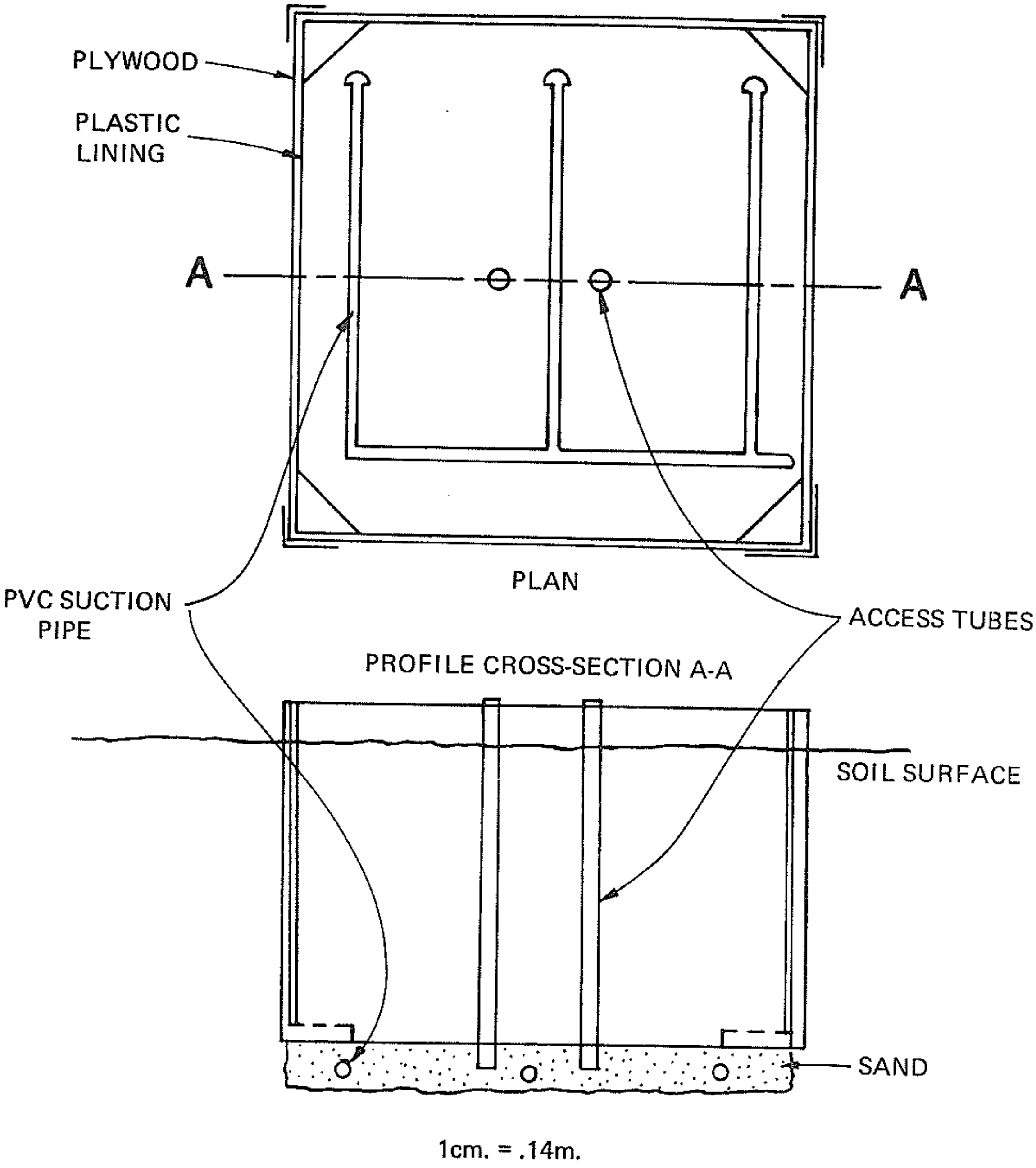


Figure 3. Plan and profile of drainage type lysimeters.

applied by flood irrigation from calibrated tanks are obtained for each crop. Water removed by means of the drainage system is also measured. All crops in the lysimeters are watered weekly to avoid moisture stress. It is desired that the amount of water applied at each irrigation is in excess of that which will be used by the crop in the current week.

Plot Configuration and Adjacent Areas

Figure 4 is a map of the plot locations and the immediate surrounding environment. Figure 5 is a detailed map of the sprinkler-line source plots showing location of irrigation risers and the nitrogen level assignments. The location of the sprinkler line source plots (also called field plots) with respect to the grounds of the experiment station can be ascertained in Figure 2.

Approximately 16,000 hectares (39,500 acres) are now under sprinkler irrigation on the plateau of the Navajo Indian Irrigation Project. Much of this land is interspaced with unirrigated rangeland or land which is fallow for at least a portion of the growing season. Therefore, data developed at the San Juan Agricultural Experiment Station are expected to reflect evapotranspiration values representative of areas near the desert edge of large irrigated fields and not the evapotranspiration rates that would occur in the center of large, irrigated blocks of land.

Calculation of Crop Evapotranspiration

The terms "evapotranspiration" and "consumptive use" of water by crop plants will be used interchangeably in this report. Consumptive use is calculated by the following equation:

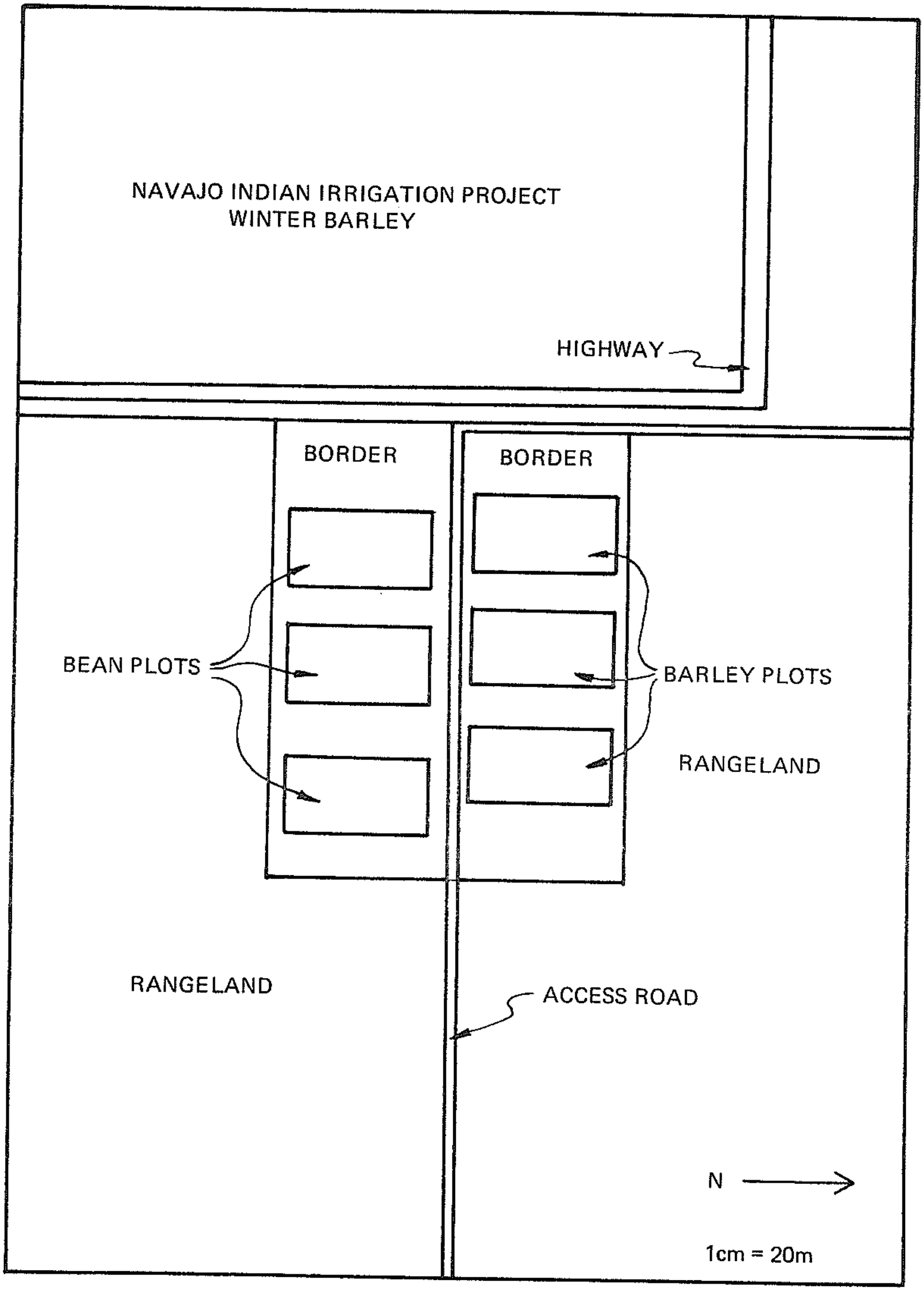


Figure 4. Detailed map of plot locations and adjacent areas.

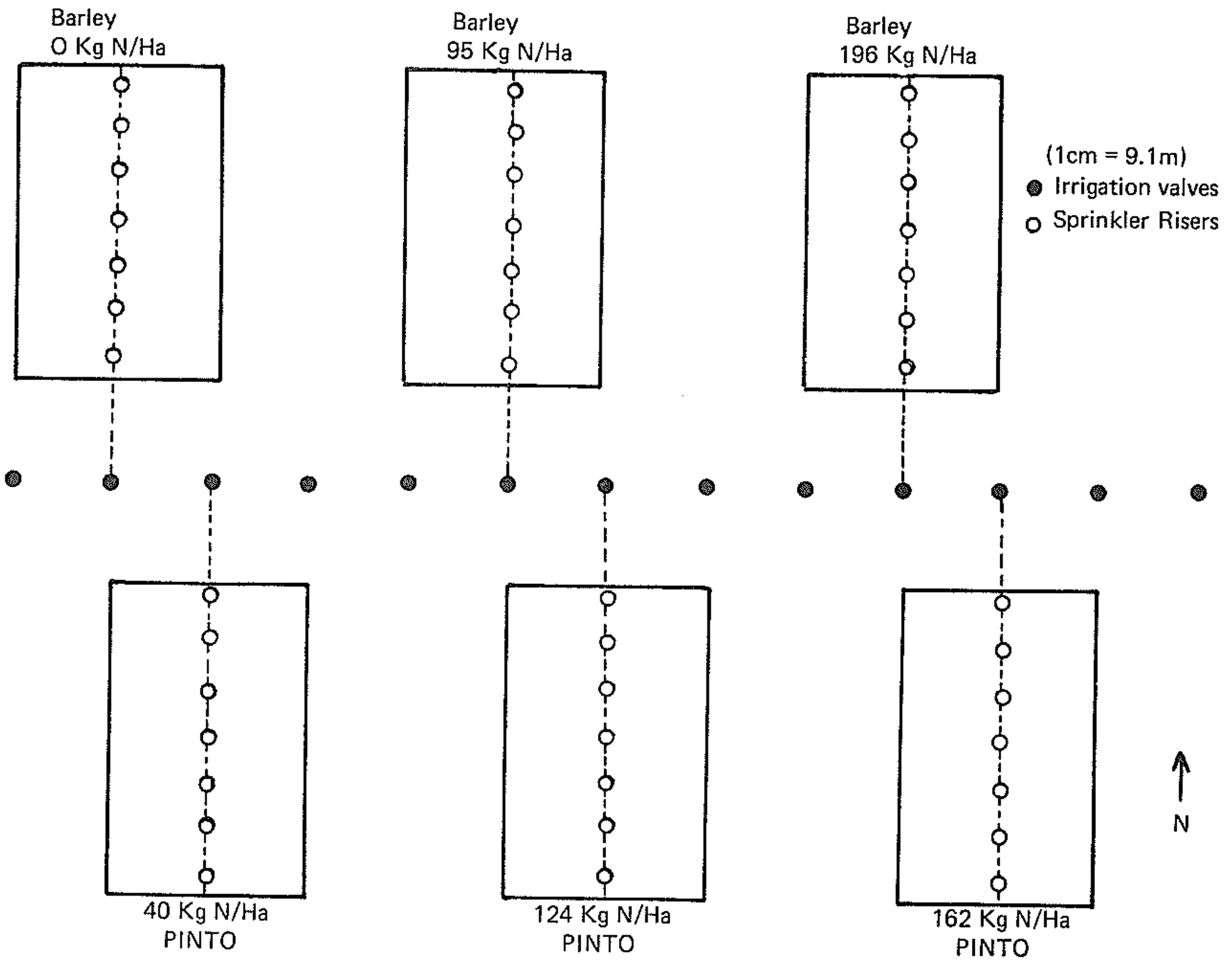


Figure 5. Plot crop and fertilizer assignments.

$$ET = I + R - D \pm \Delta SM \qquad (4)$$

where:

I = irrigation
R = precipitation
D = drainage
ΔSM = change in soil moisture

Only in the lysimeter data does this drainage term exist. Care is taken in the operation of the sprinkler-line source experiments to avoid deep drainage losses of applied irrigation water at the line (where the maximum irrigation occurs) by careful monitoring of the soil water status with the neutron probe. In addition, the presence of the caliche layer at the 1 meter depth limits deep percolation. Some non-saturated flow of water may occur, but this loss or gain is felt to be minimal when compared to the other terms of the equation. Consequently in calculation of evapotranspiration using the sprinkler line source data, drainage is assumed to be negligible.

In determining the soil moisture status, four readings are taken in each access tube each day that data are collected. The initial reading is taken at 15 centimeters depth and each additional reading in 30 centimeter increments. As mentioned above irrigation water is measured by use of catchment cans on the sprinkler-line-source plots, and from calibrated tanks before being applied by flood irrigation to the box lysimeters. Precipitation is measured by using a standard eight inch rain gauge.

RESULTS AND DISCUSSION

Spring Barley

Pertinent crop information relating to the production of the spring barley field plots and the lysimeters is summarized in Table 1.

Seasonal evapotranspiration (ET) and yields of the plots containing 0, 95, and 196 kilograms of added nitrogen per hectare (kg N/ha) are presented in Tables 2, 3, and 4, respectively. The subplots immediately under the sprinkler-line and one subplot adjacent on each side, were omitted from the tables due to excessive leakage of water at the sprinkler-line joints. Also omitted were the subplots which contained rows the seed drill failed to plant.

The combined data points of yield versus evapotranspiration from these three tables have been superimposed with the least-squares-fit equation of the form $y = ax^2 + bx + c$ (Figure 6). The equation is as follows:

$$\text{Yield (kg/ha)} = 2.46\ \text{ET}^2(\text{cm}^2) - 54.4\ \text{ET(cm)} + 414.2 \qquad (5)$$

The coefficient of determination (r^2) of the equation is .96. The addition of the ET^3 term to the equation does not significantly account for a greater percentage of the variation among the data points. A simple regression analysis of the same data yields the following equation:

$$\text{Yield (kg/ha)} = 111.6\ \text{ET(cm)} - 2104.8 \qquad (6)$$

Table 1. Spring barley crop data.[1/]

Plot Number	Added Nitrogen	Planting* Date	First Irrigation	Emergence** Date	Physiological*** Maturity	Harvest Date
1	0 kg/ha	04/09/80	04/17/80	04/21/80	07/09/80	07/31/80
2	95 kg/ha	04/09/80	04/18/80	04/21/80	07/15/80	07/31/80
3	196 kg/ha	04/09/80	04/18/80	04/21/80	07/13/80	08/01/80
Lysimeter	196 kg/ha	04/09/80	04/23/80	04/30/80	- - - -	08/01/80

[1/] 100 kg/ha of seed was drilled in 20.3 cm rows to give 134 plants/meter^2.

* Depth of planting was 6.5 cm, 56 kg/ha P_2O_5 applied at planting.

** Some barley plants appeared earlier due to high soil moisture present at planting.

*** Average of the subplots in each plot.

Table 2. Seasonal evapotranspiration and yield of spring barley grown without added nitrogen.

Subplot Distance From the Line	Seasonal ET	Yield Mean*	Yield SD	Height of Plant at Harvest
m	cm	kg/ha		cm
		Section 1		
12.8	14.5	187	64	30.5
11.9	16.8	232	156	30.5
11.0	19.0	333	135	30.5
7.3	21.7	607	282	40.5
6.4	30.4	1090	519	43.0
5.5	31.9	1021	424	46.0
4.6	32.0	1291	262	45.5
3.7	32.1	1161	408	45.5
2.7	35.0	1581	407	48.0
		Section 2		
12.8	14.5	220	145	25.5
11.0	18.8	295	74	25.5
10.1	20.6	244	76	30.5
8.2	25.6	444	132	35.5
7.3	28.3	619	201	40.6
5.5	31.9	773	157	43.0
3.7	32.4	837	79	45.7
2.7	35.1	1300	282	48.0
1.8	38.0	1213	237	47.0

* Average of three subsamples per subplot adjusted to 14 percent moisture.

Table 3. Seasonal evapotranspiration and yield of spring barley grown with 95 kg/ha of added nitrogen.

Subplot Distance From the Line	Seasonal ET	Yield Mean*	Yield SD	Height of Plant at Harvest
m	cm	kg/ha		cm
		Section 1		
12.8	15.8	170	37	30.5
11.0	19.7	364	124	33.0
10.1	23.2	399	219	33.0
9.1	26.5	631	68	35.5
8.2	30.0	870	169	35.0
7.3	33.4	1165	149	43.0
6.4	36.5	1574	252	47.0
5.5	39.9	1652	201	48.0
4.6	40.4	2539	339	50.0
2.7	42.2	3257	340	60.0
1.8	43.5	3210	78	61.0
		Section 2		
11.9	19.0	217	8	32.0
11.0	22.8	253	78	33.0
10.1	23.5	329	41	34.0
9.1	24.2	619	74	39.5
8.2	28.0	1009	122	40.5
6.4	34.2	1527	40	45.0
5.5	36.8	2004	8	48.0
4.6	39.0	2144	220	48.0
3.7	41.9	2822	147	58.5

* Average of three subsamples per subplot adjusted to 14 percent moisture.

Table 4. Seasonal evapotranspiration and yield of spring barley grown with 196 kg/ha of added nitrogen.

Subplot Distance From the Line	Seasonal ET	Yield Mean*	Yield SD	Height of Plant at Harvest
m	cm	kg/ha		cm
		Section 1		
11.9	22.6	581	194	34.0
11.0	25.1	645	74	38.0
10.0	28.0	799	108	38.0
9.1	30.9	1000	239	40.5
8.2	33.1	1617	239	43.0
6.4	39.1	2314	152	53.5
5.5	42.9	2688	520	54.5
4.6	48.2	3922	145	57.0
2.7	55.3	4401	297	71.0
1.8	57.2	5051	491	71.0
		Section 2		
12.8	16.8	352	178	33.0
11.9	19.4	324	74	33.0
11.0	22.2	534	166	35.5
9.1	29.9	799	115	39.0
8.2	33.4	1106	135	39.0
6.4	40.6	2082	71	51.0
5.5	43.9	2855	261	58.5
3.7	50.9	3912	231	73.5
2.7	54.0	4838	447	80.0

* Average of three subsamples per subplot adjusted to 14 percent moisture.

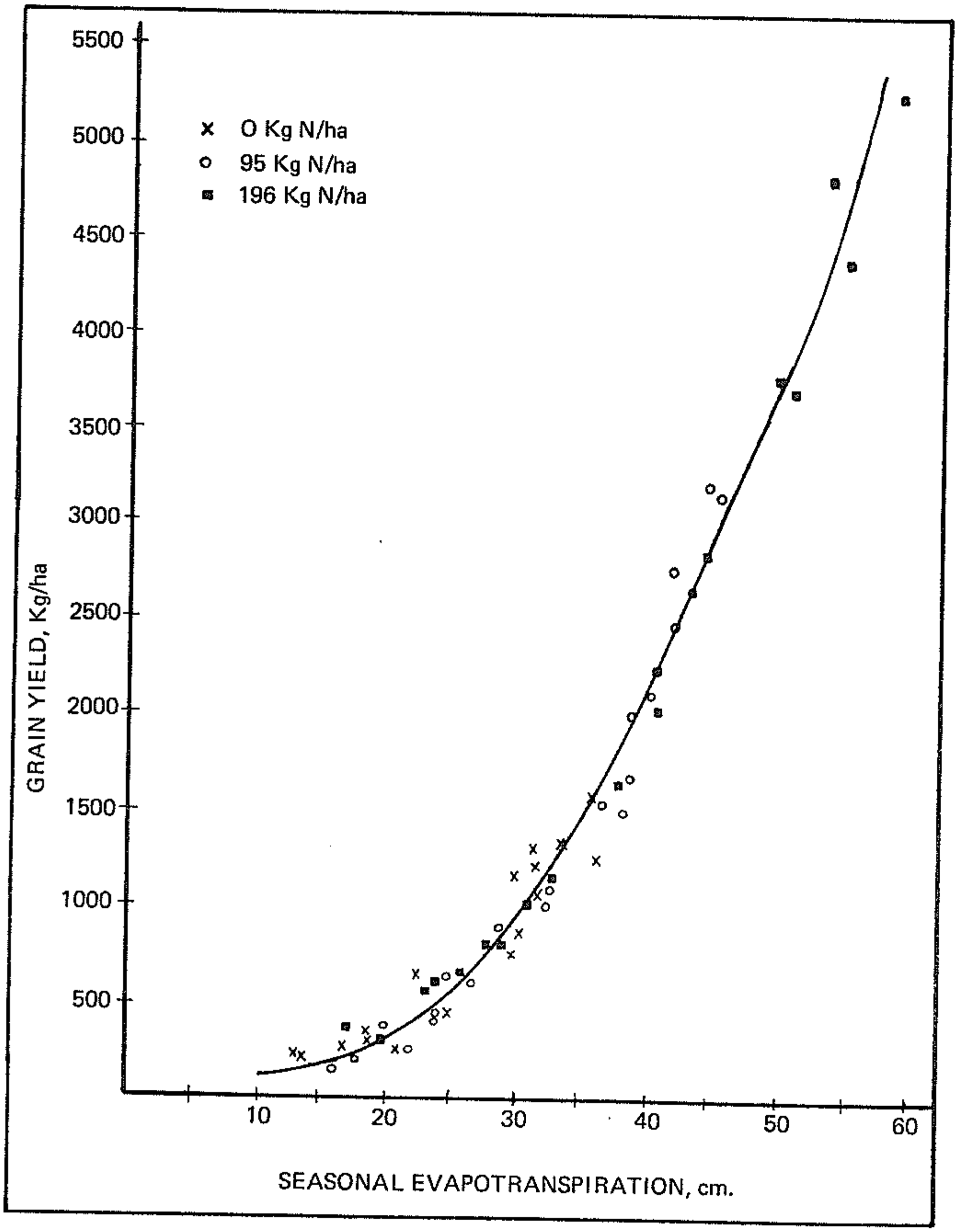


Figure 6. The curvilinear water production function for spring barley determined from the pooling of all data sets regardless of nitrogen fertility level. The equation of the curve is:

$$\text{Yield(kg/ha)} = 2.46\ \text{ET}^2(\text{cm}^2) - 54.4\ \text{ET(cm)} + 414.2,$$

$$r = .96.$$

The coefficient of determination is .89 which is inferior in accounting for the variation among data points than is the quadratic equation.

Equations of the same quadratic form as Equation 5 above have been developed for each section of the nitrogen fertility plots of the barley (Table 5). Except in two cases no significant differences were found to exist among the intercept, linear and curvilinear coefficients between any two of the equations. The exceptions are as follows: all of the equations in Table 5, except equation (C), were found to be significantly different from equation (B); and a significant difference was found to exist between equations (F) and (D). The observation that equations (A) and (B) were significantly different even though the nitrogen application rate was identical probably demonstrates that increased replication of experimental plots would be highly desirable. However, the economics of establishing and maintaining this type of plot makes increased replication unfeasable within the confines of this project budget. Significant differences between the coefficients of these equations would signify that a change in water use efficiency (WUE) occurs as the level of nitrogen fertility changes. However, the lack of similarity in response between the two sections of the low nitrogen fertility plot, the general lack of significance between the curvilinear equations even at widely differing fertility levels, and the high coefficient of determination of the pooling of all data points, (Equation 5) strongly suggests that no change in efficiency occurred with change in nitrogen fertility level.

In addition when a multiple regression equation is developed,

Table 5. Least-squares-fit quadratic equations developed from the data of each section of the barley plots; and the pairwise comparison of the equations for significant differences.

Applied N in the Plot	Section	Equation	r^2	Letter of Equation	Significant Differences*
kg/ha		Y(kg/ha), ET(cm)			
0	1^{**}	$Y = 80.6 - 15.6ET + 1.59ET^2$	.97	A	B
0	2^{**}	$Y = 588.1 - 54.1ET + 1.94ET^2$	.94	B	A, E, D, F
95	1	$Y = 2223.5 - 199.ET + 5.07ET^2$	.94	C	None
95	2	$Y = 29.2 - 42.1ET + 2.56ET^2$	.99	D	B, F
196	1	$Y = -1230.0 + 48.2ET + 1.06ET^2$	.99	E	B
196	2	$Y = 1424.4 - 120.ET + 3.37ET^2$	1.00	F	B, D

* Equation in previous column is significantly different at the .05 level from the equation below. The null hypothesis for the pairwise comparison is that the full and reduced model of the statistical procedure, has a common intercept and common linear and quadratic coefficients.

** 1 and 2 represent the western and eastern half of the plot respectively. See Figure 5 for compass directions.

using a stepwise regression technique, with yield expressed as a function of the variables; ET, N, ET^2, N^2, and ET x N (interaction) the following equation results: (yield is expressed in kg/ha, ET in centimeters, N in kg/ha of applied nitrogen, **, * denote significance at the 1 and 5 percent levels respectively).

$$Y = 2.32ET^{2**} - 51.76ET^{*} + 2.04N - .01N^{2} + .03\ ET \times N \qquad (7)$$

variable	percent of variation accounted for by variable
ET^2	95.21
ET	.71
N	.07
N^2	.12
ET x N	.14
	$r^2 = 96.25$

Even when the non-significant interaction variable is removed from the regression or either of the nitrogen variables it is not possible to obtain a significant t-statistic for either of the nitrogen variables. Equation 3 demonstrates that the ET^2 variable accounts for the great majority of the total variation present and the N and N^2 variables account for an insignificant proportion.

As a result of the similarity of the quadratic equations in Table 5 (with the exception of equation (B)) and the resulting difficulty in plotting them at a reduced scale, the data points from the two sections of each plot were pooled and a single quadratic equation calculated. The following equations result:

added N in plot (kg/ha)	equation (yield, kg/ha : ET, cm)
0	$Y = 1.2\ ET^2 - 6.7\ ET + 20.4,\ r^2 = .85$ (8)
95	$Y = 4.3\ ET^2 - 150\ ET + 1578.0,\ r^2 = .95$ (9)
196	$Y = 2.2\ ET^2 - 37.5\ ET + 243.3,\ r^2 = .98$ (10)

These equations have been plotted in Figure 7.

It should be emphasized that nitrogen is an important factor to crop growth when sufficient water is available for plant use of this nutrient. The subplots which contained the greatest quantity of applied nitrogen, transpired a greater quantity of water when available, required a greater irrigation to replace soil water stores, and produced an equivalently greater yield of grain. Those subplots with the largest transpiration rates also possessed the greater transpirational surface (Figure 8). The population of 134 plants per square meter was relatively constant among subplots with a standard deviation of 15.4.

In Figure 8, the decrease in live leaf dry-weight on the June 3 sampling date is the result of a leaf-killing frost at the end of May. The reason the decrease does not occur until the June 10 sampling date in the highest yielding subplot is not clear. The quantity of living leaf tissue present at any time during the growing season is reflected in the measured evapotranspiration of the highest and lowest yielding of all subplots (Figure 9).

Potential evapotranspiration was determined from the daily weather data using various methods. The formula used in these calculations can be found in Appendix C. The PET of each month of

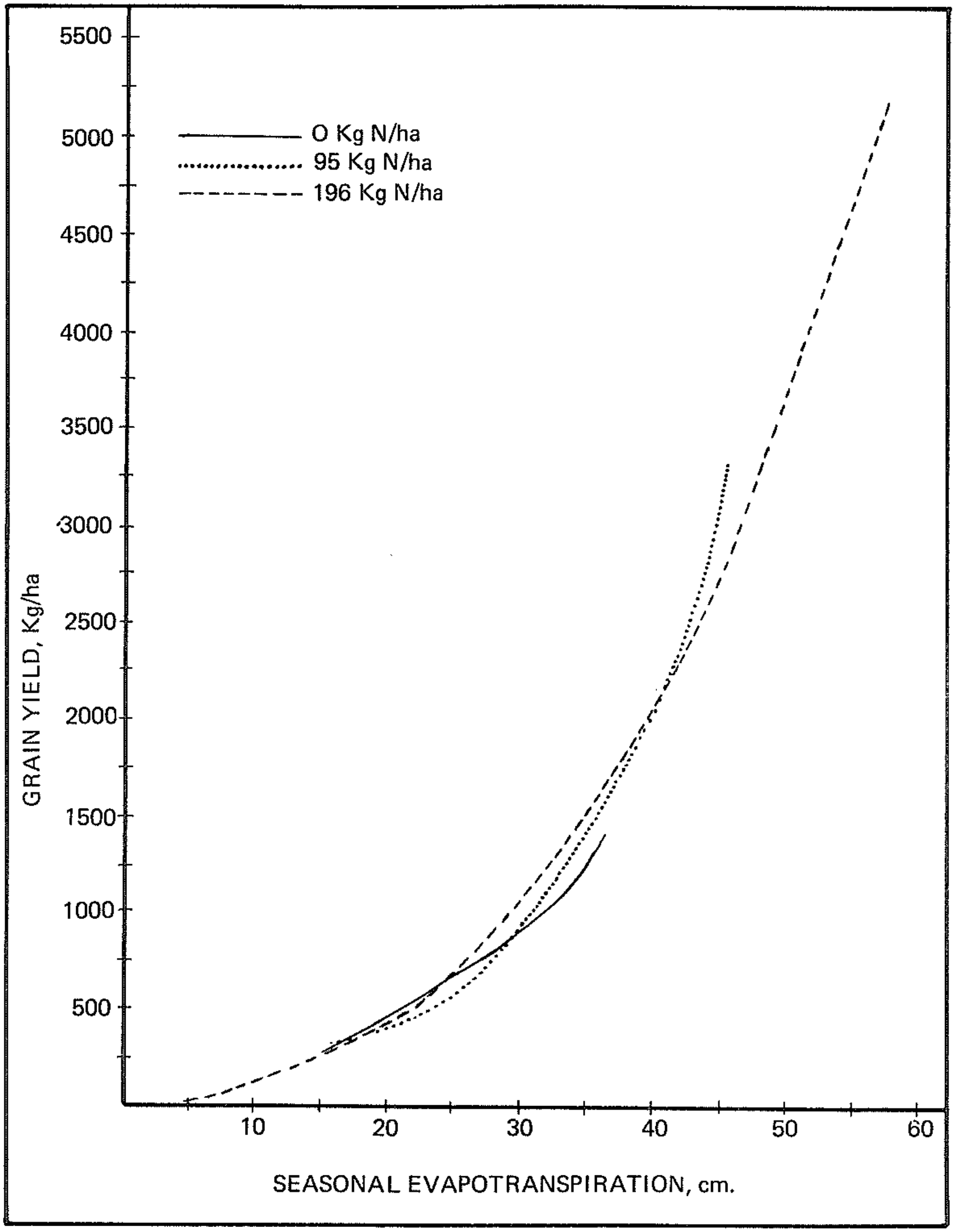


Figure 7. The water production function of spring barley for each level of plot nitrogen fertility.

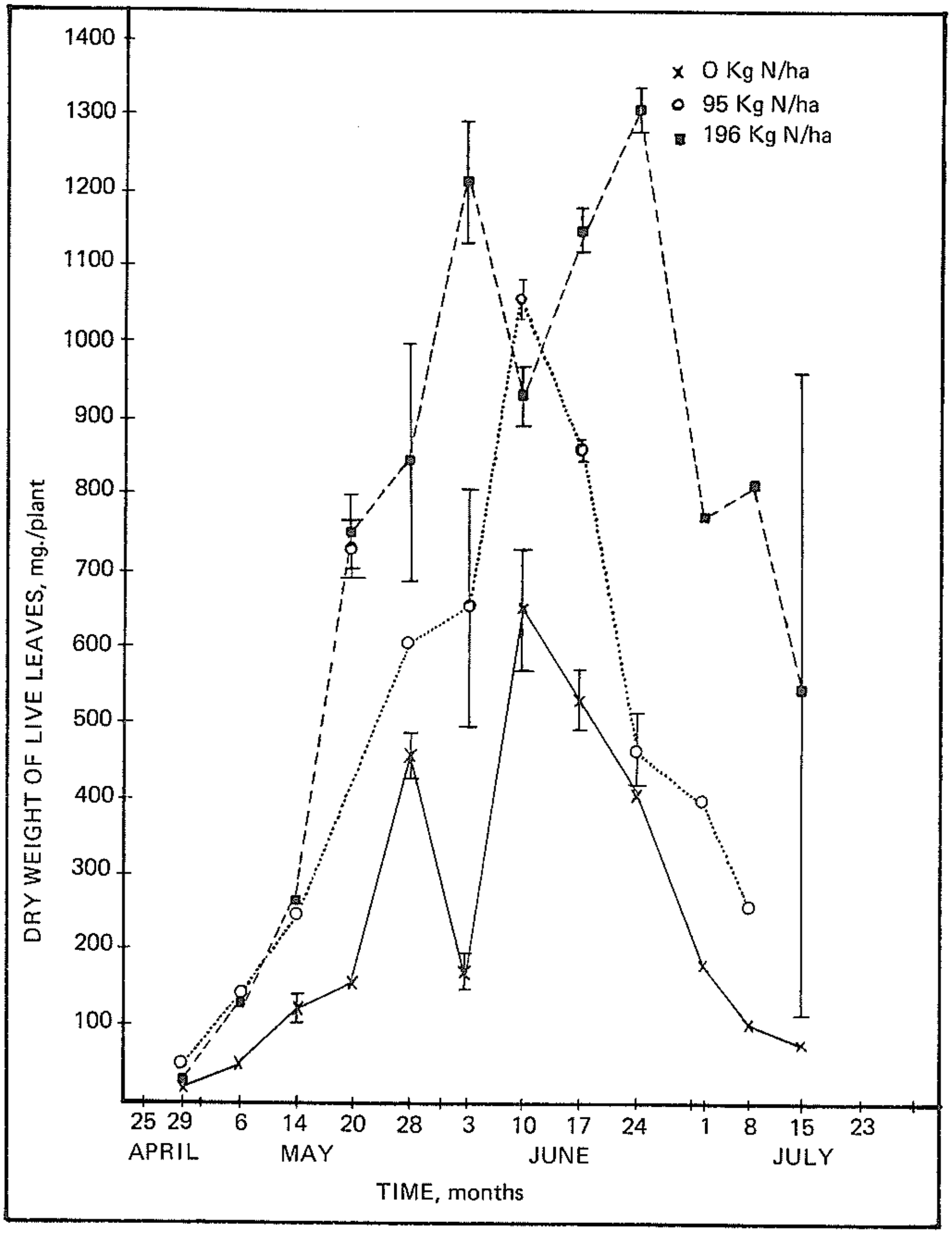


Figure 8. Weight of live leaves per plant of the highest yielding subplot in each plot for each day of the growing season. Each point is the average of two samples of three plants (bars represent one standard deviation).

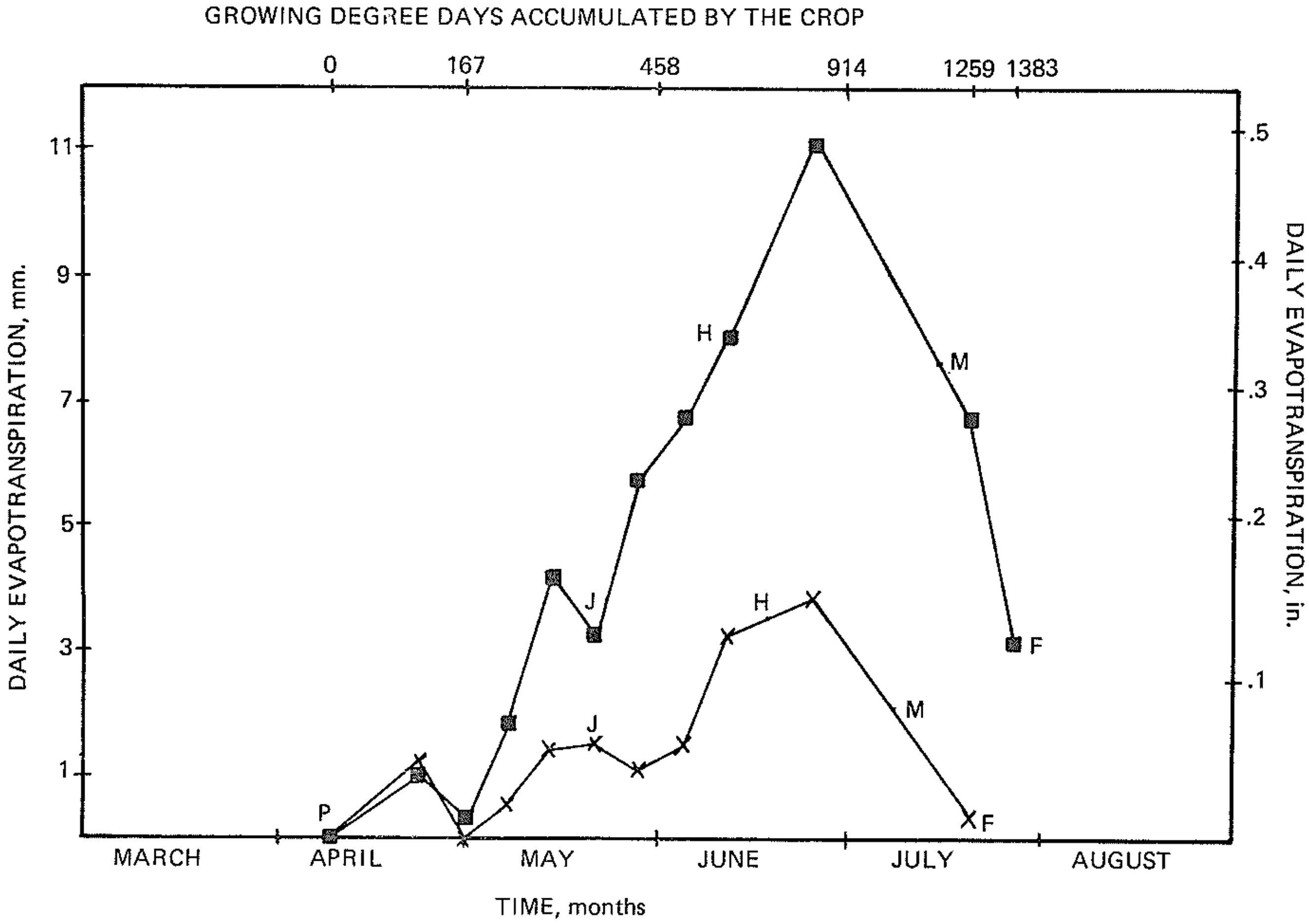


Figure 9. Daily evapotranspiration (ET) of the highest and lowest yielding subplot of spring barley for each day of the growing season. (P) planting, (J) initiation of jointing, (H) heading, (M) physiologican maturity, (F) final probe reading.

the growing season and for each method is presented in Table 6.

Daily evapotranspiration rates have been interpolated and averaged for various periods of plant development at similar yield levels (Table 7). These data have been averaged from all data points regardless of nitrogen level as insignificant changes in WUE occurred with changes in nitrogen fertility. Detailed tables of daily ET for each subplot at each level of nitrogen fertility are presented in Appendix A. In addition, the nitrogen required to produce these yields has been estimated from this season's data, and from data collected by Gregory (1976, 1979). An interesting finding is the constancy of the following relationship of this season's data for all yield levels presented in Table 7:

$$\text{Maximum daily ET, (cm)} = \text{Seasonal ET, (cm)} \times .0165 \qquad (11)$$

The standard deviation for the above factor for all yield levels is .0008. Yields of approximately 7500 kg/ha of grain have been achieved at the San Juan Experiment Station. The ET required to produce this yield has been estimated in Table 7. The seasonal ET was estimated using Equation 5, the maximum daily ET using Equation 11, and the nitrogen level required to produce this yield is as described above. By consulting this table a prospective grower of barley in northwestern New Mexico can determine the evapotranspirational requirements by growth stage, by season, or on a growing degree day basis, and the approximate quantity of nitrogen required to produce an economically desirable level of grain yield. This table does not list the phosphorous or other mineral nutrients which may need to be

Table 6. Monthly potential evapotranspiration.

Method	Time						
	April 9-30	May 1-30	June 1-30	July 1-31	August 1-31	September 1-30	October 1-19
	mm						
Penman	148.11	226.04	301.77	274.52	212.64	158.33	78.24
Priestly-Taylor	120.57	196.64	257.98	260.15	202.33	150.46	69.63
Jenson-Haise	117.24	202.44	289.97	317.51	248.17	177.83	79.40
Pan	148.39	249.90	350.78	358.67	314.74	203.39	50.27

Table 7. Daily ET and estimated nitrogen requirements of similar yield levels of spring barley.

			Growth Stage							
Yield	Seasonal ET	Total Nitrogen	Planting-Jointing 1*	2*	Jointing-Heading 1	2	Heading-Phys.Mat. 1	2	Phys.Mat.-Final 1	2
kg/ha	cm	kg/ha	Daily ET cm/day							
300	20	10	.09	.24	.21	.29	.31	.22	.16	.08
625	25	10	.10	.18	.30	.36	.40	.20	.19	.12
800	31	10	.11	.24	.32	.45	.53	.37	.36	.24
1100	33	10	.11	.24	.39	.50	.55	.34	.35	.25
1825	38	60-70	.09	.22	.54	.56	.62	.36	.37	.22
2900	43	70-85	.09	.24	.42	.61	.71	.48	.48	.24
3900	51	85-105	.11	.29	.48	.71	.84	.56	.56	.36
5050	57	120-145	.08	.30	.55	.74	1.03	.67	.67	.32
7500**	67**	195-205	---	---	---	---	1.25**	---	---	---

* First and second half, respectively, of the time in the applicable growth stage.

** Achieved maximum yields in northwestern New Mexico with optimal growing conditions and with estimated seasonal ET, daily ET, and total N required.

applied to produce these yields in specific areas. This table also assumes a harvest efficiency and an irrigation efficiency of 100 percent. The amount of water necessary as irrigation to produce the table yields would have to be adjusted upward for harvest and irrigation efficiencies more typical of a commercial farming operation. This table is most valid for growing seasons with similar PET rates to those experienced during this growing season.

The average number of growing degree days in the plant developmental stage is presented in Table 8. The greater the yield of grain the greater were the number of growing degree days which were accumulated in the grain-filling growth stages.

Table 9 is identical to Table 7 except the ET has been divided by the PET for the same period. The ET/PET ratio (also called the crop coefficient) can be used to increase or decrease the daily ET requirement presented in Table 7 in those years of higher or lower PET.

The evapotranspiration of the highest and lowest yielding subplots on a monthly basis is presented in Table 10, in conjunction with the crop coefficients based on different methods of calculating PET. This information will be used in conjunction with that in Table 9 as more data becomes available, to re-evaluate crop coefficients presently used in estimating crop consumptive use.

Another comparison of interest, which must be interpreted with caution since only one season of field data exists, is the comparison between the seasonal ET requirement of the lysimeters versus the field plots at the same yield level. Yield and ET data were collected for spring barley from lysimeters by Gregory (1976, 1977)

Table 8. Average total growing degree days per developmental stage of spring barley at similar yield levels.

			Growth Stage							
Yield	Seasonal ET	Total Nitrogen	Planting-Jointing 1*	2*	Jointing-Heading 1	2	Heading-Phys.Mat. 1	2	Phys.Mat.-Final 1	2
kg/ha	cm	kg/ha	Growing Degree Days							
300	20	10	161	177	109	131	204	250	129	148
625	25	10	161	177	131	149	238	279	108	120
800	31	10	161	177	109	131	211	244	138	150
1100	33	10	161	177	118	145	232	272	96	107
1825	38	60-70	161	177	109	131	260	315	105	123
2900	43	70-85	161	177	109	131	260	315	105	123
3900	51	85-105	161	177	109	131	260	315	105	123
5050	57	120-145	161	177	109	131	260	315	105	123

* First and second half, respectively, of the time in the applicable growth stage.

Table 9. Daily and seasonal ET/PET ratios of similar yield levels of spring barley.

			Growth Stage							
Yield	Seasonal ET/PET**	Total Nitrogen	Planting-Jointing 1*	Planting-Jointing 2*	Jointing-Heading 1	Jointing-Heading 2	Heading-Phys.Mat. 1	Heading-Phys.Mat. 2	Phys.Mat-Final 1	Phys.Mat-Final 2
kg/ha		kg/ha	Daily ET/PET							
300	.23	10	.13	.38	.23	.30	.33	.22	.22	.07
625	.28	10	.15	.28	.31	.36	.39	.23	.20	.12
800	.35	10	.16	.38	.35	.47	.56	.37	.49	.21
1100	.38	10	.16	.38	.43	.51	.53	.37	.41	.26
1825	.42	60-70	.15	.35	.59	.59	.60	.41	.38	.30
2900	.47	70-85	.15	.38	.46	.64	.69	.55	.50	.25
3900	.56	85-105	.16	.45	.53	.74	.82	.64	.58	.38
5050	.62	120-145	.12	.47	.60	.77	1.00	.77	.69	.33

* First and second half, respectively, of the time in the applicable growth stage.

** Penman used for calculation of PET.

Table 10. Monthly ET and monthly ET/PET ratios and seasonal Blaney-Criddle coefficients for the highest and lowest measured seasonal evapotranspiration of spring barley.

ET Level	Yield	Monthly ET April	 May	 June	 July	Seasonal ET
	kg/ha	cms				cms
Highest	5050	1.7	12.6	27.3	15.7	57.2
Lowest	187	1.5	3.8	8.5	.7	14.5

ET Level	Method	Monthly ET/PET April	 May	 June	 July	Seasonal Crop Coefficient
High	Penman	.11	.56	.91	.63	.62
	Priestly-Taylor	.14	.64	1.06	.70	.71
	Jenson-Haise	.14	.62	.94	.55	.64
	Pan	.11	.50	.78	.50	.54
	Blaney-Criddle					1.00
Low	Penman	.10	.17	.28	.04	.17
	Priestly-Taylor	.13	.19	.33	.04	.20
	Jenson-Haise	.13	.18	.29	.03	.18
	Pan	.10	.15	.24	.03	.15
	Blaney-Criddle					.25

and by Kallsen during 1980 (Table 11). When the evapotranspirative requirements are compared at similar yield levels between lysimeters and field grown spring barley only 70 percent of the water evapotranspired by the lysimeters was used by the field (Table 12). The reasons for this difference are not clear. This season the lysimeters were approximately seven days behind the field crop due to a later initial irrigation. The subfreezing temperatures at the end of May for the lysimeter grown barley, may have occurred at a more critical developmental stage (spike), than had occurred in the field grown barley. Another factor which could adversely affect grain yield in the lysimeters is an increase in soil salinity due to inadequate water percolation through the soil profile. Table 13 presents data showing soil salinity was not a problem. Soil salinity decreased as measured at the beginning and at the end of the season and all values are sufficiently low so as not to cause crop injury.

Pinto Beans

Pertinent crop information relating to the production of the pinto bean plots and lysimeters is summarized in Table 14. The lysimeters received their initial irrigation more than two weeks earlier than did the sprinkler-line-source plots due to difficulty encountered in placing access tubes in the field. Also, a much poorer stand of pinto beans was established in the field plots as opposed to the lysimeters. The field plots averaged three plants per square meter whereas the lysimeters averaged seven.

Seasonal ET and yields of the plots containing 40, 124, and 162 kilograms of added nitrogen per hectare are presented in Tables 15, 16, and 17 respectively. The tables also contain the

Table 11. Yearly spring barley lysimeter performance.

Year	Yield Mean*	Yield SD	Yield Mean*	Yield SD	ET/Pan Evaporation
	kg/ha		cm		
1976	3037	-	63.3	-	.52
1977	3589	424	64.6	5.4	.57
1980	3184	69	68.0	1.3	.66

* All values average of two replicates except for 1976 which was not replicated.

Table 12. Comparison of seasonal ET required to produce equivalent yields of spring barley in lysimeters versus field plots.

Measurement	Field*	Lysimeter**	Significance Level
Yield Mean (kg/ha)	3329	3270	none
Yield SD (kg/ha)	488	286	-
ET Mean (cm)	45.1	65.3	.001
ET SD (cm)	3.6	3.4	-

* Average data for 1980.

** Average data for 1976, 1977, and 1980.

Table 13. Evaluation of soil salinity in the lysimeter at planting and at harvest.

Lysimeter	Soil Depth	Salinity Planting	 Harvest
	cm	mmhos/cm	
Barley			
1	Average of 15, 80, 110	1.06	.71
2	Average of 15, 80, 110	1.06	.78
Pinto Beans			
3	0-38	1.15	.84
4	39-80	.90	.77
Corn	Not Available		

Table 14. Pinto bean crop data for 1980.[1]

Plot Number	Added Nitrogen	Added P_2O_5	Planting Date	Initial Irrigation	Emergence Date	Harvest Date	Number of Plants per Sq. Meter
	kg/ha	kg/ha					
1	40	85	May 27	June 19	June 26	Oct. 15	2.6
2	124	85	May 27	June 20	June 29	Oct. 15	2.7
3	162	85	May 28	June 21	June 29	Oct. 16	3.4
Lysimeter	168*	85	May 28	June 02	June 10**	Oct. 03	7.2

[1] The Womack selection of bean was planted at a rate of 40 to 50 kg/ha in 91.4 cm spaced rows.

* Nitrogen was applied in two applications of 84 kg/ha each, one: May 28
two: July 28.

** Estimated date.

Table 15. Seasonal evapotranspiration and yield of pinto beans grown with 40 kg/ha of added nitrogen.

Subplot Distance From the Line	Seasonal ET	Seed Yield Mean*	Seed Yield SD	Total Dry Matter Mean**	Total Dry Matter SD
m	cm	kg/ha		kg/ha	
		Section 1			
12.8	11.5	228	57	650	70
11.9	14.5	407	89	1033	213
11.0	14.5	494	94	1147	66
10.1	15.4	555	116	1327	328
9.1	16.5	653	107	1433	236
8.2	19.2	687	118	1462	329
7.3	22.4	870	177	1884	222
6.4	23.4	1098	155	2287	140
5.5	24.8	1088	64	2130	109
4.6	25.8	1320	284	2510	562
3.7	26.8	1181	195	2350	341
2.7	30.0	1555	191	3027	333
1.8	33.3	1413	245	2547	218
.9	35.4	1689	125	2956	187
		Section 2			
12.8	14.7	488	60	1057	134
11.9	15.7	624	96	1236	135
11.0	17.1	697	62	1317	88
10.1	19.4	854	71	1667	35
9.1	22.3	1020	95	1927	262
8.2	23.4	718	147	1390	286
7.3	24.9	1116	173	2134	216
6.4	29.0	1183	310	2421	216
5.5	31.7	1273	241	2460	411
4.6	33.5	1472	285	2730	377
3.7	35.6	1579	257	2803	332
2.7	35.1	1701	176	2998	216
1.8	34.9	1472	431	2761	411
.9	36.2	1620	330	2128	548

* Average of three subplots adjusted to 15.5 percent moisture.

** Average of three subplots air dry basis.

Table 16. Seasonal evapotranspiration and yield of pinto beans grown with 124 kg/ha of added nitrogen.

Subplot Distance From the Line	Seasonal ET	Seed Yield Mean*	Seed Yield SD	Total Dry Matter Mean**	Total Dry Matter SD
m	cm	kg/ha		kg/ha	
		Section 1			
12.8	11.4	329	64	957	244
11.9	13.2	539	125	1234	137
11.0	15.6	510	116	1126	208
10.1	17.4	766	135	1795	235
9.1	19.3	646	123	1492	136
8.2	20.2	1094	14	2252	301
7.3	21.8	673	238	1449	226
6.4	24.9	1319	72	2698	203
5.5	28.3	1433	219	2793	317
4.6	29.1	1351	315	2671	665
3.7	30.3	1525	139	3072	293
2.7	32.6	1659	160	3151	218
1.8	35.5	1962	187	4224	794
.9	37.0	1927	262	3881	151
		Section 2			
12.8	15.9	494	87	1114	134
11.9	17.4	663	94	1323	135
11.0	19.2	785	40	1624	150
10.1	19.6	685	65	1484	246
9.1	22.9	1197	105	2399	231
8.2	23.6	825	102	1697	156
7.3	27.2	1516	233	2946	229
6.4	29.2	1177	353	2551	634
5.5	31.2	1748	86	3411	401
4.6	32.9	1620	172	3098	378
3.7	34.7	1502	187	2805	381
2.7	34.7	2071	268	3744	308
1.8	34.6	1906	60	3643	417
.9	36.5	2034	325	3944	406

* Average of three subplots adjusted to 15.5 percent moisture.

** Average of three subplots air dry basis.

Table 17. Seasonal evapotranspiration and yield of pinto beans grown with 162 kg/ha of added nitrogen.

Subplot Distance From the Line	Seasonal ET	Seed Yield		Total Dry Matter	
		Mean*	SD	Mean**	SD
m	cm	kg/ha		kg/ha	
Section 1					
12.8	14.3	519	37	1340	12
11.9	17.0	453	91	1307	202
11.0	19.9	598	108	1768	105
10.1	20.6	563	135	1297	188
9.1	21.5	789	65	1785	77
8.2	22.5	602	144	2380	403
7.3	23.7	1088	208	2815	314
6.4	26.4	758	73	2374	626
5.5	29.1	1155	272	3661	426
4.6	32.1	1096	62	3336	426
3.7	35.7	1073	162	3063	171
2.7	36.0	1521	171	4167	93
1.8	36.5	1544	89	4224	435
.9	37.4	1961	166	4480	720
Section 2					
12.8	16.0	409	72	1362	336
11.9	18.2	392	120	1195	409
11.0	20.7	657	108	2033	278
10.1	21.9	618	159	2139	189
9.1	23.5	716	125	2401	493
8.2	24.8	703	54	2185	115
7.3	26.3	892	181	2559	322
6.4	28.8	1171	123	3781	244
5.5	31.3	1195	49	3376	383
4.6	33.9	1244	214	3181	402
3.7	36.7	1607	276	4403	394
2.7	37.8	1612	295	3882	217
1.8	38.9	1781	222	4092	157
.9	38.9	1346	363	3021	772

* Average of three subplots adjusted to 15.5 percent moisture.

** Average of three subplots air dry basis.

total dry matter (TDM) harvested from the subplot. Similar information for the lysimeters has been tabulated in Table 18.

The combined data points of yield versus seasonal ET from these three tables and from the lysimeter has been plotted superimposed with a simple regression line (Figure 10). The equation for the line is as follows:

$$\text{Yield (kg/ha)} = 58.4 \text{ ET (cm)} - 423 \qquad (12)$$

The coefficient of determination for this crop production function is .92. A curvilinear equation does not significantly account for a larger percentage of the variation than does this simple regression.

Water production functions of the same linear form have been developed for each section of each field plot, that is each level of nitrogen fertility (Table 19). The equations of Table 19 have been statistically compared in a pairwise manner for differences of slope and intercept in Table 20. A significant difference in slope signifies a change in WUE, while a change in intercept signifies a difference in the amount of ET which must occur before some seed can be produced.

The results for the pinto bean plots is more ambiguous with respect to the question of a possible change in WUE with the level of nitrogen fertility, than were the results of the barley fields. A statistical computer program available at New Mexico State University at Las Cruces on the APL system not only allows the comparison of linear functions for slope and intercept, but allows one to

Table 18. Seasonal ET and yield of lysimeters.

Lysimeter	Gram Yield	Total Dry Matter	Seasonal ET
	kg/ha	kg/ha	cm
Pinto Beans			
3	4987	8402	85.57
4	4147	8958	81.24
Barley			
1	3233	- -	68.91
2	3167	- -	67.09
Corn			
5	8534	16113	78.49
6	10395	19515	100.51

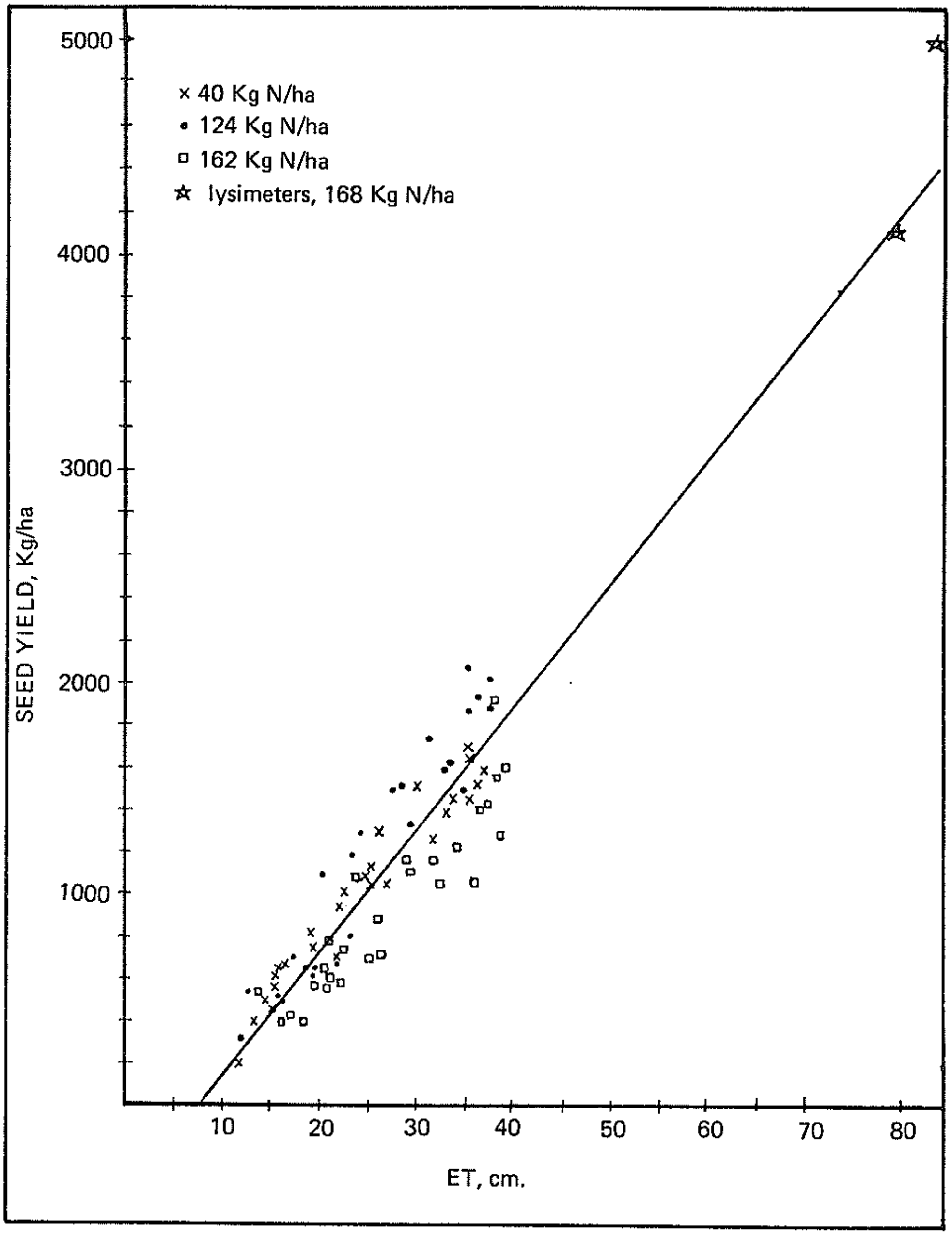


Figure 10. The water production function of pinto beans regardless of plot nitrogen fertility level. The equation of the line is:

$$\text{Yield(kg/ha)} = 58.4\ \text{ET(cm)} - 423,$$

$$r^2 = .92.$$

Table 19. Least-squares-fit linear equations derived from the data of each section, of the seed yield of pinto beans.

Applied N in the Plot	Section	Equation	r^2	Equation Identification Letter
kg/ha		Y(kg/ha);ET(cm)		
40	1*	Y = 58.76ET - 363.50	.96	A
40	2*	Y = 49.19ET - 182.62	.94	B
124	1	Y = 64.05ET - 416.17	.94	C
124	2	Y = 70.68ET - 614.70	.89	D
162	1	Y = 51.67ET - 395.63	.80	E
162	2	Y = 56.21ET - 572.26	.94	F

* The numbers 1 and 2 represent the western and eastern half of each plot respectively. Refer to Figure 5 for compass directions.

Table 20. Pairwise comparisons of the equations in Table 19 for a significant difference with respect to intercept and slope.

Equation Identification Letter	Applied N in the Plot	Section	Function Parameters**		
			Common Intercept* Common Slope	Common Intercept* Different Slope	Different Intercept* Common Slope
	kg/ha				
A	40	1***	E, F	None	None
B	40	2***	C, D, F	F	C, D
C	124	1	B, D, E, F	None	B
D	124	2	B, C, E, F	None	B
E	162	1	A, C, D	None	None
F	162	2	A, B, C, D	B	None

* The null hypothesis for the pairwise comparison is that the full and reduced model of the statistic have the listed characteristic.

** Equation is significantly different at .05 level from the equations tabulated for function parameters.

*** The numbers 1 and 2 represent the western and eastern half of each plot respectively. Refer to Figure 5 for compass directions.

compare the functions with respect to only slope and only intercept. These comparisons have been tabulated in Table 20. When both linear function parameters are compared simultaneously many of the equations for the various sections are significantly different from one another. Again, however, it should be noted that considerable variability exists between the performance of each section of the plot at the same level of nitrogen fertility. This tends to suggest that many of the differences may be more the result of random error due to plot location than of true differences. For example, section 1 of the middle fertility plot is significantly different from section 2 of the same plot. When the intercepts are compared, only equation (B) and (F) are found to be significantly different in that regard. Likewise, when the slopes are compared only equation (B) is found to be significantly different from equations (C) and (D). These equations have been plotted in Figure 11.

Total vegetative matter remaining in the plots at the time of harvest was also determined. Unfortunately, at this time some of the leaves had dessicated and had been blown from the plants in the subplots. Regression equations were developed for each section of the plots in the same manner as for the seed yield (Table 21). Pairwise comparisons of these regression equations (Table 22) demonstrate that the sections containing 162 kg/ha of nitrogen were not significantly different from the plots containing 124 kg/ha of nitrogen while both generally contained sections which were significantly different from the sections in the low fertility plot. These equations were plotted in Figure 12. A significantly less

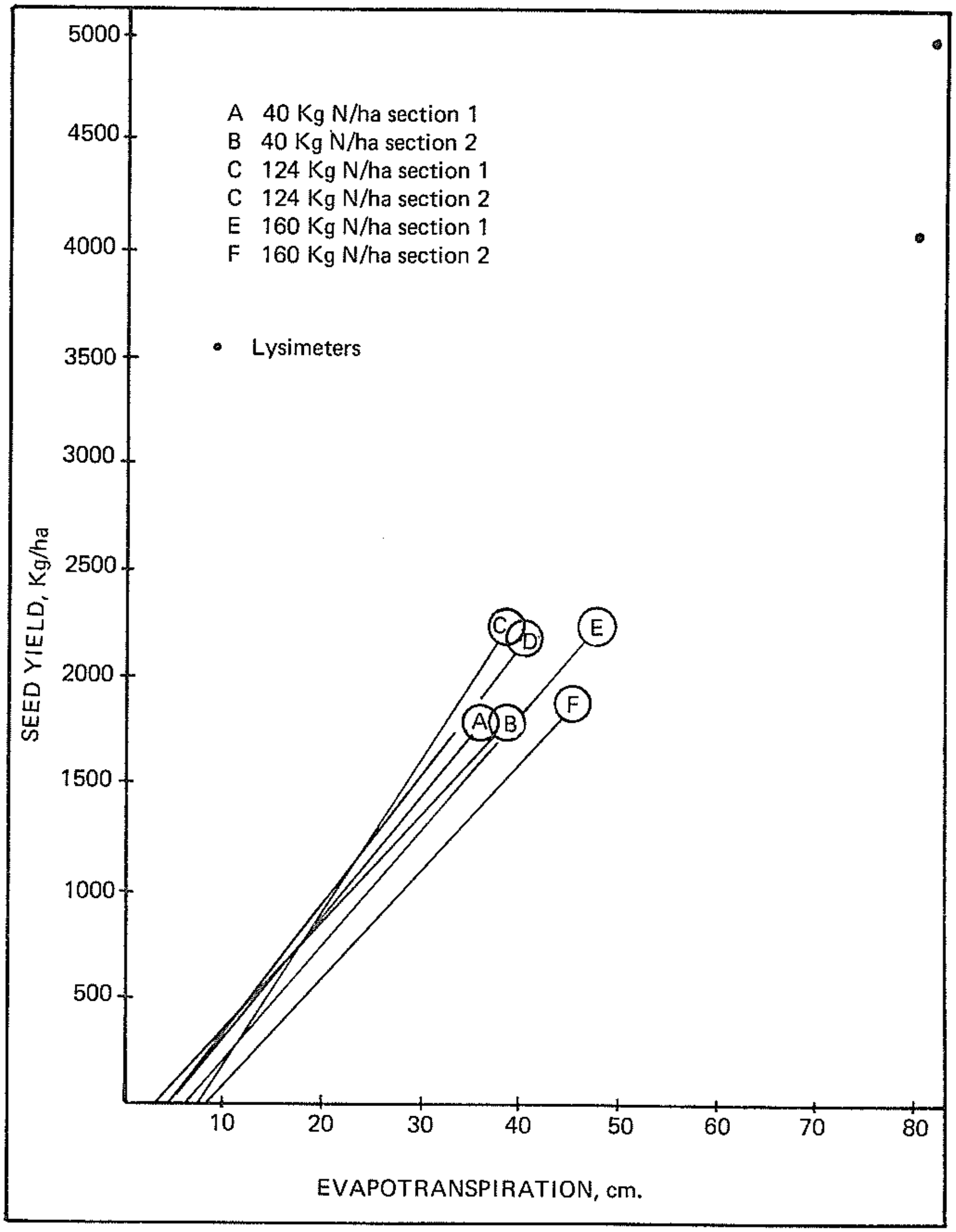


Figure 11. The water production function of pinto beans for each of the two sections at each level of nitrogen fertility.

Table 21. Least-squares-fit linear equations derived from the data of each section, of the total dry matter yield of the pinto beans.

Applied N in the Plot	Section	Equation	r^2	Equation Identification Letter
kg/ha		Y(kg/ha);ET(cm)		
40	1*	$Y = 95.61ET - 230.84$	.92	A
40	2*	$Y = 74.95ET + 73.84$	.84	B
124	1	$Y = 110.74ET - 359.69$	.88	C
124	2	$Y = 125.86ET - 856.89$	.89	D
162	1	$Y = 135.07ET - 881.64$	.87	E
162	2	$Y = 111.24ET - 410.04$	.86	F

* The numbers 1 and 2 represent the western and eastern half of each plot respectively. Refer to Figure 5 for compass directions.

Table 22. Pairwise comparison of the equations in Table 21 for a significant difference with respect to intercept and slope.

Equation Identification Letter	Applied N in the Plot	Section	Function Parameters**		
			Common Intercept* Common Slope	Common Intercept* Different Slope	Different Intercept* Common Slope
	kg/ha				
A	40	1***	E	None	E
B	40	2***	D, E, F	D	D, E, F
C	124	1	None	None	None
D	124	2	B	B	B
E	162	1	A, B	None	A, B
F	162	2	B	None	B

* The null hypothesis for the pairwise comparison is that the full and reduced model of the statistic have the listed characteristic.

** Equation is significantly different at .05 level from the equations tabulated for function parameters.

*** The numbers 1 and 2 represent the western and eastern half of each plot respectively. Refer to Figure 5 for compass directions.

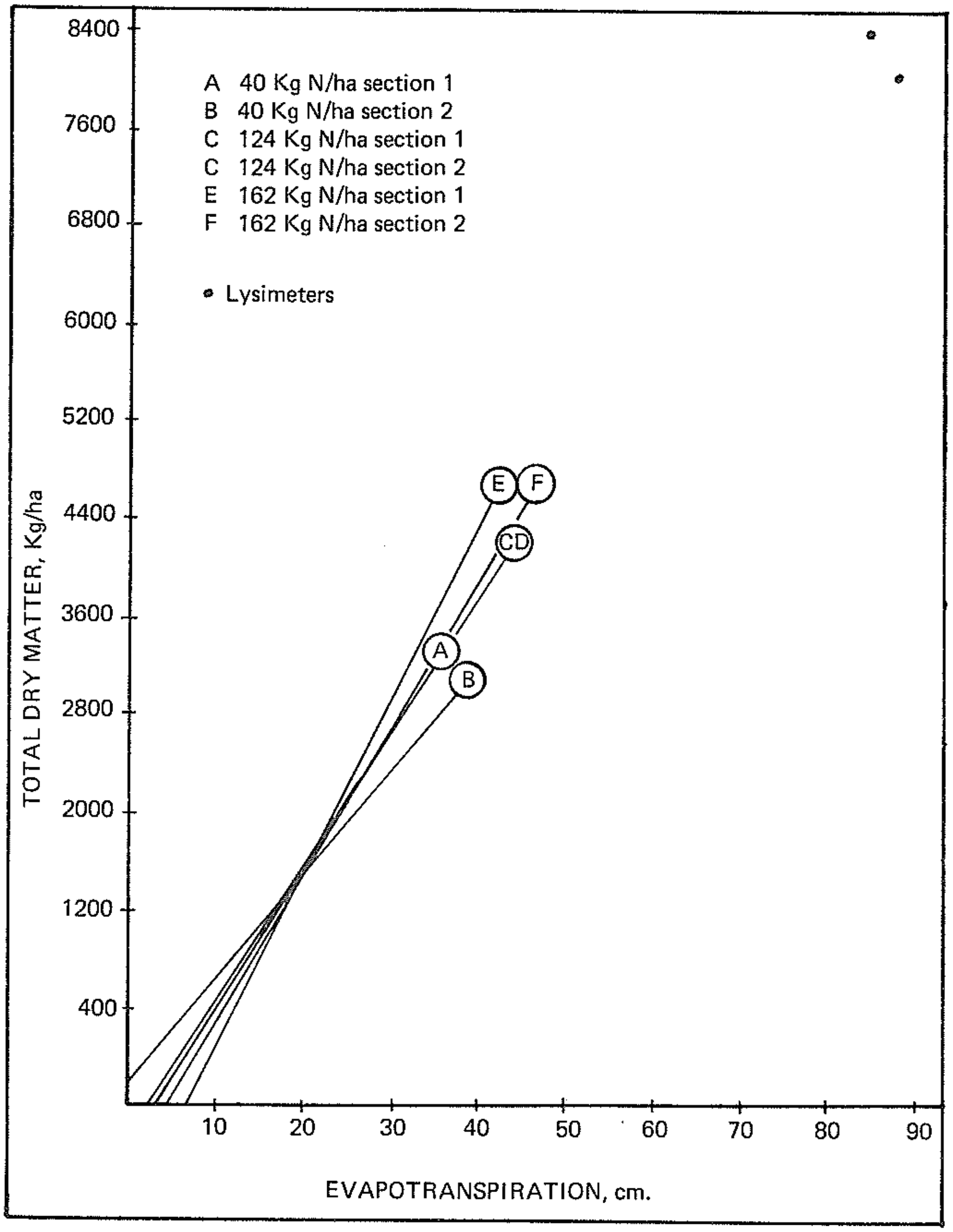


Figure 12. The relationship between total dry matter (TDM) produced by pinto beans and seasonal evapotranspiration of each section at each level of nitrogen fertility.

steep slope of the sections of the plot containing 40 kg/ha of added nitrogen would signify a decreased WUE at this fertility level with respect to dry matter production. However, since the beans of the low-nitrogen plot matured somewhat earlier than the high nitrogen plot it may be supposed that they lost a correspondingly greater percent of their leaves before the measurement of the total dry matter yield occurred.

In Figure 11, where seed yield has been plotted against seasonal ET, the plot containing 124 kg/ha of added nitrogen consistently out yielded the plot containing 162 kg/ha of added nitrogen at each evapotranspirational level. Figure 12 demonstrates however, that the total dry matter production (TDM) was similar between the two fertility levels. Since the TDM contains both the vegetative and seed components, the plot with the 162 kg/ha of added nitrogen was characterized as having a greater percentage of its TDM in vegetative matter at similar ET levels. This observation, in combination with the relatively high precision the lines appear to possess, as reflected in their high r^2 values, suggests two explanations for the decreased grain yield of the high nitrogen plots. Either the high nitrogen plot was not able to reach full yield potential due to late planting and the correspondingly more marginal growing conditions at the end of the season, or the high nitrogen level encouraged excessive vegetative growth suppressing reproductive growth. The former hypothesis is supported by the lysimeter results. Both the lysimeters and the high nitrogen fertility plots contained similar quantities of supplemental nitrogen, but the lysimeters produced yields greater than would have been predicted by the water production functions (in Table 19) developed for each section of the high nitrogen plot. Since the lysimeters had been planted two and one half weeks earlier than the sprinkler-line source plots it is suggested that the field plots simply had insufficient time to reach full yield potential.

Also of interest is the observation that the TDM versus seasonal ET line does not pass through the origin. The apparent positive x-intercept of these lines signifies some ET was required before any vegetative matter was produced. The observation that a large quantity of dry matter was lost before it could be harvested would indicate that the TDM was greater at each ET level than that which is plotted. This would tend to move y-intercept upward, and the line would pass closer to the origin.

Although the TDM measurement can provide insights into the use of water by the developing crop it is the economic yield which is of importance in a commercial farming operation. Since the water production functions of some of the sections were significantly different with respect to seed yield (Table 20), a mathematical expression was developed to account for differences in yield based on the variables, ET and N. The equation with each variable being significant at the 1 percent level is (with yield (kg/ha); nitrogen (kg/ha); ET (cm)) as follows:

$$\text{seed yield} = 51.8ET + .12ET^2 + 13.4N - .01N^2 \qquad (13)$$

The variables account for the following percentage of the total variation:

variable	variation accounted for
ET	93.1
N	1.8
ET^2	.3
N^2	.8

Althouth the t-statistic for the coefficient of each variable of Equation 13 is significant, it should be emphasized that the evapotranspiration variable accounts for the majority of the variation explained by the multiple regression equation, while the nitrogen variable account for very little. Since the stand of beans in the field was poor and the beans were planted late, this year's bean data with respect to any possible change in nitrogen fertility should be interpreted with caution. Next year's data should clarify the relationship. As discussed above, a simple regression equation of all points from all plots and the lysimeters regardless of nitrogen level, results in a water production function with a coefficient of determination of .92 (Equation 12). This relatively large coefficient of determination makes this equation valuable for predicting the seasonal ET requirements for bean production. Pinto beans in northwestern New Mexico are generally inoculated with an appropriate symbiotic bacteria of the genus Rhizobium, before planting. The plant is then able to fix the greater part of its nitrogen requirement without large quantities of supplemental nitrogen fertilization. The plant will fix nitrogen at a rate proportional to its rate of growth. Since Equation 12 is developed from a wide range of ET and N fertility levels it should adequately reflect ET requirements for pinto bean production.

Daily evapotranspiration rates have been interpolated and averaged for various periods of plant development at similar yield levels (Table 23) for each level of nitrogen fertility. Detailed tables of daily ET for each subplot containing an access tube and its distance from the sprinkler-line source is presented in Appendix A. The daily ET requirements necessary in the production of various yield levels regardless of nitrogen fertility level have been further condensed in Table 24. The same information for the lysimeter is presented in Table 25. The poor stand of pinto beans in the field resulted in no intermediate yield points between the yield value of approximately 2000 kg/ha in the sprinkler-line-source plots and the 4000-5000 kg/ha yields in the lysimeters. The yields achieved in the lysimeters are comparable to the largest yields that have currently been achieved on the San Juan Agricultural Experiment Station.

Differences in maximum yield were not as apparent from one sprinkler-line-source plot to another as was the case with the barley plots. This is probably attributable to the low plant density and the lateness of the initial irrigation with respect to the time remaining in the growing season. Each plant had sufficient nitrogen in the low fertility plots, as a result of the lack of competition with its neighbors, so that nitrogen was not the limiting factor to growth as was the case in the barley plots. The most probable limiting factor to growth in the subplots under the sprinkler-line source was the length of time available for growth. Thus it

Table 23. Average daily ET of pinto beans interpolated to similar yield levels.

		Time Period							
		June	July		August		September		October
Yield	Added N	19-30	1-16	17-31	1-16	17-31	1-15	16-30	1-13
kg/ha	kg/ha	Daily ET cm/day							
200	40	.06	.06	.08	.11	.20	.07	.09	.05
400	40	.06	.06	.13	.13	.25	.12	.14	.10
	124	.07	.07	.14	.13	.25	.15	.18	.06
	162	.05	.05	.12	.17	.25	.19	.17	.03
600	40	.06	.06	.17	.15	.30	.16	.18	.14
	124	.08	.08	.13	.14	.35	.24	.26	.05
	162	.06	.06	.15	.24	.34	.21	.21	.09
800	40	.09	.09	.16	.19	.33	.17	.22	.10
	124	.09	.09	.14	.15	.33	.27	.26	.05
	162	.11	.11	.16	.24	.32	.25	.23	.09
1000	40	.12	.12	.17	.24	.38	.18	.25	.09
	124	.10	.10	.17	.19	.37	.28	.22	.03
	162	.15	.15	.18	.27	.36	.28	.33	.11
1200	40	.17	.17	.21	.29	.43	.19	.27	.16
	124	.11	.11	.20	.23	.41	.29	.18	.02
	162	.16	.16	.21	.30	.52	.33	.39	.15
1500	40	.15	.15	.29	.37	.52	.15	.25	.07
	124	.18	.18	.21	.25	.49	.36	.37	.08
	162	.15	.15	.26	.32	.57	.42	.28	.14
1800	124	.17	.17	.23	.29	.55	.25	.38	.18
	162	.23	.23	.27	.30	.47	.47	.46	.31

Table 24. Average daily ET at similar yield levels from all pinto bean plots regardless of nitrogen level.

		Time Period							
		June	July		August		September		October
Yield	Seasonal ET	6-30	1-16	17-31	1-16	17-31	1-15	16-30	1-13
kg/ha	cm	Daily ET cm/day							
200	13.0	.06	.06	.09	.10	.23	.13	.14	.05
600	17.8	.07	.07	.15	.09	.33	.10	.22	.10
850	21.8	.11	.11	.15	.20	.33	.24	.25	.06
1175	26.6	.15	.15	.20	.27	.44	.26	.29	.11
1525	26.3	.16	.16	.25	.31	.53	.32	.31	.10
1825	36.4	.20	.26	.26	.30	.51	.35	.43	.25
	GDD/Period								
	1384	271	194	193	207	148	139	123	109

Table 25. Average daily ET, ET/PET ratio, seasonal ET, yield, and GDD of the lysimeter-grown pinto beans.

Lysimeter Number	Yield	Seasonal ET	Time Period									
			May	June		July		August		September		October
			29-31	1-15	16-30	1-16	17-31	1-16	17-31	1-15	16-30	1-13
	kg/ha	cm	Daily ET cm/day									
3	4987	85.6	-.01	.29	.39	.67	.76	1.19	1.09	.83	.30	.13
4	4147	81.2	.13	.31	.30	.63	.74	1.19	1.09	.79	.29	.06
		Seasonal ET/PET*	Daily ET/PET									
3	4987	.88	-.01	.29	.38	.78	.84	1.61	1.73	1.66	.55	.24
4	4147	.83	.14	.31	.30	.73	.81	1.61	1.73	1.58	.53	.11
		GDD/Period										
		1461	23	151	174	194	193	207	148	139	123	109

* PET calculated by Penman method.

is not possible to determine detailed recommendations as to nitrogen requirements of pinto beans. One hundred sixty-eight kilograms of total nitrogen per hectare was sufficient to produce yields of 5000 kg/ha without inoculation of the seed with symbiotic bacteria.

Table 26 is identical to Table 24 except the ET has been divided by the PET for the same period. The same information is presented for the lysimeters in Table 25.

The monthly evapotranspiration of the highest (a lysimeter) and the lowest (a subplot) yielding experimental unit is presented in Table 27, in conjunction with the ET/PET ratios based on the different methods of calculating PET. During the month of August the ET/PET ratios were 1.67 and 1.75 for the PET calculated by the Penman and Priestly-Taylor methods, respectively.

The daily ET for these same highest and lowest ET rates have been plotted against time in Figure 13. The growing degree days have also been included in most tables as a guide to timing irrigation requirements for a developing crop. By timing irrigations with respect to growing degree days, adjustment can be made for planting dates which differ from those on which our tables were based. The information in Table 25 and Table 26 will be used to re-evaluate crop coefficients presently used in estimating consumptive use of pinto beans.

Changes in WUE with Changes in Nitrogen Fertility

Analysis of the data from the spring barley plots demonstrates an inconsequential or insignificant change in WUE with changes in nitrogen fertility, with respect to grain yield. The pinto bean plots do demonstrate a change in WUE, but as previously discussed

Table 26. Average daily ET/PET ratio of pinto beans at similar yield levels from all plots regardless of nitrogen level.

		Time Period							
	Seasonal	June	July		August		September		October
Yield	ET/PET*	6-30	1-16	17-31	1-16	17-31	1-15	16-30	1-13
kg/ha	cm	Daily ET/PET							
200	.16	.06	.07	.10	.14	.37	.26	.25	.10
600	.22	.07	.08	.16	.12	.52	.20	.40	.20
850	.26	.11	.13	.16	.27	.52	.48	.45	.13
1175	.32	.15	.17	.22	.36	.70	.52	.53	.23
1525	.32	.16	.19	.27	.42	.84	.64	.56	.21
1825	.44	.20	.23	.28	.41	.81	.70	.78	.52
	GDD/Period								
	1384	271	194	193	207	148	139	123	109

* PET calculated by Penman method.

Table 27. Monthly ET, monthly ET/PET ratios and seasonal Blaney-Criddle coefficients for the highest and lowest measured seasonal evapotranspiration of pinto beans.

		Monthly ET						
ET Level	Yield	May	June	July	August	September	October	Seasonal ET
	kg/ha	cm						cm
Highest	4987	-.04	10.38	22.09	35.48	16.48	.38	85.57
Lowest	228	- -	.74	2.40	4.84	2.73	.78	11.50

		Monthly ET/PET						
ET Level	Method	May	June	July	August	September	October	Seasonal Crop Coefficient
High	Penman	-.01	.34	.80	1.67	1.07	.23	.86
	Priestly-Taylor	-.02	.40	.85	1.75	1.12	.26	.94
	Jenson-Haise	-.02	.36	.70	1.43	.95	.22	.80
	Pan	-.01	.30	.62	1.13	.83	.17	.67
	Blaney-Criddle	- -	- -	- -	- -	- -	- -	1.22
Low	Penman	- -	.03	.09	.23	.17	.12	.12
	Priestly-Taylor	- -	.03	.09	.24	.18	.12	.13
	Jenson-Haise	- -	.03	.08	.20	.15	.14	.11
	Pan	- -	.03	.07	.16	.13	.16	.09
	Blaney-Criddle	- -	- -	- -	- -	- -	- -	.16

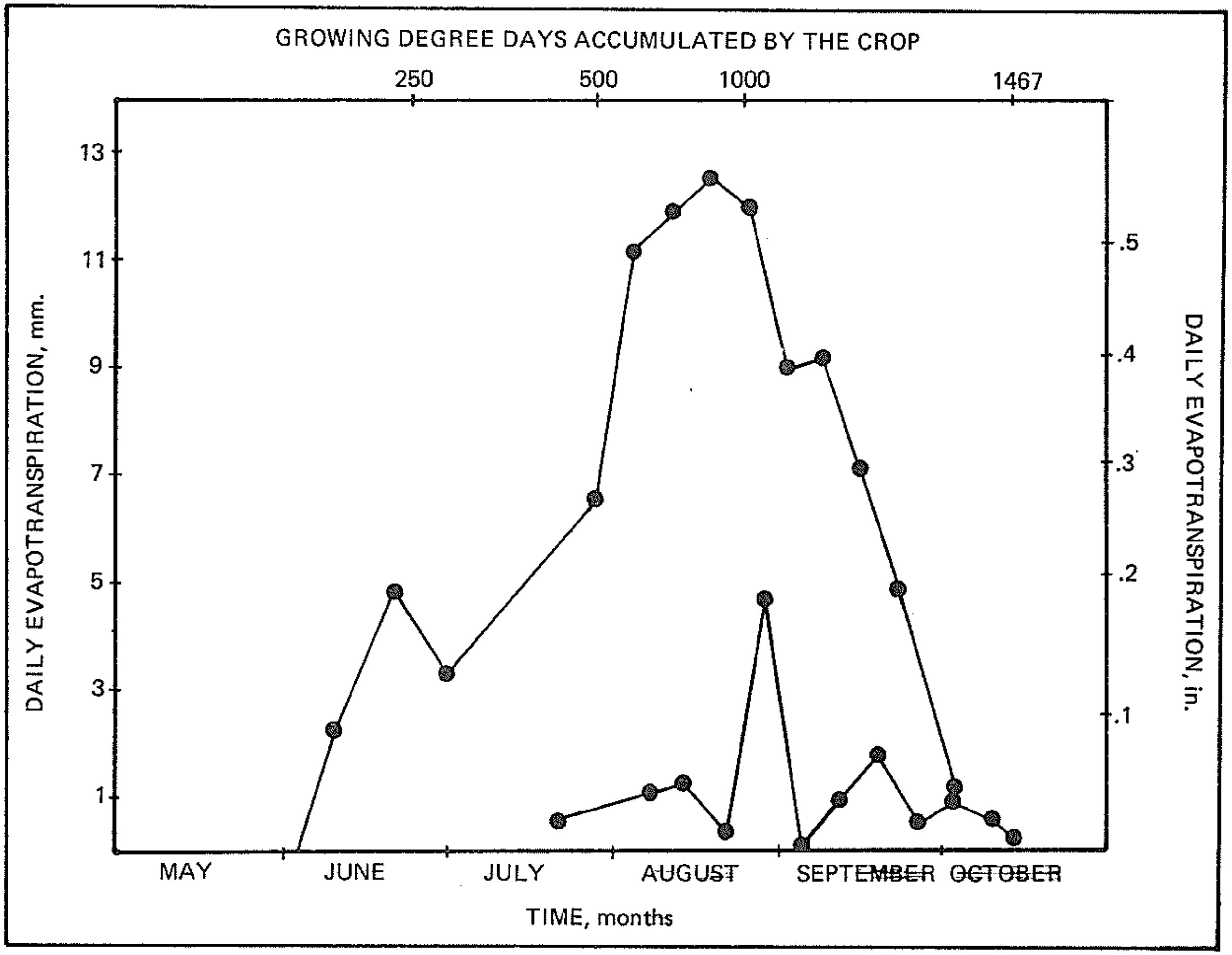


Figure 13. Daily evapotranspiration of the highest and lowest pinto bean yields for each day of the growing season.

the change is probably the result of the length of the growing season. The data which were obtained from the spring barley crop were much more characteristic of proper production practices than were those obtained from the beans. The plant density of the spring barley was at recommended levels and had been planted and initially irrigated at an optimal time allowing all plots to reach maturity under satisfactory growing conditions. This was not the case with the pinto beans. As discussed above for the barley and beans it would appear that nitrogen's main effect is on the rate of growth and the prolongation of the maturation period. If the growing season is insufficiently long to make allowances for this delayed maturity a change in WUE will occur, but it will be the result of climatic conditions, not of changes in WUE with respect to biochemical or physiological characteristics of nitrogen-use within the plant. Hexem and Heady (1978) have shown changes in efficiency with respect to the relationship between yield and plant use of applied water as the level of nitrogen fertility changes. These authors experimented with many crops, including wheat and corn, but did not experiment with barley or beans. However, within the limits of common rates of fertilization for each crop, the crop response in their study was almost always a decrease in WUE with a decrease in nitrogen fertilization. This is not the pattern displayed by our beans in plots or lysimeters where the response was inconsistent, and certainly was not the pattern displayed by the barley plots where little if any change in WUE occurred among fertility treatments. Hexem and Heady did not measure ET but only applied water. The probability of losing water to deep percolation in fields containing low levels of nitrogen fertility, with their correspondingly slow growth and CU, is much enhanced without some means of monitoring soil moisture status. The initial results of our project do not support the concept of variable WUE with varying levels of nitrogen fertility.

The Mathematical Form of the Water Production Function

Stewart and Hagan (1973) determined that the relationship between grain yield and seasonal ET for grain corn to be linear (r^2 = .98 for the 1971 season) between levels of 4500-12500 kg/ha of yield. Hanks et al. (1976) also stated a strong linearity between yield and seasonal ET. Neither of these groups however, displayed low yield levels. Turk et al. (1980) using the same plot design as our project, reported a highly curvilinear relationship in the lower seed yield values of cowpeas (*Vigna unguiculata* L.), similar to the relationship that we obtained with spring barley. The curvilinear relationship between yield and seasonal ET that we achieved in our barley plots denotes an increased water-use efficiency as the level of crop evapotranspiration increases. The water production functions obtained for pinto beans in all of our plots, individually and combined, is highly linear even at the low yield levels. The linear function signifies no change in WUE with changes in the level of ET. The reason or reasons for the differences between the mathematical form of the crop production functions is not known, but further research in the remaining years of this project will give high priority to the resolution of this question. One hypothesis for the curvilinear relationship is the possible increase in the quantity of water evaporated from plots further from the line compared to those in close proximity to the line. The green leaf area index (GLAI) of the subplots close to the line was significantly greater than those at distances from the line (Table 28). This may have provided a gradient of increased soil evaporation, depending upon GLAI and quantity of water applied in the subplot. In those subplots further from the sprinkler-line source evaporation may have increased as a result of a soil surface more exposed to sun and wind. As distance from the line increases evaporation from the soil becomes a more important factor, as it accounts for an increasing percentage of the total ET due to the low rates of plant transpiration.

The barley plot without added nitrogen had the smallest change in GLAI between any two distances from the sprinkler line source on any date, compared to the barley plots with the intermediate and high nitrogen fertility level. Generally speaking, the greater the difference in GLAI between distances from the line, the greater was the percentage of variation accounted for by the curvilinear coefficient of determination (Table 28). The larger area of transpirative leaf surface of barley in the high and middle fertility plots necessitated frequent irrigations during the week as a result of the low water holding capacity of the soil and the difficulty encountered in finding long wind-free periods in which to irrigate. This probably increased the amount of water lost through evaporation, especially in those subplots having more unshaded soil surface due to a lower GLAI and an intermediate application of water.

As a result of the poor stand of pinto beans in the field plots GLAI, although not measured, was visibly low with much

Table 28. GLAI of subplots at 3 distances from the sprinkler-line-source at each level of nitrogen fertility and the percentage of the variation accounted for by linear and curvilinear functions.

Added N	Distance from Line	Sampling Date May 6	June 10	June 17	June 24	July 1	Crop Production Function r^2 Curvilinear	Linear
kg/ha	m	GLAI						
0	12.0	.14	1.06	.78	1.75	.40	.85	.84
	6.5	.20	1.50	1.21	1.77	.53		
	0.0	.16	2.73	2.39	3.39	1.24		
95	12.0	.29	1.45	.96	1.62	.81	.95	.89
	6.5	.38	3.22	2.27	4.32	1.76		
	0.0	.55	4.19	5.12	3.94	2.57		
196	12.0	.19	1.82	.70	.86	.64	.98	.95
	6.5	.19	4.14	4.00	2.76	3.04		
	0.0	.48	4.45	6.38	6.00	3.81		

unshaded soil visible even in subplots immediately adjacent to the sprinkler lines. Evaporation rates in these plots, with respect to percentage of applied water, may have been similar at varying distances from the line. In addition, due to the low plant density, irrigations of the bean plots occurred less frequently than those of the barley plots. The highest, middle, and low nitrogen fertility plots were irrigated 27, 23, and 23 times respectively for the barley plots; and 21, 22, and 20 times respectively for the pinto plots. Many of these irrigations were terminated with less than a centimeter of applied water due to the development of a wind which distorted the sprinkler application pattern. In order to avoid wilting of the pinto bean plants in the subplots close to the line we did find it necessary to irrigate in light winds. By examining Tables 15, 16, and 17 it can be observed that the subplots on the eastern side of the sprinkler line in each plot (section 2) received a greater application of irrigation water at an equivalent distance from the sprinkler-line souce.

Hence, differences in evaporation may account for the observation that the curvilinear equation resulted in a higher coefficient of determination for the barley plots than did the simple regression. Methods are currently being devised whereby soil evaporation can be monitored.

Another aspect which was different in the production of these crops and which may have affected the form of the water production function is the mechanical harvesting of the spring barley as opposed to the hand harvesting of the bean plots. The harvesting combine may not have been as efficient in harvesting the grain from the characteristically shorter culms of plants further from the sprinkler-line source. Portions of next season's barley will be hand harvested to eliminate any source of mechanical harvest error.

Corn

Pertinent crop data relating to the production of the corn are presented in Table 29.

Seasonal ET, daily ET, yield and GDD data for the corn lysimeter are presented in Table 30. The seasonal ET versus yield relationship for this year's lysimeter results demonstrate good agreement with the crop production function developed by Gregory in past years.

The equation of the previously developed crop production function is as follows:

$$\text{Yield (kg/ha)} = 89.1 \text{ ET (cm)} + 2104.7 \qquad (14)$$

The coefficient of determination is .92. If the CU, measured in centimeters, of the high and low yielding lysimeters are placed in Equation 14, predicted yields are 11063 ± 1660 and 9100 ± 1589 kg/ha, respectively. The dispersion values indicate the limits imposed by the 95 percent confidence interval. The actual yields were 10395 and 8534 kg/ha, respectively, which are well within the 95 percentile confidence interval.

If this year's lysimeter results are placed in the simple regression of the seasonal ET versus yield relationship from which Equation 10 was developed the following equation results:

$$\text{Yield (kg/ha)} = 86.6 \text{ ET (cm)} + 2209 \qquad (15)$$

Table 29. Lysimeter corn crop data.[1/]

Lysimeter Number	Added Nitrogen	Added P_2O_5	Planting Date	Initial Irrigation	Emergence Date	Harvest Date
	kg/ha	kg/ha				
5	112	67	May 14	May 14	May 23	Oct. 23
6	112	67	May 14	May 14	May 23	Oct. 23

[1/] Pioneer 3195 was planted at a rate of 20 kg/ha in 91.4 cm spaced rows.

Table 30. Average daily ET, ET/PET ratio, seasonal ET, yield, and GDD of the lysimeter-grown grain corn.

			Time Period									
Lysimeter Number	Yield	Seasonal ET	May 14-31	June 1-15	June 16-30	July 1-16	July 17-31	August 1-16	August 17-31	September 1-15	September 16-30	October 1-17
	kg/ha	cm	Daily ET cm/day									
5	8534	78.5	.16	.32	.29	.75	.86	1.02	.81	.44	.36	.15
6	10395	100.5	.24	.44	.64	1.15	1.14	1.02	.92	.60	.39	.07
		Seasonal ET/PET*	Daily ET/PET									
5	8534	.68	.20	.32	.29	.87	.95	1.38	1.29	.88	.65	.35
6	10395	.87	.29	.44	.63	1.34	1.25	1.38	1.46	1.20	.71	.16
			GDD									
		1572	125	151	174	194	193	207	148	139	123	118

* PET calculated by Penman method.

The coefficient of determination is .92.

The positive y-intercept of Equations 14 and 15 probably indicates significant error in the measurement of the lower yield values. The y-intercept of the water production function developed for corn in California by Stewart and Hagan (1973) was -3172 kg/ha.

CONCLUSION

The report contains the results of the research for the first year of the project. The repeatability of the results will be determined in the remaining years of the investigation.

The experimental project crops were spring barley, pinto beans, and grain corn. Crop coefficients have been developed for various yield levels based on seasonal ET, and for intermediate time intervals based on GDD and growth stages. The results clearly demonstrate that the magnitude of the crop coefficient is directly dependent on the yield level and the method of determining PET. Crop coefficients greater than unity were regularly attained at the higher yield levels.

Water production functions based on this season's data have been developed for spring barley and for pinto beans. The form of the mathematical relationship of the water production functions requires further investigation.

The yield of grain corn produced this season in the lysimeters was accurately predicted using the seasonal consumptive use by a previously developed water production function. The water production functions for spring barley, pinto beans, and grain corn are presented in Equations 5, 12, and 15.

The results support the hypothesis that no change in WUE occurs with change in the level of nitrogen fertility, but are not definitive. The major effect of nitrogen fertility appears to be on the rate and duration of crop growth and water use and not the efficiency with which plants use absorbed water.

LIST OF ABBREVIATIONS

CU	consumptive use
ET	evapotranspiration
GDD	growing degree days
GLAI	green leaf area index
N	nitrogen
PET	potential evapotranspiration
SD	standard deviation
TDM	total dry matter
WUE	water use efficiency
Y	yield

DEFINITION OF TERMS

Consumptive Irrigation Requirement - The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water that is required consumptively for crop production.

Consumptive Use - The quantity of water transpired by plants, retained in plant tissue, and evaporated from adjacent soil surfaces in a specified time period. As used herein, consumptive use is sysnonymous with evapotranspiration.

Crop Coefficient - The ratio of evapotranspiration to potential evapotranspiration.

Evapotranspiration - See consumptive use.

Green Leaf Area Index - The ratio of the total live leaf lamina surface area (based on the measurement of one side of each leaf measured only) compared to a unit area of soil surface.

Harvest Efficiency - The dry weight of the economic yield harvested as compared to the dry weight of the economic yield produced in the field.

Irrigation Efficiency - The volume of water stored in soil for evapotranspiration compared to the volume of water delivered for this purpose.

Neutron Probe - An instrument, based upon the principle of neutron moderation, for determination of soil-moisture content.

Potential Evapotranspiration - The rate of evapotranspiration from an extended surface of a short green crop actively growing, completely shading the ground and growing with non-limiting soil moisture conditions.

Water Production Function - The relationship between economic yield and seasonal consumptive use of a crop.

Water Use Efficiency - The ratio of the weight of dry matter produced compared to the consumptive use of the plant.

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APPENDIX A

Daily evapotranspiration of spring barley and pinto beans at varying nitrogen levels and at varying distances from the sprinkler-line source.

Table A1. Daily evapotranspiration of spring barley grown without the addition of nitrogen.

Distance from Line	Yield	Seasonal ET	Growth Stage Planting-Jointing 1*	2**	Jointing-Heading 1	2	Heading-Phys.Mat 1	2	Phys.Mat.-Final 1	2
m	kg/ha	cm	Daily ET cm/day							
12.8	187	14.5	.08	.12	.13	.32	.33	.07	.07	.07
12.8	220	14.5	.11	.20	.18	.21	.20	.09	.06	.06
11.0	295	18.8	.09	.23	.27	.32	.30	.21	.07	.07
11.0	333	19.0	.10	.15	.20	.30	.33	.15	.15	.15
8.2	607	21.7	.11	.13	.25	.41	.34	.16	.16	.16
5.5	773	31.9	.11	.22	.29	.47	.62	.31	.23	.28
5.5	1021	31.9	.09	.25	.38	.50	.61	.32	.30	.30
3.7	1161	32.1	.12	.21	.40	.61	.38	.36	.37	.37
1.8	1213	38.0	.15	.27	.44	.57	.69	.42	.40	.40
			Average Growing Degree Days in Period***							
			161	178	129	163	190	227	98	111

* First half of the time in the applicable growth stage.

** Second half of the time in the applicable growth stage.

*** Values averaged for each period (see Appendix B for more detailed values at each yield level).

Table A2. Daily evapotranspiration of spring barley grown with 95 kg/ha of added nitrogen.

Distance from Line	Yield	Seasonal ET	Growth Stage							
			Planting-Jointing		Jointing-Heading		Heading-Phys.Mat.		Phys.Mat-Final	
			1**	2**	1	2	1	2	1	2
m	kg/ha	cm	Daily ET cm/day							
12.8	170	15.8	.05	.20	.18	.22	.29	.20	.12	.10
11.9	253	22.8	.12	.40	.23	.29	.26	.25	.25	.08
11.0	364	19.7	.06	.16	.23	.26	.35	.18	.18	-0-
9.1	619	24.2	.12	.22	.33	.33	.35	.13	.13	.17
9.1	631	26.5	.05	.20	.28	.34	.49	.24	.24	.14
7.3	1165	33.4	.10	.21	.43	.37	.57	.31	.31	.15
5.5	1652	39.9	.06	.21	.47	.60	.66	.45	.45	.15
5.5	2004	36.8	.12	.22	.60	.52	.57	.28	.28	.32
3.7	2822	41.9	.11	.31	.43	.62	.68	.41	.41	.15
1.8	3210	43.5	.08	.19	.44	.62	.69	.49	.49	.38
			Average Growing Degree Days in Period***							
			161	178	109	131	261	315	105	123

* First half of the time in the applicable growth stage.

** Second half of the time in the applicable growth stage.

*** Values averaged for each time period (see Appendix B for more detailed values at each yield level).

Table A3. Daily evapotranspiration of spring barley grown with 196 kg/ha of added nitrogen.

			Growth Stage							
Distance from Line	Yield	Seasonal ET	Planting-Jointing 1*	Planting-Jointing 2**	Jointing-Heading 1	Jointing-Heading 2	Heading-Phys.Mat. 1	Heading-Phys.Mat. 2	Phys.Mat.-Final 1	Phys.Mat.-Final 2
m	kg/ha	cm	Daily ET cm/day							
11.0	534	22.2	.09	.19	.31	.37	.32	.15	.11	.10
11.0	645	25.1	.10	.17	.33	.35	.42	.27	.24	-0-
9.1	799	29.9	.10	.25	.34	.43	.44	.43	.43	.19
9.1	1000	30.9	.07	.24	.29	.46	.49	.34	.34	.04
5.5	2688	42.9	.09	.22	.36	.57	.75	.53	.53	.20
5.5	2855	43.9	.08	.23	.45	.64	.74	.47	.47	.24
3.7	3912	50.9	.11	.29	.48	.71	.84	.56	.56	.36
1.8	5051	57.2	.08	.30	.55	.74	1.03	.67	.67	.32
			Average Growing Degree Days in Period***							
			161	178	109	131	236	280	138	151

* First half of the time in the applicable growth stage.

** Second half of the time in the applicable growth stage.

*** Values averaged for each period (see Appendix B for more detailed values at each yield level).

Table A4. Daily evapotranspiration of pinto beans grown with 40 kg/ha of added nitrogen.

Distance from Line	Yield	Seasonal ET	Time Period June 6–30	 July 1–16	 17–31	 August 1–16	 17–31	 September 1–15	 16–30	 October 1–13
m	kg/ha	cm	Daily ET cm/day							
12.8	488	14.7	.06	.06	.08	.07	.27	.17	.22	.08
12.8	228	11.5	.06	.06	.09	.11	.21	.08	.10	.06
11.0	697	17.1	.07	.07	.12	.09	.32	.20	.18	.06
11.0	494	14.5	.07	.07	.10	.14	.24	.12	.16	.15
9.1	1020	22.2	.11	.11	.16	.23	.33	.19	.26	.05
9.1	653	16.5	.05	.05	.13	.24	.33	.15	.15	.28
7.3	1116	24.9	.14	.14	.16	.22	.33	.19	.26	.08
7.3	870	22.4	.11	.11	.16	.22	.41	.16	.24	.08
5.5	1273	31.7	.24	.24	.25	.24	.51	.28	.26	.41
5.5	1088	24.8	.12	.12	.16	.31	.46	.10	.29	.11
3.7	1579	35.6	.24	.24	.31	.37	.54	.27	.30	.17
3.7	1181	26.8	.16	.16	.22	.34	.37	.18	.28	.09
1.8	1413	33.3	.19	.19	.29	.34	.43	.32	.12	.11
1.8	1472	34.9	.03	.03	.23	.36	.56	.31	.33	.13

Table A5. Daily evapotranspiration of pinto beans grown with 124 kg/ha of added nitrogen.

Distance from Line	Yield	Seasonal ET	Time Period June 6-30	 July 1-16	 17-31	 August 1-16	 17-31	 September 1-15	 16-30	 October 1-13
m	kg/ha	cm	Daily ET cm/day							
12.8	329	11.4	.07	.07	.07	.02	.22	.12	.14	.06
12.8	494	15.9	.05	.05	.13	.07	.30	.19	.21	.04
11.0	510	15.6	.09	.09	.14	.10	.31	.25	.23	.07
11.0	785	19.2	.03	.03	.02	.15	.32	.27	.26	.05
9.1	646	19.3	.08	.08	.14	.13	.31	.25	.23	.07
9.1	1197	22.9	.11	.11	.20	.23	.41	.29	.18	.02
7.3	673	21.8	.08	.08	.12	.26	.40	.22	.35	.08
7.3	1516	27.2	.15	.15	.23	.31	.42	.59	.32	.09
5.5	1433	28.3	.17	.17	.15	.22	.51	.30	.37	.05
5.5	1748	31.2	.15	.15	.23	.20	.48	.19	.37	.11
3.7	1525	32.6	.20	.20	.18	.18	.53	.34	.43	.05
3.7	1502	34.7	.20	.20	.26	.28	.48	.19	.37	.11
1.8	1962	35.5	.20	.20	.27	.32	.60	.29	.43	.05
1.8	1906	34.7	.16	.16	.23	.39	.59	.22	.45	.13

Table A6. Daily evapotranspiration of pinto beans grown with 162 kg/ha of added nitrogen.

Distance from Line	Yield	Seasonal ET	Time Period June 6-30	 July 1-16	 17-31	 August 1-16	 17-31	 Septemner 1-15	 16-30	 October 1-13
m	kg/ha	cm	Daily ET cm/day							
12.8	519	14.3	.05	.05	.08	.34	.29	.17	.16	.06
12.8	409	16.0	.05	.05	.12	.17	.25	.19	.17	.03
11.0	598	19.9	.10	.10	.14	.17	.36	.16	.26	.11
11.0	651	20.7	.08	.08	.21	.24	.33	.20	.19	.06
9.1	789	21.5	.13	.13	.16	.22	.14	.14	.23	.07
9.1	716	23.5	.10	.10	.18	.24	.41	.29	.22	.07
7.3	1088	23.7	.12	.12	.16	.22	.41	.20	.39	.06
7.3	892	26.3	.13	.13	.16	.23	.48	.37	.24	.07
5.5	1155	29.1	.16	.16	.19	.32	.48	.26	.36	.15
5.5	1195	31.3	.16	.16	.17	.27	.57	.35	.25	.12
3.7	1073	35.7	.24	.24	.26	.37	.54	.38	.63	.27
3.7	1607	36.7	.08	.19	.26	.33	.60	.44	.34	.14
1.8	1544	36.5	.20	.20	.26	.32	.58	.46	.26	.19
1.8	1781	38.9	.22	.22	.27	.30	.45	.47	.44	.29

APPENDIX B

Accumulated growing degree days for spring barley plants at varying distance from the sprinkler-line source.

Table B1. Total growing degree days per developmental stage of spring barley grown without added nitrogen.

Distance from Line	Yield	Growth Stage							
		Planting-Jointing		Jointing-Heading		Heading-Phys.Mat.		Phys.Mat.-Final	
		1*	2**	1	2	1	2	1	2
m	kg/ha	Growing Degree Days							
12.8	187	161	177	153	202	145	195	105	121
12.8	220	161	177	109	131	149	186	155	173
11.0	295	161	177	109	131	149	186	155	173
11.0	333	161	177	153	202	145	195	105	121
8.2	607	161	177	153	202	220	240	50	55
5.5	773	161	177	109	131	211	244	105	121
5.5	1021	161	177	153	202	220	240	50	55
3.7	1161	161	177	109	131	211	244	104	121
1.8	1212	161	177	109	131	260	315	50	55

* First half of the time in the applicable growth stage.

** Second half of the time in the applicable growth stage.

Table B2. Total growing degree days per developmental stage of spring barley grown with 95 kg/ha of added nitrogen.

Distance from Line	Yield	Growth Stage Planting-Jointing 1*	 2**	 Jointing-Heading 1	 2	 Heading-Phys.Mat. 1	 2	 Phys.Mat.-Final 1	 2
m	kg/ha	Growing Degree Days							
12.8	170	161	177	109	131	260	315	105	123
11.9	253	161	177	109	131	260	315	105	123
11.0	364	161	177	109	131	260	315	105	123
9.1	619	161	177	109	131	260	315	105	123
9.1	631	161	177	109	131	260	315	105	123
7.3	1165	161	177	109	131	260	315	105	123
5.5	1652	161	177	109	131	260	315	105	123
5.5	2004	161	177	109	131	260	315	105	123
3.7	2822	161	177	109	131	260	315	105	123
1.8	3210	161	177	109	131	260	315	105	123

* First half of the time in the applicable growth stage.

** Second half of the time in the applicable growth stage.

Table B3. Total growing degree days per developmental stage of spring barley grown with 196 kg/ha of added nitrogen.

Distance from Line	Yield	Growth Stage Planting-Jointing 1*	 2**	 Jointing-Heading 1	 2	 Heading-Phys.Mat. 1	 2	 Phys.Mat.-Final 1	 2
m	kg/ha	Growing Degree Days							
11.0	534	161	177	109	131	211	244	170	179
11.0	645	161	177	109	131	211	244	170	179
9.1	799	161	177	109	131	211	244	170	179
9.1	1000	161	177	109	131	211	244	170	179
5.5	2687	161	177	109	131	260	315	105	123
5.5	2855	161	177	109	131	260	315	105	123
3.7	3911	161	177	109	131	260	315	105	123
1.8	5051	161	177	109	131	260	315	105	123

* First half of the time in the applicable growth stage.

** Second half of the time in the applicable growth stage.

APPENDIX C

Equations describing the computation of potential evapotranspiration used in the text.

APPENDIX C

Equations describing the computation of potential evapotranspiration used in the text are as follows:

Method 1 - Penman

$$E_o = \frac{\Delta Rn + \gamma Ea}{\Delta + \gamma} \tag{1}$$

$$Ea = 15.36\ (1.0 + 0.0062U_2)\ (e_s - e) \tag{2}$$

where

E_o is potential evaporation (cm/day)

Ea is an aerodynamic component

Δ is slope of the saturation vapor pressure vs. temperature curve at the air temperature (mb $^oC^{-1}$)

Rn is net radiation, expressed (ly day $^{-1}$) or (cal cm^{-2} day^{-1}); ly = cal cm^{-2}. To convert Rn from cal cm^{-2} day^{-1} to cm day^{-1}, Rn is divided by L.

L is latent heat of vaporization (cal g^{-1})

U_2 is wind speed (km/day) at a height of 2 m

e_s is saturation vapor pressure (mb)

e is actual vapor pressure (mb)

γ is a psychrometric constant (mb $^oC^{-1}$)

$$\gamma = \frac{C_P P}{0.622L} \tag{3}$$

C_p is specific heat of air (cal g^{-1} $^oC^{-1}$)

P is atmospheric pressure (mb).

Method 2 - Jensen-Haise

$$E_o = C_T \ (T - Tx) \ Rn \tag{4}$$

$$C_T = \frac{1}{C_1 + C_2 \ . \ CH} \tag{5}$$

$$CH = \frac{50 \text{ mb}}{(e_2 - e_1)} \tag{6}$$

where e_2 and e_1 are saturation vapor pressure at mean maximum and mean minimum temperatures, respectively, for the warmest month of the year in the area.

$C_2 = 13^\circ F$ or $7.6^\circ C$

$C_1 = 68^\circ F - (3.6^\circ F \times \text{elev. in ft}/1000)$ (7)

$C_1 = 38 - (2^\circ C \times \text{elev. in m}/305)$ (8)

$Tx = 27.5^\circ F - (p.25 \ (e_2 - e_1) - \text{elev. in ft}/1000$ (9)

$Tx = -2.5^\circ F - (0.14 \ (e_2 - e_1) - \text{elev. in m}/550$ (10)

T is average air temperature.

Method 3 - Priestley-Taylor

$$E_o = \alpha\left(\frac{\Delta}{\Delta \quad \gamma}\right) \ . \ Rn \tag{27}$$

where

Rn is net radiation expressed (cm/day)

α is a proportionality constant equal to 1.40 ± 0.10

Δ and γ are defined as in equation (1).

Method 4 - Pan

E_o = Pan

Pan is evaporation in cm/day measured from a U.S. Weather Bureau Class A Pan.

Method 5 - Blaney-Criddle

$$u = kf \text{ or } U = K\Sigma \frac{pt}{100} \tag{28}$$

where

u = monthly consumptive use, inches depth

$f = \frac{t \times p}{100}$ = monthly consumptive use factor

k = empirical consumptive-use crop coefficient for the month

p = monthly percentage of annual daytime hours

U = consumptive use, in inches, for the season or period

K = empirical consumptive-use crop coefficient for the season or period

F = sum of monthly consumptive-use factors for the season or period

t = mean monthly temperature in degrees Fahrenheit.