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

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

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ABSTRACT

The water requirement for growth of spring barley, pinto beans, and alfalfa was investigated in northwestern New Mexico. Results strongly suggest that the level of nitrogen fertility does not alter the water-use efficiency (WUE) of spring barley when WUE is expressed as a function of transpiration. WUE may change, depending on irrigation scheduling, if WUE is expressed as a function of evapotranspiration. We attribute this difference to differential soil-water evaporation. Further evidence supports the hypothesis that a common function exists independent of season, with respect to a given crop, relating economic yield to transpiration. Crop coefficients based on various methods of calculating potential evapotranspiration were found to vary considerably, as much as 50 percent, between years due in part to the difference in the evaporation component of the measured evapotranspiration. Consequently, caution should be exercised in using crop coefficients to predict alfalfa, pinto beans, and spring barley seasonal or intra-seasonal water requirements when the crops are grown under conditions requiring frequent light irrigation.

Keywords: evaporation, transpiration, evapotranspiration, potential evapotranspiration, water-use efficiency, nitrogen, crop coefficients

TABLE OF CONTENTS

MATERIALS AND METHODS (Continued)

APPENDICES

LIST OF TABLES

Table Page

LIST OF FIGURES

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

INTRODUCTION

In a recent publication (2) the New Mexico Water Resources Research Institute describes the serious situation with respect to the water available for growth in northwestern New Mexico. In fact, existing adjudications and proposed future commitments of the water of the San Juan River Basin have increased to such an extent that twice the dependable flow of water in the river, as measured at the town of Shiprock, New Mexico, will be required if all proposals for water diversion are developed (15). This extreme and unmeetable demand for water reemphasized the need for the efficient use of water presently diverted for irrigation purposes.

However, to increase the efficient use of water for agriculture, the relationships between plant and water, soil and water, and water and atmosphere need to be elucidated as they interact in the crop environment. This report is an investigation into these relationships to provide guidelines on how the problem of predicting crop water-use may best be approached. Whereas data presented in this report may have some immediate utility in scheduling irrigations, the primary purpose is to provide insights into, and identify problems associated with, procedures utilized in predicting crop water-use from season to season and from location to location.

OBJECTIVES

The objectives are as follows for the 1980-1981 project year:

1. Develop the water-production function for spring barley (Hordeum vulgare), pinto beans (Phaseolus vulgaris), and alfalfa (Medicago sativa).
2. Determine how the level of nitrogen fertility in the field affects the water-use production function for spring barley and pinto beans.
3. Measure the driving climatological variables used in the Blaney-Criddle, Priestly-Taylor, Jensen-Haise, and Penman equations to evaluate the utility of these formulae in estimating the crop evapotranspiration requirements.

CONCLUSIONS RESPECTIVE TO THE OBJECTIVES

1. Conclusion for Objective 1:

Our data support the hypothesis that differential evaporation, related to the scheduling of irrigation, can result in large differences in the parameters of the water-production function. In environments of high atmospheric evaporative demand these differences could result in large water application errirs if the chosen frequency of irrigation, or the leaf area index (LAI) achieved by the crop is even moderately different from that utilized to produce the water-production function. We have produced evidence suggesting that when economic yield of a given crop is expressed as a function of transpiration (T), the relationship is constant for a location regardless of seasonal differences in atmospheric demand as measured by currently accepted potential evapotranspiration (PET) formulae, irrigation frequency, or the LAI achieved by the crop.

2. Conclusion for Objective 2:

Although we were unable to determine the effect of nitrogen (N) fertility on pinto beans, our spring barley data suggest that N fertility does not affect the water-use efficiency (WUE) when the efficiency is expressed as the weight of economic yield produced per depth of water transpired. The level of N fertility may affect the WUE when the WUE is expressed as the weight of economic yield produced per depth of water evapotranspired as a result of differences in evaporation associated with the interaction of the duration and frequency of irrigation with the degree of ground cover achieved by the crop.

3. Conclusion for Objective 3:

When economic yield is expressed as a function of evapotranspiration (ET), no differences in measured ET levels necessary to produce a given level of yield between or within seasons could be accounted for by the potential evapotranspiration measurement. In addition, the measured ET of the high yielding subplots, based on intervals of one to two weeks, were as much as twice the measured PET accumulation of the same period. Large amounts of advective energy exist in the Farmington area, that are not always accounted for by the PET formulae, resulting in an underestimation of ET based on PET measurements. We feel that differences between seasons, with respect to evaporative demand and itś affect on crop transpiration, are small when compared to differential evaporation (E) associated with irrigation management.

RECOMMENDATIONS

1. The most promising method of predicting crop water-use appears to be the development of a function relating the economic yield of a crop to the transpiration requirement. This relationship, on the basis of results produced in this report for the crop spring barley, is constant from season to season for a given cultivar and perhaps crop. However, to determine this relationship, a method will have to be devised to separate soil-water evaporation from transpiration in the field. Recent advances in infrared thermometry suggest that this may be the tool to accomplish this task. Once evaporation losses can be separated from transpiration, data can be obtained and simple models produced that will calculate the amount of evaporation that can be expected at each irrigation event. Irrigation events can then be adjusted accordingly to ensure that the crop transpirational need is fulfilled. This approach is the only approach suggested by our data that will have sufficient accuracy to be of predictive value on not only a seasonal basis but at time intervals within a season as well.

2. The value of the PET measurement for predicting crop ET requirement is seriously questioned by the data produced in this report. We recommend that the PET concept be rigorously reexamined

to determine if this measurement can account for differences in seasonal ET measured between seasons and locations, in highly advective environments and with respect to water-deficit crop research.

MATERIALS AND METHODS

The Site

The study site is on the San Juan Agricultural Experiment Station (New Mexico State University) which is 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 (NIIP). The elevation of the site is 1719 meters above sea level, the annual precipitation is approximately 18 centimeters, and the prevailing wind direction is from the west.

Climatological Data

The climatological data obtained include daily maximum and minimum temperatures (using thermometers) and humidity (using a hygrothermograph). Psychrometric readings are taken at weekly intervals to ensure proper calibration of the hygrothermograph. The climatological data further include solar radiation measured by pyronometer, 24-hour total wind accumulation measured at a height of 2 meters using a cup anemometer, evaporation from a U.S. Weather Bureau Class A Evaporation Pan, and precipitation using a standard 8-inch rain gauge.

Last season's climatological data had been collected at a weather station that was surrounded by bare soil. This situation tended to result in pan evaporation losses and relative humidities that were not characteristic of irrigated farmlands. Thus, in 1981 the weather station was moved to an area surrounded by irrigated crops. The vegetation immediately surrounding the weather station consisted of alfalfa which was maintained at a 10 centimeter height.

The Bureau of Reclamation maintains a complete weather station for collection of potential evapotranspiration related climatological parameters, that is located approximately 5 kilometers from our experimental plots. When the 1981 climatological data obtained from the Bureau of Reclamation and from the San Juan Agricultural Experiment Station were calculated, using the PET formulae presented in Appendix A, they yielded similar values (Table 1). Thus, the PET values which resulted from data collected in 1980 by personnel of the Bureau of Reclamation, would likely yield values which are more characteristic of the PET rates actually encountered by the crops grown in our 1980 plots, than would the values obtained from data collected in 1980 at the bare-soil surrounded climatological station.

Hence, all PET and growing-degree-day (GDD) values contained in this partial completion report with respect to the 1980 results, have been recalculated using climatological data supplied by the Bureau of Reclamation. The 1981 PET rates have been calculated

Table 1. Comparison of the monthly potential evapotranspiration as measured by the Bureau of Reclamation (B.R.) and the San Juan Experiment Station (S.J.E.S.) for 1981.

Method	Agency	Month						
		April	May	June	July	August	September	October*
		mm						
Penman	B.R.	189	195	229	232	198	145	45
	S.J.E.S.	185	199	241	220	194	153	48
Jensen-Haise	B.R.	168	184	252	266	231	159	47
	S.J.E.S.	176	195	289	289	248	178	51
Priestly-Taylor	B.R.	170	180	225	222	195	135	39
	S.J.E.S.	175	191	253	242	205	149	43
Pan	B.R.	195	219	221	248	195	135	38
	S.J.E.S.	193	214	290	273	223	178	104
Vapor Pressure Deficit	B.R.	281	293	503	569	465	319	89
	S.J.E.S.	294	354	481	445	424	348	103

* Only partial PET accumulation presented; October 1 through 14.

from data collected at the San Juan Branch Agricultural Experiment Station at the new site.

Soil

The experimental plots were established in an area which had been left fallow the previous year. The land was plowed to a depth of 50 centimeters, disked, fertilized as required, and harrowed. Fertilizer was applied in pelleted form.

The soil type is Wall sandy loam (72-74 percent sand, 11-14 percent silt, and 12-15 percent clay) with a 1-3 percent slope. The soil classification is a Typic Camborthid, coarse, loamy, mixed, calcareous, mesic family. Field capacity of the soil was determined to be approximately 19-21 percent by volume in the upper 1.5 meter of soil profile and 15-19 percent by volume in the 1.5-2.5 meter depth.

Sprinkler-Line-Source Plots (SLS Plots)

The plot design was described in a previous publication (12) but sufficient change in the design has been made to warrant a new description.

Figure 1 diagrams the basic plot design, but only the alfalfa plot contains lysimeters. This design was developed by Hanks, et al. (7). 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 0.5 liters per second. The overlapping sprinkler patterns create a

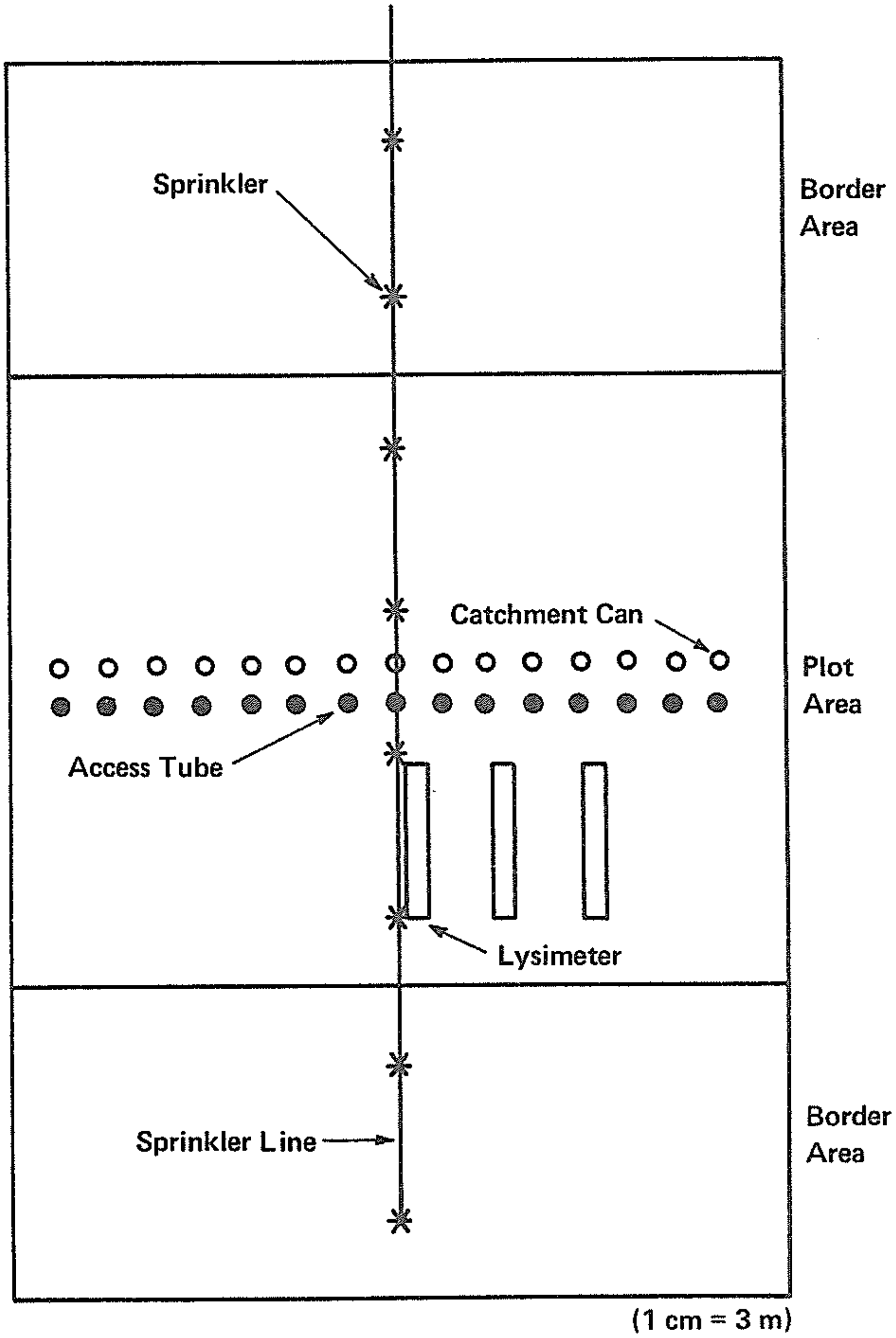

Figure 1. The design of the alfalfa sprinkler-line-source plot.

plot 24.3 meters by 30.3 meters 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 12.2 meters in length on each end of the actual 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 eastern section of each plot was identified as "section 1"; the western section as "section 2."

Each section is divided into subplots. The length of the subplot is measured parallel to the sprinkler line while the width is measured at right angles to it. The width of the subplot is determined by the row spacing of the crop, while the length is determined by the limit imposed by the 24.4 meter width of the plot. Each of the subplots is further divided into three equal parts along the 24.4 meter length of the subplot to allow three yield subsamples in each subplot. The length of the subsampled areas vary slightly from crop to crop depending on the space required for auxiliary measurements made within the subplot area. The width and length of the subsampled areas within the subplot have been tabulated in Table 2.

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

Table 2. Dimensions of the subsampled areas.

Crop	Subsample Area		Distance Between Access Tubes
	Width	Length	
Alfalfa	.91 m	6.1 m	1.8 m
Pinto Bean	.86 m	7.6 m	1.7 m
Barley	1.00 m	7.1 m	2.0 m

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. The seasonal ET of the subplots between plots containing access tubes was estimated as being the average of that of the two adjacent subplots. Yields were measured in all subplots.

Alfalfa

The cultivar "WL-309" was planted in the sprinkler-line-source plot in the fall of 1980. The seed was coated with a nitrogen-fixing bacterial innoculant. Prior to planting, three drainage-type lysimeters were constructed in the plot. The plan of construction of the alfalfa lysimeters is presented in Figure 2. All plot areas, both inside and outside the lysimeters, were planted contemporaneously. In March of 1981, 50 kilograms per hectare (Kg/ha) of P_2O_5 was applied. However, evapotranspiration measurements were not begun until April.

The alfalfa was harvested using a walking-type sickle-bar mower, except for the plants in the lysimeters which were cut with a manually operated hedge clipper. The alfalfa was cut at a height of approximately 4 centimeters above ground level. All reported harvest weights of alfalfa are adjusted to 0 percent moisture based on a gravimetric sample taken from each subplot at each cutting. The length of the access tubes in the non lysimeter portion of the alfalfa SLS plot was 3 meters.

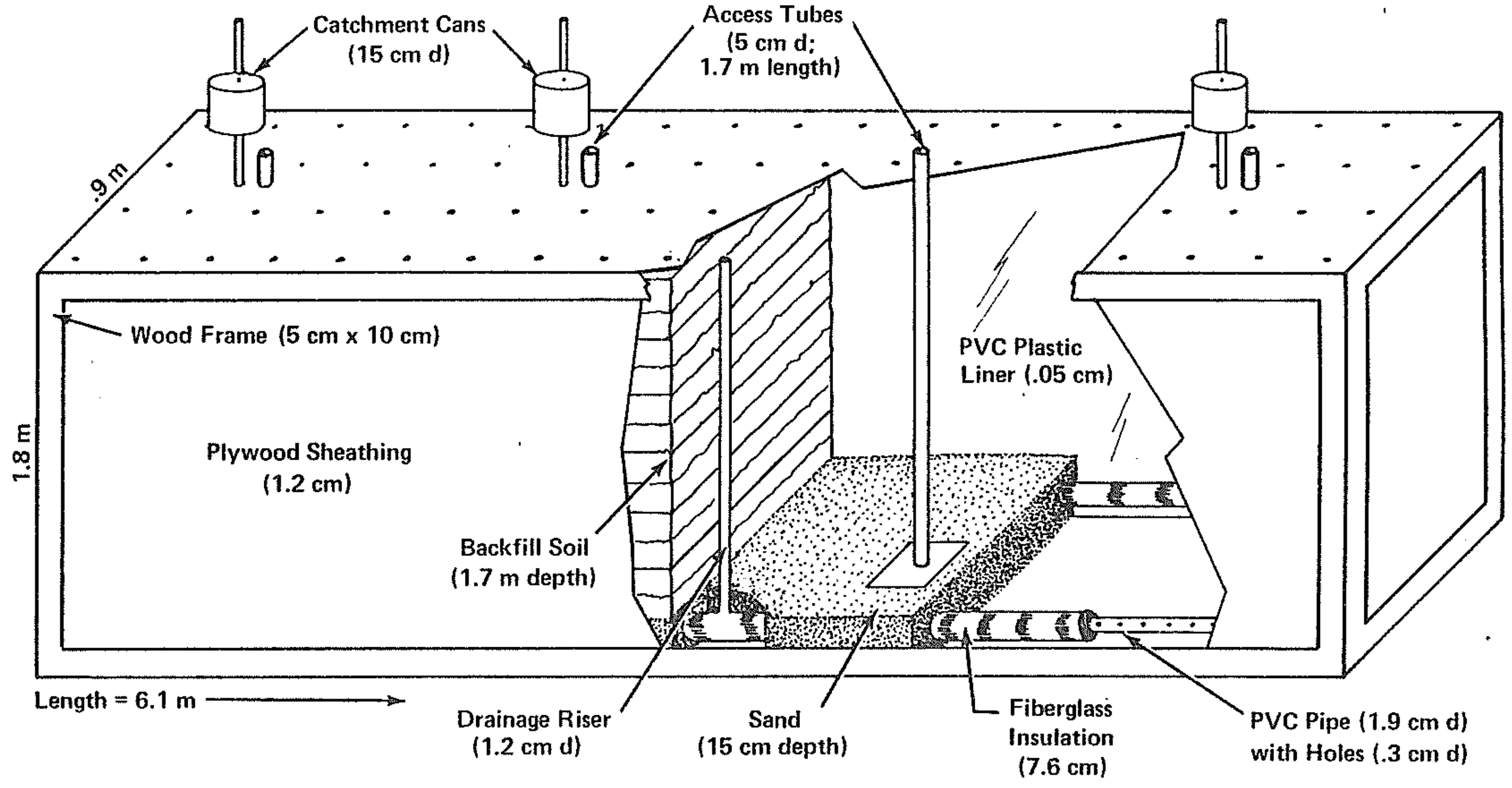

Figure 2. The design of the alfalfa lysimeters; centimeter (cm), diameter (d), and meter (m).

GDD accumulation by alfalfa are calculated using the following formula:

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

The temperatures are reported in degrees centigrade. Maximum and minimum temperatures, above or below which no further GDD are accumulated, are placed at 30 and 5 degrees centigrade, respectively. Daily temperature values beyond these limits are given the limit value when GDD are calculated.

Spring Barley

This report contains the results of barley data produced during the 1980 and 1981 growing seasons. Specific information on the production practices for the 1980 plots can be found in the previous partial completion report for this project (12). In certain instances the reporting of results in this report will be different from the presentation in the previous report. These changes will be noted herein.

The cultivar "Steptoe" was chosen again this season for planting. The rate of nitrogen application was 0, 80, and 180 kilograms of nitrogen per hectare in the low, medium, and high nitrogen-level plots, respectively. The initial quantity of nitrate nitrogen in the top 1.2 meters of soil profile before application was 55 Kg/ha in the low and middle level nitrogen plots, and 140 Kg/ha in the high nitrogen plot, which yields a total nitrogen availability of 55, 135, and 320 Kg/ha respectively, at the beginning of the season. In addition, 100 Kg/ha of P_2O_5 was applied to all plots.

In this report the 3 sprinkler-line-source plots are differentially identified on the basis of the quantity of nitrogen which was utilized by the highest yielding subplot in each of the plots. Nitrogen utilization was calculated using a relationship developed by Gregory (6) and by data produced by Kallsen, et al. (12), specifically for the soils of the San Juan Branch Agricultural Experiment Station. The equation of the relationship is as follows:

$$\underset{\text{Kg/ha}}{\text{Nitrogen Utilized}} = \frac{\text{Yield(Kg/ha)} - 219.5}{35.5} \qquad (2)$$

This equation was used for calculation of nitrogen utilization for barley during both growing seasons.

As stated in last year's partial completion report, data obtained from subplots directly under the sprinkler-line were not presented due to leakage of unmeasured water at the joints of the sprinkler line which occurred when the system was turned on and off. Subsequent investigation has demonstrated that the water leakage at the joints is approximately equal to 0.14 centimeters of water being equally distributed over the entire surface of the subplot for each irrigation. Thus, the measured evapotranspiration of the subplots directly under the sprinkler line are increased by 0.14 centimeter every time the plot was irrigated. It was thus possible to include data produced in the subplots under the sprinkler lines for 1980 and 1981. The water-production functions of barley for 1980 have been recalculated and the results presented in this report.

All green leaf tissue was removed at weekly intervals from two random samples of a one-tenth square meter area in high, middle, and low yielding subplots in each plot. Tissue removed included the entire blade clipped at its attachment to the sheath. Very light green leaves or those that had begun to yellow or brown were discarded. Leaves were removed from all tillers as well as the primary culm. These samples were dried in an oven at 80 degrees centigrade for a period of one week for the determination of dry weight. LAI was obtained by a weighing procedure.

All biomass data are reported adjusted to 0 percent moisture. Yield of grain, however, is adjusted to 14 percent moisture. Barley grain was harvested using two methods. Data used to calculate the water-production function were harvested by a small self-cleaning self-propelled combine from subplots described earlier. Total above-ground biomass data were obtained by cutting two swaths 1.5 meters in length through each subplot using a manually operated hedge clipper. The subplots were located adjacent to those which were harvested by machine. The total above-ground biomass was weighed and threshed. The grain obtained was weighed separately, and non-grain biomass obtained by subtraction. This procedure allowed a comparison to be made between hand versus machine-harvested grain as well as a measure of the total biomass produced. Harvest ratios were calculated as the ratio of hand-harvested grain yield calculated at 14 percent moisture to the total biomass calculated at 0 percent moisture.

Physiological maturity was determined by weekly sampling of all grain spikes produced in a one-tenth square meter area and drying them for a week in the same manner described for green leaf tissue. The time at which the heads ceased to increase in dry weight was deemed to be an estimate of physiological maturity. The growth stages jointing and heading were determined visually. Timing of the developmental stages should be considered estimates. Growing-degree-days accumulated by spring barley are calculated according to Equation 1.

Pinto Beans

The cultivar "San Juan Red" was planted at a rate of 60 kilograms of seed per hectare. A differential nitrogen application was applied to the three sprinkler-line-source plots; however, it was later learned that both the seed planted last year and this year had been innoculated with a nitrogen-fixing rhizobium, thereby negating the differential nitrogen applications which had been made. Phosphorous was applied at a rate of 110 Kg/ha of P_2O_5. The herbicide, trifluralin, was incorporated preplant.

The timing of the developmental stages of the crop were noted when: 1) the primary stalk contained 9 visually apparent nodes, 2) first flowers appeared, and 3) 50 percent of the pods had changed color from green to striped. Since the developing bean crops of each of the two seasons had accumulated similar total GDD, the GDD accumulated during the growth stages in 1981 are used to determine the equivalent timing of the growth stage during the 1980 season, thereby allowing a comparison of crop coefficients between seasons.

The pinto beans were harvested by hand. The whole plant was pulled from the soil, allowed to air dry for a month in an empty greenhouse, and then threshed using a stationary thresher. Only seed weights were recorded. All reported seed weights of the pinto beans are adjusted to 15.5 percent moisture.

Growing-degree-day accumulation by pinto bean are calculated using the following formula:

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

The temperatures are reported in degrees centigrade. Maximum and minimum temperatures, above or below which no further GDD are accumulated, are placed at 30 and 10 degrees centigrade, respectively. Daily temperature values beyond these limits are given the limit value when GDD are calculated.

Pinto Bean and Spring Barley Lysimeter Design and Operation

Pinto bean (cultivar "San Juan Red") and spring barley (cultivar "Steptoe") were planted in two lysimeters for each crop at the site shown in Figure 3. A detailed description of the construction was given in the partial completion report of the 1980 results (12). Figure 4 diagrams the basic construction.

These lysimeters were flood irrigated. The quantity of applied water was measured from calibrated tanks. Water which was not

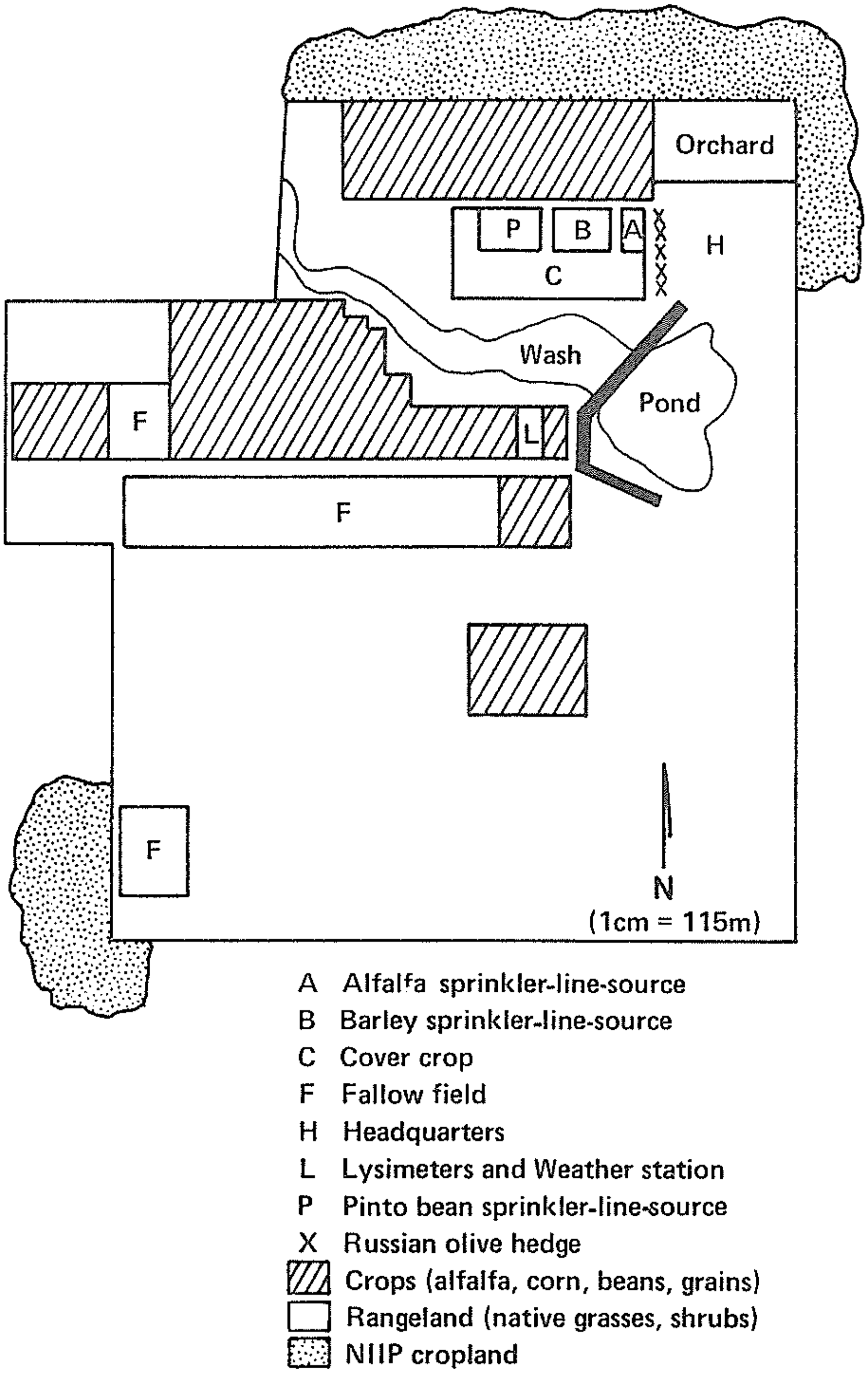

Figure 3. Map of the San Juan Agricultural Experiment Station and surrounding lands.

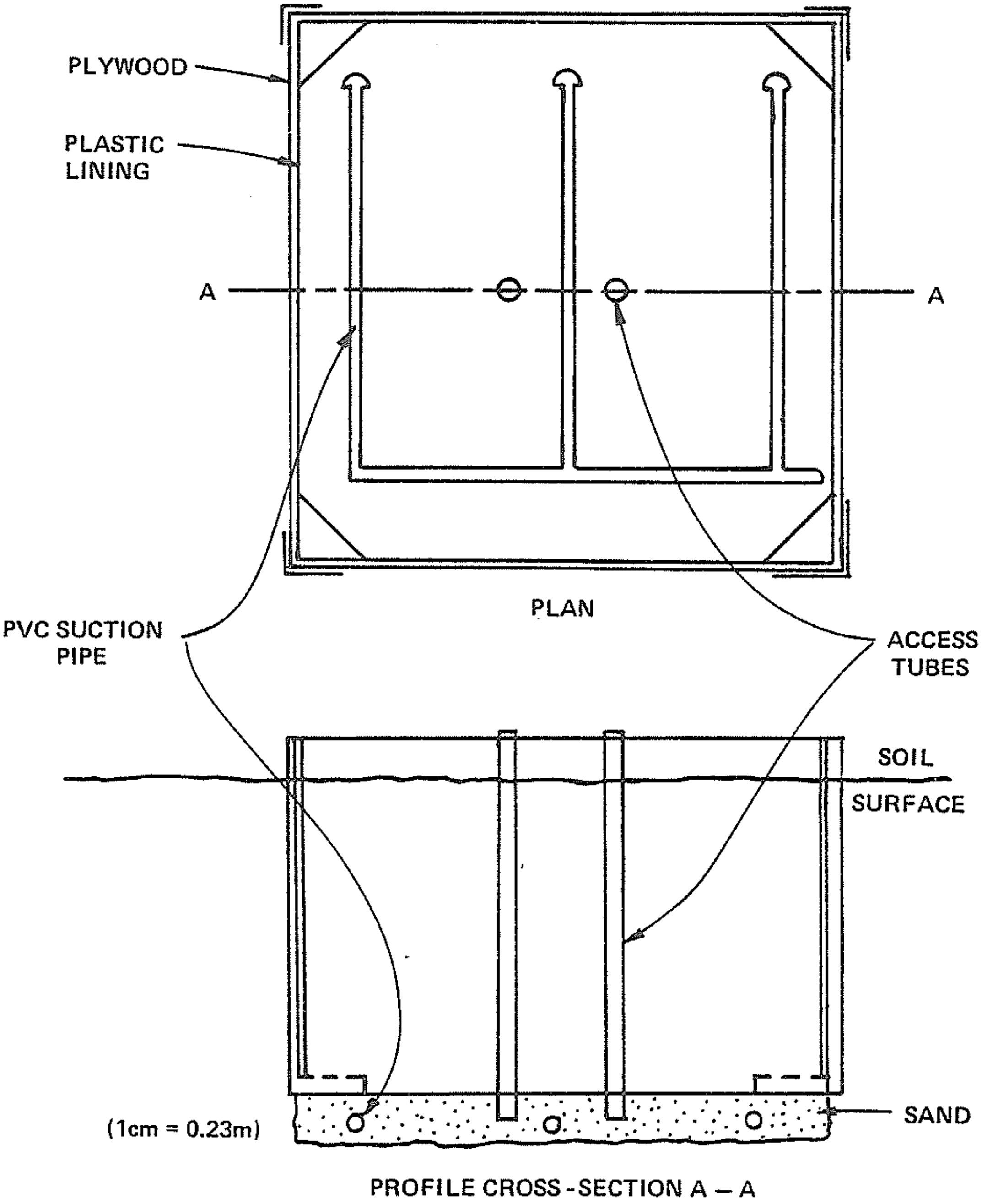

Figure 4. Plan and profile of the spring barley and pinto bean lysimeters.

utilized by the crop was removed through the drainage system by suction created with a vacuum pump. The lysimeters were watered weekly to minimize moisture stress. Irrigation was monitored so that the water applied was slightly in excess of that which would be utilized by the crop in the current week.

The two lysimeters assigned to each crop were surrounded by a 15 meter wide border planting on each side which consisted of a cultivar identical to that planted in the lysimeters. These plantings were bordered on the west by 150 meters of alfalfa cover and by 40 meters to the east. However, the pinto bean border adjacent to the lysimeters became so weedy early in the season, that a nonselective herbicide was applied resulting in the pinto bean lysimeters being surrounded by 15 meters of bare soil in all directions for the majority of the season.

The rate of seeding and phosphorous application in the lysimeters for the two crops was identical to the sprinkler-line-source plots. The lysimeters were given a split application of nitrogen which totaled 180 Kg/ha. As was the case with the sprinkler-line-source plots, this application was later learned to have been unnecessary in the case of the beans as they had been innoculated with a nitrogen-fixing rhizobium.

Plot Configuration and Adjacent Areas

Figure 5 is a map of the 1981 plot locations and the immediate surrounding environment. Numbers in the plots show the quantity of applied nitrogen in Kg/ha. The location of the sprinkler-line-source plots with respect to the grounds of the experiment station can be ascertained in Figure 3.

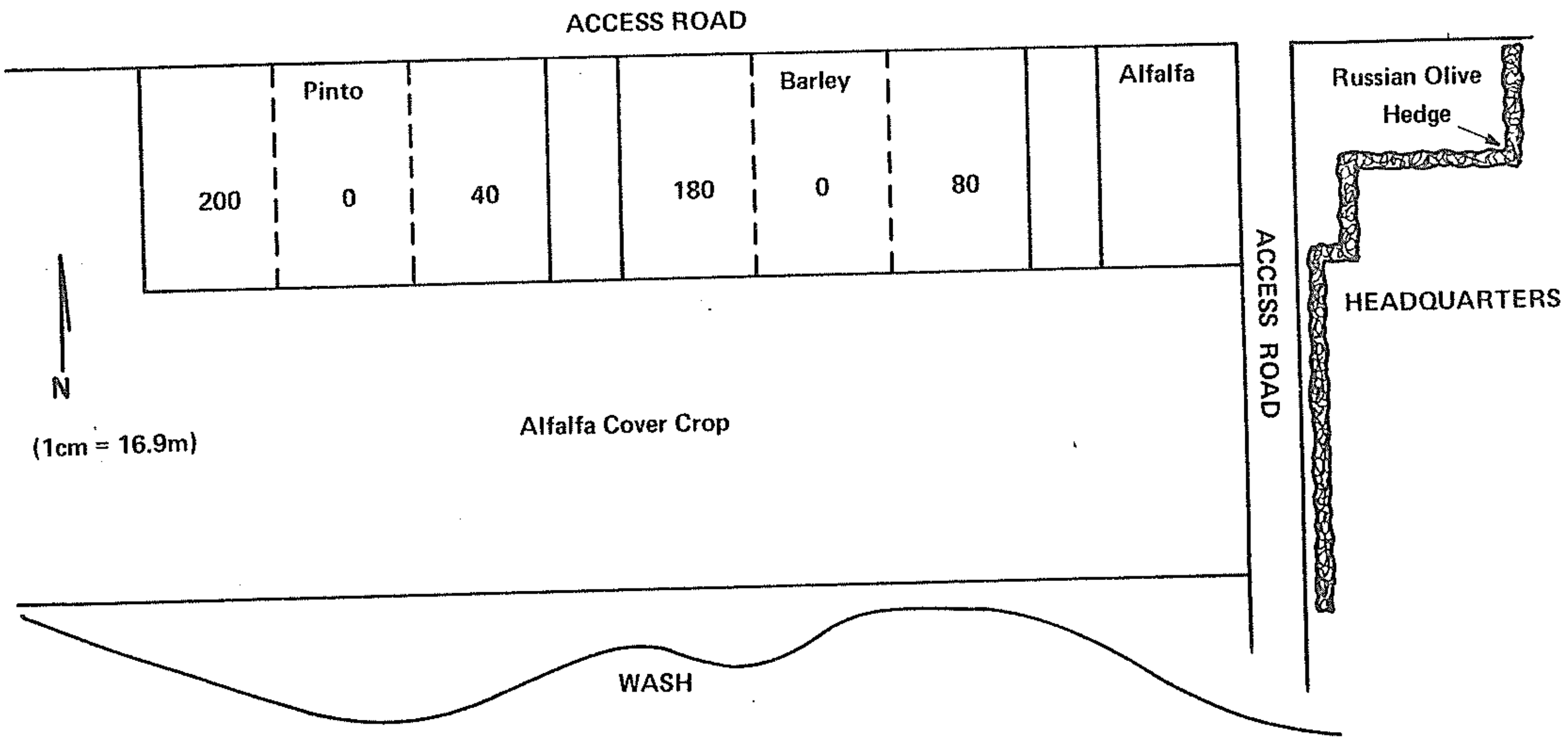

Figure 5. Large scale map of the SLS plots (showing quantities of applied N) and the immediate surrounding environs.

Approximately 20,000 hectares 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 rates representative of areas near the desert edge of large irrigated fields and not the rates that would occur in the center of large irrigated blocks of land.

Calculation of Crop Evapotranspiration

Evapotranspiration is calculated using the following equation:

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

where

I = irrigation

P = precipitation

D = drainage

ΔSM = change in soil moisture

Only in the lysimeter data does the 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 maximum irrigation occurs), by careful monitoring of the soil water status 0.5 meters below the rhizosphere with the neutron probe. Some nonsaturated flow of water may occur but experimental results obtained in the alfalfa field this season demonstrate that this loss or gain is minimal 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 soil moisture status, the initial reading is taken at the 15 centimeter depth, with each additional reading taken in 30 centimeter increments. In the barley and pinto bean plots, 4 readings were taken in each access tube each day that these data were collected except for the tube under the line in which 6 readings were taken. Ten readings were taken in each access tube in the alfalfa plot with the exception of the alfalfa lysimeters where 5 readings were made. As mentioned earlier, irrigation water was measured with catchment cans on the sprinkler-line-source plots, and from calibrated tanks before being applied by flood irrigation to the pinto and barley lysimeters. Precipitation was measured with a standard 8-inch rain gauge.

Methods of Estimating Soil-Water Evaporation

Three methods have been utilized to estimate soil-water evaporation as follows:

Method 1.

Soil-water evaporation of all points of the water-production function is assumed to be the intercept of the total-above-ground biomass versus ET relationship. This method was previously used by Hill (9) and Retta (18).

Method 2.

The evaporation at any given yield level of the water-production function is determined as the x-intercept of the line tangent to the water-production function at the particular point of the function for which an estimate of E is desired.

Method 3.

A method of estimating soil-water evaporation was developed based on the work of Al-Khafaf (1) and Ritchie (19). The procedure calculates stage one evaporation, of irrigations and precipitations greater than or equal to ten millimeters, by Equation 5.

$$E_s = E_0 \, e^{-0.623 \text{ LAI}} \tag{5}$$

where

E_s = soil-water evaporation, mm

E_0 = potential evaporation (Penman), mm

LAI = leaf area index

Stage two evaporation, of irrigations and precipitations greater than or equal to ten millimeters, is calculated by Equation 6.

$$E_s = a(t)^{0.6} \tag{6}$$

where

E_s = soil-water evaporation, mm

t = time in days

a = alpha (a constant based on soil texture), mm

Irrigations less than ten millimeters are calculated by Equation 7.

$$E_s = Q \times c \tag{7}$$

where

Q = quantity of water in the irrigation or precipitation, mm

c = soil-water evaporation constant

The manner in which evaporation is calculated by these equations depends on the degree of ground cover achieved by the crop. Three degrees of ground cover are recognized in the model. A leaf area index between 0.0 and 0.5 is called the bare-soil condition, between 0.5 and 2.5 the incomplete-cover condition, and between 2.5 and 4 the complete-cover condition.

When the crop is in the bare-soil condition, Equation 5 is used to calculate evaporation until an accumulated value of soil evaporation has reached 6 millimeters. Then Equation 6 is used to calculate stage two evaporation, in the time remaining after stage one evaporation has terminated, until the time of the next irrigation or precipitation event that is greater than 10 millimeters. The alpha constant for Equation 6 is set at 3.5 since the experimental site possessed a sandy-loam soil texture (19). The quantity of water available for evaporation at each step is limited by the total amount of water in the irrigation or precipitation.

An irrigation of precipitation less than 10 millimeters is treated as if eight-tenths (Equation 7, (c) = 0.8) of the event evaporates. These light irrigations or precipitations for the purpose of calculating soil-water E by Equations 5 and 6 are treated as if they never occur, but are simply multiplied by the constant of Equation 7 and summed into the calculated E for the period.

The complete-cover condition is treated similarly to the bare-soil condition except for the following exceptions: the time in which stage one evaporation is allowed to proceed is limited to 2 days; the time in which stage two evaporation is allowed to proceed is likewise limited to two days; and the amount of soil-water E of irrigations and precipitations of less than 10 millimeters is reduced to one-tenth (Equation 7, (c) = 0.1) of the event. The stage one evaporation is limited to 2 days based on the observation in the field that the soil surface under the complete-cover canopy is very dry two days after an irrigation. Although the plant canopy does shade the ground, the crop at complete cover is transpiring at a very high rate which greatly reduces the water available for soil-water evaporation in the top 20 centimeters of soil profile. The reduced factor (c) is based on the assumption that some of the light irrigations and precipitations decrease the quantity of water lost by the plant in the form of transpiration and should not be attributed to soil-water evaporation loss.

The incomplete-cover condition is treated similarly to the bare-soil condition with a few exceptions. The time in which stage one evaporation is allowed to proceed is limited to 4 days, and the time in which stage two evaporation is allowed to proceed is limited to 5 days. These time intervals were chosen because they were intermediate between the bare soil and complete cover condition, and agreed reasonably well with the visual soil-surface-moisture status, as observed in the field. Estimated evaporation as calculated by this method, was relatively insensitive to changes in the magnitude on these intervals since twice weekly irrigations or precipitations were routine. In addition, the amount of soil-water E of irrigation and precipitation events of less than 10 millimeters is reduced to six-tenths (Equation 7, $(c) = 0.6$) of the event.

In Appendix B, Table B1, a comparison of estimated versus measured E in the bare-soil condition is presented. An abbreviated test of the sensitivity of Method 3, based on changing some of the parameters of the equations, is presented in Appendix B, Table B2.

This method of calculating soil-water evaporation is utilized in estimating evaporation from five subplots of each of the spring barley SLS plots of 1980 and 1981. A range of yield levels was selected in each section of the plot ranging from a subplot near the edge of the SLS plot, one from the middle, and one under the sprinkler-line source. In 1981 the subplots examined were 12, 8 and 0 meters; and in 1980, 11, 5.5, and 0 meters from the line-source sprinkler in each section of the plot. Leaf area index measurements were made as described earlier in all subplots in 1981. Leaf area index values for 1980 were interpolated based on yield levels and growing degree days of the subplots examined in 1981. All irrigation and precipitation events were tabulated and placed in a data set for computer calculation, with the associated Julian day of occurrence, the LAI value, and the number of days before the next event. These data were placed in tables of the form presented in Table B3 of the Appendix B for each of the five subplots in the plots. Table B3 is the data from the subplot immediately under the line-source sprinkler in the high nitrogen plot of 1981.

Calculated soil-water evaporation was then subtracted from the measured ET of the subplot to provide the estimate of transpiration. The resulting functions of yield expressed as a function of T for each of the plots produced in 1980 and 1981 were then compared for significant differences.

The Method of Determining the Mathematical Form of the Water-Production Function

The water-production functions presented in this report are based on the fit of the individual data points (with yield as the dependent variable and ET as the independent variable) to an equation of the form:

$$Y = A(ET)^2 + B(ET) + C \tag{8}$$

where

Y = economic yield

ET = evapotranspiration

A,B,C = equation coefficients which result for a best-fit-least-squares regression procedure

Non-significant coefficients based on the magnitude of their regression-associated t-statistic, are removed from the equation and the equation is recalculated and presented with only the significant coefficients remaining. Non-significant coefficients were not removed from the water-production functions reported in the 1980 results (12).

When functions were compared for significant differences with respect to function parameters, all functions were fit to an identical equation form for the purpose of the comparison.

GDD as an Index of Crop Evapotranspiration

There exists for alfalfa, barley, and pinto beans, as well as for many crops of northwestern New Mexico, a wide range of planting dates, or in the case of alfalfa cutting dates, which will provide an economically feasable crop harvest. However, by changing the planting or cutting date, crop ET during a given time period, as a result of the particular developmental stage falling on a different calendar day, will change significantly. Thus, tables of crop ET or crop coefficients calculated on a monthly basis have little value except perhaps if an identical planting date is chosen to that on which the tables are based. In a large farming operation such as the Navajo Indian Irrigation Project, a same day planting is of course not practicable due to limitations of manpower and machine. Bean planting will usually occur over a period of three weeks to a month. Hence, tables in this report, with respect to crop ET requirement, have been indexed to the GDD accumulation of the crop.

The Nature of the Stress Imposed by Deficit Water Application Using a Sprinkler-Line-Source

As distance from the line-source sprinkler increases a constant fractional decrease in the water application rate occurs assuming the following:

1. the line is operated under wind-free conditions;
2. the pressure in the line source is constant at each irrigation; and
3. rainfall is negligible.

Since the quantity of applied water is based upon maintaining the rhizosphere of the subplot under the line-source sprinkler at field capacity on a weekly basis, those subplots at increasing distance from the line are subjected to a constant but fractional water availability of that which exists under the line at near-optimal water availability. This fractional water availability is expressed throughout the growing season at all developmental stages, with the severity of the deficit increasing with distance from the line. Thus, those plants in this design at distance from the line become preconditioned to water deficit, since they never encounter a near-optimal water availability.

Other researchers have found that crops possess "critical developmental stages" when water deficit effects are more pronounced (3, 4, 8, 14, 16). If indeed this is the case, then the yield, as given in this report at each level of ET, would be subject to improvement if the water available for ET had been maximized at the critical developmental stages and minimized at noncritical stages. Most of these authors, however, had irrigated their respective crops near-optimally until imposition of the stress. Singh (23), investigating wheat, separates experimental treatments into plots which had grown continually under water deficit conditions such as occurred in our study, and those which were subjected to an imposed water deficit after having adapted initially to conditions of near-optimal water availability. He describes the treatments as sensitized and nonsensitized to water deficit. Singh found that nonsensitized plants indeed appear to possess critical developmental stages whereas the sensitized or preconditioned plants possessed them to a much lesser extent. Singh further stated that for optimal deficit-irrigation allocation some anticipated water deficit should occur in developmental stages considered to be critical growth stages.

The validity of the water-production functions developed in this report are based on imposing the water stress uniformly throughout the growing season as described above. Imposing the stress in a different manner, but allowing a similar total quantity of evapotranspiration, would likely change the resultant yields depending on the nature of the stress, but would not necessarily increase them.

Parameters of the Water-Production Function as They Relate to Water-Use Efficiency

The water-use efficiency, defined as the weight of economic yield produced per depth of water utilized as ET, is constant for a water-production function only if the function passes through the origin. Since the water-production functions developed in this report have a positive x-intercept, the WUE increases as the level of ET increases. For functions with identical y-intercept the function with the steeper slope has the greater WUE at any given level of yield. A curvilinear water-production function that is concave upward, of the form presented in this report, denotes an increase in the rate of increase in WUE as the level of ET increases.

RESULTS AND DISCUSSION

Spring Barley

Pertinent crop information relating to the development and production of the spring barley SLS plots is summarized in Table 3.

Contained in the partial completion report of the 1980 results (12) is Table 12, which presents information demonstrating that the water required to produce a given level of yield appeared to be much higher in the lysimeters than in the SLS plots. This same apparent result was obtained again this season, until a close examination of the lysimeters determined that they were leaking. Hence, water that was being lost to deep drainage was being attributed to crop ET. The lysimeters had apparently been leaking for a number of years and this observation would explain why the ET required to produce approximately 3000 Kg/ha of grain in 1976 and 1977, was erroneously reported to be approximately 55 centimeters in an earlier Water Resources Research Institute publication (20). An ET of this magnitude, as determined by the SLS plots, should produce generally speaking, a yield of approximately 6200-6700 Kg/ha of grain.

Seasonal evapotranspiration and yield of the 1980 SLS plots utilizing 30, 112, and 196 Kg/ha of N are presented in Tables 4, 5, and 6, respectively.

The water-production functions were developed from the data of yield versus ET, as presented in Tables 4, 5, and 6, of each

Table 3. Spring barley crop production data.

Year	Planting* Date	Emergence Date	Heading Date	Physiological Maturity	Final Probe Reading	Harvest Date
1980#	4/09/80	4/18/80	6/10/80	7/13/80	7/28/80	7/31/80
1981#	4/03/81	4/14/81	6/03/81	7/01/81	7/12/81	7/28/81

* 100 Kg/ha of seed was drilled at a depth of 6.5 cm to yield 134 plants/meter^2.

\# Event dates are averages of all subplots.

Table 4. Seasonal evapotranspiration and yield of spring barley utilizing a maximum of 30 Kg/ha of nitrogen for 1980.

Subplot Distance from the Line	Seasonal ET	Yield Mean*	Yield SD
m	cm	Kg/ha	
	Section 1		
12.8	14.5	220	145
11.0	18.8	295	74
10.1	20.6	244	76
8.2	25.6	444	132
7.3	28.3	619	201
5.5	31.9	773	157
3.7	32.4	837	79
2.7	35.1	1300	282
1.8	38.0	1213	237
0	44.6	1274	345
	Section 2		
12.8	14.5	187	64
11.9	16.8	232	156
11.0	19.0	333	135
7.3	21.7	607	282
6.4	30.4	1090	519
5.5	31.9	1021	424
4.6	32.0	1291	262
3.7	32.1	1161	408
2.7	35.0	1581	407
.9	41.2	1127	419
0	44.6	1274	345

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

Table 5. Seasonal evapotranspiration and yield of spring barley utilizing a maximum of 112 Kg/ha of nitrogen for 1980.

Subplot Distance from the Line	Seasonal ET	Yield Mean*	Yield SD
m	cm	Kg/ha	
	Section 1		
11.9	19.0	217	8
11.0	22.8	253	78
10.1	23.5	329	41
9.1	24.2	619	74
8.2	28.0	1009	122
6.4	34.2	1527	40
5.5	36.8	2004	8
4.6	39.0	2144	220
3.7	41.9	2822	147
.9	44.2	3531	491
0	48.3	4200	373
	Section 2		
12.8	15.8	170	37
11.0	19.7	364	124
10.1	23.2	399	219
9.1	26.5	631	68
8.2	30.0	870	169
7.3	33.4	1165	149
6.4	36.5	1574	252
5.5	39.9	1652	201
4.6	40.4	2539	339
2.7	42.2	3257	340
1.8	43.5	3210	78
0	48.3	4200	373

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

Table 6. Seasonal evapotranspiration and yield of spring barley utilizing a maximum of 196 Kg/ha of nitrogen of 1980.

Subplot Distance from the Line	Seasonal ET	Yield Mean*	SD
m	cm	Kg/ha	
	Section 1		
12.8	16.8	352	178
11.9	19.4	324	74
11.0	22.2	534	166
9.1	29.9	799	115
8.2	33.4	1106	135
6.4	40.6	2082	71
5.5	43.9	2855	261
3.7	50.9	3912	231
2.7	54.0	4838	447
.9	59.4	6498	421
0	61.5	7176	160
	Section 2		
11.9	22.6	581	194
11.0	25.1	645	74
10.0	28.0	799	108
9.1	30.9	1000	239
8.2	33.1	1617	239
6.4	39.1	2314	152
5.5	42.9	2688	520
4.6	48.2	3922	145
2.7	55.3	4401	297
1.8	57.2	5051	491
0	61.5	7176	160

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

section of the SLS plots of 1980. These water-production functions are presented in Table 7. A plot of the yield versus seasonal ET data points that are presented in Table 4 exhibited a plateau at a yield level of approximately 1500 Kg/ha of grain yield, suggesting the ET levels in excess of approximately 38 centimeters reflected deep drainage losses and did not increase plant ET. Hence, the data which are presented in Table 4 relating ET to yield, which were collected at a distance closer than 1.8 meters from the line-source sprinkler, were not included in the calculation of the water-production function of the low-nitrogen SLS plot of 1980.

The water-production functions presented in Table 7 have been plotted in Figure 6. The majority of the water-production functions are not significantly different from one another when the parameters of the functions are statistically compared (Table 7) which indicated to us, when the results of the 1980 season were analyzed, that the water-use efficiency does not change as the level of nitrogen fertility changes.

Seasonal ET and the grain yield of the 1981 SLS plots utilizing a maximum of 61, 102, and 189 Kg/ha of N are presented in Tables 8, 9, and 10, respectively. The grain yield versus ET data points have been plotted in Figure 7. All of the data points could not be plotted as a result of significant point overlap. The water-production functions of each section of the 1981 plots were calculated based on this data, and are presented in Table 11 and have been plotted in Figure 8. The results are very different from those obtained in 1980 and it appears that in 1981,

Table 7. Least-square-fit quadratic equations developed from the grain yield data of each section of the 1980 barley plots; and the pairwise comparison of the equations for significant differences.

Nitrogen[1/]	Section	Equation	r^2	Letter of Equation	Significant Difference[2/]
Kg/ha		Y(Kg/ha),ET(cm)			
196	1*	$Y = 1799 - 146.6(ET) + 3.8(ET)^2$	1.00	A	C,D,E,F
196	2*	$Y = -565 + 1.8(ET)^2$	.97	B	None
112	1	$Y = -678 + 2.1(ET)^2$	.98	C	A,E
112	2	$Y = 1933 - 176.9(ET) + 4.7(ET)^2$	.96	D	A
30	1	$Y = -76 + 0.9(ET)^2$	.93	E	A,C,F
30	2	$Y = -95 + 1.3(ET)^2$	.97	F	A,E

[1/] Refers to estimated nitrogen utilized by highest yielding subplot in the plot.

[2/] Equation in previous column is significantly different at the 0.05 probability level from the equations 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 eastern and western half of the plot respectively. See Figure 4 in Reference (12) for compass directions.

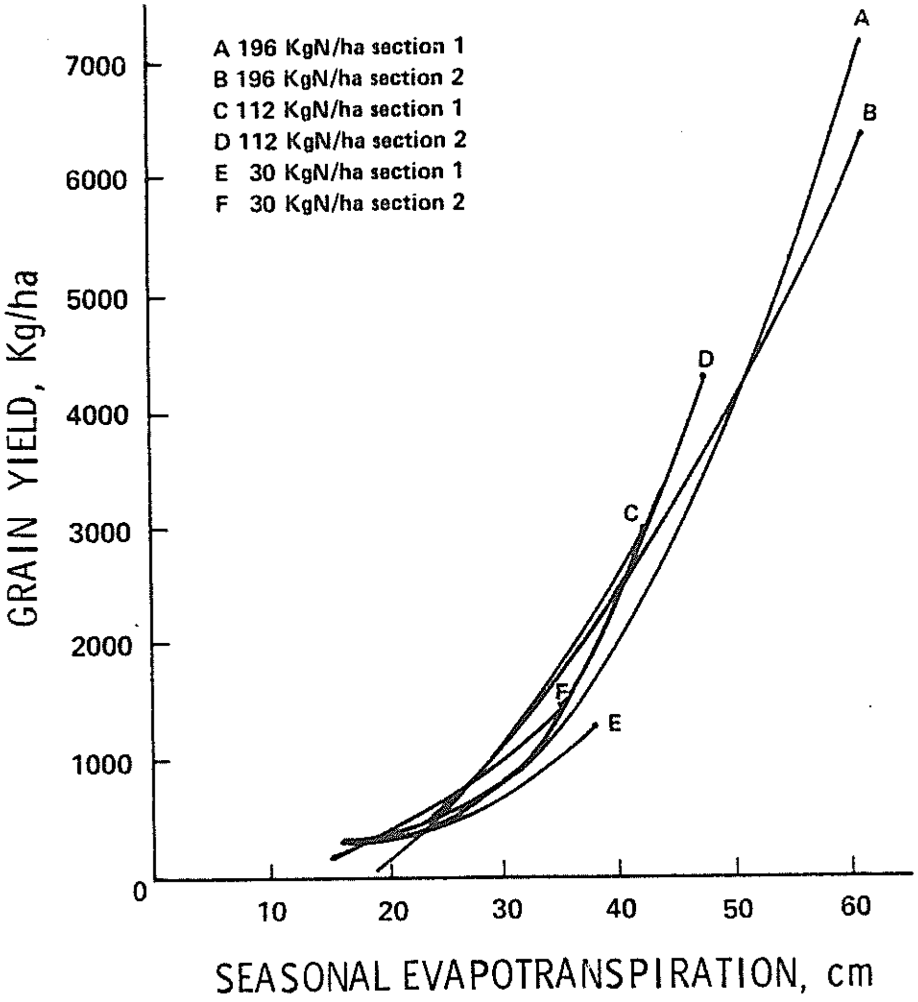

Figure 6. The water-production functions of each section of the spring barley SLS plots, 1980.

Table 8. Seasonal evapotranspiration and yield of spring barley utilizing a maximum of 61 Kg/ha of nitrogen for 1981.

Subplot Distance from the Line	Seasonal ET	Grain Yield* Mean	Grain Yield* SD
m	cm	Kg/ha	
	Section 1		
14.0	13.3	250	39
13.0	13.5	136	68
12.0	13.7	113	39
11.0	16.2	204	68
10.0	20.0	273	118
9.0	23.7	568	219
8.0	27.3	886	68
7.0	29.7	1090	0
6.0	32.0	1545	172
5.0	34.7	1227	491
4.0	37.4	2249	613
3.0	38.4	2453	594
2.0	39.5	2476	142
1.0	39.3	2226	454
0.0	39.1	2431	464
	Section 2		
14.0	15.7	136	118
13.0	19.6	704	350
12.0	23.4	795	433
11.0	25.3	909	284
10.0	27.2	1090	236
9.0	29.5	1431	297
8.0	31.8	1318	239
7.0	31.5	1636	360
6.0	31.2	1567	180
5.0	32.8	1817	39
4.0	34.5	2340	172
3.0	35.6	2794	312
2.0	37.4	2407	432
0.0	39.1	2430	464

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

Table 9. Seasonal evapotranspiration and yield of spring barley utilizing a maximum of 102 Kg/ha of nitrogen for 1981.

Subplot Distance from the Line	Seasonal ET	Grain Yield* Mean	Grain Yield* SD
m	cm	Kg/ha	
	Section 1		
14.0	16.3	1022	297
13.0	18.6	522	172
12.0	20.9	909	142
11.0	24.0	1113	79
10.0	27.1	1295	180
9.0	29.9	2112	118
8.0	32.7	2249	312
7.0	33.3	2975	208
6.0	34.0	3225	416
5.0	36.4	3657	454
4.0	38.9	3904	629
3.0	39.3	4201	307
	Section 2		
14.0	21.2	522	322
13.0	22.8	1068	275
12.0	24.3	1045	307
11.0	24.9	954	272
10.0	25.5	1499	204
9.0	27.5	1454	315
8.0	29.2	1569	184
7.0	32.0	1790	376
6.0	34.9	2771	611
5.0	35.5	2816	930
4.0	36.2	3657	343

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

Table 10. Seasonal evapotranspiration and yield of spring barley utilizing a maximum of 189 Kg/ha of nitrogen for 1981.

Subplot Distance from the Line	Seasonal ET	Grain Yield* Mean	SD
m	cm	Kg/ha	
	Section 1		
14.0	15.4	1278	242
13.0	17.2	1278	133
12.0	19.0	1534	226
11.0	22.9	1512	384
10.0	26.7	2578	712
9.0	29.7	2535	616
8.0	32.7	3260	406
7.0	36.6	4048	449
6.0	40.4	4325	994
5.0	44.4	5092	942
4.0	48.4	5709	580
3.0	49.3	6200	683
2.0	50.5	6008	258
1.0	53.9	6562	90
0.0	57.3	6626	181
	Section 2		
14.0	22.0	1853	98
13.0	25.5	2152	111
12.0	28.9	2322	184
11.0	30.6	2578	352
10.0	32.3	3132	224
9.0	33.6	3494	169
8.0	34.9	3899	98
7.0	38.4	3664	258
6.0	41.8	5411	256
5.0	45.0	5433	385
4.0	48.2	6136	352
3.0	50.0	6029	471
2.0	51.7	6413	226
1.0	54.5	6926	493
0.0	57.3	6626	181

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

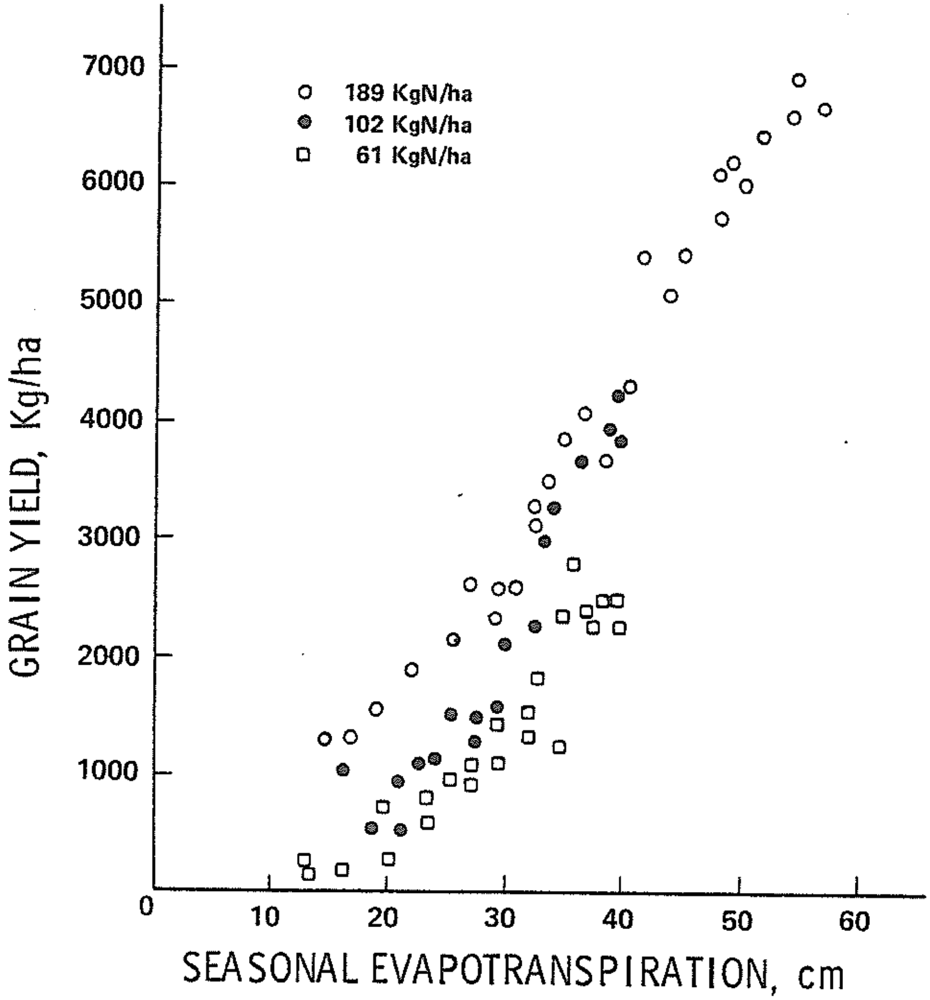

Figure 7. The plot of the measured grain yield of spring barley versus the seasonal ET, 1981. SLS plots are identified by the N utilization of the highest yielding subplot of the plot.

Table 11. Least-square-fit quadratic equations developed from the grain yield data of each section of the 1981 barley plots; and the pairwise comparison of the equations for significant differences.

Nitrogen[1/]	Section	Equation	r^2	Letter of Equation	Significant Difference[2/]
Kg/ha		Y(Kg/ha),ET(cm)			
189	1*	$Y = -1308 + 143.6\ (ET)$	.98	A	C,D,E,F
189	2*	$Y = -1934 + 159.9\ (ET)$	.96	B	C,D,E,F
102	1	$Y = -334 + 2.8\ (ET)^2$	.95	C	A,B,E,F
102	2	$Y = -703 + 2.9\ (ET)^2$	.91	D	A,B,E,F
61	1	$Y = -250.8 + 1.7\ (ET)^2$	.96	E	A,B,C,D
61	2	$Y = -244 + 1.9\ (ET)^2$	.89	F	A,B,C,D

[1/] Refers to estimated nitrogen utilized by highest yielding subplot in the plot.

[2/] Equation in previous column is significantly different at the 0.05 probability level from the equations 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 eastern and western half of the plot respectively. See Figure 5 for compass direction.

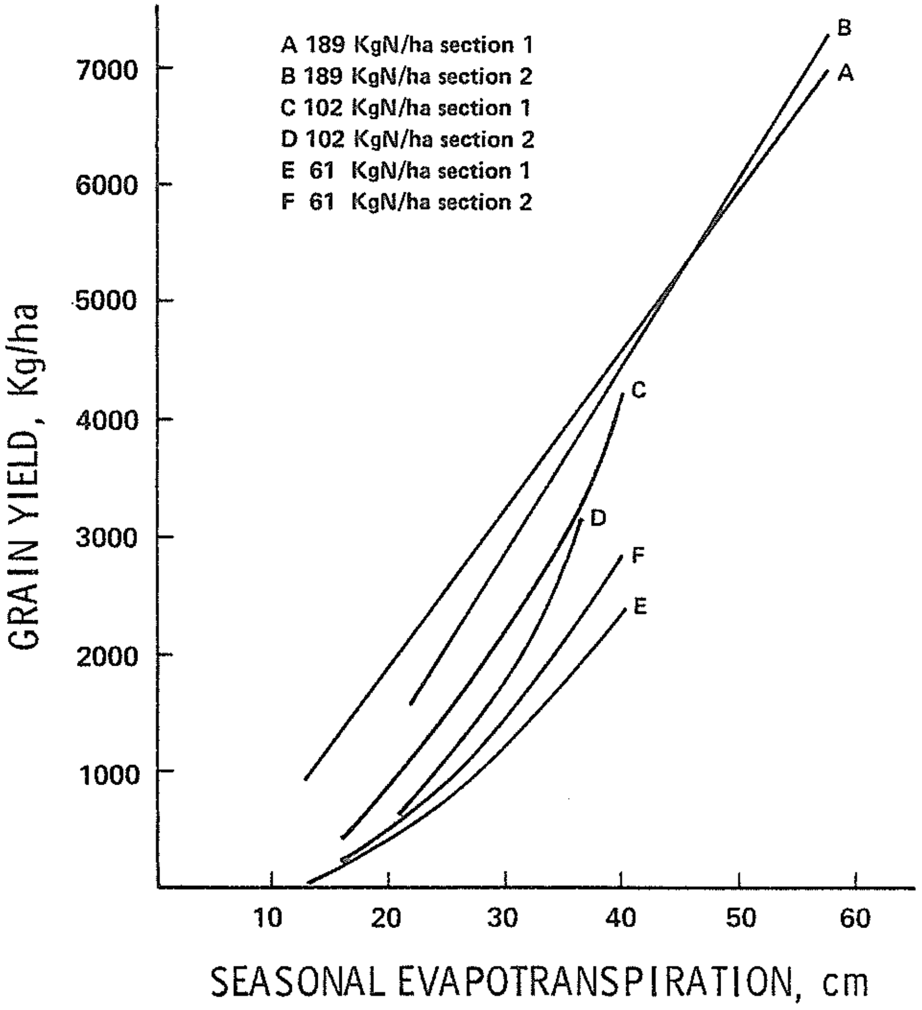

Figure 8. The water-production function of each section of the spring barley SLS plots, 1981.

nitrogen had a significant effect on the efficiency by which plants utilized the water available for ET. However, since the level of nitrogen fertility appeared to have little effect in 1980 but great effect in 1981, other factors were explored which might explain the differences in the results between years, with respect to the effect of nitrogen fertility on crop water-use efficiency, more satisfactorily than did the level of N fertility. The most obvious factor to examine was soil-water evaporation. The experimental design of the SLS plots does not include randomization with respect to N fertility level. The primary reason that SLS plots were not randomized with respect to fertilizer level, by banding fertilizer at right angles to the sprinkler-line source across the width of the plot, was that if the high-nitrogen subplot on the line was watered optimally, the low-nitrogen plot would be grossly over-irrigated in the majority of the subplots. In our design, since each level of nitrogen fertility has its own sprinkler-line source, the frequency of irrigation can be very different from plot to plot due to differing water requirements of a 7000 Kg/ha grain yield as opposed to a 1100 Kg/ha grain yield, in the subplots under the sprinkler-line source. As frequency and duration of the irrigation event and the degree of ground cover achieved by the crop vary, so also do the soil-water evaporation losses and thus the ET required to produce a given level of yield. As will be discussed further and as is shown by Equation 5, evaporation is a complex phenomenon and is greatly influenced by crop LAI.

Since evaporation is very difficult to separate from transpiration in the field, factors associated with evaporation which can be quantified, were placed in a multiple stepwise regression as independent variables, with the dependent variable being grain yield. The independent variables of the stepwise regression are described in Appendix C, Table C1. Only those subplots which contained an access tube were included in the multiple regression which allowed 74 observations. The stepwise regression selected the variables to be entered in the multiple regression equation based on the relative significance of the variable's F-statistic.

The manner in which the N variable was assigned to the 74 subplots merits further explanation. The N variate assigned to each of the subplots in a given SLS plot, is the maximum N utilization of the highest yielding subplot of that plot, i.e. usually the subplot under the sprinkler-line source. By assigning the N variable in this manner the N variable becomes a measure of the N which is available for crop growth and yield if water availability is near optimal. As distance from the line increases the water available for crop growth and yield decreases, but the N available for growth remains constant even though less N is utilized. Thus, this N variable is not a measure of the simple effect of N on yield. The analysis of the data in this manner, with N variable assigned in this way, provides a measure of the water-use efficiency of a given nitrogen availability by the slope of the water production function at that point. A non-significant N variable then, which may result from the multiple regression, does not denote that N is non-significant with respect to economic yield, only that the level of N in the field did not affect the water-use efficiency of the crop.

The results of the stepwise multiple regression demonstrated that many of the variables were interrelated, as one would expect, and many were equally valuable in accounting for variations in grain yield. Two of the steps, Steps 2 and 5, are presented in Appendix C, Table C2, to show the coefficients of the variables which account for most of the variability. The fraction of the variability accounted for by each of the significant variables, of the total variability accounted for by the multiple coefficient of determination, is presented in Appendix C, Table C3. By Step 2 of the regression (Table C2) 94 percent of the total variation has been accounted for. However, as Step 5 of the regression demonstrates, based on the relative values of the F-statistic of the coefficients which result when other significant variables are entered, other variables appear to be of equal value in accounting for differences in yield. All of the significant variables, except Variable 10 which is the square of ET, are interactions of two variables and all demonstrate the importance, in accounting for differences in yields among subplots, of factors associated with evaporation. Only one significant variable, the interaction of nitrogen (Variable 2) with the number of irrigations and precipitations greater than 2.5 millimeters (Variable 9), is associated with the level of N fertility and only in relation to the number of irrigations and precipitations. This observation suggests that it is not transpiration-related differences in water-use accounting for nitrogen effects, but only differences in E associated with irrigation frequency as influenced by the level of relative yield obtainable with a given N fertility level in the field.

The variables entered during Step 2 of the stepwise multiple regression account for 94 percent of the total variation present. Rather than develop a multiple regression equation from five variables, which would be necessary at Step 5, the simpler equation of Step 2 was chosen. This decision was also based on the observation that most of the variables are different measures of the same phenomenon: soil-water evaporation. The multiple stepwise regression equation is as follows:

$$Y = 2.03(ET)^2 - 0.03(R \times P) + 1282 \qquad (9)$$

where

Y = yield (Kg/ha)

ET = seasonal evapotranspiration (cm)

R = the ratio of applied water to the total ET (and multiplied by 100 to give percent)

P = seasonal potential evapotranspiration (mm) as calculated by the Penman method

The smaller the value of R, the greater is the percent of the total water evapotranspired by the crop that will come from soil storage. The greater the percent of water which comes from soil storage the lesser will be the evaporation losses associated with post-planting irrigation. The greater the PET, the greater will be the soil-water evaporation losses at an irrigation. To illustrate this relationship a range of values of ET (in the range of experimentally measured values in the field) were entered in Equation 9, and held constant while the R x P interaction was allowed to vary. The results are presented in Figure 9. Curve A and B of Figure 9 were calculated as if only 30 percent of the total seasonal ET was the result of applied irrigation water with 70 percent coming from soil stores or from precipitations (which usually were negligible). Whereas, an R-value of 30 percent frequently occurred at the edge of the SLS plots it could not occur at the high-yield levels since soil storage would not be sufficient to supply 70 percent of the seasonal ET. Theoretically this situation could occur if the roots had an underground water supply such as a high water table, which did not suffer evaporation losses. The important observation to be made from Figure 9 is that the greater the percentage of the ratio of water which is applied to the total water use of the crop, the lesser is the WUE of the crop at any given level of yield. The increase in the R-value which occurs from the edge to the center of the SLS plot denotes a decrease in the rate of increase in WUE which would have occurred had the R-value remained constant.

Also, note that an increase in the PET results in a decrease in the WUE. The significance of the PET variable in the multiple regression suggests that the PET concept may have some usefulness in predicting changes in soil-water evaporation associated with increased evaporative demand. The change in WUE is greatest at

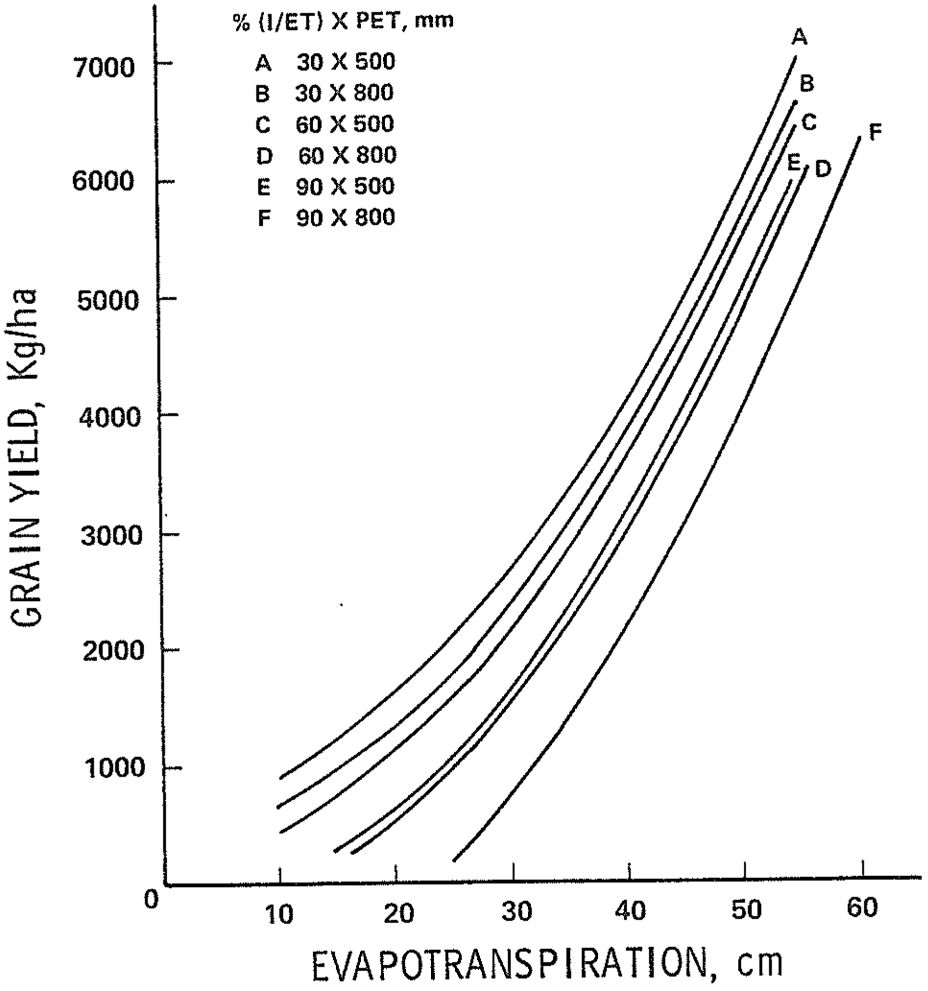

Figure 9. The relationship between grain yield and seasonal ET of spring barley when the product of the percentage of the ratio of seasonal irrigation (I) to seasonal ET as multiplied by the seasonal PET, varies.

the low-yield levels with changes in R and P signifying the interaction of R and P with yield.

The relatively linear nature of the curves above yield levels of 2000 Kg/ha also suggests that water-production functions not showing yields below this yield will be linear, but offset depending upon the R and P values of the environment in which they are produced.

The significance of variables of the stepwise multiple regression, associated with soil-water evaporation, prompted an attempt to separate evaporation from transpiration by means of Method 3 previously described in the Materials and Methods section. Tables 12 and 13 present the measured seasonal ET and evaporation which were calculated by means of this method. Transpiration, as presented in the tables, was calculated by subtracting evaporation from ET.

Water-production functions (with yield expressed as a function of ET) were developed individually, from the data of the five subplots within each SLS plot as listed in Tables 12 and 13, for the six SLS plots of 1980 and 1981. When the six SLS plots were compared for significant differences with respect to a common slope and intercept of their respective functions, an F-statistic of 5.5 was obtained indicating that the functions were significantly different at the one-percent probability level. However, when functions relating yield to transpiration were developed for the six SLS plots from data presented also in Tables 12 and 13, the comparison among the functions with respect to a common slope and

Table 12. Measured evapotranspiration, estimated evaporation and transpiration of selected subplots of the spring barley SLS plots for 1980.

N level	Section	Number of Irrigations	Distance from Line	Yield	ET	T	E
Kg/ha			m	Kg/ha	cm		
196	1	23	11	645	25.1	3.0	22.1
196	1	26	5.5	2688	42.9	21.7	21.2
196	1,2	27	0	7176	61.5	41.0	20.5
196	2	27	5.5	2855	43.9	20.7	23.2
196	2	27	11	534	22.2	4.3	17.9
112	1	21	11	364	19.7	2.5	17.2
112	1	22	5.5	1652	39.9	12.1	27.8
112	1,2	22	0	4200	48.3	28.7	19.6
112	2	22	5.5	2004	36.8	8.2	28.6
112	2	22	11	253	22.8	6.6	16.2
30	1	19	11	333	19.0	6.2	12.8
30	1	23	5.5	1021	32.0	8.5	23.5
30	2	23	5.5	773	31.9	8.4	23.5
30	2	23	11	295	18.8	5.6	13.2

Table 13. Measured evapotranspiration, estimated evaporation and transpiration of selected subplots of the spring barley SLS plots for 1981.

N level	Section	Number of Irrigations	Distance from Line	Yield	ET	T	E
Kg/ha			m	Kg/ha	cm		
189	1	14	12	1534	19.0	8.1	10.9
189	1	17	8	3260	32.7	18.9	13.8
189	1,2	17	0	6626	57.3	44.2	13.1
189	2	17	8	3899	34.9	21.8	13.1
189	2	17	12	2322	28.9	13.8	15.1
102	1	17	12	1045	24.3	12.1	12.2
102	1	18	8	1569	29.2	11.6	17.6
102	1	18	3*	4202	39.3	19.6	19.7
102	2	18	8	2249	32.7	11.6	21.1
102	2	18	12	909	20.9	5.2	15.7
61	1	19	12	113	13.7	3.9	9.8
61	1	19	8	886	27.3	6.6	20.7
61	1,2	19	0	2431	39.9	15.1	24.8
61	2	19	8	1318	31.8	9.8	22.0
61	2	19	12	795	23.4	5.9	17.5

* Subplots closer to line were ruined by unmeasured water.

y-intercept resulted in an F-statistic of 0.88, which was not significant even at the 10-percent level of probability.

What was particularly noteworthy about this finding is that the water-production functions developed from two seasons of data were transformed to an identical function, even though the PET as measured by the Penman's method varied greatly between these seasons (724 millimeters in 1980 and 593 millimeters in 1981) from planting to physiological maturity. This comparison further supports the hypothesis that the T required to produce a given level of yield changes little from season to season, and possibly from location to location, and that it is the evaporation component of ET that results in the observed disparity with respect to the parameters of the water-production function from season to season.

Since no significant differences exist between the slopes and intercepts of the functions of the individual SLS plots, all of the data points are combined into a common relationship relating yield to transpiration. This function is expressed in Equation 10.

$$\text{Yield (Kg/ha)} = -222 + 167.1\ (\text{T, cm}) \qquad (10)$$

Equation 10 has a coefficient of determination of 0.93.

As can be observed in Tables 12 and 13, a very large percentage of the total ET is evaporation. This is especially true in the subplots near the edge of the SLS plots. This observation is not surprising when the number of irrigations are considered (the list of the dates of irrigation and precipitation events which occurred in the subplots under the respective sprinkler-line sources are presented in Appendix D). Observe from Tables 12 and 13 that the number of irrigations between fertility levels are only moderately different, yet the water-production functions are very different.

This relationship between yield and transpiration has been graphed in Figure 10 and the data points used to develop the regression equation have been plotted. Note that the function comes close to passing through the origin which one would expect in this type of relationship. Another interesting observation is that the removal of evaporation from the ET term reduced the curvilinearity that was present in the water-production functions, suggesting that this curvilinearity is the result of differential evaporation rates associated with various yield levels. Other investigators have presented curvilinear functions for cowpeas (25) and winter wheat (9).

Portions of the subplots were harvested by hand in 1981 and compared with yields obtained by the combined harvested grain that is presented in Tables 8, 9, and 10. No significant differences exist in the hand-harvested versus machine-harvested water-production functions with respect to their curvilinearity proving that the curvilinearity is not the result of a differential harvest efficiency of the combine associated with plant height. The total-above-ground biomass data obtained from the two hand-harvested areas of the subplots are presented in Tables 14, 15, and 16 for the SLS plots utilizing 61, 102, and 189 Kg/ha of N, respectively. The grain yields presented in these tables are based on a total harvested area of

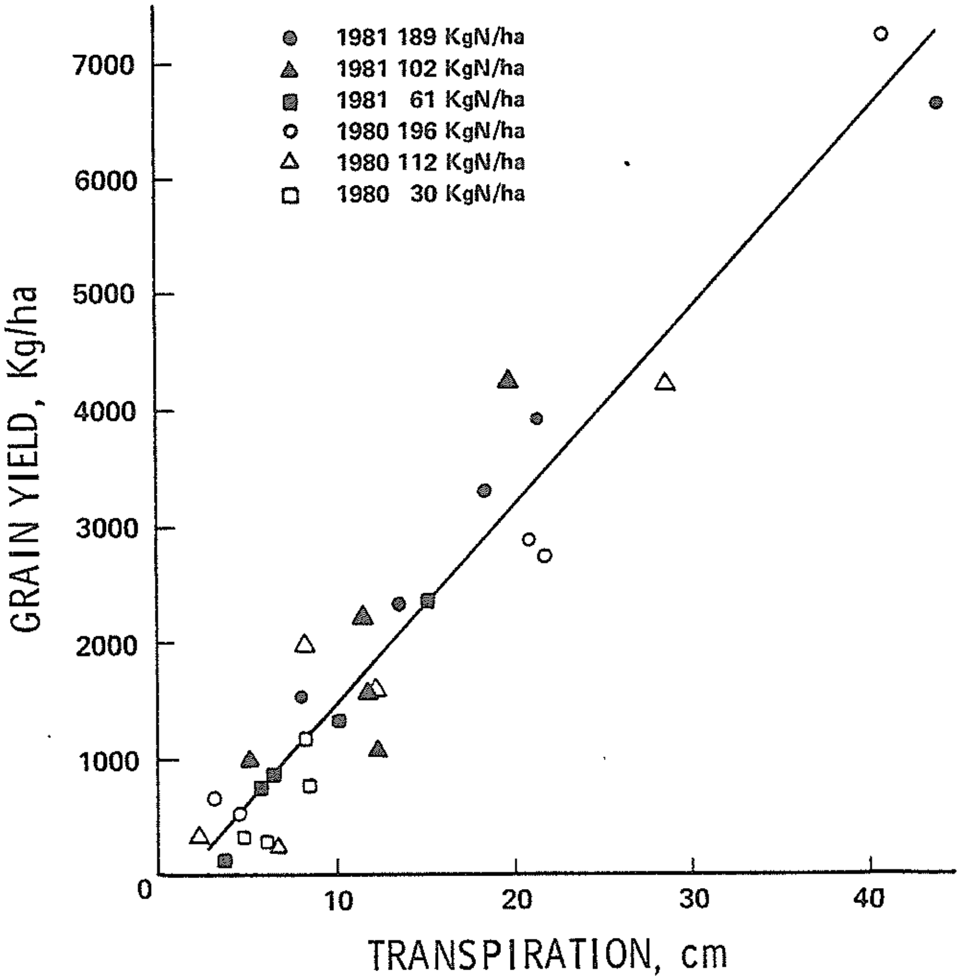

Figure 10. The relationship between grain yield of spring barley, and seasonal transpiration, 1980 and 1981. The equation of the line is $Y(Kg/ha) = -222 + 167.1(T,cm)$; $r^2 = 0.93$.

Table 14. Seasonal evapotranspiration, biomass yield, and harvest ratios for spring barley utilizing a maximum of 61 Kg/ha of nitrogen for 1981.

Subplot Distance from the Line	Seasonal ET	Grain Yield[1] Mean	Grain Yield[1] SD	Biomass[2] Mean	Biomass[2] SD	Harvest Ratio
m	cm	Kg/ha		Kg/ha		
		Section 1				
14.0	13.3	442	208	1031	566	.43
13.0	13.5	88	83	429	202	.21
12.0	13.7	162	188	573	-	.28
11.0	16.2	162	188	587	20	.27
10.0	20.0	442	208	1303	182	.34
9.0	23.7	294	0	1432	0	.21
8.0	27.3	884	834	2004	405	.44
7.0	29.7	1474	0	2863	405	.51
6.0	32.0	1769	417	3436	810	.51
5.0	34.7	1474	417	3006	1012	.49
4.0	37.4	1621	625	2863	2424	.57
3.0	38.4	2063	417	3722	1215	.55
2.0	39.5	1621	625	2004	2430	.81
1.0	39.3	2358	417	4868	810	.48
0.0	39.1	2210	625	5011	607	.44
		Section 2				
14.0	15.7	310	396	716	202	.43
13.0	19.6	442	208	1718	0	.26
12.0	23.4	589	0	1718	0	.34
11.0	25.3	737	208	2004	405	.37
10.0	27.2	589	0	2291	0	.26
9.0	29.5	1032	208	2577	0	.40
8.0	31.8	737	208	2434	1417	.30
7.0	31.5	1032	1042	3865	607	.27
6.0	31.2	1474	0	3150	405	.47
5.0	32.8	1474	0	2720	607	.54
4.0	34.5	1769	417	4009	405	.44
3.0	35.6	2211	208	5297	202	.42
2.0	37.4	2063	0	3865	202	.53
0.0	39.1	2211	625	5011	607	.44

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[1] Average of the two hand-harvested subsamples per subplot adjusted to 14 percent moisture.

[2] Average of the two hand-harvested subsamples per subplot adjusted to 0 percent moisture.

Table 15. Seasonal evapotranspiration, biomass yield, and harvest ratios for spring barley utilizing a maximum of 102 Kg/ha of nitrogen for 1981.

Subplot Distance from the Line	Seasonal ET	Grain Yield[1] Mean	SD	Biomass[2] Mean	SD	Harvest Ratio
m	cm	Kg/ha		Kg/ha		
		Section 1				
14.0	16.3	737	208	2577	405	.29
13.0	18.6	442	208	1718	405	.26
12.0	20.9	1032	208	3579	1012	.29
11.0	24.0	737	208	3006	607	.25
10.0	27.1	1326	208	4152	203	.32
9.0	29.9	1621	208	4724	1012	.34
8.0	32.7	1621	625	5154	810	.31
7.0	33.3	2505	208	6156	607	.41
6.0	34.0	2358	416	6442	607	.37
5.0	36.4	2505	208	6156	1012	.41
4.0	38.9	2210	208	6013	1214	.37
3.0	39.3	2947	834	7301	2632	.40
		Section 2				
14.0	21.2	590	417	1575	607	.37
13.0	22.8	1032	625	2863	810	.36
12.0	24.3	1032	625	2577	405	.40
11.0	24.9	590	417	1861	1012	.32
10.0	25.5	1326	208	3293	1417	.40
9.0	27.5	1032	208	3293	607	.31
8.0	29.2	1032	208	2720	1012	.38
7.0	32.0	1621	208	3722	1620	.44
6.0	34.9	2211	625	5154	2429	.43
5.0	35.5	2505	1042	5583	2632	.49
4.0	36.2	2652	834	5583	607	.48

[1] Average of the two hand-harvested subsamples per subplot adjusted to 14 percent moisture.

[2] Average of the two hand-harvested subsamples per subplot adjusted to 0 percent moisture.

Table 16. Seasonal evapotranspiration, biomass yield, and harvest ratios for spring barley utilizing a maximum of 189 Kg/ha of nitrogen for 1981.

Subplot Distance from the Line	Seasonal ET	Grain Yield[1] Mean	Grain Yield[1] SD	Biomass[2] Mean	Biomass[2] SD	Harvest Ratio
m	cm	Kg/ha		Kg/ha		
		Section 1				
14.0	15.4	590	0	2148	203	.27
13.0	17.2	590	0	1861	203	.32
12.0	19.0	442	208	2004	-	.22
11.0	22.9	590	0	2434	203	.24
10.0	26.7	1474	0	3865	1012	.38
9.0	29.7	1474	0	4295	1215	.34
8.0	32.7	1916	208	5583	607	.34
7.0	36.6	2505	625	5011	607	.50
6.0	40.4	3242	-	7731	0	.42
5.0	44.4	4127	834	8304	1619	.50
4.0	48.4	4274	208	9449	1214	.45
3.0	49.3	3979	625	8447	2227	.47
2.0	50.5	5158	1459	10451	3036	.49
1.0	53.9	4127	-	8017	0	.51
0.0	57.3	5158	1042	10594	2025	.49
		Section 2				
14.0	22.0	884	417	3150	810	.28
13.0	25.5	1179	0	3436	0	.34
12.0	28.9	1326	208	4295	405	.31
11.0	30.6	1474	417	4724	1012	.31
10.0	32.3	1769	417	4724	1012	.37
9.0	33.6	2358	417	6013	405	.39
8.0	34.9	2211	625	6442	1822	.34
7.0	38.4	2947	417	7874	203	.37
6.0	41.8	3831	417	8303	1214	.46
5.0	45.0	4127	834	9306	607	.44
4.0	48.2	4569	1042	8590	2025	.53
3.0	50.0	4569	625	9306	1417	.49
2.0	51.7	5453	625	11167	2430	.49
1.0	54.5	5158	1042	10021	2430	.51
0.0	57.3	5158	1042	10594	2025	.49

[1] Average of the two hand-harvested subsamples per subplot adjusted to 14 percent moisture.

[2] Average of the two hand-harvested subsamples per subplot adjust to 0 percent moisture.

3 square meters at each distance from the line as compared to 21 square meters for the grain yields presented in Tables 8, 9, and 10. Thus, the grain yields in the three latter tables should be considered more representative of the yields obtainable at the respective measured ET, under the conditions extant during the 1981 season. The biomass data have been plotted in Figure 11. Functions relating the above-ground biomass and seasonal ET have been developed from data presented in Figure 11. These functions are all linear and are presented in Table 17. The functions are plotted in Figure 12.

Figures 13, 14, and 15 are plots of the water-production functions superimposed with the relationship of biomass and ET for the SLS plots utilizing a maximum of 61, 102, and 189 Kg/ha of N, respectively. These figures have been presented to demonstrate that both the water-production functions and the biomass yield versus ET functions appear to have similar x-intercepts. This observation is also in agreement with data presented in last season's partial completion report with respect to pinto beans (Figure 12 in (12)). The x-intercept of the biomass versus ET relationship (Method 1) has been suggested as a means of estimating E at all yield levels of the water-production function (9, 18). If so, Figures 13, 14, and 15 demonstrate that the x-intercept of the water-production function would be equally valuable as a measure of seasonal evaporation. However, as Tables 12 and 13 show, the greater estimated seasonal E (as determined by the evaporation model, Method 3) occurring at the higher yield levels connotes that the x-intercept of the biomass yield versus ET

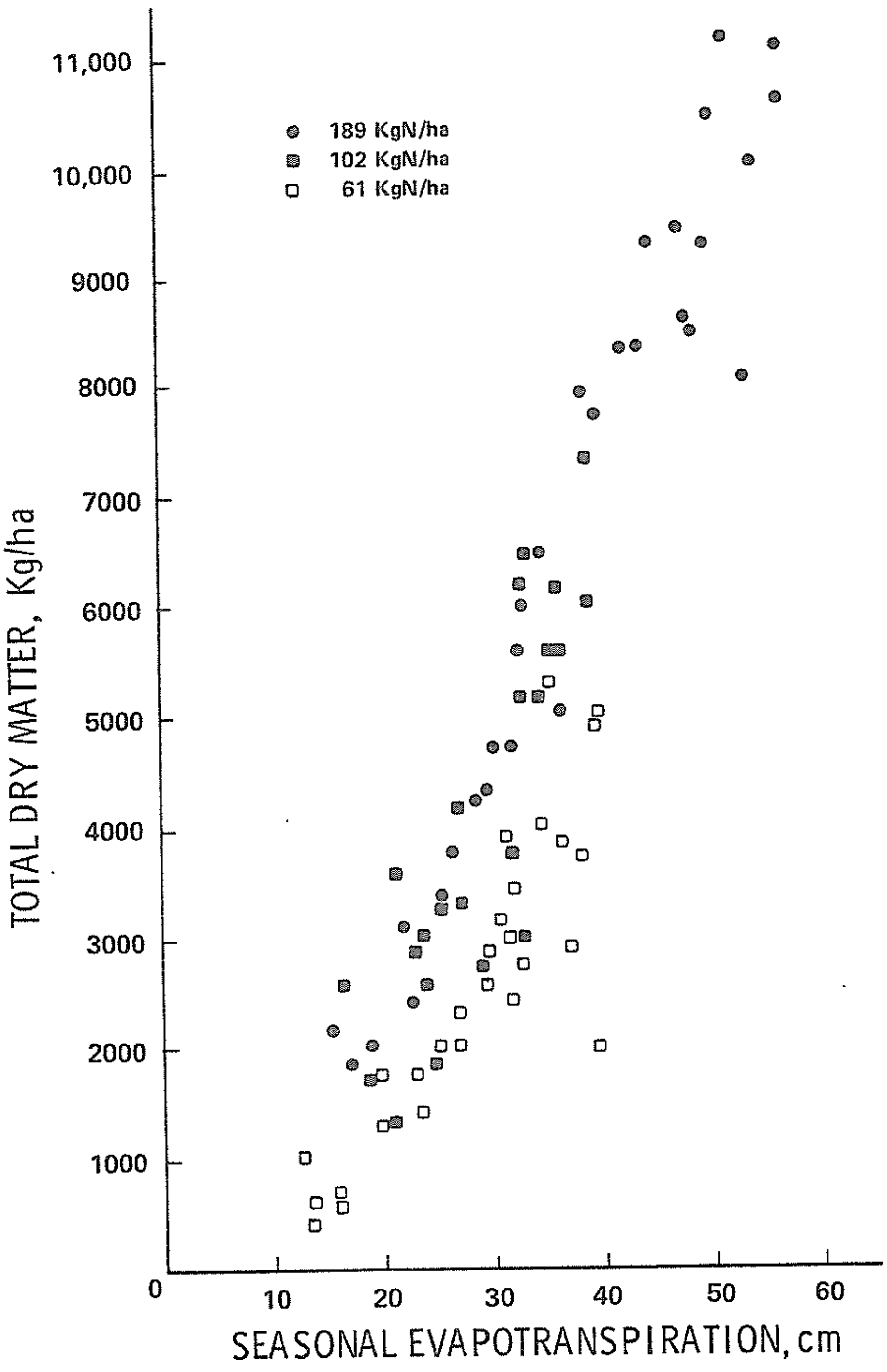

Figure 11. The plot of the total above-ground biomass (dry matter) yield of spring barley versus the seasonal ET, 1981. Due to significant point overlap it was not possible to plot all data points.

Table 17. Least-square-fit linear equations developed from the biomass data of each section of the 1981 barley plots; and the pairwise comparison of the equations for significant differences.

Nitrogen[1/]	Section	Equation	r^2	Letter of Equation	Significant Difference[2/]
Kg/ha		B(Kg/ha), ET(cm)			
189	1*	B = -1873 + 217.3(ET)	.93	A	C,D,E,F
189	2*	B = -2132 + 235.3(ET)	.94	B	C,D,E,F
102	1	B = -1444 + 211.5(ET)	.89	C	A,B,D,E,F
102	2	B = -3430 + 241.9(ET)	.85	D	A,B,C,E,F
61	1	B = -1175 + 125.9(ET)	.76	E	A,B,C,D
61	2	B = -2221 + 174.7(ET)	.80	F	A,B,C,D

[1/] Refers to estimated nitrogen utilized by highest yielding subplot in the plot.

[2/] Equation in previous column is significantly different at the 0.05 probability level from the equations below. The null hypothesis for the pairwise comparison is that the full and reduced model of the statistical procedure has a common intercept and linear coefficient. No significant differences exist among the six equations with reapect to their y-intercepts.

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

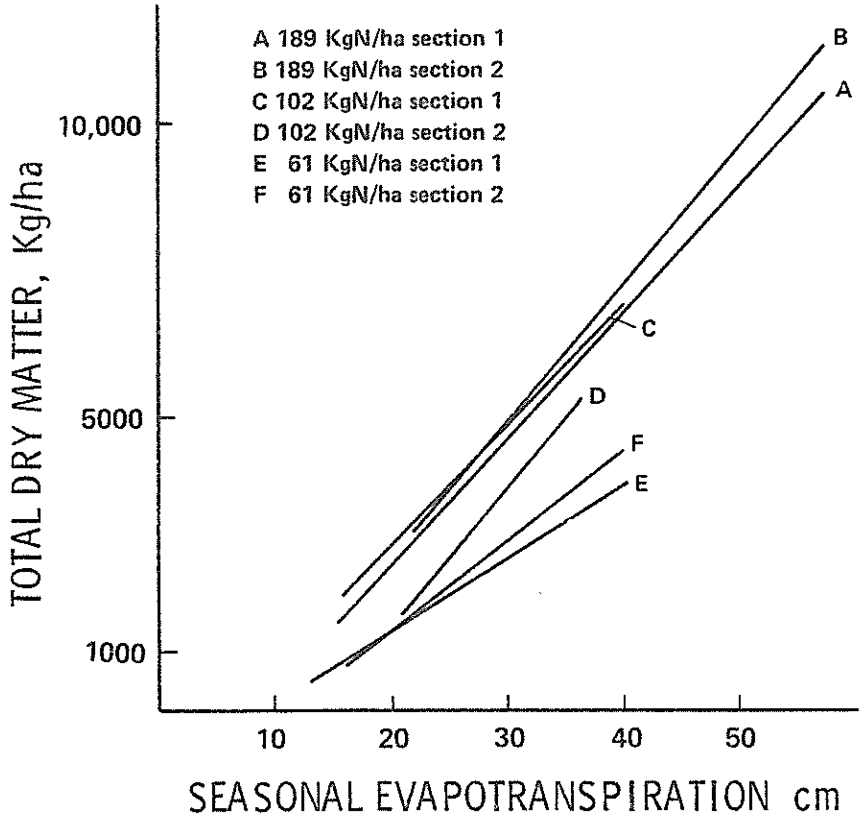

Figure 12. The relationship between biomass (dry matter) yield of spring barley and seasonal ET of each section of the SLS plots, 1981.

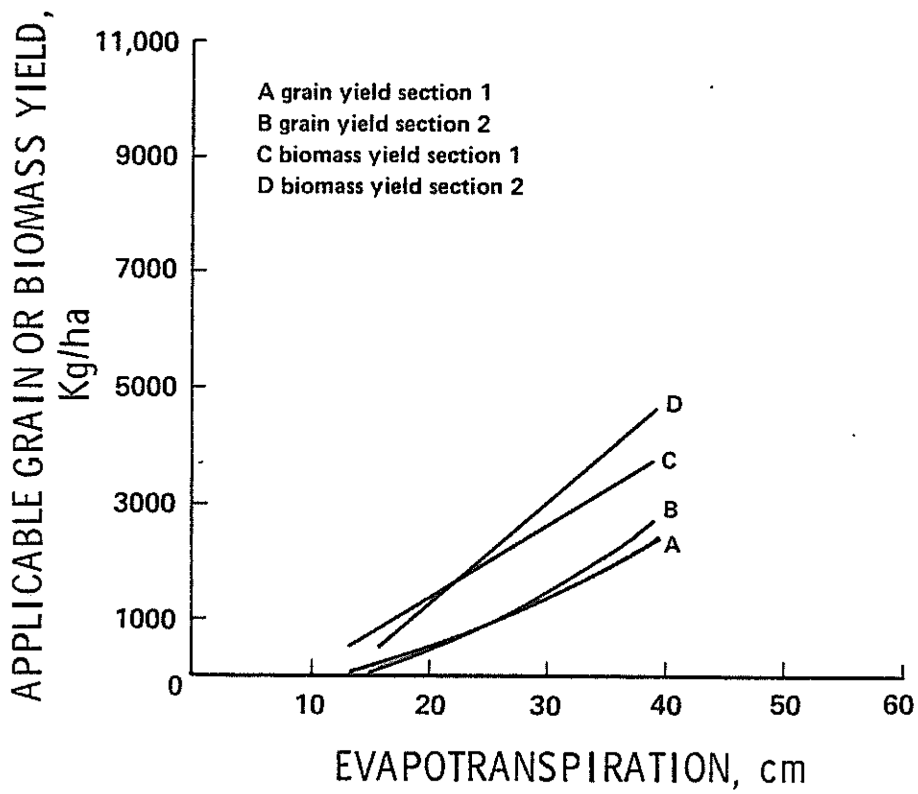

Figure 13. The water-production functions and the relationships of biomass yield to seasonal ET of the sections of the barley SLS plot utilizing a maximum of 61 Kg N/ha, 1981.

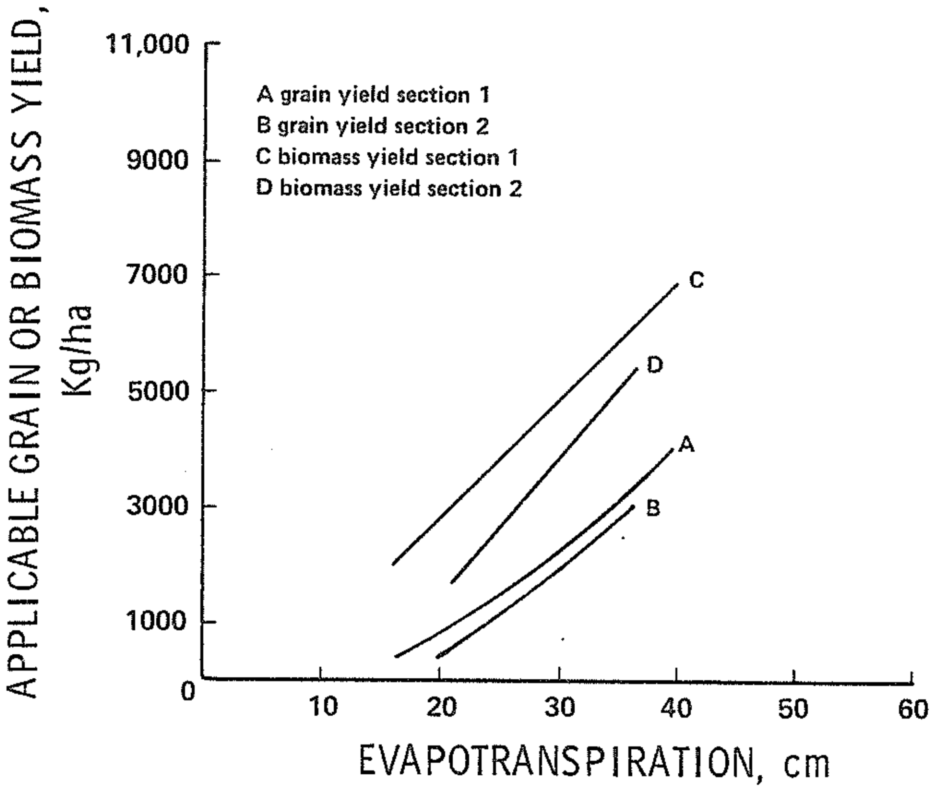

Figure 14. The water-production functions and the relationships of biomass yield to seasonal ET of the sections of the barley SLS plot utilizing a maximum of 102 Kg N/ha, 1981.

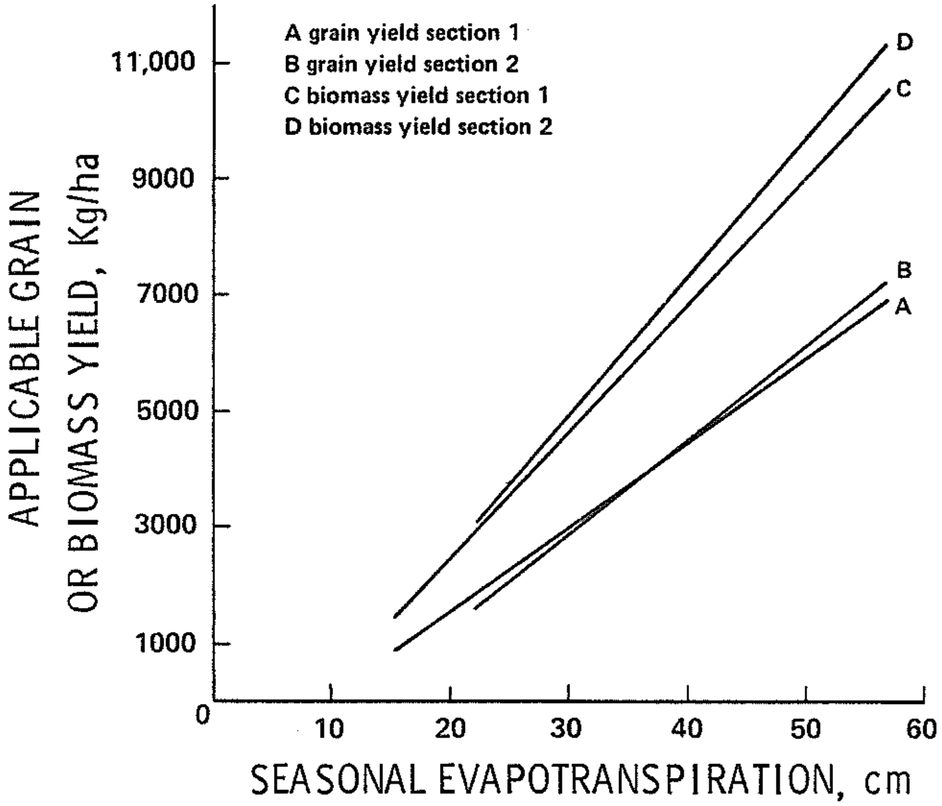

Figure 15. The water-production functions and the relationships of biomass yield to seasonal ET of the sections of the barley SLS plot utilizing a maximum of 189 Kg N/ha, 1981.

relationship is a poor indicator of the seasonal E of the crop spring barley, except perhaps at the low yield levels which are adjacent to the x-intercept. A mathematical method of calculating E from the functions presented in Figures 13, 14, and 15, which would give results more similar to those attained with Method 3 as discussed above, is by the determination of the x-intercept of the line tangent to the water-production function at the yield level for which an estimation of E is desired (Method 2). Table 18 presents the results which are obtained by comparing the three methods of estimating evaporation. The table clearly shows that the more similar results are obtained between Methods 2 and 3.

Figures 16 and 17 present data showing why the water-production functions may be a better indicator of evaporation than is Method 1 (the x-intercept of the biomass versus ET function). In Figure 16 the maximum LAI achieved by the plants of the subplot have been plotted versus the maximum daily ET measured at the maximum LAI of the subplot (the data utilized to produce Figures 16 and 17 is located in Appendix E, Table E1). Observe that at the maximum LAI achieved (approximately 3) a wide range of average maximum daily ET are possible. The line drawn through the points has not been mathematically fit to these points but has been eye-fit to demonstrate the apparent two-stage relationship. Figure 17 is related to Figure 16 but instead of ET being the abscissa the seasonal yield achieved by the subplot has been substituted. These figures demonstrate that once a threshold level of yield or daily ET has been reached, the maximum LAI achieved by the plant is

Table 18. A comparison of three methods of calculating evaporation from selected subplots of the 1981 SLS plots.

Nitrogen[1/]	Section	Method	Subplot Distance from Line m 12	8	0
Kg/ha			E,cm		
61	1	1*	9.3	9.3	9.3
		2*	12.2	16.4	21.8
		3*	9.8	20.7	24.8
61	2	1	12.7	12.7	12.7
		2	14.5	17.9	21.6
		3	17.5	22.0	24.8
102	1	1	6.8	6.8	6.8#
		2	14.6	16.6	21.2
		3	12.2	17.6	19.8
102	2	1	14.2	14.2	14.2#
		2	16.2	22.7	22.7
		3	15.7	21.1	19.8
189	1	1	8.6	8.6	8.6
		2	9.1	9.1	9.1
		3	10.9	13.8	13.1
189	2	1	9.1	9.1	9.1
		2	12.1	12.1	12.1
		3	15.1	13.1	13.1

1/ Refers to the utilization of nitrogen in the highest yielding subplot of the plot.

* 1 refers to the biomass intercept method, 2 to the x-intercept of the line tangent to the point on the water production function, and 3 to evaporation model as calculated by Equations 5, 6, and 7.

This subplot is 2 meters from the line source. Subplots closer were destroyed when an irrigation pipe burst.

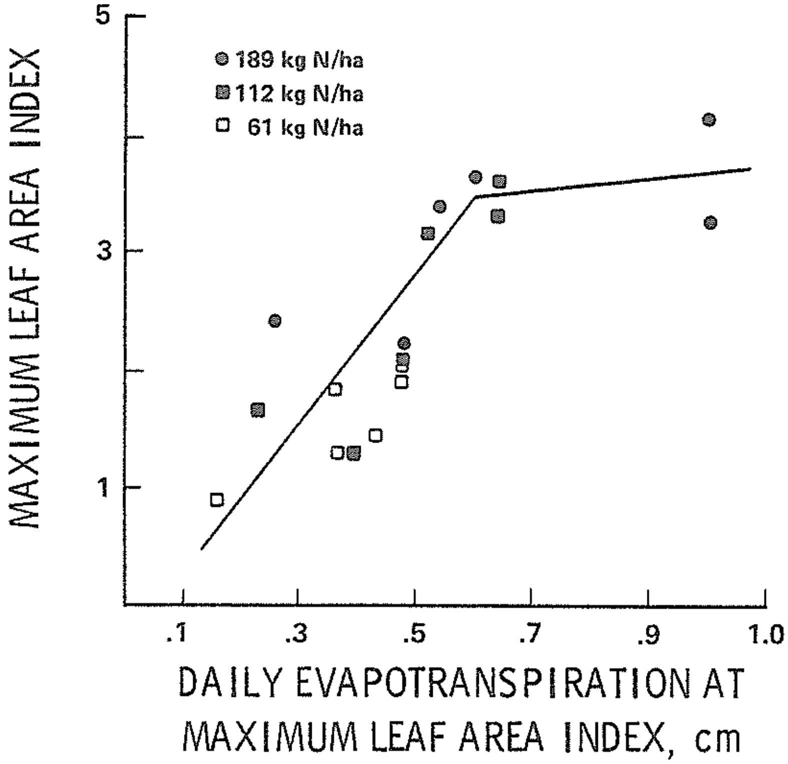

Figure 16. The relationship between the maximum leaf area index achieved by the spring barley subplot and the daily ET of the subplot at maximum leaf area index.

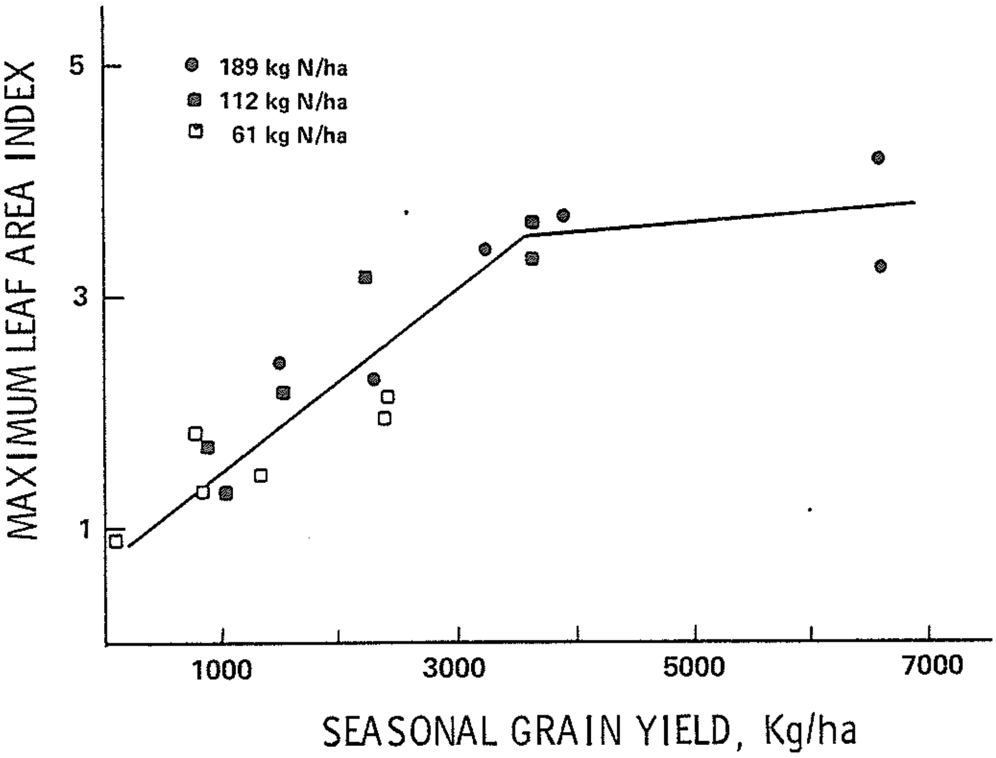

Figure 17. The relationship between maximum leaf area index achieved by the spring barley subplot and the eventual seasonal grain yield.

no longer correlated to these variates. Since the maximum LAI produced by the plants of the subplot must be directly correlated with the total non-grain biomass it follows that plants of similar LAI and thus non-grain biomass, can have different ET rates when LAI is greater than 3, and thus, eventually different economic yields. The total non-grain above-ground biomass as measured in the high-N SLS plot supports this assertion. Figure 18 is a plot of the non-grain biomass versus seasonal ET. The equation of Curve A of Figure 18 is as follows:

$$\text{non-grain biomass} = -1.56(\text{ET})^2 + 211.4(\text{ET}) - 1830 \quad (11)$$

where

non-grain biomass is measured in Kg/ha

ET is measured in centimeters

$r^2 = 0.84$

Curve B has also been displayed as a more likely theoretical best-fit of the data points since we hypothesize that a linear or concave upward relationship exists between non-grain biomass yield and ET, unless the crop surpasses an LAI of 3, which occurs at the higher yield levels and the higher rates of seasonal ET. Hence, seasonal economic yield and ET can increase even though non-grain biomass remains constant. This evidence supports the hypothesis that the grain component of the total above-ground biomass is that which results in the apparent good relationship between total above-ground biomass yield and ET. It is further hypothesized that the decreased ET and yield at similar LAI and non-grain

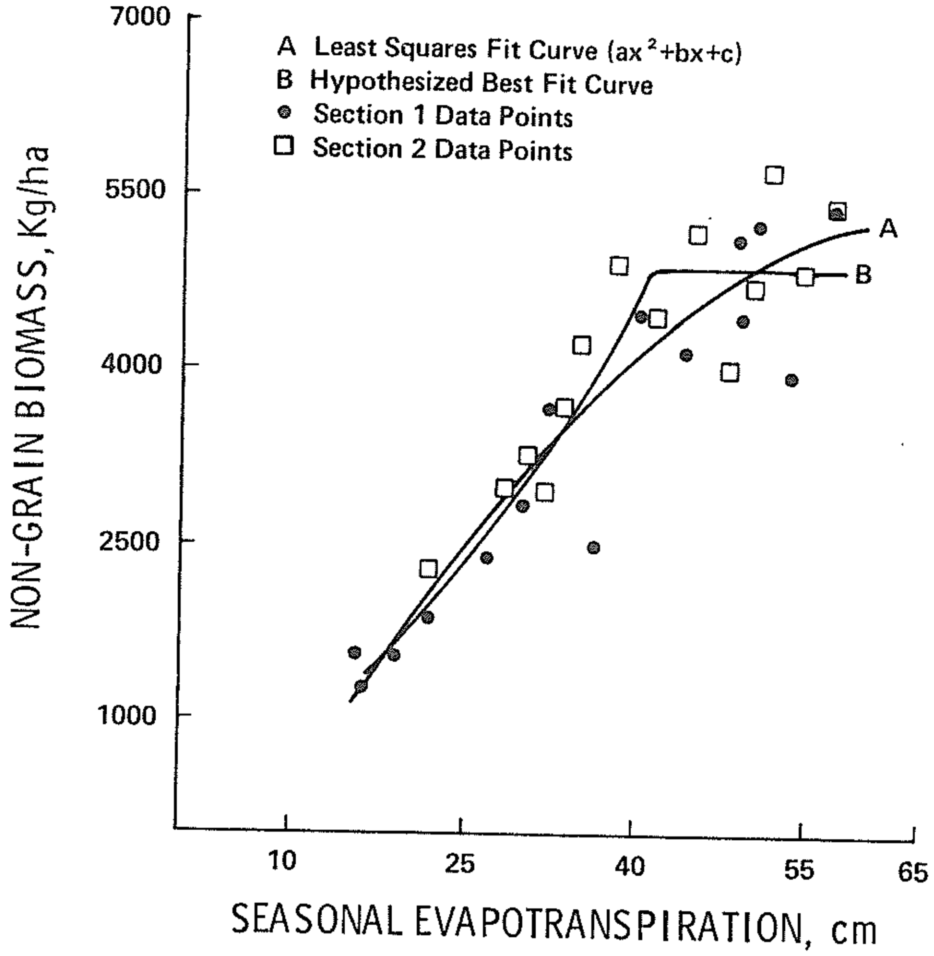

Figure 18. The relationship of seasonal ET and the nongrain biomass of the plot utilizing a maximum of 189 Kg N/ha, 1981.

biomass yield levels is the result of stomatal closure of mildly stressed plants subjected to greater water deficit than those more adjacent to the line source sprinkler. If the stomates close, not only does transpiration become negligible but the decrease in transpiration is directly correlated to the decreased diffusion of carbon dioxide into the leaf, thereby decreasing the assimilation of CO_2 into economic yield. Thus, an increase in economic yield cannot occur without a concomitant increase in transpiration. The water-production function probably provides a better indication of the photosynthate production of the crop at the higher ET levels than does the relationship between biomass yield and ET. The similarity between the seasonal ET estimates provided by Methods 2 and 3 (Table 18), also suggests that the water-production function appears to be more sensitive (as reflected in its curvilinearity) to changes in the magnitude of the evaporation components of ET and to the relative proportion of E to T.

Theoretically, some plant growth is necessary before measureable economic yield occurs associated with the development of reproductive structures. However, it has been the observation of the authors that barley and bean plants 10 centimeters in height are capable of producing small yields of hand-harvestable grain. The amount of leaf area necessary to produce some economic yield is very small, for all practical purposes negligible. Hence, we suggest that the relationship between economic yield and transpiration passes through the origin. Since this function passes close to the origin it is further suggested that the lateral displacement of a given point of the water-production function to the right, is the result of evaporation, and this evaporation can be numerically quantified as the x-intercept of the line tangent to the given point of the function.

The observation that biomass yield in alfalfa, which in this instance is the economic yield, is well correlated with ET, is probably the result of harvesting the alfalfa at one-tenth full bloom when the plant is in the vegetative exponential growth stage. This growth stage is characterized by a majority of the photosynthate production being directly partitioned into increased vegetative growth. Under these conditions the good correlation between yield and ET is expected.

Not only does the irrigator need to know how much water is required seasonally by the crop, but when during the season this water will be required. However, the differences in the parameters of the water production functions between the 1980 and 1981 growing seasons and within the 1981 growing season, make this type of determination difficult. As an example of the difficulties encountered, the daily ET requirement versus the accumulated GDD has been plotted in Figure 19 from selected 1980 and 1981 subplots which possessed similar yield levels. As discussed above, the large differences displayed are probably the result of differential evaporation and not transpirational differences.

The daily ET of those subplots which possessed access tubes, of the SLS plots utilizing 61, 102, and 189 Kg/ha of N, are presented in Tables F1, F2, and F3, respectively, in Appendix F.

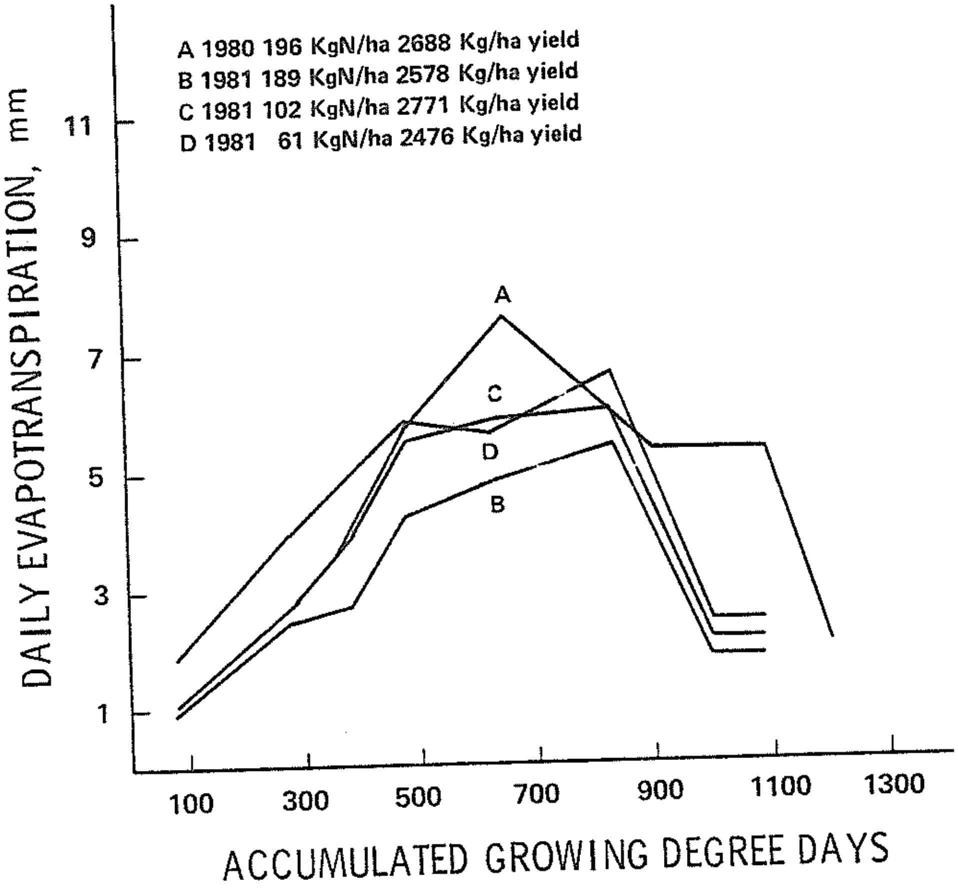

Figure 19. A comparison of the daily ET of similar yielding subplots of spring barley of 1980 and 1981.

These tables also contain the GDD accumulation, developmental stages, distances from the line source, and the yield of the subplot. Similar data for the SLS plots produced in 1980 have been previously published (12). The daily ET values presented are actually the average daily ET values of the period as averaged based on weekly measurements. Maximum daily ET values can be considerably higher. Seasonal GDD accumulation versus time during the growing season has been plotted for barley and alfalfa in Appendix G, Figure G1.

Table 19 is a comparison of the seasonal ET and daily ET of the high-nitrogen plots of 1980 and 1981 with yield interpolated to similar levels. The measured ET in the other 1981 SLS plots for equivalent yield levels would be significantly different. The GDD accumulations at the base of the table are most accurate for the higher yield levels. A shortening of the maturation period of 5 to 6 days was noted at the lower, generally sub-economic yield levels. This phenomenon was also observed by other investigators (5,16).

Note in this table, the large differences in the seasonal ET required to produce identical yield levels between years, especially at the lower yield levels. Another interesting observation which will be discussed further, is that the peak water use in 1980 occurred in the first half of the heading-to-physiological-maturity developmental stage, but occurred in the second half of this stage in 1981.

The estimated amount of N required to produce the yield is also given in this table. Sparrow (24) presented data showing that N utilization in excess of approximately 125 Kg/ha did not

Table 19. Average daily ET, seasonal ET, and nitrogen utilization of barley for the 1980 and 1981 growing seasons, interpolated to common yield levels, as determined in the plot with the highest nitrogen application and utilization.

				Growth Stage							
Yield	N#	Year	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
Kg/ha	Kg/ha		cm	ET cm/day per Period							
1000	22	1980	31	.11	.24	.37	.48	.54	.35	.37	.25
		1981	15	.06	.16	.27	.19	.17	.24	.08	.08
2000	50	1980	37	.09	.22	.53	.57	.63	.38	.39	.22
		1981	24	.07	.22	.22	.32	.35	.29	.18	.18
3000	80	1980	42	.09	.24	.43	.62	.72	.49	.49	.25
		1981	32	.10	.23	.30	.47	.52	.61	.20	.20
4000	105	1980	51	.10	.29	.49	.71	.86	.57	.57	.35
		1981	39	.11	.27	.39	.58	.64	.72	.27	.27
5000	135	1980	57	.08	.30	.55	.74	1.03	.67	.67	.32
		1981	42	.11	.32	.40	.70	.77	.86	.34	.34
6000	160	1980	61	.11	.27	.53	.79	1.05	.72	.72	.34
		1981	51	.14	.28	.42	.79	.89	1.04	.38	.38
7000	190	1980	64	.15	.24	.52	.84	1.08	.77	.77	.36
		1981	55	.12	.30	.42	.87	.98	1.07	.41	.41
			Seasonal GDD	Average GDD Accumulated by Barley in 1980 and 1981							
			1215	156	177	92	116	205	255	98	116

\# Nitrogen required to produce this yield.

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

increase grain yields of spring barley in England. This result demonstrates the danger inherent in applying data obtained in one location to predict performance in another. Sparrow also obtained yields of greater than 5000 Kg/ha with an N application of only 50 Kg/ha. A nitrogen utilization of this magnitude would only produce approximately 2000 Kg/ha of grain yield in northwest New Mexico. It is difficult to reconcile differences of this magnitude on the basis of location, and the performance of our plots suggests that the values given in Sparrow's paper are significantly in error.

Figure 20 is a plot of daily ET versus accumulated GDD for the highest yielding subplot of the high-N plots of 1980 and 1981. These two plots are similar which could be expected on the basis of their more similar seasonal ET as compared to the plots presented in Figure 19.

Method 3 of the three methods of calculating soil-water evaporation has the advantage of not only estimating E on a seasonal basis but also at time intervals within the season. Figure 21 presents a plot of daily ET versus time superimposed on the plot of the daily T versus time in the growing season for a yield level of 1534 and 6626 Kg/ha of grain. Both of these yield levels were measured in subplots of the 1981 high-N SLS plot. Curve B of the Figure suggests that the peak ET, discussed earlier with respect to the latter half of the heading-to-physiological-maturity developmental stage, as is presented in Table 19 for 1981, and as is shown in Curve A of this Figure,

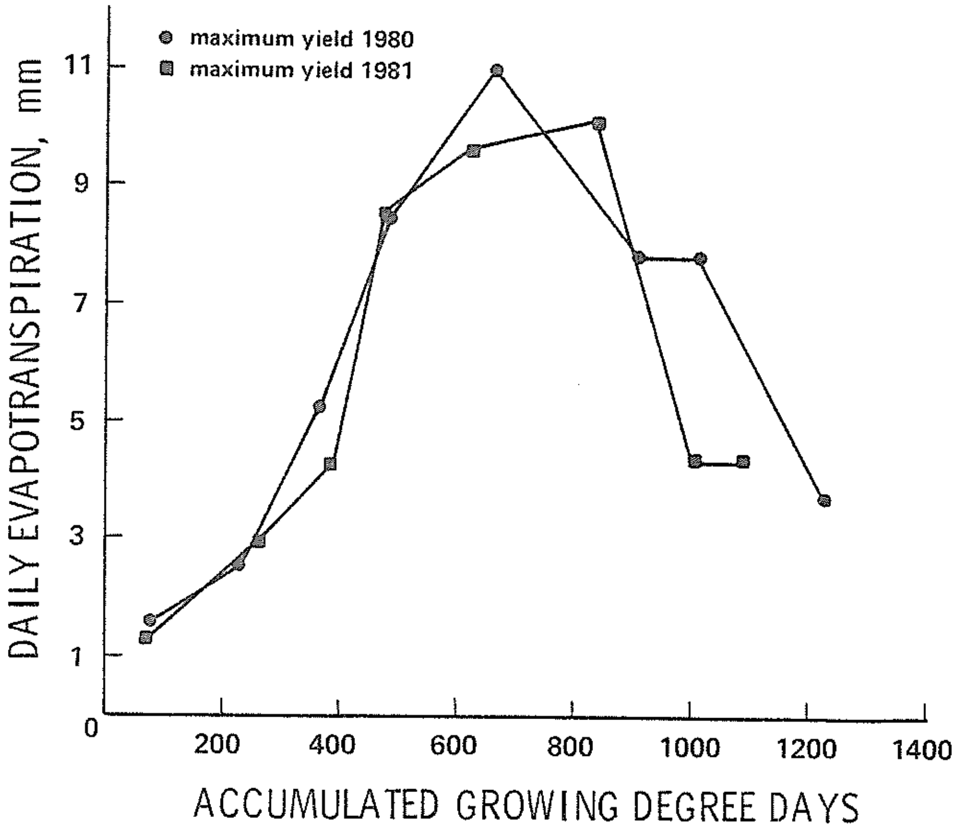

Figure 20. A comparison of daily ET of the highest yielding subplot of spring barley of 1980 and 1981.

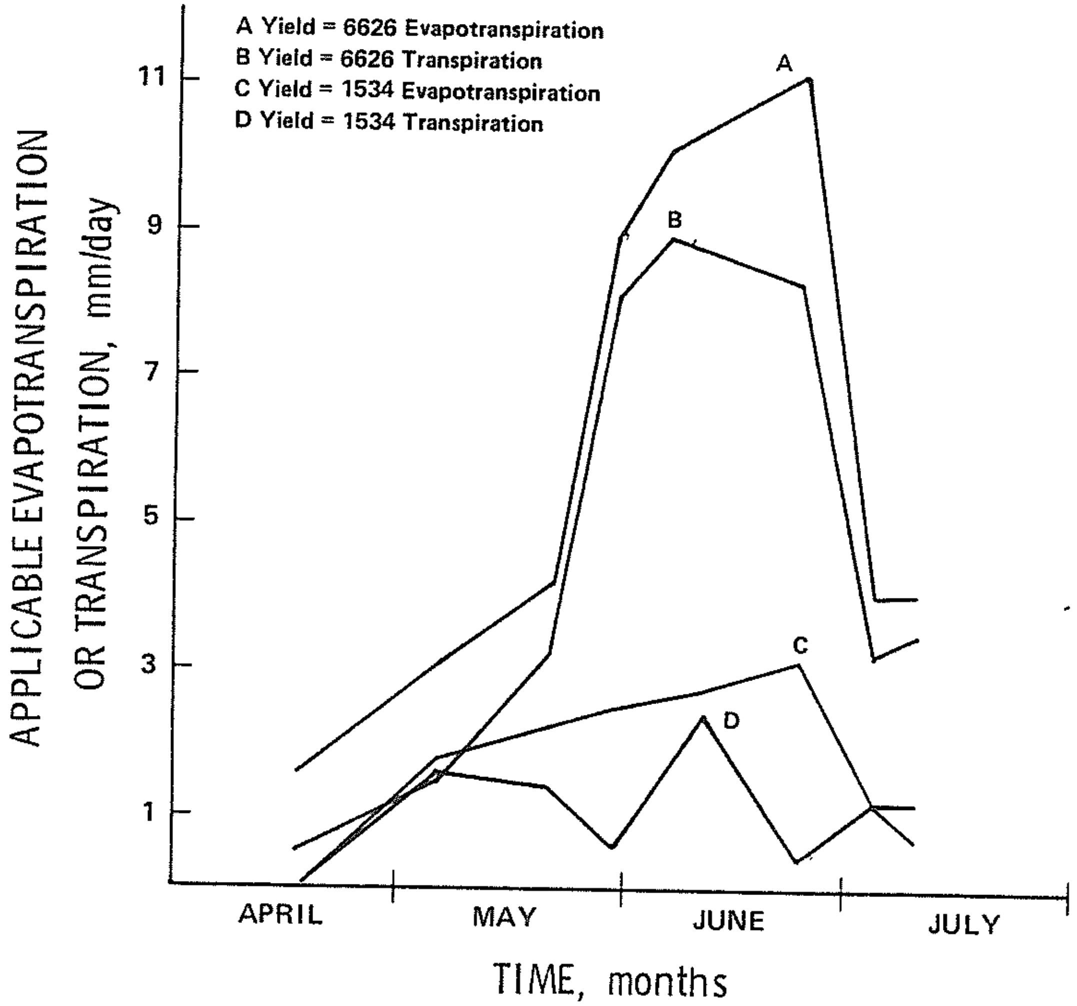

Figure 21. A comparison of transpiration and evapotranspiration of the highest and lowest yielding subplot of the spring barley SLS plot utilizing a maximum of 189 Kg N/ha.

is largely the result of soil-water evaporation. Transpiration (Curve B) actually peaked in the first half of this developmental stage as was the case in 1980.

Table 20 is identical to Table 19, but the daily ET has been divided by the daily PET (as calculated by the Penman method) to give the crop coefficient. Likewise, the seasonal ET was divided by the seasonal PET to give a seasonal crop coefficient. The seasonal crop coefficients tend to be more similar between growing seasons at the higher yield levels, but do nothing to explain the differences at the low yield levels. In addition, differences between seasons in the magnitude of the crop coefficients, calculated on shorter time intervals within the season, are large. The magnitude of the crop coefficients in 1981 during the heading stage suggest that ET proceeded at a rate independent of the measured PET, since the measured ET was similar to that measured in 1980. The general utility of the crop coefficient for the purpose of predicting irrigation requirement will be discussed more rigorously in a later section.

Pinto Beans

Pertinent crop information related to the production of the pinto bean SLS plots and lysimeters of the 1980 and 1981 growing seasons is summarized in Table 21. Note that the SLS plots of 1981 were initially irrigated one month earlier than the plots planted in 1980, which also advanced emergence and maturity by approximately the same length of time. Generally by May, the soils of the San Juan Agricultural Experiment Station have dried

Table 20. Average daily ET/PET, seasonal ET/PET, and nitrogen utilization of barley for the 1980 and 1981 growing seasons, interpolated to common yield levels, as determined in the plot with the highest nitrogen application and utilization.

				Growth Stage							
			Seasonal ET/PET+	Planting-Jointing		Jointing-Heading		Heading-Phys.Mat.		Phys.Mat.-Final	
Yield	N#	Year		1*	2*	1	2	1	2	1	2
Kg/ha	Kg/ha		cm	Daily ET/PET							
1000	22	1980	.37	.18	.40	.42	.54	.59	.42	.39	.29
		1981	.23	.10	.25	.38	.35	.21	.29	.10	.11
2000	50	1980	.44	.15	.37	.61	.64	.69	.46	.41	.25
		1981	.36	.12	.34	.31	.59	.42	.35	.23	.26
3000	80	1980	.50	.15	.40	.49	.69	.79	.59	.51	.29
		1981	.48	.17	.35	.42	.86	.63	.74	.25	.28
4000	105	1980	.60	.17	.48	.56	.79	.95	.68	.60	.40
		1981	.59	.19	.41	.55	1.07	.77	.88	.34	.38
5000	135	1980	.67	.13	.50	.64	.83	1.13	.80	.70	.37
		1981	.63	.19	.49	.56	1.29	.93	1.05	.43	.48
6000	160	1980	.72	.18	.45	.61	.88	1.15	.86	.76	.39
		1981	.77	.24	.43	.59	1.45	1.08	1.27	.48	.54
7000	190	1980	.75	.25	.40	.60	.93	1.18	.92	.81	.41
		1981	.83	.20	.46	.59	1.59	1.19	1.30	.52	.58
			Seasonal GDD	Average GDD Accumulated by Barley in 1980 and 1981							
			1215	156	177	92	116	205	255	98	116

\# Nitrogen required to produce this yield.

\+ PET calculated by the Penman method.

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

Table 21. Pinto bean crop production data.

Year	Location	Planting Date	First Irrigation	Emergence Date	Final Probe Reading	Harvest Date	Number of Plants per Square Meter
1980	Plots*	05/27/80	06/20/80	06/28/80	10/13/80	10/15/80	2.9
	Lysimeter	05/28/80	06/02/80	06/10/80	10/03/80	10/03/80	7.2
1981	Plots*	05/14/81	05/18/81	05/27/81	09/02/81	09/03/81	8.5
	Lysimeter	05/15/81	06/11/81	05/28/81	09/02/81	09/03/81	7.0

* Event dates are averages of all subplots.

to such an extent that an irrigation or heavy rain is required to germinate planted seed. Thus, usually shortly after the initial irrigation is the point at which crop growth begins. Also of note, is the observation that the SLS plots and the lysimeters contained a more similar plant population as compared to the situation which occurred in 1980.

As discussed in an earlier section a differential nitrogen application had been made in the SLS plots at planting; however, it was later determined that the beans were fixing atmospheric nitrogen. Hence, the three bean plots will be referred to on the basis of their relative respective compass positions as western, central, and eastern (Figure 5). Seasonal ET and yields of the eastern, central, and western SLS plots are presented in Tables 22, 23, and 24. These data have been plotted in Figure 22. It was not possible to plot all data points from these tables in this Figure due to substantial point overlap. The yield versus seasonal ET data points of the 1980 season can be found in Kallsen et al. (12). Water-production functions for each section of each plot are developed from the data tabulated in Tables 22, 23, and 24, and are presented in Table 25. The data were first fit, using a best least-squares-fit procedure, to a quadratic model ($ax^2 + bc + c$) for the purpose of comparing the functions for significant differences. In all cases the quadratic fit accounted for an equal or greater percentage of the total variation present than did the fit of a simple linear model. Only Equations (C) and (F) were not significantly different from each

Table 22. Seasonal evapotranspiration and yield of pinto beans grown in the east sprinkler-line-source plot for 1981.

Subplot Distance from the Line	Seasonal ET	Yield Mean[1/]	Yield SD
m	cm	Kg/ha	
	Section 1*		
11.9	23.9	760	201
11.1	26.4	1178	249
10.2	28.9	1266	267
9.4	31.4	1570	116
8.5	33.9	1621	266
7.7	34.6	2102	191
6.8	35.2	2254	44
6.0	38.4	2305	158
5.1	41.6	2583	474
4.3	44.0	2685	267
3.4	46.5	2837	244
2.6	47.1	3090	351
1.7	47.8	3330	209
0.9	52.0	3115	211
0.0	56.2	3419	395
	Section 2*		
11.9	29.3	1076	122
11.1	33.9	1444	114
10.2	38.4	1570	316
9.4	37.7	1760	258
8.5	37.0	1912	368
7.7	39.2	2267	420
6.8	41.3	1874	232
6.0	42.9	2406	316
5.1	44.6	3001	237
4.3	48.0	2809	384
3.4	51.4	2975	365
2.6	50.3	2913	267
1.7	49.1	3432	309
0.9	52.7	2887	431
0.0	56.2	3419	395

[1/] Average of three subsamples per subplot adjusted to 15.5 percent moisture.

* Section 1 and Section 2 designate east and west side of the plot, respectively.

Table 23. Seasonal evapotranspiration and yield of pinto beans grown in the central sprinkler-line-source plot for 1981.

Subplot Distance from the Line	Seasonal ET	Yield Mean[1/]	Yield SD
m	cm	Kg/ha	
	Section 1*		
11.9	24.2	1165	44
11.1	26.7	1304	171
10.2	29.2	1228	406
9.4	30.2	836	201
8.5	31.1	1393	458
7.7	33.3	1355	19
6.8	35.5	1621	343
6.0	37.6	1520	331
5.1	39.7	1596	263
4.3	42.1	2102	761
3.4	44.5	2039	365
2.6	44.8	2127	821
1.7	45.1	2989	1049
0.9	47.4	2583	331
0.0	49.8	2989	175
	Section 2*		
11.9	26.6	342	58
11.1	28.1	507	219
10.2	29.6	737	167
9.4	30.9	709	133
8.5	32.1	709	244
7.7	34.0	962	488
6.8	36.0	1314	490
6.0	38.1	1393	539
5.1	40.2	1596	622
4.3	41.2	1418	614
3.4	42.2	2241	646
2.6	44.0	2267	742
1.7	45.8	1963	546
0.9	47.8	2609	488
0.0	49.8	2989	175

[1/] Average of three subsamples per subplot adjusted to 15.5 percent moisture.

* Section 1 and Section 2 designate east and west side of the plot, respectively.

Table 24. Seasonal evapotranspiration and yield of pinto beans grown in the west sprinkler-line-source plot for 1981.

Subplot Distance from the Line	Seasonal ET	Yield Mean[1]	Yield SD
m	cm	Kg/ha	
	Section 1*		
11.9	25.0	709	44
11.1	27.9	583	44
10.2	30.7	1038	116
9.4	33.8	988	131
8.5	36.9	1545	43
7.7	38.4	1140	131
6.8	39.9	1773	116
6.0	42.6	1596	76
5.1	45.3	1722	418
4.3	49.1	1912	305
3.4	52.9	2761	614
2.6	53.5	2545	611
1.7	54.1	2457	833
0.9	56.8	3128	735
0.0	59.5	3204	932
	Section 2*		
11.9	26.7	203	44
11.1	28.4	152	132
10.2	30.0	291	96
9.4	31.6	393	122
8.5	33.1	684	152
7.7	35.9	772	79
6.8	38.8	1178	38
6.0	41.8	1469	158
5.1	44.8	1849	244
4.3	47.0	1760	323
3.4	49.3	2545	559
2.6	51.2	2773	625
1.7	53.1	3026	556
0.9	56.3	3178	979
0.0	59.5	3204	932

[1] Average of three subsamples per subplot adjusted to 15.5 percent moisture.

* Section 1 and Section 2 designate east and west side of the plot, respectively.

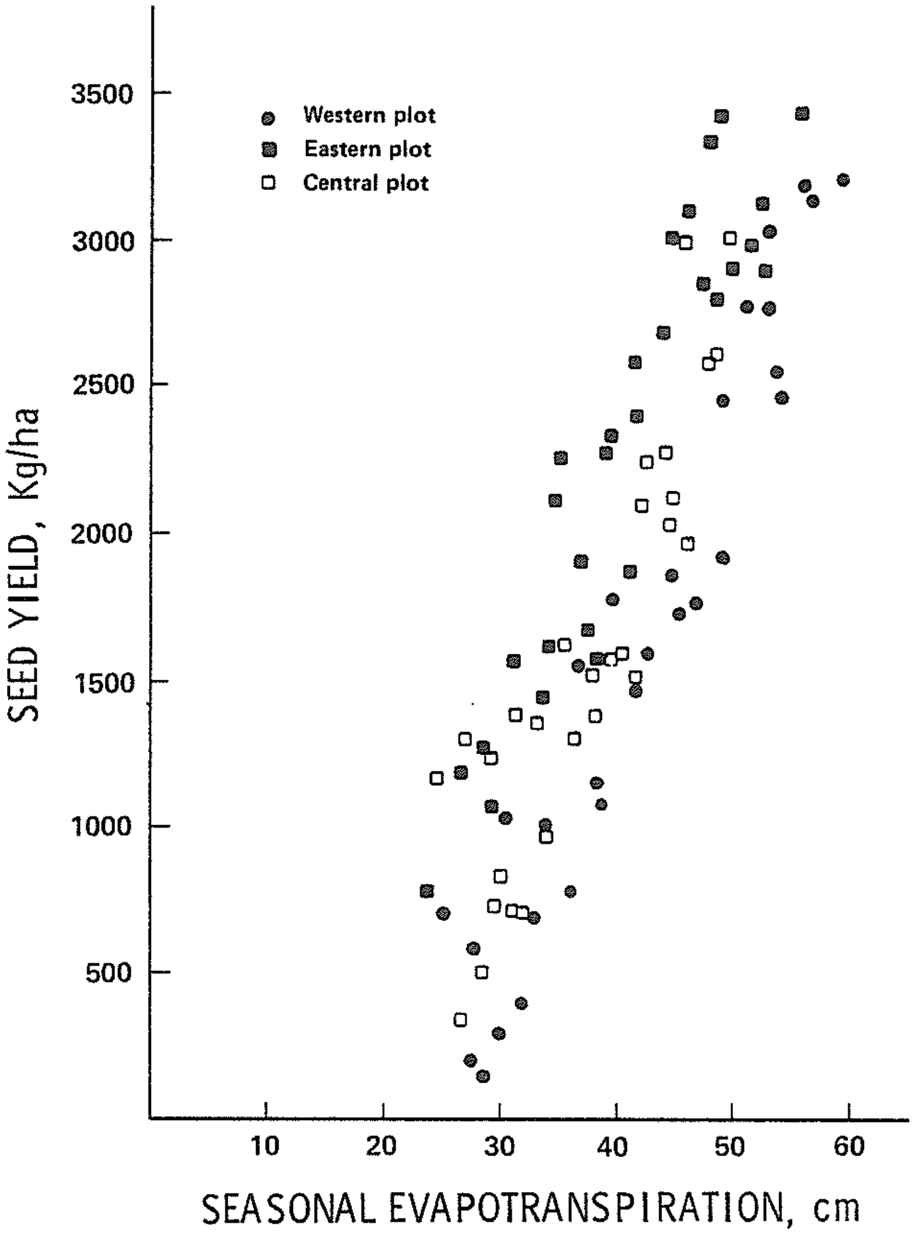

Figure 22. The plot of the measured seed yield of pinto beans versus the seasonal ET, 1981.

Table 25. Least-square-fit quadratic equations developed from the data of each section of the 1981 pinto bean plots; and the pairwise comparison of the equations for significant differences.

Plot	Section	Equation Y(Kg/ha),ET(cm)	r^2	Letter of Equation	Significant Difference[1/]
western*	1#	$Y = 74.5 + 0.9(ET)^2$	.95	A	B,C,D,E,F
western	2#	$Y = -2860.0 + 105.8(ET)$	.98	B	A,C,D,E,F
central	1	$Y = 322.8 + 1\ (ET)^2$	.84	C	A,B,D,E
central	2	$Y = -611.7 + 1.4(ET)^2$	.95	D	A,B,C,E,F
eastern	1	$Y = -1037.7 + 84.5(ET)$	.94	E	A,B,C,D,F
eastern	2	$Y = -1536.6 + 90.2(ET)$	.87	F	A,B,D,E

1/ Equation in previous column is significantly different at the 0.05 probability level from the equations 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.

* Refers to plot location with respect to location of other pinto plots. See Figure 5 for compass directions.

\# 1 and 2 represent the eastern and western half of the plot respectively. See Figure 5 for compass direction.

other. Even water-production functions produced in different sections of the identical plot were significantly different.

After this comparison was made non-significant variables were eliminated from the equations, based on a t-test of the partial regression coefficients. These equations with their coefficients of determination are presented in Table 25. Some of the water-production functions are significantly curvilinear, others are not. These water-production functions have been plotted in Figure 23. The lines or curves have not been drawn beyond seasonal ET rates measured in the sections of the SLS plots. Generally speaking, the water-production functions of the two sections within each SLS plot are more similar to one another than are sections between plots which suggests again, that the sprinkler-line source and the manner which it is operated is the dominant environmental variable in the plot. The large differences demonstrate the variability which can exist between SLS plots having similar yields, and which are produced in the same season. Another observation which should be noted is that the barley and alfalfa SLS plots were located on comparatively flat land, while the pinto bean plots contained areas of steeper slopes. Although care was taken to avoid puddling of irrigation water some runoff may have occurred in some areas of the plots.

Since it was determined that all SLS plots had been fixing nitrogen the seasonal ET versus yield points of the three plots of each year have been combined into two data sets respectively, and a regression line developed for each. The results are

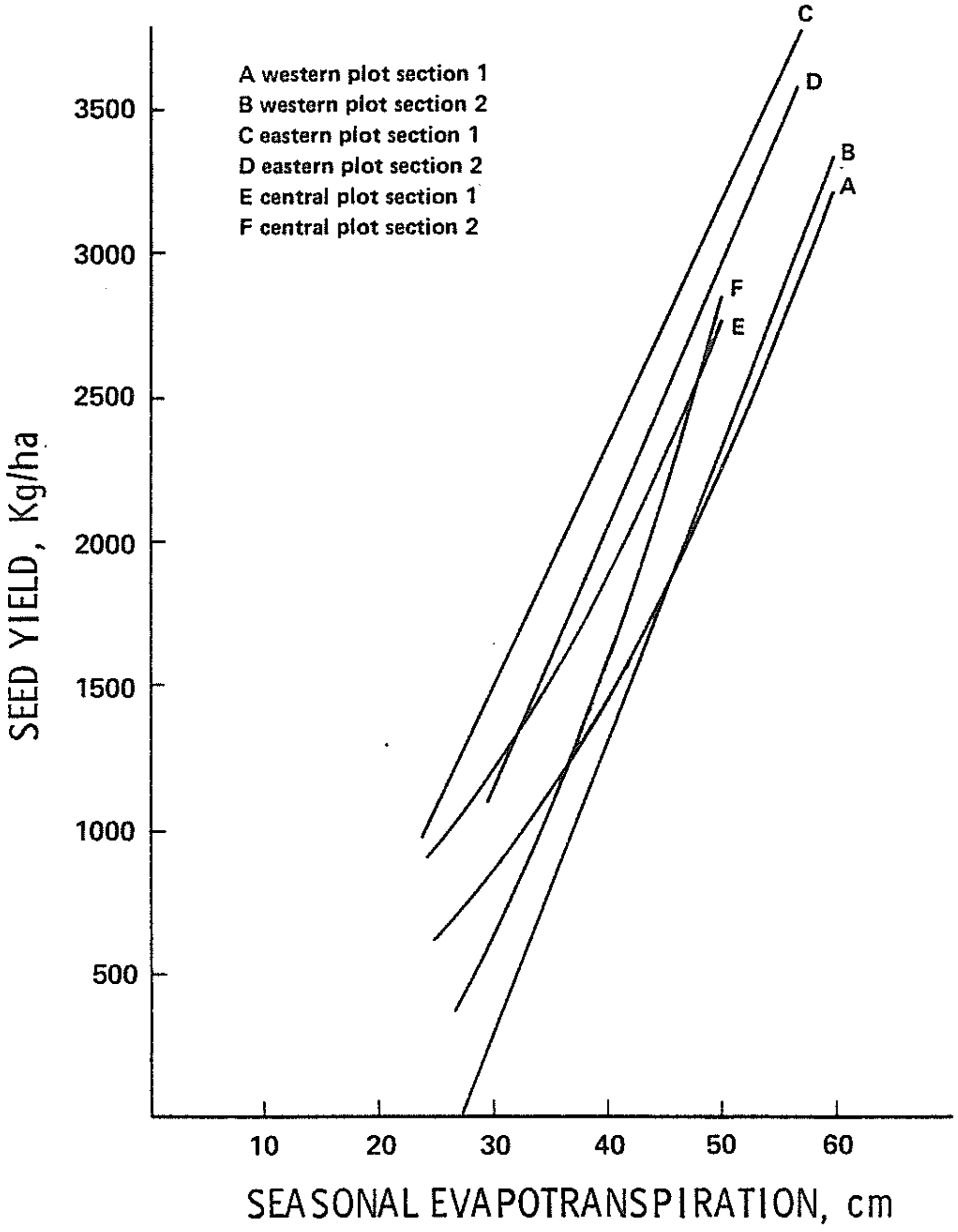

Figure 23. The water-production functions of each section of the pinto bean SLS plots, 1981.

presented in Figure 24. The solid lines represent areas of observed ET rates. The lysimeter yields and seasonal ET have been plotted but were not used in developing the regression lines. The dashed lines are extensions of the line to show the relation of the lysimeters to the water-production functions of the SLS plots. In 1981 the SLS plots yielded much better than did the 1980 plots. Even though the method of irrigation of the lysimeter is by a flood method and the SLS plot is by sprinkler, the lysimeter yields were not far from the water-production function, especially when the coefficients of determination (0.88 and 0.77, respectively for 1980 and 1981) of the lines are considered. This observation tends to suggest that interception of applied water by the crop canopy does not significantly alter the evapotranspiration requirement of crops grown under sprinkler irrigation. Note also, that the 1981 lysimeter-grown pinto beans possessed a slightly greater water-use efficiency than did the pinto beans grown in the SLS plots. The increased water-use efficiency of the 1981 lysimeter-grown pinto beans may be due to decreased evaporation in the lysimeters, as opposed to the 1981 SLS plots, as a result of fewer irrigations. The 1981 SLS plots were irrigated an average of 24 times, whereas the lysimeters were only irrigated 12 times. This differs from the 1980 season in that the SLS plots were irrigated an average of 21 times as opposed to 17 times for the lysimeters.

The lysimeter results are also interesting in that the yields in the lysimeters for both years are much greater than those

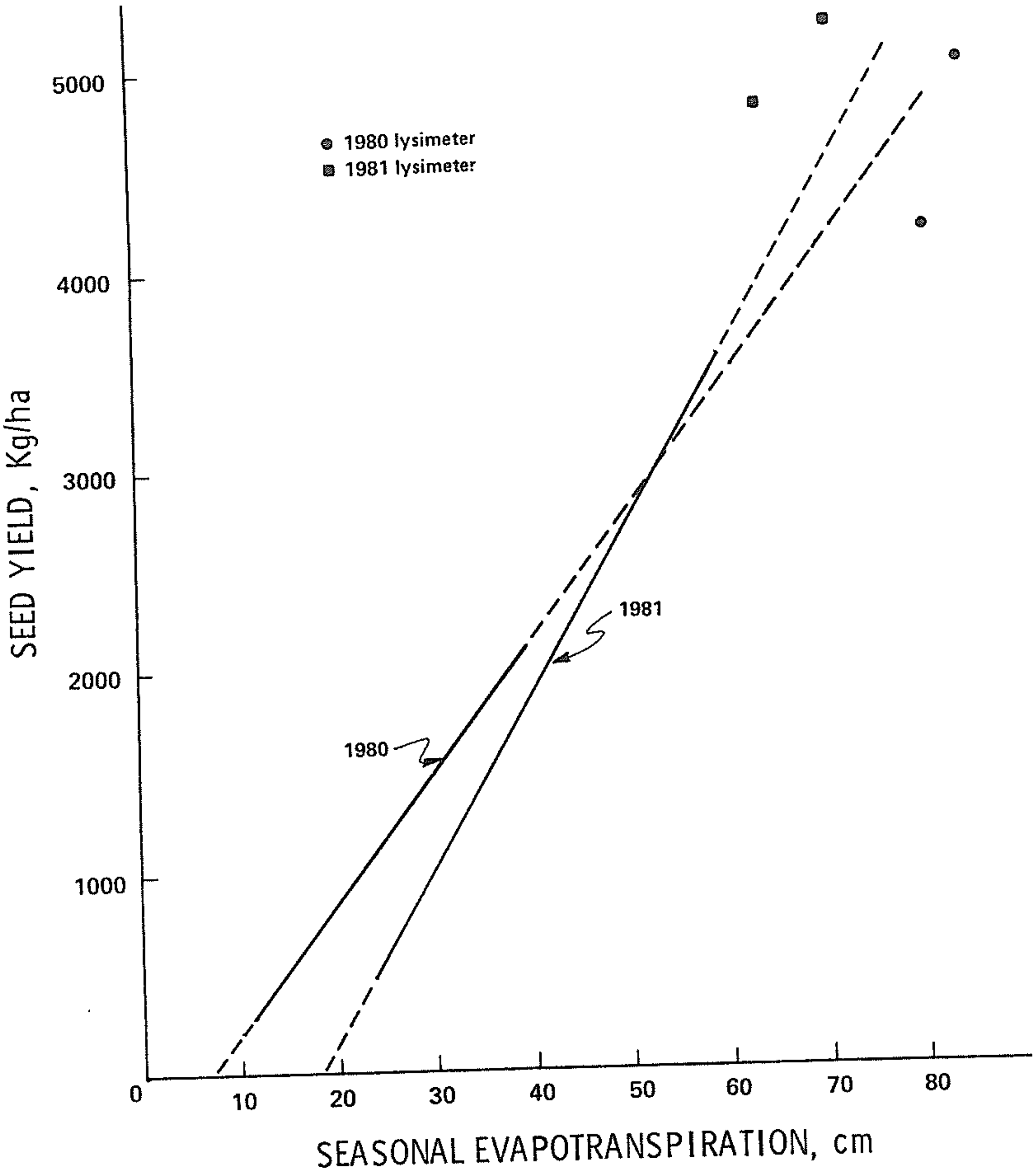

Figure 24. The water-production functions of pinto beans developed from all SLS plot data of 1980 and 1981. The equations of the lines are for 1980 Y(Kg/ha) = -347 + 55.8(ET,cm), $r^2 = 0.86$; and for 1981 Y(Kg/ha) = -1592 + 85.8(ET,cm), $r^2 = 0.77$.

produced in the SLS plots in the field. One hypothesis for this increased yield is that the black plastic, which provides a border around the lysimeter, tends to catch and hold heat at the beginning of the season when night temperatures are lower, which increases the growth rate. Since leaf area appears to initially accumulate in a "compound interest manner" (11, 17), it is suggested that early in the season warm temperatures promote rapid growth of leaf area which in turn, provides a greater area of photosynthate production which eventually results in greater economic yield. Measured evapotranspiration values in the lysimeters and in the SLS plots support this hypothesis (Figure 25). Note in Figure 25, the much greater daily ET rate of the lysimeters as opposed to the largest yielding SLS plot during the month of June.

In Table 26 daily and seasonal ET rates have been averaged from the data of subplots with similar yield levels, and interpolated to common yield levels for the purpose of comparing yearly performance. The actual observed data points for 1981 can be found in the Appendix in Tables F4, F5, and F6. The same data for 1980 can be found in Kallsen et al. (12). The daily ET as expressed in Table 26 is the average of the respective periods based on a measurement time interval of one week. The water use on a seasonal basis at the 500 and 1000 Kg/ha yield levels during 1981 was much greater in 1981 than in 1980. Note, that to produce 500 Kg/ha of beans required 17.3 centimeters of water in 1980 and 29.3 centimeters in 1981. Much of this difference may be due to differential evaporation losses.

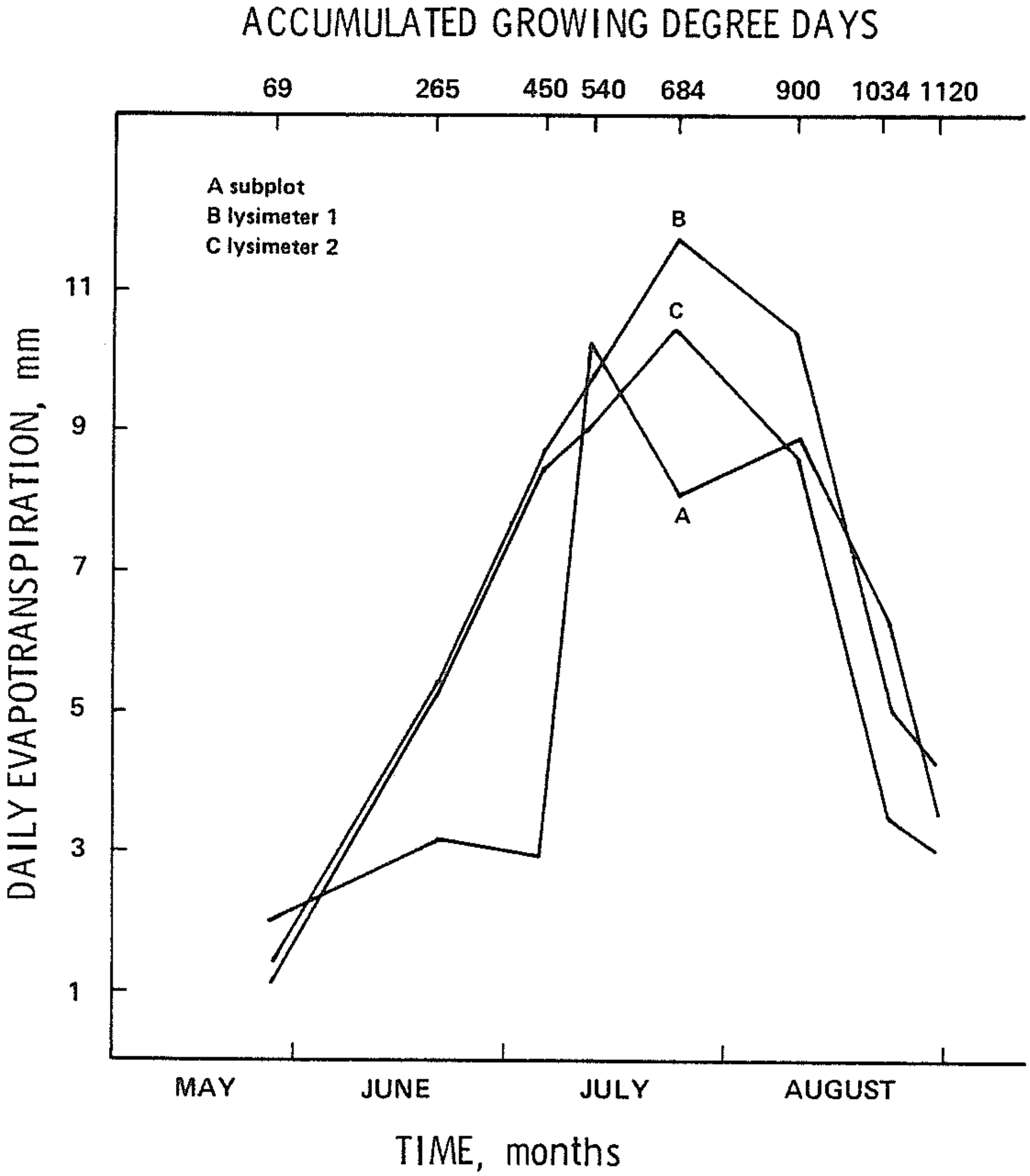

Figure 25. A comparison of daily ET of the lysimeters and the highest yielding subplot of the pinto bean SLS plots, 1981.

Table 26. Average daily and seasonal evapotranspiration of field-grown pinto beans interpolated to similar yield levels for 1980 and 1981.

			Growth Stage							
			Planting to Nine-Nodes		Nine-Nodes to First Flower		First Flower to 50% Pod Stripe		50% Pod Stripe to Final	
Yield	Year	Seasonal ET	1*	2*	1	2	1	2	1	2
Kg/ha		cm	Daily ET cm/day							
500	1980	17.3	.07	.10	.14	.16	.24	.18	.16	.08
	1981	29.3	.17	.22	.19	.78	.30	.39	.15	.08
1000	1980	23.9	.12	.14	.18	.23	.32	.26	.22	.08
	1981	31.3	.17	.23	.19	.69	.43	.36	.20	.13
1500	1980	31.6	.19	.26	.26	.81	.51	.49	.27	.17
	1981	38.2	.17	.28	.23	.90	.55	.63	.29	.22
2000	1981	42.4	.17	.28	.23	.90	.55	.63	.29	.22
2500	1981	46.6	.18	.29	.28	.98	.65	.57	.49	.35
3000	1981	50.2	.22	.31	.27	1.00	.71	.69	.41	.28
3500	1981	54.4	.25	.36	.29	1.18	.74	.71	.40	.31
		Seasonal GDD	Average GDD Accumulated by Pintos in 1980 and 1981							
		1127	148	251	81	79	216	196	84	73

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

If the x-intercept of the water-production function can be used to estimate evaporation losses, then it can be seen in Figure 24 that the x-intercept of 1981 was much greater in magnitude than in 1980. Actual average daily ET/period were more similar between years at 1500 Kg/ha yield level. Average GDD accumulated during the season and within developmental stages is also presented.

Crop coefficients have been calculated for the pinto bean SLS plots and are presented in Table 27. Table 27 has an identical format to Table 26 except the seasonal ET and daily ET/period values have been divided through by the seasonal PET and average daily PET/period. Potential evapotranspiration is calculated by the Penman method. Note the differences in the seasonal crop coefficients between years and between periods. Note also the magnitude of the crop coefficients at all 1981 yield levels for the period Nine-Nodes to First Flower. Seasonal GDD accumulation versus time during the growing season has been plotted for pinto beans in Appendix G, Figure G2. The significance of these observations will be discussed in a later section.

The same information as is presented in Tables 26 and 27 for the SLS plots is contained in Table 28 for the lysimeter-grown beans. Yields of the magnitude of those presented in this table would not be expected, nor would one want to attempt to produce them, in a commercial farming operation. They are the result of a peculiar microenvironment associated with the lysimeters. A yield of 3000-3500 Kg/ha is considered excellent under irrigated agriculture in northwestern New Mexico.

Table 27. Average daily and seasonal ET/PET of field-grown pinto beans interpolated to similar yield levels for 1980 and 1981.

			Growth Stage							
			Planting to Nine-Nodes		Nine-Nodes to First Flower		First Flower to 50% Pod Stripe		50% Pod Stripe to Final	
Yield	Year	Seasonal ET/PET	1*	2*	1	2	1	2	1	2
Kg/ha		cm	Daily ET/PET#							
500	1980	.21	.08	.11	.17	.21	.34	.31	.27	.15
	1981	.38	.25	.26	.24	1.25	.42	.60	.22	.14
1000	1980	.29	.15	.16	.22	.30	.46	.45	.37	.15
	1981	.41	.25	.27	.29	1.10	.61	.56	.29	.23
1500	1980	.38	.23	.29	.32	1.05	.73	.85	.45	.33
	1981	.50	.25	.33	.35	1.44	.78	.98	.42	.39
2000	1981	.55	.25	.33	.28	1.44	.78	.98	.42	.39
2500	1981	.61	.27	.35	.35	1.57	.92	.88	.70	.62
3000	1981	.66	.33	.37	.34	1.60	1.00	1.07	.59	.49
3500	1981	.71	.38	.43	.36	1.89	1.05	1.10	.57	.55
		Seasonal GDD	Average GDD Accumulated by Pintos in 1980 and 1981							
		1127	148	251	81	79	216	196	84	73

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

\# PET calculated by the Penman method.

Table 28. Yield, GDD, and average daily and seasonal ET, ET/PET, of 1980 and 1981 lysimeter-grown pinto beans.

			Growth Stage							
Year and Lysimeter Number	Yield	Seasonal ET	Planting to Nine-Nodes 1*	Planting to Nine-Nodes 2*	Nine-Nodes to First Flower 1	Nine-Nodes to First Flower 2	First Flower to 50% Pod Stripe 1	First Flower to 50% Pod Stripe 2	50% Pod Stripe to Final 1	50% Pod Stripe to Final 2
	Kg/ha	cm	Daily ET cm/day							
1980/1	4987	85.6	.31	.54	.73	.76	1.14	.97	.49	.25
1980/2	4147	81.2	.31	.47	.69	.74	1.14	.95	.47	.23
1981/1	5314	71.5	.11	.52	.87	.98	1.17	1.04	.51	.43
1981/2	4775	64.7	.14	.53	.85	.89	1.04	.86	.35	.30
		Seasonal ET/PET#	Daily ET/PET							
1980/1	4987	.88	.33	.64	.76	.90	1.46	1.70	.69	.46
1980/2	4147	.83	.33	.56	.74	.88	1.46	1.67	.66	.41
1981/1	5314	.76	.17	.62	1.09	1.56	1.65	1.60	.73	.77
1981/2	4775	.69	.21	.63	1.06	1.41	1.46	1.32	.50	.54
		Accumulated GDD	GDD/Period							
1980		1205	151	267	88	92	228	208	94	77
1981		1131	144	254	82	83	218	197	86	66

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

\# PET calculated by the Penman method.

Pinto beans also appear to possess differential maximum daily ET rates and seasonal yield levels, independent of the maximum leaf area index achieved by the crop, once a minimum level of LAI has been achieved. These relationships have been plotted in Figures 26 and 27, respectively. The data points have been tabulated in Table E2, Appendix E.

Alfalfa

Pertinent crop information relating to the production of the alfalfa SLS plot is summarized in Table 29. Alfalfa plants were observed to have approximately six small leaves when the initial probe readings were taken.

Seasonal ET and yield of harvests (cuttings) one through four are presented in Tables 30, 31, 32, and 33, respectively.

The water-production functions based on the best least-squares fit of the data points shown in Tables 30, 31, 32, and 33 are presented in Table 34. The data points were not significantly curvilinear so were fit to a linear model. The intercepts and slopes of the water-production functions produced from data obtained in the lysimeters were not significantly different from those produced in the non-lysimeter area of the SLS plot. This observation demonstrates that upward nonsaturated flow of water from depths below the rhizosphere of the alfalfa was negligible. Since the slopes and intercepts of the lysimeter and non-lysimeter water-production functions were not significantly different, the data points were combined in calculating the functions shown in Table 34. The functions in Table 34 have been plotted in Figure 28.

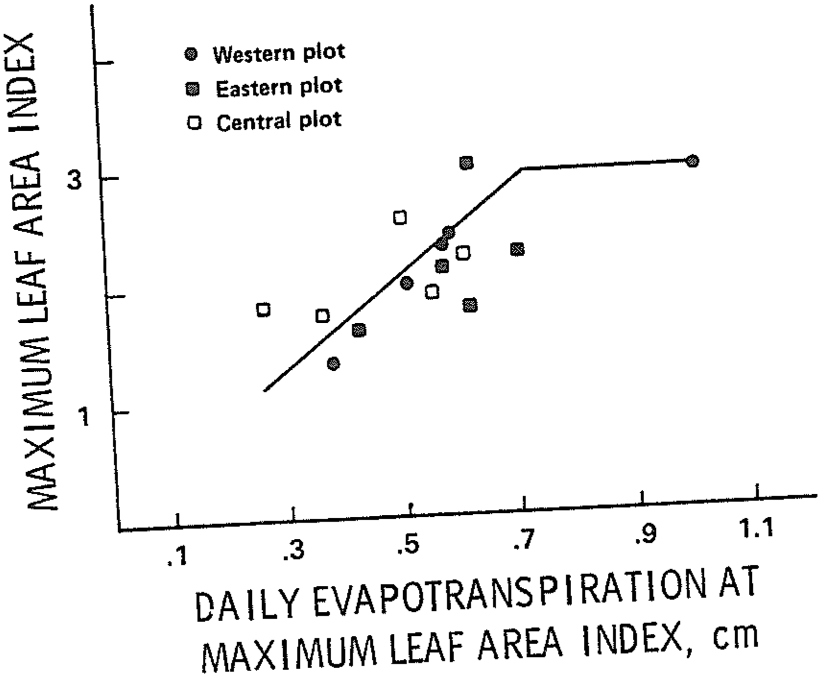

Figure 26. The relationship between the maximum leaf area index achieved by the pinto bean subplot and the daily ET of the subplot at maximum leaf area index.

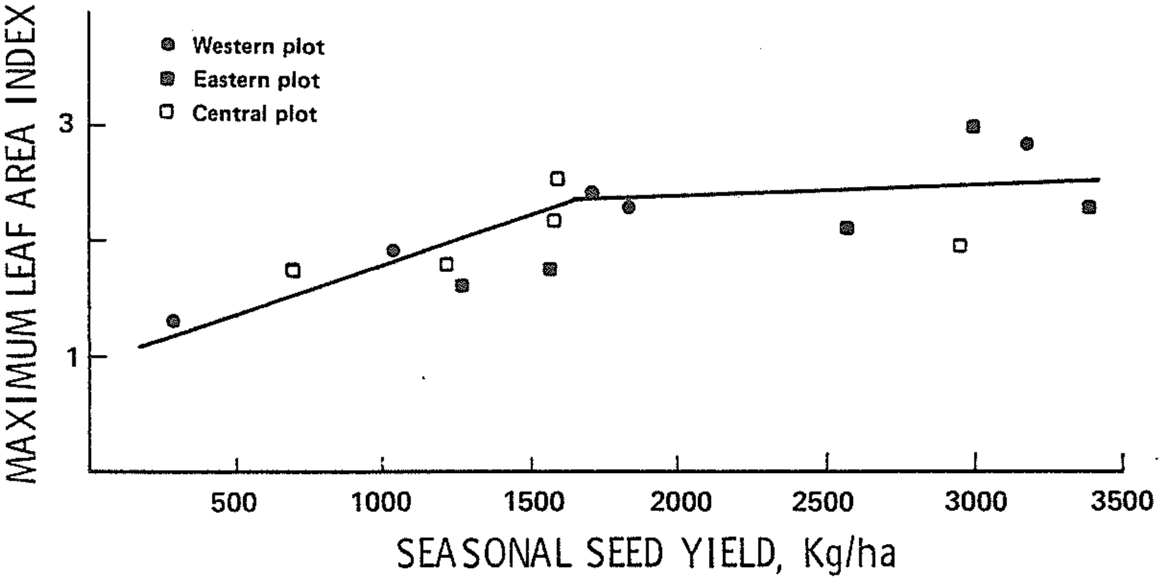

Figure 27. The relationship between maximum leaf area index achieved by the pinto bean subplot and the eventual seed yield.

Table 29. Alfalfa crop production data for 1981.

Planting Date	Emergence Date	Initial Probe Reading	Cutting Dates				Final Probe Reading
			First	Second	Third	Fourth	
08/22/80	08/26/80	04/09/81	06/16/81	07/23/81	08/25/81	10/13/81	10/14/81

Table 30. Evapotranspiration and yield of the first cutting of alfalfa.

Distance from the Line	Yield Kg/ha	SD	ET
m			cm
	Section 1#		
12.8	929	387	9.3
11.9	1557	328	15.3
11.0	3414	369	21.2
10.1	3701	505	27.0
9.1	4671	163	32.8
8.2	4752	429	34.8
7.3	4138	348	36.7
7.1*	5613	-	50.7
6.4	4807	480	38.3
5.5	4971	387	39.9
4.6	5217	23	41.6
3.8*	6744	-	54.9
3.7	5244	226	43.3
2.7	5053	404	43.0
1.8	4780	263	42.7
.9	5982	997	44.5
.5*	6924	-	60.1
0	6009	400	46.2
	Section 2#		
12.8	2240	237	20.3
11.9	3141	95	24.6
11.0	3250	263	28.8
10.1	3851	426	32.1
9.1	4479	95	35.3
8.2	4944	250	34.8
7.3	4889	533	34.2
6.4	4998	434	38.3
5.5	4998	410	42.5
4.6	5189	331	41.8
3.7	5490	498	41.1
2.7	5326	217	42.3
1.8	5517	657	43.4
.9	5763	189	44.8
0	6009	400	46.2

\# Section 1 and Section 2 designate east and west side of the plot, respectively.

* Lysimeter 1, 2, and 3, respectively.

Table 31. Evapotranspiration and yield of the second cutting of alfalfa.

Distance from the Line	Yield Kg/ha	SD	ET
m			cm
	Section 1#		
12.8	191	95	16.4
11.9	328	82	19.8
11.0	983	217	23.2
10.1	1502	171	26.5
9.1	2376	375	29.8
8.2	3605	1002	33.8
7.3	3715	620	37.9
7.1*	1704	-	28.7
6.4	4725	520	37.3
5.5	4288	581	36.8
4.6	4506	498	36.5
3.8*	4138	-	41.9
3.7	4403	990	36.3
2.7	4179	246	35.6
1.8	4015	295	35.0
.9	4178	469	37.8
.5*	4646	-	40.5
0	3851	394	40.5
	Section 2#		
12.8	1284	237	22.9
11.9	1584	189	26.7
11.0	1939	171	30.6
10.1	1748	494	32.5
9.1	1830	263	34.3
8.2	3086	884	34.5
7.3	3960	824	34.7
6.4	4615	331	36.7
5.5	4452	404	38.7
4.6	4370	331	39.4
3.7	3906	420	40.1
2.7	4343	357	37.8
1.8	3988	546	35.5
.9	3851	394	38.0
0	3851	394	40.5

\# Section 1 and Section 2 designate east and west side of the plot, respectively.

* Lysimeter 1, 2, and 3, respectively.

Table 32. Evapotranspiration and yield of the third cutting of alfalfa.

Distance from the Line	Yield Kg/ha	SD	ET
m			cm
	Section 1#		
12.8	66	28	8.2
11.9	492	217	11.1
11.0	1093	125	13.9
10.1	1693	47	16.3
9.1	1775	206	18.7
8.2	2294	75	20.5
7.3	2950	156	22.2
7.1*	2499	-	17.4
6.4	3387	47	25.3
5.5	3250	206	28.3
4.6	3387	70	30.1
3.8*	3319	-	22.4
3.7	3359	75	32.0
2.7	3523	142	30.8
1.8	3359	426	29.6
.9	3441	475	29.6
.5*	4392	-	29.8
0	3523	220	29.7
	Section 2#		
12.8	137	47	7.9
11.9	137	47	10.1
11.0	710	47	12.4
10.1	1639	700	15.1
9.1	1939	341	17.9
8.2	2321	501	19.7
7.3	3031	886	21.5
6.4	3114	456	22.1
5.5	3633	206	22.7
4.6	4042	331	22.8
3.7	3878	171	22.9
2.7	4015	82	28.1
1.8	3469	47	33.4
.9	3947	430	31.5
0	3523	220	29.7

Section 1 and Section 2 designate east and west side of the plot, respectively.

* Lysimeter 1, 2, and 3, respectively.

Table 33. Evapotranspiration and yield of the fourth cutting of alfalfa.

Distance from the Line	Yield Kg/ha	SD	ET
m			cm
	Section 1#		
12.8	36	19	10.5
11.9	164	142	13.2
11.0	669	144	15.8
10.1	1065	142	18.0
9.1	1311	217	20.2
8.2	1855	93	21.2
7.3	2294	17	22.3
7.1*	2393	-	23.1
6.4	2294	246	22.6
5.5	2567	206	22.9
4.6	2759	261	24.1
3.8*	3171	-	25.6
3.7	2540	17	25.3
2.7	2622	217	27.2
1.8	2404	125	29.1
.9	2950	150	31.7
.5*	3351	-	29.0
0	2759	180	34.3
	Section 2#		
12.8	191	95	11.2
11.9	246	142	12.1
11.0	437	263	13.0
10.1	628	451	14.7
9.1	1038	331	16.5
8.2	1721	537	18.8
7.3	2185	576	21.0
6.4	2485	387	21.9
5.5	2731	171	22.8
4.6	3114	142	24.6
3.7	2977	95	26.5
2.7	3059	171	27.1
1.8	3141	125	27.8
.9	2950	141	31.0
0	2759	180	34.3

Section 1 and Section 2 designate east and west side of the plot, respectively.

* Lysimeter 1, 2, and 3, respectively.

Table 34. The water-production functions developed for each cutting and for the seasonal accumulation based on lysimeter and nonlysimeter results for 1981.

Harvest	Equation*	r^2
	(Y,Kg/ha;ET,cm)	
First Cutting	$Y = 252 + 118(ET)$	.92
Second Cutting	$Y = -3575 + 201(ET)$	.83
Third Cutting	$Y = -777 + 154(ET)$	.81
Fourth Cutting	$Y = -1409 + 155(ET)$	.84
Seasonal Accumulated	$Y = -6321 + 164(ET)$	.94

* All yields are adjusted to 0 percent moisture. Only the slopes of the equations of the third and fourth cutting are identical at the 0.05 probability level.

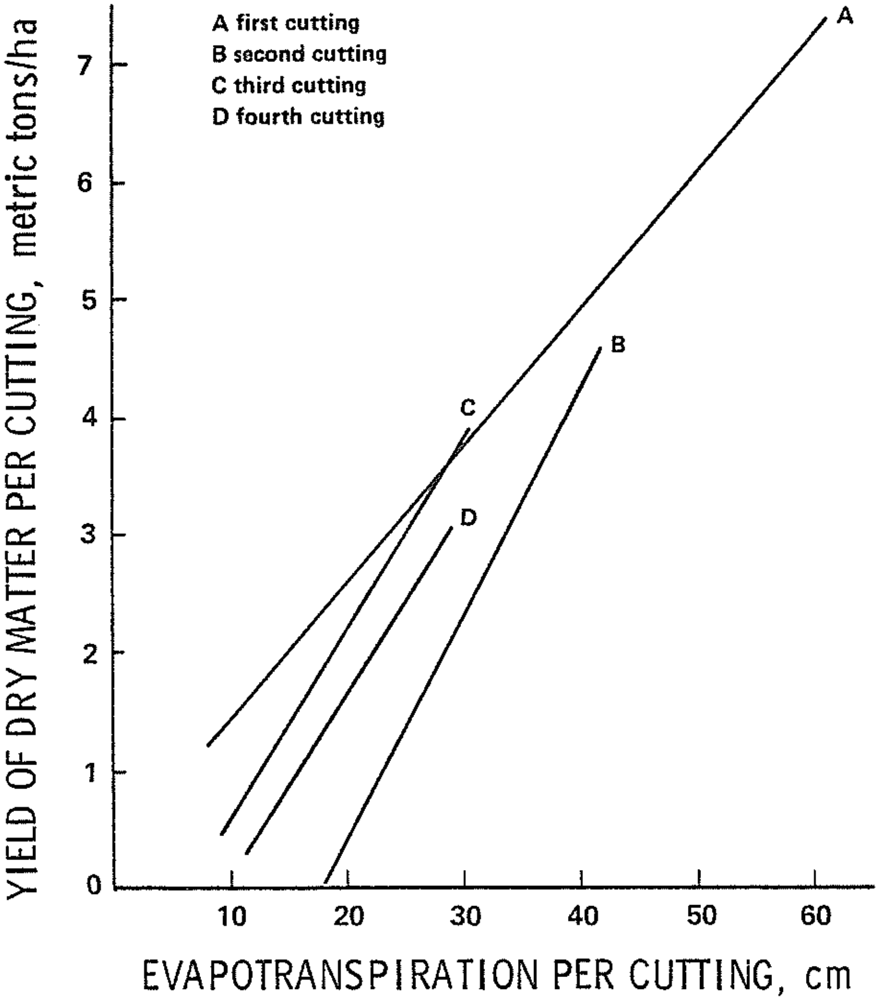

Figure 28. The water-production functions, with respect to individual cuttings, of the alfalfa SLS plot, 1981.

The slightly positive y-intercept of the water-production function of the first cutting is probably the result of making the initial neutron probe reading after some early spring growth had occurred. An observation of importance is that with one exception described in Table 34, the slope and intercept of the water-production functions of each cutting were significantly different. This signifies that the water-use efficiency was different at each of the cutting periods, and that the quantity of ET that was required to produce some initial yield was also different. Again, however, it is not possible to determine if the difference in water-use efficiency among cuttings is attributable to differences in ET or T (as a result of differences in evaporative demand or intraseasonal variations in physiological processes within the plant affecting dry-matter partitioning, or to differences in only the E component, as a result of different irrigation frequency between cuttings). The results presented herein for the spring barley suggest the latter explanation.

The seasonal yield and ET has been accumulated from the four cuttings in Table 35. An accumulated seasonal yield of 19.3 metric tons per hectare was achieved in the lysimeter closest to the sprinkler-line source, and yields measured outside the lysimeters regularly were of the order of 16 metric tons, even though this was the initial season of production. Figure 29 is a plot of the seasonally accumulated data presented in Table 35. The equation of the line shown in this figure is presented in Table 34.

Table 35. Accumulated seasonal evapotranspiration and yield of alfalfa.

Distance from the Line	Seasonal Yield	Seasonal ET
m	Kg/ha	cm
	Section 1#	
12.8	1221	44.4
11.9	2540	59.4
11.0	6159	74.0
10.1	7962	87.8
9.1	10133	101.5
8.2	12537	110.3
7.3	13097	119.0
7.1*	12209	120.0
6.4	15213	123.5
5.5	15077	127.9
4.6	15869	132.3
3.8*	17371	144.8
3.7	15547	136.8
2.7	15377	136.6
1.8	14558	136.5
.9	16552	143.6
.5*	19313	159.4
0	16142	150.6
	Section 2#	
12.8	3851	62.1
11.9	5108	73.5
11.0	6337	84.8
10.1	7866	94.4
9.1	9286	104.0
8.2	12072	107.8
7.3	14066	111.4
6.4	15213	119.0
5.5	15814	126.7
4.6	16716	128.6
3.7	16251	130.6
2.7	16743	135.3
1.8	16115	140.0
.9	16511	145.3
0	16142	150.6

\# Section 1 and Section 2 designate east and west side of the plot, respectively.

* Lysimeter 1, 2, and 3, respectively.

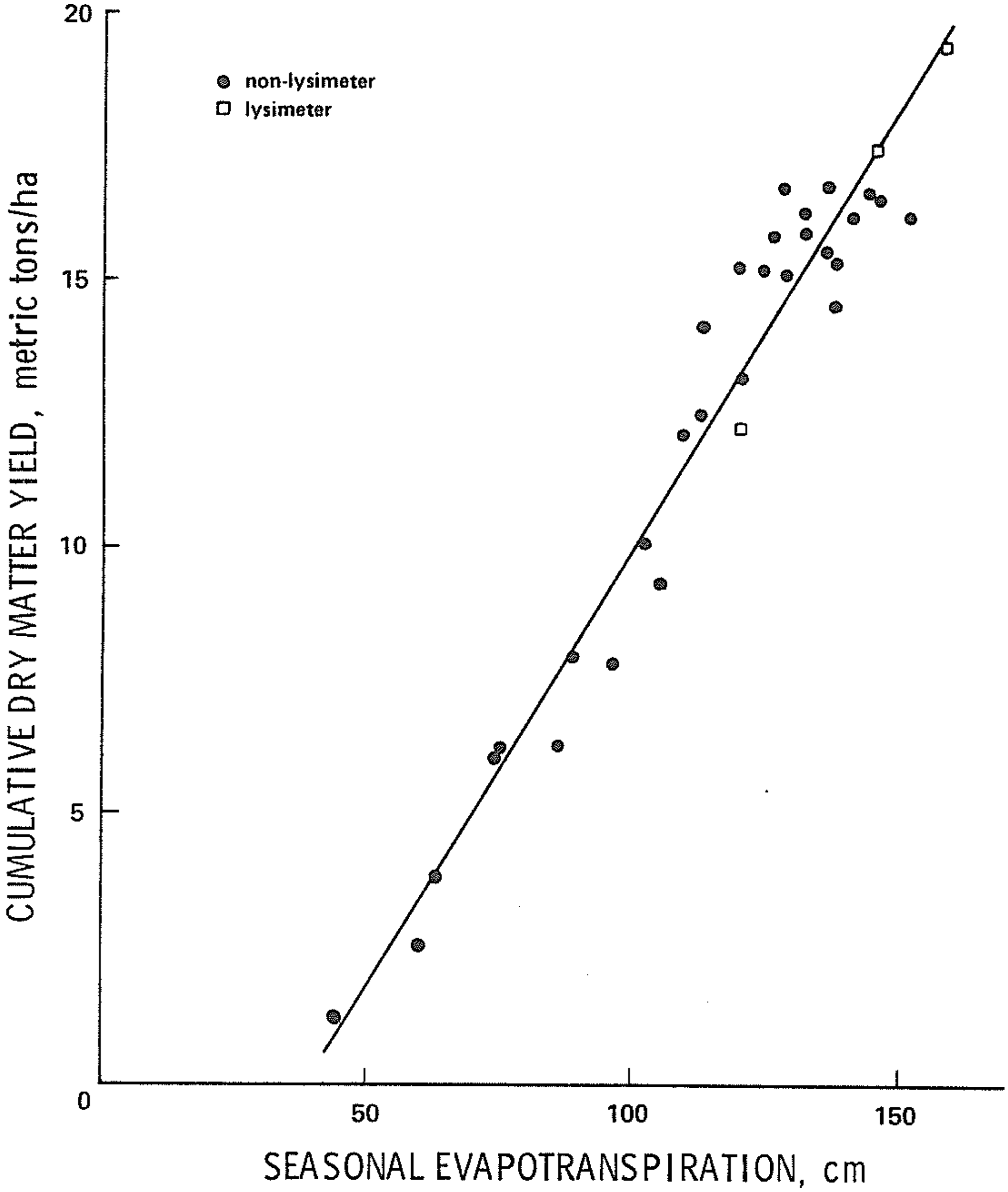

Figure 29. The water-production function of the seasonal cumulative yield of the alfalfa SLS plot, 1981. The equation of the line is Y(Kg/ha) = -6321 + 164(ET,cm), $r^2 = 0.94$.

Average daily ET for periods based on accumulations of approximately 200 GDD are presented in Table 36 for yield levels averaged to similar levels. Actual measured yields and daily ET values can be found in Table F7, Appendix F, at each distance from the line. The first alfalfa cutting occurred at approximately one-half full bloom, while the second, third, and fourth cutting occurred at one-tenth full bloom. Of interest is the observation that the latter three cuttings all accumulated approximately 600 GDD from the time they were initially cut to the time of harvest at one-tenth full bloom. Thus, it appears that the GDD formula (Equation 1) may be a good index of alfalfa growth in this area.

Crop coefficients are presented in Table 37 for the identical yield levels which appear in Table 36. Note the magnitude of the crop coefficients at the higher yield levels during the middle period of the second cutting. An ET/PET ratio of 2.36 was obtained at the yield level of 19 metric tons. This type of result again questions what exactly it is that is being measured by the PET calculation. The ability of the various PET formulae to account for the differences in the water-production functions will be discussed in the following section.

The Utility of the PET Concept in Water-Deficit Crop Research

The basic purpose of PET concept is the provision of a method whereby crop ET can be estimated without resorting to actual measurement of ET in the field. The PET measurement is to provide an estimate of the evapotranspirative demand of the

Table 36. Average daily evapotranspiration of new alfalfa interpolated to similar yield levels at selected intervals of each cutting for 1981.

		GDD/Period												
	Seasonal	First Cutting				Second Cutting			Third Cutting			Fourth Cutting		
Yield	ET	200	200	206	105	196	196	226	197	202	188	205	199	189
t/ha*		Daily ET cm/day												
1.00	44.4	.17	.20	.04	.04	.22	.34	.71	.34	.24	.19	.22	.22	.23
4.00	62.1	.22	.25	.38	.38	.48	.21	.68	.30	.25	.17	.24	.31	.18
6.00	79.4	.22	.40	.43	.43	.51	.88	.79	.46	.34	.37	.32	.30	.30
10.00	102.0	.28	.54	.61	.61	.79	1.12	.76	.65	.47	.48	.41	.42	.37
12.00	120.0	.38	.71	.90	.90	.56	1.06	.54	.61	.43	.46	.50	.53	.48
13.00	119.0	.29	.64	.61	.61	.98	1.17	.97	.84	.64	.49	.50	.44	.48
14.00	124.0	.29	.52	.79	.79	.96	1.30	.67	.99	.68	.55	.47	.60	.51
15.00	130.5	.31	.69	.75	.75	1.05	1.36	.73	1.02	.80	.59	.46	.55	.50
16.00	140.4	.33	.77	.72	.72	1.07	1.44	.74	1.00	.81	.66	.61	.69	.61
17.00	144.8	.38	.74	1.03	1.03	.74	1.52	.88	.92	.57	.48	.46	.61	.56
19.00	159.4	.38	.74	1.16	1.16	1.09	1.68	.68	1.13	.77	.67	.46	.79	.61
		GDD Accumulated/Cutting												
		200	401	607	711	196	392	618	197	399	588	205	404	593
		GDD Accumulated/Season												
		200	401	607	711	907	1103	1329	1527	1729	1917	2122	2321	2510

* Adjusted to 0 percent moisture.

Table 37. Average daily ET/PET of new alfalfa interpolated to similar yield levels at selected intervals of each cutting for 1981.

		GDD/Period												
	Seasonal	First Cutting				Second Cutting			Third Cutting			Fourth Cutting		
Yield	ET/PET	200	200	206	105	196	196	226	197	202	188	205	199	189
t/ha*		Daily ET/PET												
1.00	.37	.28	.30	.06	.05	.25	.48	1.01	.48	.39	.28	.44	.43	.59
4.00	.52	.36	.38	.60	.44	.54	.29	.97	.43	.40	.25	.48	.60	.46
6.00	.67	.36	.60	.68	.50	.58	1.24	1.12	.66	.55	.54	.65	.58	.77
10.00	.86	.46	.81	.96	.71	.90	1.57	1.08	.93	.75	.70	.83	.82	.95
12.00	1.01	.62	1.07	1.42	1.04	.64	1.49	.77	.88	.69	.67	1.01	1.03	1.23
13.00	.99	.47	.96	.96	.71	1.11	1.64	1.38	1.21	1.03	.71	1.01	.85	1.23
14.00	1.04	.47	.78	1.25	.91	1.09	1.83	.95	1.42	1.09	.80	.95	1.17	1.30
15.00	1.09	.50	1.04	1.18	.87	1.19	1.91	1.04	1.47	1.28	.86	.93	1.07	1.28
16.00	1.18	.54	1.16	1.14	.83	1.21	2.02	1.05	1.44	1.30	.96	1.23	1.33	1.56
17.00	1.21	.62	1.11	1.62	1.19	.84	2.13	1.25	1.32	.91	.76	.93	1.18	1.43
19.00	1.34	.62	1.11	1.83	1.34	1.24	2.36	.97	1.62	1.24	.98	.93	1.53	1.56
		GDD Accumulated/Cutting												
		200	401	607	711	196	392	618	197	399	588	205	404	593
		GDD Accumulated/Season												
		200	401	607	711	907	1103	1329	1527	1729	1917	2122	2321	2510

* Adjusted to 0 percent moisture.

atmosphere and provide a means of adjusting water application to this changing atmospheric demand.

A currently accepted definition of potential evaporation (PET) is as follows:

> The rate of evaporation from an extended surface of a short green crop actively growing, completely shading the ground, of uniform height, and not short of water.

When PET measurements are used to calculate crop coefficients in circumstances of severe water stress, three of the precepts of the above definition are violated. The severely stressed crop does not completely shade the ground (see Appendix E, Tables E1 and E2), the crops are severely deficient in available water and thus, are not actively growing. This is likely part of the reason that such generally poor agreement exists at the low yield levels, in the data produced herein, between crop coefficients which were produced in different growing seasons.

In addition, the northwestern New Mexico evaporative demand is severe. A large percentage of each irrigation is lost to the plant through simple evaporation from the ground surface. If the crop is irrigated more frequently during one growing season than in another, or if during one season the crop is irrigated at night as opposed to the day, large differences in total crop ET will become apparent between years that will have very little relation to differences in measured PET. The PET value would do nothing to account for the difference between yield and seasonal ET of the crop because only the evaporation component of the evapotranspiration measurement will be different. For a meaningful comparison of the effectiveness of various methods of calculating PET it will be necessary to develop an effective means of separating evaporation from crop transpiration. Table 38 is a list of the calculated PET, accumulated by month, for various methods of calculating PET. This same information calculated on a seasonal basis for each of the crops is presented in Table 39.

In Table 40 several methods of calculating PET have been compared by correlating monthly PET accumulation for 1980 and 1981. As can be observed in the tables the coefficients of determination are high, signifying that any of the methods are probably of equal value for the purpose of calculating crop coefficients. The method which is the most different from the Penman method is the vapor pressure deficit (VPD). The excellent correlation of the Pan method with the Penman is interesting in that the pan method is relatively simpler to obtain and requires little calibration of weather instrumentation.

Shouse et al. (21) in a three-season experiment using cowpeas determined that not only was a Penman method of calculating PET well correlated with actual weekly crop ET, once the LAI of the crop was greater than 2, but they were of the same magnitude. These authors also found the Penman method to be superior to the Pan and other PET-calculation methods for predicting crop water use in a highly advective environment. As has been previously discussed and will be discussed further below, our data do not support these findings.

Current irrigation research is being funded with the idea that the crop coefficient (ET/PET ratio) should provide a means whereby

Table 38. Monthly potential evapotranspiration for 1980 and 1981.

Method	Year	April	May	June	July	August	September	October*
		mm						
Penman	1980	173	216	269	267	223	173	105
	1981	185	199	241	220	194	153	48
Jensen-Haise	1980	137	202	284	302	247	180	93
	1981	176	195	289	289	248	178	51
Priestly-Taylor	1980	149	202	260	256	210	159	88
	1981	175	191	253	242	205	149	43
Pan	1980	196	234	270	292	236	173	99
	1981	193	214	290	273	223	178	104
VPD	1980	237	308	511	609	499	365	222
	1981	294	354	481	445	424	348	103

* Only partial PET accumulations presented; 1980-October 1-19, 1981-October 1-14.

Table 39. Seasonal PET calculated by different methods for the crops for 1980 and 1981.

			Crop						
					Alfalfa Cuttings				
Method	Units	Year	Pinto Beans*	Spring Barley	First	Second	Third	Fourth	Seasonal Accumulation
Penman	mm	1980	828	848	–	–	–	–	–
		1981	762	662	465	273	233	221	1193
Jensen-Haise	mm	1980	902	859	–	–	–	–	–
		1981	920	727	488	351	296	254	1388
Priestly-Taylor	mm	1980	780	789	–	–	–	–	–
		1981	782	676	463	296	245	211	1216
Blaney-Criddle#	mm	1980	641	572	–	–	–	–	–
		1981	608	497					951
Pan	mm	1980	855	888	–	–	–	–	–
		1981	871	745	519	330	267	251	1368
VPD	mb	1980	1831	1540	–	–	–	–	–
		1981	1860	1216	767	549	478	496	2291

* Due to different planting dates the 1980 table values refer only to the SLS plots.

These values represent the F values only. They were not multiplied by the crop constant.

Table 40. Simple correlation of monthly PET among different methods of calculating PET for 1980 and 1981.

Method	Jensen-Haise	Priestly-Taylor	Pan	VPD
	r^2			
	April 1, 1980 to October 24, 1981			
Penman*	.94	.97	.97	.74
Jensen-Haise	-	.96	.88	.91
Priestly-Taylor	-	-	.95	.77
Pan	-	-	-	.67
	April 1, 1981 to October 14, 1981			
Penman	.89	.98	.91	.89
Jensen-Haise	-	.96	.96	.97
Priestly-Taylor	-	-	.96	.93
Pan	-	-	-	.90

* See Appendix A for methods of calculating PET.

crop evapotranspiration requirements can be adjusted upward or downward depending on the atmospheric evaporative demand. The greater the potential evapotranspiration, the greater should be the crop evapotranspiration. The PET measurement has also been suggested to have utility in transferring the water-production function from location to location.

To determine if indeed the PET methods would account for observed differences in the parameters of the water-production functions for spring barley and pinto beans between seasons, and for alfalfa between cuttings, a comparision based on crop coefficients was made throughout the range of measured yield levels. Tables 41 and 42 are the result of this comparison between years for spring barley and pinto beans, respectively.

Table 41 is based only on the performance of the plots receiving the high nitrogen application. The various water-production functions produced in 1981 for spring barley illustrate, as described in greater detail in an earlier sections, that the differences in evaporation between plots probably mask any differences in crop ET that are the result of differential atmospheric evaporative demand between seasons. However, since a comparison was desired and since the yield levels were similar, the high-nitrogen plots were chosen for the comparison. The comparison was made by expressing seasonal yield first as a funtion of measured ET and then as a function of the appropriate crop coefficient for each of the PET methods. The hypothesis on which this comparison was based is that the more similar the parameters

Table 41. A comparison of barley crop coefficients as calculated by various PET methods, with respect to their ability to account for seasonal differences in the parameters of the water-production functions for 1980 and 1981. Only the plots containing the high-level N application are compared.

Reduced Model*	ET	ET/ Penman	ET/Jensen-Haise	ET/Priestly-Taylor	ET/ Pan	ET/ VPD
	Value of F					
Common Intercept Common Slope (df = 2/46)	90.0#	7.8#	23.7#	23.3#	18.2#	8.7#
Common Intercept Different Slope (df = 1/46)	12.8#	12.8#	12.8#	12.8#	12.8#	12.8#
Different Intercept Common Slope (df = 1/46)	.6	7.9#	2.2	2.2	3.2	7.0#

* The null hypothesis for the pairwise comparison is that the full and reduced model of the statistical procedure have the characteristics listed below. The smaller the magnitude of the value of F the more similar are the functions between years.

The reduced model is significantly different from the full model at the 0.05 probability level.

Table 42. A comparison of pinto bean crop coefficients as calculated by various PET methods, with respect to their ability to account for seasonal differences in the parameters of the water-production functions for 1980 and 1981. The yield versus ET or appropriate crop coefficient of all subplots have been combined for each season.

Reduced Model*	ET	ET/ Penman	ET/Jensen-Haise	ET/Priestly-Taylor	ET/ Pan	ET/ VPD
	Value of F					
Common Intercept Common Slope (df = 2/167)	21.9#	31.5#	18.5#	18.8#	18.4#	20.6#
Common Intercept Different Slope (df = 1/167)	36.9#	36.9#	36.9#	36.9#	36.9#	36.9#
Different Intercept Common Slope (df = 1/167)	24.1#	15.3#	27.7#	27.0#	27.9#	26.0#

* The null hypothesis for the pairwise comparison is that the full and reduced model of the statistical comparison have the characteristics listed below. The smaller the magnitude of the value of F the more similar are the functions between years.

The reduced model is significantly different from the full model at the 0.05 probability level.

of the water-production function between years, the greater is the value of the PET method as a tool for predicting crop ET between seasons or potentially between locations.

Table 41 contains the F-statistic which results when the functions developed for each of the two years are compared. The greater the F-statistic the greater is the difference between the functions. If the F-statistic of the test is greater for the comparison between years, in which yield is expressed as a function of the crop coefficient, than it is for the comparison, also between years, of seasonal yield expressed as a function of seasonal ET, then the former procedure is inferior to the latter as a means of accounting for differences between years in the amount of water required to produce a given yield.

The various PET methods are compared based on the examination of the similarity of the functions with respect to their slope and y-intercept. The term "df" refers to the degrees of freedom of the comparison. The left-hand column of the table, under the heading "Reduced Model," refers to the function parameters which are to be tested for significant differences between years. The null hypothesis of the comparison is that the functions which are to be compared have the stated characteristics of slope and y-intercept.

The various PET methods do appear to have some utility in accounting for some of the differences between years as reflected in their smaller F-values for the reduced model that assumes a common slope and y-intercept, when compared to the F-value of

90 obtained when yield is expressed as a function of ET. However, when evaluated on the basis of only the parameter of slope, the non-significantly different slopes of the water-production functions of 1980 and 1981 become significantly different using the Penman and VPD crop coefficients, even though these methods appear to be of greater value when both the slope and the y-intercept are being evaluated concomitantly. If other water-production functions produced in 1981 would have been compared with the 1980 results, an entirely different set of F-values would have been obtained demonstrating the impossible task that a PET method must accomplish to account for the variability which exists between seasons and locations with respect to the quantity of water, expressed as ET, required to produce a given level of yield.

The results presented in Table 42 are of the same form as those presented in Table 41. The functions which are compared are the result of the pooling of all of the data points, yield versus ET or ET/PET, of the pinto bean SLS plots in the year in which they were produced. The results presented in Table 42 reemphasize the failure of the crop coefficients to account for differences in the parameters of the water-production functions between years when yield is expressed as a function of the crop coefficient. In Table 42, the pinto bean yield versus ET relationship accounts for function-parameter differences between years in a similar manner to the yield versus crop coefficient relationships.

The water-production functions for each alfalfa cutting of 1981 are compared in the same manner in Table 43. Again, the yield versus ET relationship is as good or better in accounting for differences between cuttings than are the yield versus crop coefficient relationships. This observation is made not to suggest that the yield versus ET relationship is effective in accounting for differences between cuttings, or in the case of barley and beans between years, since the magnitude of the F-values demonstrate that the functions are significantly different. The purpose is to emphasize that the PET values do not improve the predictability of ET based on the two years of data we have collected, when yield is expressed as a function of the ET/PET ratio.

The crop coefficient may have value if expressed as the ratio of T/PET yet this statement has yet to be proven. Our data show that the water-production function is not made transferable from season to season as a result of adjustments based on PET differences between time. The results presented in Tables 41, 42, and 43 demonstrate that the crop coefficient presented in Tables 20, 27, and 37 probably have no more value than the ET values presented in Tables 19, 26, and 36 for determining the respective crop's water use.

Table 43. A comparison of alfalfa crop coefficients as calculated by various PET methods, with respect to their ability to account for differences among cuttings in the parameters of the water-production functions for 1981.

Reduced Model*	ET	ET/ Penman	ET/Jensen Haise	ET/Priestly Taylor	ET/ Pan	ET/ VPD
	Value of F					
Common Intercept Common Slope (df = 6/120)	20.4#	148.2#	119.9#	149.1#	141.6#	87.2#
Common Intercept Different Slope (df = 3/120)	15.6#	15.6#	15.6#	15.6#	15.6#	15.6#
Different Intercept Common Slope (df = 3/120)	9.3#	11.3#	10.6#	13.6#	12.2#	5.7#

* The null hypothesis for the comparison is that the full and reduced model of the statistical procedure have the characteristics listed below. The smaller the magnitude of the value of F the more similar are the functions.

The reduced model is significantly different from the full model at the 0.05 probability level.

LIST OF ABBREVIATIONS

E	evaporation
ET	evapotranspiration
GDD	growing-degree-days
LAI	leaf area index
N	nitrogen
PET	potential evapotranspiration
T	transpiration
SD	standard deviation
SLS	sprinkler-line-source
WUE	water-use efficiency
Y	yield

DEFINITION OF TERMS

Access Tube - A metal tube, usually aluminum, placed in the ground, for the purpose of providing access to the rhizosphere for neutron probe measurement

Advection - Horizontal transfer of heat energy by large-scale motions of the atmosphere.

Biomass - Refers to the above ground portion of the plant. Used interchangeably with dry matter in this report.

Crop Coefficient - The ratio of evapotranspiration occurring with a specific crop at a specific stage of growth to potential evapotranspiration occurring at that time.

Economic Yield - That portion of the crop normally harvested for sale.

Evapotranspiration - The quantity of water transpired by plants, retained in plant tissue, and evaporated from adjacent soil surfaces in a specified time period.

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

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.

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.

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

Water-Production Function - The relationship between economic yield and the seasonal evapotranspiration of a crop.

Water-Use Efficiency - The weight of economic yield produced to the depth of water which evapotranspired.

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APPENDIX A

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

APPENDIX A

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}); 1y = 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 $^oC^{-1}$)

$$\gamma = \frac{C_pP}{0.622L} \tag{3}$$

where

C_P is specific heat of air (cal g^{-1} $^{o}C^{-1}$)

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.

$C_2 = 13^{o}F$ or $7.6^{o}C$

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

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

$$Tx = 27.5^{o}F - (0.25 \ (e_2 - e_1) - \text{elev. in ft}/1000 \tag{9}$$

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

T is average air temperature.

Method 3 - Priestley-Taylor

$$E_o = \alpha(\frac{\Delta}{\Delta + \gamma}) \ . \ Rn \tag{11}$$

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

$$u = kf \text{ or } U = (KF) \tag{12}$$

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 $(\Sigma \frac{t \times p}{100})$

t = mean monthly temperature in degrees Fahrenheit.

Method 6 - Vapor Pressure Deficit

Assumptions:

Minimum relative humidity occurs at the maximum daily temperature, and this is when the minimum daily vapor pressure occurs.

Maximum relative humidity occurs at the minimum daily temperature, and this is when the maximum daily vapor pressure occurs.

Saturated daily vapor pressure is calculated at the mean of the daily high and low temperature.

Actual daily vapor pressure is calculated as the average of the minimum and maximum daily vapor pressure.

The vapor pressure deficit is calculated as the saturated vapor pressure minus the actual vapor pressure.

APPENDIX B

Tables associated with determining the validity
of Method 3 for calculation of
soil-water evaporation.

APPENDIX B

The largest component of evapotranspiration which exists during the period of time beginning when the crop is planted and ending when the crop has achieved a minimum value of leaf area index, can generally be characterized as evaporation. Water use from planting to the point in time when the crop had achieved a leaf area index of 0.5 was determined based on Method 3 for the subplots that have been graphed in Figure 10 to determine if the evaporation model used herein adequately predicts soil-water evaporation when plant cover is minimal. Table B1 presents the results of this comparison.

Table B1. A comparison of modeled and measured evaporation.

High-Nitrogen Plot 1981 - Yield	Evaporation Comparison* Measured	Estimated
Kg/ha	cm	
1278	1.33	1.37
6626	3.04	3.29

* The period of time over which the evaporation occurred was 19 days.

As Table B1 demonstrates, the method used to calculate evaporation appears to yield satisfactory results when transpiration is not a consideration.

Table B2. Sensitivity test of the method of calculating the soil-water evaporation (Method 3).

Change in the model parameters of Method 3	Seasonal Evaporation			
	High N Plot		Low N Plot	
	1980	1981	1980	1981
	Yield Level Kg/ha			
	7176	6626	1021	2431
	cm			
No change	20.5	13.1	23.5	24.8
10 mm limit for insignificant irrigations increased to 20 mm	22.6	14.0	24.3	25.4
10 mm limit for insignificant irrigations decreased to 5 mm	20.7	12.9	20.7	20.1
Exponent of Equation 6 decreased from .6 to .5	20.1	13.0	23.0	24.1
Constant c of Equation 7 increased to .8 for complete and incomplete cover conditions	23.0	15.3	24.3	25.8
Time limit for stage one evaporation in the complete-cover condition is increased from 2 days to 4 days	20.5	13.3	23.5	24.8
Time limit for stage two evaporation is increased from 2 days to 6, in the complete-cover condition	21.7	14.2	23.5	24.8
The LAI limit for the bare-soil condition is increased from .5 to 1.0	20.5	13.3	22.6	24.7
The LAI limit for the complete-cover condition is increased from 2.5 to 3.0	20.5	13.7	23.5	24.8
The exponent of Equation 5 is decreased from -.623 to -.8	19.8	12.5	23.5	24.8
The a coefficient in Equation 6 is decreased from 3.5 to 1.5	18.8	11.8	23.5	24.8

Table B3. An example of the crop data required to calculate soil-water evaporation. 1/

Julian Date	Number of Days in the Event*	LAI	Quantity of Water
			mm
108	1	.12	10
109	4	.12	5
113	2	.12	8
115	6	.19	19
121	1	.33	1
122	6	.51	1
128	4	.87	5
132	4	1.83	16
136	1	2.15	29
137	8	2.76	14
145	2	3.13	7
147	1	3.18	7
148	1	3.18	3
149	3	3.18	6
152	1	3.18	55
153	1	3.18	1
154	1	3.69	4
155	6	3.58	22
161	1	3.02	50
162	7	3.02	21
169	1	3.02	26
170	3	3.02	28
173	4	2.30	32
177	1	1.57	98
178	3	1.57	1
181	1	1.57	11
182	6	.91	7
188	5	.36	3
193	1	.22	1

1/ These data were obtained from the subplot under the line source of the sprinkler barley SLS plot that utilized 189 Kg/ha of N for 1981.

* The event is either an irrigation or precipitation. Precipitations of less than 1 millimeter were not included in the calculations.

APPENDIX C

Detailed list of variables and results of the spring barley step-wise multiple regression equation.

Table C1. The list of variables as entered in the stepwise multiple regression of yield (the dependent variable) versus 9 independent variables and their products that are associated with soil-water evaporation.

Number of Variable	Description of Variable
1	Seasonal evapotranspiration (ET), cm
2	N utilized by the highest yielding subplot of plot, kg/ha
3	Initial soil water in the soil profile, cm
4	Percent (seasonal irrigation/seasonal ET)
5	Percent (seasonal precipitation/seasonal ET)
6	Potential ET (planting to physiological maturity by Penman), mm
7	Number of irrigations per season
8	Number of irrigations and precipitations per season
9	Number of irrigations and precipitations greater than 2.5 mm per season
10	Square of variable 1
11	Square of variable 2
12	Square of variable 3
13	Square of variable 4
14	Square of variable 5
15	Square of variable 6
16	Square of variable 7
17	Square of variable 8
18	Square of variable 9

The remaining 43 variables were selected interactions of the 18 variables listed above.

Table C2. The results of the stepwise multiple regression at Step 2 and at Step 5.

STEP 2

Multiple R^2 = .94 Std. Error of Estimate = 448 F of the Analysis of Variance = 554

Y-intercept = 1281.89

Variable	Coefficient	Std. Error of Coefficient	Std. Regression Coefficient	Tolerance	F to Remove
10	2.028	.066	.893	1	940.8
6x4	-0.033	.003	-.377	1	167.9

STEP 5

Multiple R^2 = .96 Std. Error of Estimate = 298 F of the Analysis of Variance = 390

Y-intercept = 2123.79

Variable	Coefficient	Std. Error of Coefficient	Std. Regression Coefficient	Tolerance	F to Remove
10	1.872	.073	.825	.63	664.0
2x9	0.148	.044	.133	.42	11.4
6x4	-0.016	.005	-.189	.19	10.6
6x7	-0.128	.029	-.244	.21	19.2
16x15	-0.000*	.000	-.119	.51	11.4

* This coefficient did not print out as a result of computer rounding.

Table C3. Summary table of the amount of variation accounted for by each of the significant variables to Step 5 of the stepwise multiple regression.

Step No.	Variable*	Multiple R^2	Increase in R^2	No. of Independent Variables Included
1	10	.797	.797	1
2	6x4	.940	.142	2
3	16x15	.943	.004	3
4	6x7	.949	.006	4
5	2x9	.956	.007	5

* The variables are identified in Table C1, Appendix C .

APPENDIX D

List of crop irrigations and precipitations.

Table D1. Dates of spring barley irrigation and precipitation for 1980 and 1981.

Irrigation		Precipitation	
1980	1981	1980	1981
4/17*	4/18*	4/25	4/19
4/18	4/23	4/29	5/01
4/25	4/25	5/01	5/02
5/12	5/08	5/06	5/04
5/16	5/12	5/07	5/06
5/23	5/16	5/08	5/13
5/27	5/25	6/07	5/17
5/30	6/01		5/27
5/31	6/04		5/28
6/05	6/10		5/29
6/06	6/11		6/02
6/09	6/18		6/03
6/11	6/19		6/05
6/13	6/22		6/27
6/16	6/26		6/30
6/20			7/01
6/23			7/07
6/27			7/12
7/03			
7/04			
7/10			
7/11			
7/16			
7/18			

* These dates are applicable to the subplot under the SLS of the plot with the highest N application. The subplot was irrigated twice, once in the morning and once in the afternoon of 06/11 and 06/26 of 1981; and 06/06, 06/20, and 06/27 of 1980.

Table D2. Dates of pinto beans irrigation and precipitation for 1980 and 1981.

Irrigation		Precipitation	
1980	1981	1980	1981
6/19	5/18	6/07	5/17
6/23	6/09	7/31	5/27
6/27	6/25	8/06	5/28
6/30	6/18	8/14	5/29
7/03	6/19	8/18	6/02
7/04	6/22	8/22	6/03
7/10	9/29	8/23	6/27
7/11	7/10	8/24	6/30
7/18	7/12	9/05	7/01
7/25	7/14	9/08	7/07
8/02	7/20	9/09	7/16
8/05	7/29	9/10	7/24
8/14	7/30	10/12	7/26
8/28	7/31		8/10
9/04	8/01		8/11
9/18	8/02		8/21
9/29	8/04		
	8/07		
	8/10		
	8/12		
	8/15		
	8/17		
	8/18		
	8/20		
	8/25		

Table D3. Dates of alfalfa irrigation and precipitation for 1981.

Irrigation		Precipitation
4/20	8/02	4/19
4/23	8/04	5/01
4/25	8/06	5/02
4/27	8/08	5/04
4/29	8/10	5/06
4/30	8/12	5/13
5/04	8/14	5/17
5/06	8/17	5/27
5/07	8/18	5/28
5/12	8/19	5/29
5/13	9/01	6/02
5/16	9/04	6/03
5/18	9/08	6/05
5/21	9/11	6/27
5/26	9/12	6/30
5/27	9/13	7/01
6/01	9/14	7/07
6/04	9/16	7/12
6/10	9/18	7/25
6/11	9/20	7/26
6/19	9/22	8/11
6/22	9/28	8/16
6/26	9/30	8/21
6/28	10/02	9/04
6/30	10/08	9/05
7/07		9/06
7/10		9/09
7/12		9/17
7/15		9/23
7/17		10/01
7/18		10/02
7/20		10/12
7/27		
7/29		
7/31		

APPENDIX E

Yield and daily ET of spring barley and pinto beans at maximum LAI.

Table E1. Evapotranspiration of spring barley at maximum leaf area index of selected yield levels for 1981.

Yield	Maximum LAI	Daily ET
Kg/ha		cm/day
	High-Level Nitrogen	
1534	2.4	.26
2322	2.2	.48
3260	3.4	.54
3899	3.7	.60
6626	4.1	1.01
6626	3.2	1.01
	Middle-Level Nitrogen	
909	1.7	.23
1045	1.3	.40
1569	2.1	.48
2249	3.2	.52
3672	3.6	.64
3672	3.3	.64
	Low-Level Nitrogen	
113	.9	.16
886	1.3	.37
795	1.8	.36
1318	1.5	.43
2431	2.1	.48
2431	1.9	.48

Table E2. Evapotranspiration of pinto beans at maximum leaf area index of selected yield levels for 1981.

Yield	Maximum LAI	Daily ET
Kg/ha		cm/day
	East Sprinkler-Line-Source Plot	
1266	1.6	.43
1570	1.8	.62
3001	3.0	.63
2583	2.1	.58
3419	2.3	.71
	Central Sprinkler-Line-Source Plot	
737	1.8	.27
1228	1.8	.37
1596	2.5	.51
1596	2.2	.61
2989	1.9	.56
	West Sprinkler-Line-Source Plot	
291	1.3	.38
1038	1.9	.52
1722	2.4	.59
1849	2.3	.58
3204	2.9	1.02

APPENDIX F

Distance from line, yield, GDD, seasonal ET, and daily ET during specific growth stages for the crops spring barley, pinto beans, and alfalfa for those subplots having access tubes, 1981.

Table F1. Daily evapotranspiration of the spring barley plot which utilized a maximum of 61 KgN/ha for 1981.

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							
14.0	250	13.3	.05	.12	.16	.16	.16	.22	.15	.15
14.0	136	15.7	.07	.16	.20	.31	.20	.23	.14	.14
12.0	113	13.7	.07	.15	.07	.13	.16	.26	.13	.13
12.0	795	23.4	.12	.19	.20	.33	.36	.40	.21	.21
10.0	273	20.0	.07	.22	.44	.24	.24	.12	.15	.15
10.0	1090	27.2	.16	.23	.32	.35	.35	.48	.18	.18
8.0	886	27.3	.07	.29	.68	.37	.37	.47	.17	.17
8.0	1318	31.8	.15	.30	.35	.42	.45	.55	.19	.19
6.0	1545	32.0	.13	.33	.39	.43	.43	.55	.16	.16
6.0	1567	31.2	.14	.32	.37	.39	.40	.56	.18	.18
4.0	2249	34.5	.13	.35	.50	.50	.51	.72	.16	.16
4.0	2340	34.5	.13	.35	.37	.52	.55	.50	.25	.25
2.0	2476	39.5	.18	.39	.49	.58	.56	.66	.24	.24
2.0	2407	36.8	.10	.38	.49	.54	.54	.69	.17	.17
0.0	2430	39.9	.13	.37	.32	.46	.52	.66	.24	.24
		Seasonal GDD	GDD in Period							
		1144	161	190	79	98	191	241	82	102

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

Table F2. Daily evapotranspiration of the spring barley plot which utilized a maximum of 102 KgN/ha for 1981.

			Growth Stage							
Distance from Line	Yield	Seasonal ET	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							
14.0	1022	16.3	.10	.17	.25	.22	.20	.22	.10	.10
14.0	522	21.2	.09	.16	.23	.32	.32	.33	.23	.23
12.0	909	20.9	.11	.20	.28	.27	.28	.35	.13	.13
12.0	1045	24.3	.08	.19	.35	.42	.43	.34	.24	.24
10.0	1295	27.1	.04	.22	.33	.38	.41	.45	.21	.21
10.0	1499	25.5	.06	.19	.32	.42	.41	.43	.21	.21
8.0	2249	32.7	.11	.23	.34	.50	.56	.60	.18	.18
8.0	1569	29.2	.09	.24	.32	.46	.48	.50	.20	.20
6.0	3225	34.0	.13	.05	.35	.54	.59	.59	.32	.32
6.0	2771	34.9	.10	.26	.39	.54	.58	.60	.21	.21
4.0	3904	38.9	.13	.31	.48	.60	.63	.71	.18	.18
4.0	3657	36.2	.08	.29	.41	.59	.65	.58	.25	.25
		Seasonal GDD	GDD in Period							
		1144	161	190	79	98	191	241	82	102

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

Table F3. Daily evapotranspiration of the spring barley plot which utilized a maximum of 189 KgN/ha for 1981.

Distance from Line	Yield	Seasonal ET	Growth Stage: 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							
14.0	1278	15.4	.06	.16	.27	.19	.17	.24	.08	.08
14.0	1853	22.0	.07	.23	.23	.32	.36	.30	.18	.18
12.0	1534	19.0	.07	.21	.22	.25	.27	.31	.12	.12
12.0	2322	28.9	.09	.24	.27	.42	.48	.54	.18	.18
10.0	2578	26.7	.12	.22	.32	.38	.40	.44	.19	.19
10.0	3132	32.3	.12	.22	.30	.54	.60	.68	.26	.26
8.0	3260	32.7	.10	.24	.30	.49	.54	.63	.21	.21
8.0	3899	34.9	.12	.22	.62	.54	.60	.68	.26	.26
6.0	4325	40.4	.11	.31	.39	.61	.67	.76	.29	.29
6.0	5411	41.8	.14	.26	.60	.66	.74	.78	.35	.35
4.0	5709	48.4	.10	.33	.41	.78	.87	.95	.39	.39
4.0	6136	48.2	.14	.35	.35	.75	.86	.89	.45	.45
2.0	6008	50.5	.14	.28	.42	.79	.89	1.04	.38	.38
2.0	6413	51.7	.12	.29	.42	.85	.95	1.02	.43	.43
0.0	6626	57.3	.16	.31	.42	.89	1.01	1.11	.40	.40
		Seasonal GDD	GDD in Period							
		1144	161	190	79	98	191	241	82	102

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

Table F4. Daily evapotranspiration of pinto beans grown in the east sprinkler-line-source plot for 1981.

			Growth Stage							
			Planting to Nine-Nodes		Nine-Nodes to First Flower		First Flower to 50% Pod Stripe		50% Pod Stripe to Final	
Distance from line	Yield	Seasonal ET	1*	2*	1	2	1	2	1	2
m	Kg/ha	cm	Daily ET cm/day							
11.9	760	23.9	.18	.13	.16	.43	.25	.30	.12	.18
11.9	1076	29.3	.20	.21	.20	.51	.44	.26	.11	.19
10.2	1266	28.9	.20	.15	.19	.44	.40	.41	.16	.21
10.2	1570	38.4	.23	.27	.17	.73	.54	.43	.19	.22
8.5	1621	33.9	.19	.19	.15	.55	.40	.50	.25	.20
8.5	1912	37.0	.17	.23	.21	.58	.54	.47	.27	.25
6.8	2254	35.2	.11	.19	.16	.78	.54	.49	.26	.23
6.8	1874	41.3	.25	.26	.17	.73	.54	.50	.29	.23
5.1	2583	41.6	.18	.24	.19	.77	.55	.57	.32	.25
5.1	3001	44.6	.19	.28	.30	.61	.54	.59	.38	.32
3.4	2837	46.5	.21	.27	.23	.89	.58	.66	.36	.25
3.4	2975	51.4	.26	.30	.18	.92	.64	.74	.41	.28
1.7	3330	47.8	.18	.27	.17	1.00	.75	.65	.47	.18
1.7	3432	49.1	.22	.32	.19	.86	.57	.63	.52	.37
0.0	3419	56.2	.25	.36	.29	1.18	.74	.71	.40	.31
		Seasonal GDD	GDD in Period							
		1131	151	254	82	72	218	197	86	75

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

Table F5. Daily evapotranspiration of pinto beans grown in the central sprinkler-line-source plot for 1981.

			Growth Stage							
			Planting to Nine-Nodes		Nine-Nodes to First Flower		First Flower to 50% Pod Stripe		50% Pod Stripe to Final	
Distance from Line	Yield	Seasonal ET	1*	2*	1	2	1	2	1	2
m	Kg/ha	cm	Daily ET cm/day							
11.9	1165	24.2	.20	.18	.22	.40	.37	.22	.07	.06
11.9	342	26.6	.17	.27	.26	.95	.25	.18	.09	.05
10.2	1228	29.2	.23	.21	.25	.66	.40	.29	.08	.06
10.2	737	29.6	.14	.26	.24	1.00	.31	.30	.12	.02
8.5	1393	31.1	.19	.22	.29	.74	.44	.31	.14	.08
8.5	709	32.1	.16	.26	.17	.95	.44	.36	.11	.03
6.8	1621	35.5	.26	.27	.25	.70	.49	.39	.19	.10
6.8	1314	36.0	.18	.31	.28	1.02	.44	.37	.17	.12
5.1	1596	39.7	.17	.27	.28	.99	.56	.48	.24	.15
5.1	1596	40.2	.16	.32	.27	.88	.59	.47	.23	.16
3.4	2039	44.5	.23	.29	.25	1.19	.57	.59	.26	.17
3.4	2241	42.2	.18	.34	.20	.95	.57	.54	.27	.22
1.7	2989	45.1	.25	.31	.23	1.12	.97	.60	.26	.18
1.7	1963	45.8	.20	.31	.25	1.20	.65	.65	.28	.19
0.0	2989	49.8	.26	.36	.30	1.20	.65	.53	.40	.29
		Seasonal GDD	GDD in Period							
		1131	151	254	82	72	218	197	86	75

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

Table F6. Daily evapotranspiration of pinto beans grown in the west sprinkler-line-source plot for 1981.

			Growth Stage							
			Planting to Nine-Nodes		Nine-Nodes to First Flower		First Flower to 50% Pod Stripe		50% Pod Stripe to Final	
Distance from Line	Yield	Seasonal ET	1*	2*	1	2	1	2	1	2
m	Kg/ha	cm	Daily ET cm/day							
11.9	709	25.0	.15	.16	.15	.70	.34	.83	.14	.07
11.9	203	26.7	.20	.23	.15	.74	.26	.26	.32	.05
10.2	1038	30.7	.16	.20	.09	.53	.45	.44	.25	.13
10.2	291	30.0	.15	.25	.18	.93	.32	.34	.22	.04
8.5	1545	36.9	.18	.23	.31	.75	.48	.73	.35	.20
8.5	684	33.1	.07	.29	.13	1.18	.35	.21	.30	.14
6.8	1773	39.9	.17	.25	.25	.96	.53	.52	.36	.19
6.8	1178	38.8	.08	.29	.18	1.08	.52	.52	.36	.15
5.1	1722	45.3	.16	.32	.38	.99	.55	.60	.46	.25
5.1	1849	44.8	.17	.36	.31	1.02	.55	.55	.38	.23
3.4	2761	52.9	.20	.32	.32	.98	.73	.78	.50	.32
3.4	2545	49.3	.19	.29	.28	1.07	.67	.64	.53	.32
1.7	2457	54.1	.17	.34	.36	1.11	.72	.50	.62	.48
1.7	3026	53.1	.17	.32	.36	1.06	.76	.71	.54	.41
0.0	3204	59.5	.20	.31	.29	1.25	.81	.89	.62	.35
		Seasonal GDD	GDD in Period							
		1131	151	254	82	72	218	197	86	75

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

Table F7. Average daily evapotranspiration of new alfalfa at selected intervals within each cutting for 1981.

Distance from Line	Seasonal Yield	First Cutting				Second Cutting			Third Cutting			Fourth Cutting		
		GDD/period												
		200	200	206	105	196	196	226	197	202	188	205	199	189
m	t/ha*	Daily ET/period												
12.8	1.22	.17	.20	.04	.04	.22	.34	.71	.34	.24	.19	.22	.22	.23
12.8	3.85	.22	.25	.38	.38	.48	.21	.68	.30	.25	.17	.24	.31	.18
11.0	6.16	.18	.37	.34	.34	.41	.69	.77	.48	.34	.40	.33	.32	.33
11.0	6.34	.26	.43	.52	.52	.60	1.06	.80	.43	.33	.34	.30	.27	.27
9.1	10.13	.26	.52	.59	.59	.74	.98	.76	.65	.47	.50	.46	.45	.40
9.1	9.29	.30	.56	.62	.62	.84	1.26	.76	.65	.47	.45	.35	.38	.33
7.3	13.10	.29	.64	.61	.61	.98	1.17	.97	.84	.64	.49	.50	.44	.48
7.3	14.07	.25	.30	.85	.85	.92	1.22	.76	.85	.54	.49	.40	.52	.43
7.1#	12.21	.38	.71	.90	.90	.56	1.06	.54	.61	.43	.46	.50	.53	.48
5.5	15.08	.28	.66	.72	.72	1.03	1.33	.73	1.07	.75	.63	.46	.53	.49
5.5	15.81	.35	.70	.73	.73	1.05	1.33	.85	.94	.65	.41	.43	.54	.47
3.8#	17.37	.38	.74	1.03	1.03	.74	1.52	.88	.92	.57	.48	.46	.61	.56
3.7	15.55	.29	.72	.79	.79	1.07	1.39	.62	1.06	.99	.69	.49	.57	.54
3.7	16.25	.33	.75	.65	.65	.99	1.42	.92	.79	.62	.58	.50	.67	.53
1.8	14.56	.32	.74	.73	.73	1.00	1.38	.58	1.13	.82	.60	.53	.68	.59
1.8	16.12	.34	.74	.73	.73	1.06	1.39	.56	1.05	1.00	.79	.59	.63	.60
0.5#	19.31	.38	.74	1.16	1.16	1.09	1.68	.68	1.13	.77	.67	.46	.79	.61
0.0	16.14	.32	.83	.79	.79	1.15	1.52	.74	1.17	.81	.60	.74	.77	.69
		GDD accumulated/cutting												
		200	401	607	711	196	392	618	197	399	588	205	404	593
		GDD accumulated/season												
		200	401	607	711	907	1103	1329	1527	1729	1917	2122	2321	2510

\# Denotes a lysimeter.

* Adjusted to 0 percent moisture.

APPENDIX G

Seasonal GDD accumulation versus time during the growing season for barley, alfalfa, and pinto beans, 1980 and 1981.

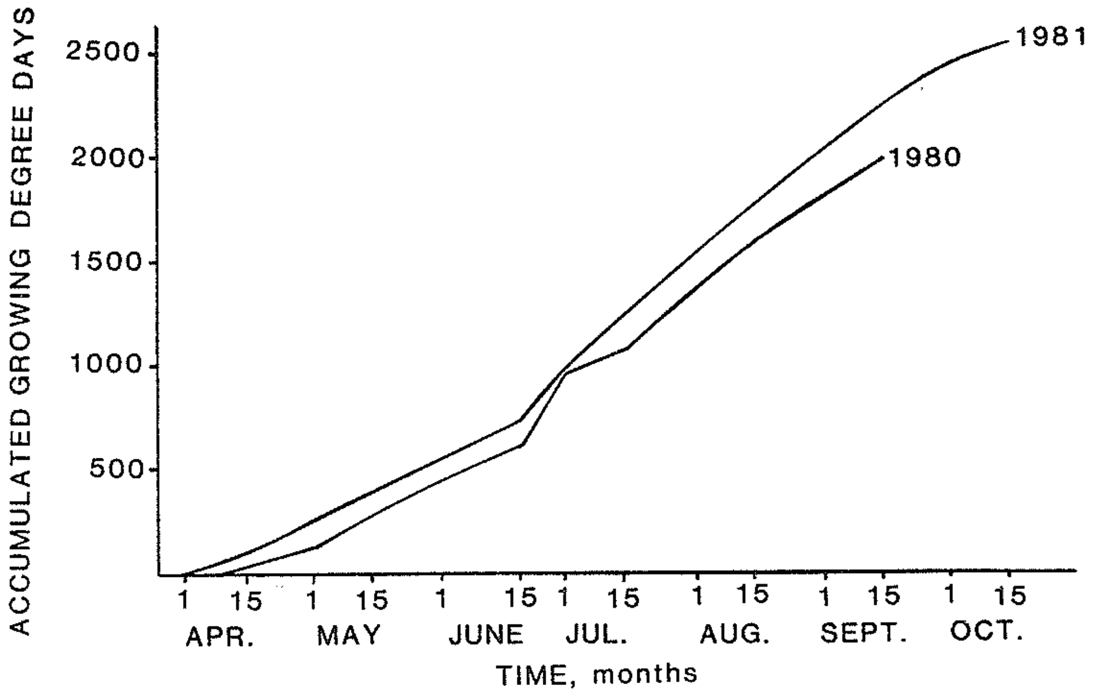

Figure G1. Seasonal GDD accumulation versus time during the growing season for alfalfa and barley.

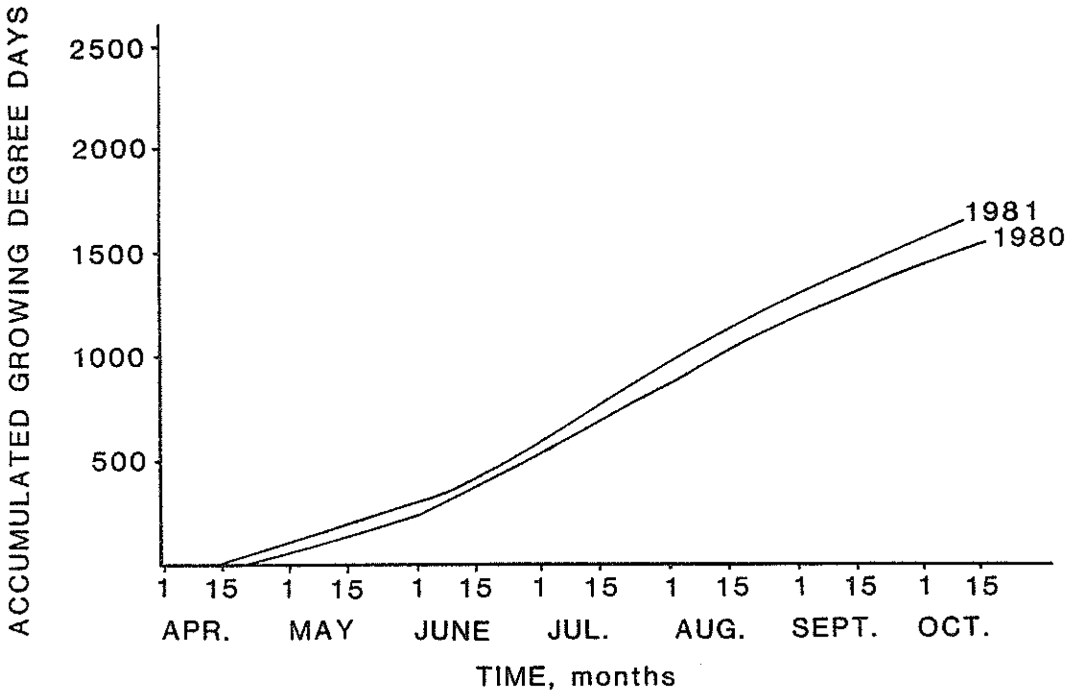

Figure G2. Seasonal GDD accumulation versus time during the growing season for pinto beans.