THE EFFECTS OF DECREASED WATERING ON WHEAT AND BARLEY YIELDS

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ABSTRACT

Water resource planners use a water-production function, which is the relationship between yield and evapotranspiration (E) to determine the economic impact of various water allocation decisions. Wheat and barley were irrigated with a range of water levels using a sprinkler-line-source to determine yield and evapotranspiration under deficit irrigation.

The water-production functions for spring and winter barley were different and varied under different levels of fertilizer. However, expressing the data in terms of relative yield and relative evapotranspiration produced a common water production function. The grain water-production functions for the winter wheat under nonnitrogen stress conditions were the same over years. The average wheat water-production function at Clovis, New Mexico, was statistically different from a derived wheat water-production function in Yuma, Arizona. However, when the water-production functions were again expressed in relative yield and relative E terms, the production functions became statistically the same ($P \leq 0.05$) and transferable to either site. The transferability of a water-production function from location to location can be accomplished, when expressed in relative terms, under varying climate conditions and varying fertilizer levels. Water stress also affects the physiological development rate and physiological characteristics of both barley and wheat. The changes in the physiological characteristics of the crops can be used to estimate the resulting decrease in yield caused by moisture stress.

Keywords: water-production functions, evapotranspiration, yield.

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INTRODUCTION

Agriculturally usable water is currently the most limiting factor to potential crop production in New Mexico. Because the supply of water is not likely to increase significantly, efficient means using available water will have to be developed. As the ground water declines in the High Plains area and the cost of pumping increases, farmers will have to use irrigation water more efficiently and at times supply less than a full irrigation to the crop.

OBJECTIVES

The general objectives of the proposed research were to develop the crop production function for wheat and barley. Specifically, the objectives were:

1. To set up a plot designed to irrigate wheat with a decreasing total water application using a sprinkler-line-source.
2. To measure the total evapotranspiration throughout the growing season and associated yield at selected points from the irrigation line and derive the crop production function.
3. To investigate the effect of moisture stress on the physiological development of wheat and barley.

MATERIALS AND METHODS

Methods

The study site was located 24 kilometers north of Clovis, New Mexico, at the Plains Branch Experiment Station. The soil type at the site is a Pullman clay loam, fine-loamy, mixed, thermic torretic palenstall. The irrigation water quality is 0.421 mhos/cm. Four wheat plots were planted October 14, 1980, and a single wheat plot was planted October 14, 1981, in variety Tamex and irrigated using a sprinkler-line-source on 102 cm wide beds. Prior to planting, each of the four plots in 1980 received different nitrogen fertilizer applications which were, respectively, 0, 56, 112, and 168 kg/ha of nitrogen per hectare. The wheat plot planted in 1981 received 168 kg/ha of nitrogen. The fertilizer was applied as anhydrous ammonia.

In 1980, prior to planting and fertilization, soil samples were taken. Analysis showed that there were 102 kg/ha of residual nitrogen in the top 91 cm of the soil profile, and 75 kg/ha of that was in the top 60 cm of the soil profile. This amount can be added to the fertilizer treatments to give the total fertilizer available for plant growth. In 1981, the wheat plot had a residual nitrogen content prior to planting of 176 kg/ha in the top 91 cm.

The wheat plants were germinated with a furrow irrigation in 1980 and a sprinkler irrigation in 1981 that brought the top meter of the root zone to field capacity. On December 24, 1980, a green-bug infestation occurred that destroyed wheat plots receiving 56 and 169 kg/ha. The other two plots were then sprayed with Parathione. The green-bug infested plots were plowed and replanted to spring barley, Schuyler variety, January 14, 1981, and again furrow irrigated for germination. On October 14, 1981, another barley plot was planted. It received a split application of 0 and 150 kg/ha of nitrogen on either side of the sprinkler line and was sprinkler irrigated for germination. The residual nitrogen prior to fertilization was 63 kg/ha in the top 91 cm of the soil profile.

All plots were subsequently irrigated using a sprinkler-line-source (Figure 1) when the plant-available soil moisture at the sprinkler line had been depleted by no more than 50 percent. This resulted in five irrigations for the wheat plots each year, three irrigations for the spring barley and five irrigations for the winter barley plots.

The sprinkler-line-source provides adequate water throughout the growing season near the sprinkler line while applying a decreasing water application perpendicular to the line. Sprinklers were spaced every 6.1 m along the line and operated at three bars pressure, producing an effective diameter of 15 m. The system was operated late in the evening when the wind was less than 3 kilometers per hour. Evapotranspiration was determined in every other bed of each plot by measuring the parameters which are described by Equation 1:

$$E = I + R - D \pm \Delta SM \qquad (1)$$

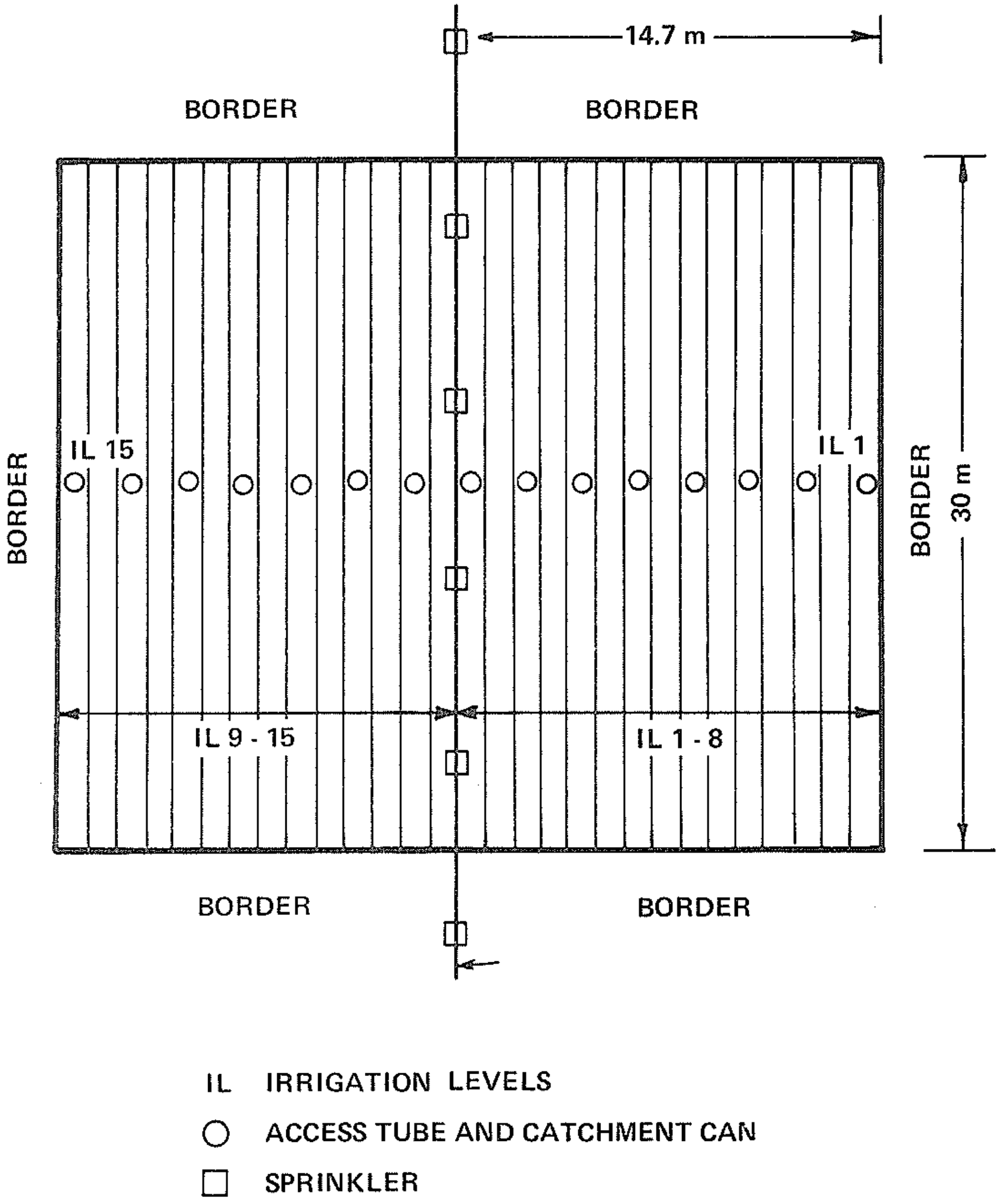

Figure 1. Details of the layout of the sprinkler-line-source.

where

E = evapotranspiration (cm)

I = irrigation (cm)

R = rainfall (cm)

D = drainage (cm)

ΔSM = change in soil moisture (cm)

To measure irrigation, catchment cans were installed across the field in every other bed in a spacing of 2.03 m. Catchment cans were read after each irrigation and were raised as the crop grew so that they were above the crop canopy. Rainfall was measured with a standard 20 cm rain gauge located next to the plots. Drainage was assumed to be negligible. Change in soil moisture was determined from neutron soil moisture readings. Neutron access tubes were installed adjacent to the catchment cans to the depth of 1.5 m and soil moisture measurements were taken triweekly throughout the growing season.

The wheat was harvested June 23, 1981, and July 7, 1982, and the barley July 20, 1981, and July 8, 1982. Biomass and grain yield were measured from these harvests. Harvest plots on each bed were 102 cm wide. The plot located 14.7 m from the line was designated as irrigation level 1, and the plot located 13.7 m from the line on the adjacent side became irrigation level 15. Both barley and wheat were hand-harvested in 1981 using a sickle mower and run through a thrashing machine to determine the grain yield. There were three replicas, 9 m long, of each subplot. In 1982, to save harvest time, a combine was used to harvest wheat and barley grain after hand-harvesting of biomass samples 0.25 m^2 at each level.

Evapotranspiration was determined by interpolation from adjacent rows for the alternate row where yield but not evapotranspiration was measured.

Weather data were measured daily at a nearby climate station. The data included solar radiation, maximum and minimum temperature and humidity, 24 hour wind run, Class A pan evaporation, and rainfall. Growing degree days (G) are calculated using the following formula:

$$G = \frac{(\text{daily temp. max.} + \text{daily temp. min.})}{2} - \text{Base Temp.} \qquad (2)$$

The temperatures are reported in degrees centigrade. The maximum and minimum temperature limits are placed at 30°C and 5°C respectively, for barley, and the base temperature is 5°C. There are no temperature limits set for wheat and the base temperature was set at zero. Daily temperature values beyond these limits are given the limit value when G is calculated.

Methods and Materials Used in Taking Biomass Samples

Biomass samples were taken on selected dates at four or five selected irrigation levels, during the growing period, from both barley and wheat plots. A rectangular metal frame having an inside area of 0.5 m^2 in 1981 and 0.25 m^2 in 1982 and a length equal to the plant bed spacing (102 cm) was utilized in taking samples. The frame was laid directly over the planting bed with the width of the frame lying parallel to the bed length. All plants rooted within the frame area were cut off at the soil surface and removed from the field for determination of above ground weight. A single sample was taken in 1981 and four samples were taken in 1982 at each selected irrigation level. As plant size restricted the use of the metal frame, a ruler was used to measure an equal area and samples were taken in exactly the same manner. Further, samples were taken outside the "subplots" to be harvested, but within the zone of the maximum sprinkler overlap.

Immediately after sampling, the plants were separated into their component parts of leaves, stem, and grain. Only live green material was weighed. Dry weights of the samples were measured after at least 48 hours of oven drying at 80°C. As plant size increased, drying time was extended to 72 hours.

The mean number of shoots per m^2 was determined by taking a subsample of 10 plants per biomass sample, determining the mean shoot number per plant, and multiplying this mean by the number of plants per m^2. Plant height was determined from 10 randomly selected plants prior to harvesting. Height was measured from the soil surface to the top of an outstretched leaf in the vegetation stage and then to the top of the spike, not including the awns, for the rest of the growing season.

Procedures Used in Determination of Leaf-Area-Index

Before oven drying, representative subsamples of leaf matter were obtained from plants taken in the biomass samples discussed above, at each irrigation level. The leaf sampled did not include the collar. The leaf segments sampled were laid out on a sheet of graph or botany paper of a known weight and area, and traced. The "paper leaves" were

Table 1. Monthly precipitation during the barley and wheat growing season for Clovis, New Mexico, in two seasons (1981 and 1981 - 82), compared to the long-term monthly average.

Month & Crop Growth Period	Long Term Monthly Average	Spring Barley 1980 - 81	Winter Wheat 1980 - 81	Winter Wheat & Barley 1981 - 82
	cm	cm	cm	cm
October	3.30		.10	1.17
November	1.27		.55	1.40
December	1.07		.61	.05
January	.87	.40	.40	.10
February	1.07	.89	.89	.43
March	1.40	2.41	2.41	.56
April	1.91	2.36	2.36	.45
May	4.50	4.14	4.14	5.71
June	5.79	6.83	6.83	5.38
July	7.47	4.90	0	1.70
Totals	28.65	21.93[1]	18.29[2]	16.95[3]

[1] Represents rain in growing season 1/14-7/20.

[2] Represents rain in growing season 10/14-6/23.

[3] Represents rain in growing season 10/14-7/6.

then cut out and weighed on a sensitive torsion balance. In 1982, samples were photocopied instead of traced. The leaf-area was determined based on the known density (grams/cm^2) of the paper and the weight of the paper leaves, which had the same dimensions as the actual plant leaves. After oven drying the leaf matter of a known area and weight, an actual plant-leaf density was obtained. Using the density, leaf-area-index (L) was calculated from the biomass data.

BARLEY EXPERIMENT RESULTS

Monthly measured precipitation and long term average monthly precipitation are presented in Table 1. The spring barley received rainfall near the long-term average, whereas the winter barley received rainfall below the average.

Evapotranspiration was estimated using a linear interpolation for those locations where E was not measured but where grain and biomass yield were measured. Spring barley grain, biomass, yield, and E for 1982 (the average of the points equal the distance from the sprinkler line) for selected irrigation levels are presented in Table 2. The grain water-production functions for the spring barley (Figure 2), which received 56 kg/ha and 168 kg/ha of nitrogen, are presented in Table 3. Plots closer than 4.6 m from the line of the 0 nitrogen plot are not presented because overwatering of the plot caused deep drainage, which could not be accounted for in the calculated E. The two grain water-production functions are statistically ($P \leq 0.05$) different, but have statistically the same slope. The same was true

Table 2. Grain yield, biomass yield, harvest ratio, and seasonal evapotranspiration (E) of spring barley at Clovis, New Mexico, 1981.

Subplot distance from line	E	Grain Yield at 14 percent moisture	Biomass Yield at 0 percent moisture	Harvest Ratio grain/biomass
m	cm	kg/ha	kg/ha	
	Average of 2 points equal distance from sprinkler line for plot receiving 56 kg N/ha			
14.7	33.5	888	3223	.24
13.7	33.7	993	3087	.22
12.7	33.8	1070	3860	.24
11.7	34.9	1231	4401	.24
10.7	36.3	1192	4236	.24
9.7	37.1	1490	4514	.28
8.6	38.0	1471	4557	.28
7.6	38.3	1753	4646	.31
6.6	40.0	1838	5122	.31
5.6	43.2	1913	4964	.33
	Average of 2 points equal distance from sprinkler line for plot receiving 168 kg N/ha			
14.7	36.0	930	3110	.26
13.7	38.1	914	3200	.25
12.7	40.2	932	3120	.26
11.7	40.2	1057	3117	.29
10.7	41.1	1283	3488	.32
9.7	42.8	1574	4200	.32
8.6	44.3	1403	3654	.33
7.6	46.8	1892	4550	.36
6.6	49.4	1880	4409	.37
5.6	51.2	2280	5050	.39
4.6	53.1	2427	5228	.40
3.5	53.3	2345	5463	.37
2.5	53.0	2088	4819	.37
1.5	52.9	2417	5407	.38
0.5	52.4	1594	4550	.30

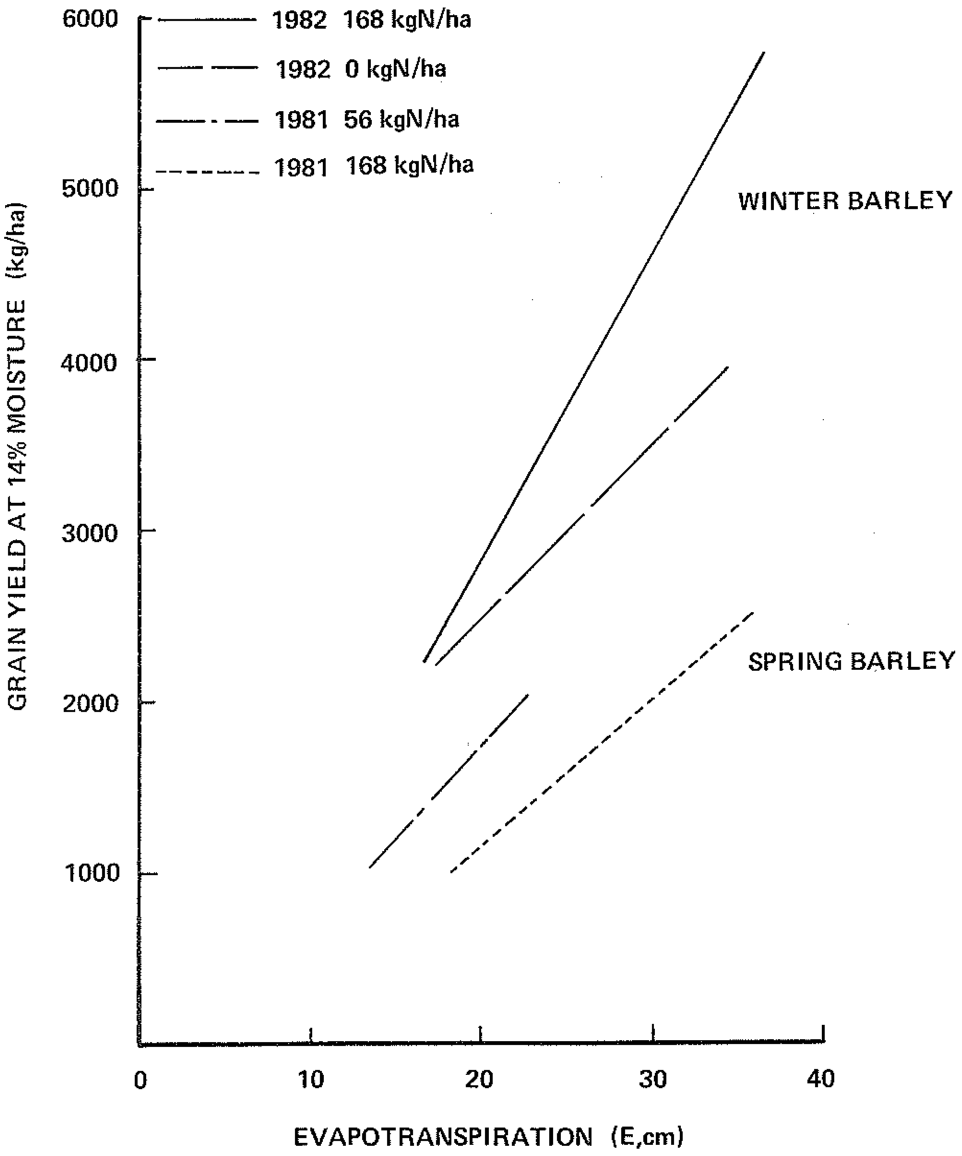

Figure 2. Yield of barley as related to evapotranspiration.

Table 3. Grain and biomass water-production functions and harvest ratios (H) for spring barley, computed using measured evapotranspiration (E) at Clovis, New Mexico, for 1981.

Applied Nitrogen in Plot	Equation Number	Equation	Coefficient of Determination
kg/ha		Grain at 14 percent Moisture Content	
56	1	Y (kg/ha) = -2671.00 + 109.9 E (cm)a[1/]	0.89
168	2	Y (kg/ha) = -2222.22 + 83.97 E (cm)a	0.86
		Biomass at 0 percent Moisture Content	
56	3	Y (kg/ha) = -1584.20 + 161.0 E (cm)b[1/]	0.74
168	4	Y (kg/ha) = -1938.76 + 133.04 E (cm)b	0.89
		Harvest Ratio (H) (grain/biomass)	
56	5	H = -0.151 + 0.011 E (cm)c[2/]	0.89
168	6	H = 0.004 + 0.007 E (cm)c	0.73
Combined	7	H = 0.0034 + 0.0071 E (cm)	0.82

1/ Slopes of the equations followed by the same letter are statistically ($P \leq 0.05$) the same.

2/ Slopes and intercepts of the equations followed by the same letter are statistically ($P \leq 0.05$) the same.

of the biomass water-production functions. The water use efficiency, or the slope of the water-function of the spring barley at Clovis, is low compared to the water use efficiency of spring barley grown in other locations in New Mexico (Kallsen et al., 1981; Sammis et al., 1979).

The climatic conditions at Clovis, New Mexico, are not suitable for growing spring barley and it is not normally grown there. Finkner (1971) reported that spring barley yield is normally 50 percent of winter barley yield.

When the harvest ratio (H) is computed (grain yield divided by the total biomass) both plots have statistically the same regression line (Table 3, Equations 5, 6, and 7). The harvest ratios are low because of the low grain yield but increase with increased E. Regression lines of unaveraged yield, biomass, and harvest ratio versus E along with the data are presented in Appendix A.

The grain yield, biomass, and seasonal E for the 1982 winter barley harvest are presented in Table 4. The data are presented for each side of the sprinkler line because one side of the line received no nitrogen fertilizer. Also, three subplots of the 0 nitrogen plot adjacent to the sprinkler line are not presented because of over-watering plots. Table 5 and Figure 2 present the grain water-production function for the plots. Grain water-production functions are statistically ($P \leq 0.05$) different. Differences in grain water-production functions of spring barley receiving different nitrogen

Table 4. Grain yield and seasonal evapotranspiration (E) of winter barley at Clovis, New Mexico, 1982.

Subplot distance from line	E	Grain Yield at 14 percent moisture	Biomass Yield at 0 percent moisture	Harvest Ratio grain/biomass
m	cm	kg/ha	kg/ha	
		Plot receiving 0 kg N/ha		
13.7	34.1	2131	4271	.43
12.7	38.3	1866		
11.7	42.5	2782	5741	.42
10.7	43.6	3233		
9.7	44.6	2829	6615	.37
8.6	47.4	3328		
7.6	50.1	3516	6416	.47
6.6	50.7	3578		
5.6	51.3	3564	7122	.43
4.6	51.8	3790		
3.5	52.2	3863	7208	.46
		Subplot receiving 168 kg N/ha		
14.7	39.2	2237	3834	.50
13.7	40.7	2494		
12.7	42.3	3122	5988	.45
11.7	42.3	3165		
10.7	42.3	3580	7155	.43
9.7	43.5	3189		
8.6	44.6	3168	6976	.39
7.6	48.1	4565		
6.6	51.6	5144	8255	.54
5.6	53.0	5397		
4.6	54.5	5199	10396	.43
3.5	55.1	5077		
2.5	55.7	5735	11336	.43
1.5	55.8	5204		

* Based on hand harvest data of small plots.

Table 5. Grain and biomass water-production functions and harvest ratios for winter barley, computed using measured evapotranspiration (E) at Clovis, New Mexico, 1982.

Applied Nitrogen in Plot	Equation Number	Equation	Coefficient of Determination
kg/ha		Grain at 14 percent Moisture Content	
0	2	Y(kg/ha) = -1657.0 + 108.0 E(cm)b[1/]	0.90
168	1	Y(kg/ha) = -4787.2 + 185.9 E(cm)a	0.93
		Biomass at 0 percent Moisture Content	
0	4	Y(kg/ha) = - 679.3 + 150.8 E(cm)c[1/]	0.90
168	3	Y(kg/ha) = -9629.6 + 367.5 E(cm)d	0.90

[1/] Equations followed by the same letter are statistically ($P \leq 0.05$) the same.

amounts were shown by Kallsen et al. (1982) to be due to differences in soil evaporation caused by differences in leaf-area-index (L) due to the nitrogen deficiency. The soil evaporation component of E could not be calculated for winter barley because L measurements were not taken.

Because the plots were harvested with a combine, data were collected only on biomass from small plots adjacent to the combined plots. The biomass water-production function derived from these data is presented in Table 5. The biomass water-production functions are statistically different ($P \leq 0.05$) between plots for the same reason that the grain water-production functions are statistically different. The harvest ratio data, presented in Table 4, show a trend for increasing harvest ratio with E as was observed for spring barley. However, the linear relationships are not well defined, having coefficients of determination of less than 0.2, and so are not presented.

The water-production functions are different between 1981 and 1982 because 1981 data represent spring barley and 1982 data represent winter barley. The grain relative water-production functions derived by expressing yield and E as a percentage of maximum yield and maximum E for a particular plot and year, are presented in Table 6. The grain relative water-production functions for both years then become statistically ($P \leq 0.05$) the same. It is interesting to note that the intercept of the combined relative water-production function indicates that 46 percent of E in any year has to occur before any yield is achieved. Most of this 46 percent yearly E is attributed to soil

Table 6. The relationship between relative yield (Y_r) and relative evapotranspiration (E_r) of barley at Clovis, New Mexico.

Year	Applied Nitrogen in Plot	Equation	r^2
	kg/ha		
1981	56	$Y_r = -1.392 + 2.480 E_r$	89
1981	168	$Y_r = -0.916 + 1.844 E_r$	85
1982	0	$Y_r = -0.429 + 1.406 E_r$	90
1982	168	$Y_r = -0.835 + 1.808 E_r$	93
Combined Data		$Y_r = -0.820 + 1.791 E_r$	

evaporation losses. Only a small amount of this E percentage is attributed to transpiration, which is needed to create a minimal plant size before grain production occurs. When the data are presented in terms of relative E and relative yield, the differences in soil evaporation from year to year and between plots are marked. If an estimate can be made of the amount of soil evaporation that occurs from each yield level, then a common water-production function, expressed as the relationship between yield and transpiration, probably can be determined. If soil evaporation is the same for each evapotranspiration level, the intercept of the bio-mass water-production functions will give an estimate of the soil evaporation. However, because the L changes substantially from the edge of the field to the sprinkler line, soil evaporation (a function of L) will be different at each point. Further work needs to be conducted to develop methods to separate soil evaporation from transpiration either through direct measurements or by estimating evaporation through measurements of potential evapotranspiration (E_o), L, and soil moisture content.

Table 7 presents the seasonal E, yield, and E/E_o ratios of the highest, middle, and lowest measured E of spring and winter barley. The method of calculating the Penman and the Blaney-Criddle E_o is described by Sammis et al. (1979). Pan potential evapotranspiration is simply the measured pan evaporation for the time period. The E/E_o ratio for spring barley under nonmoisture stress conditions determined at Farmington, New Mexico, using flood irrigated lysimeter data is 0.58 for the Penman method, 0.58 for the Pan method, and 0.96 for the Blaney-Criddle method (Sammis et al., 1979). These ratios are higher than

Table 7. Seasonal evapotranspiration (E), yield and E/E_o ratios, for the highest, middle, and lowest measured seasonal E of spring and winter barley.

E Level[#]	Yield	E/E_o Ratio		
		Penman Method*	Pan Method*	Blaney-Criddle Method*
cm	kg/ha			
		Spring Barley 1981		
36.0	930	0.31	0.31	0.44
46.8	1892	0.40	0.40	0.57
52.9	2417	0.46	0.45	0.65
		Winter Barley 1981 - 1982		
39.2	2237	0.26	0.29	0.40
48.1	4565	0.32	0.36	0.50
55.8	5204	0.37	0.42	0.57

[#] Data from plots receiving 168 kg N/ha.

* Barley (spring 1981/winter 1981-1982) E_o : Penman (115.9 cm/150.1 cm), Pan (117.8 cm/132.1 cm), Blaney-Criddle (81.2 cm/98.2 cm).

those measured at Clovis (0.46), however, the yield at Farmington in the lysimeters was 3570 kg/ha compared to 2417 kg/ha at Clovis. Kallsen et al. (1982) computed a yield of 2500 kg/ha and E/E_o ratio of 0.45, the same as at Clovis, based on the Penman method, at Farmington, New Mexico, using data from a sprinkler-line-source experiment identical to the Clovis experiment.

Winter barley at Artesia, New Mexico, had an E/E_o ratio of 0.7 for the Penman method, 0.65 for the Pan method, and 0.87 for the Blaney-Criddle method; again higher than the ratios measured at Clovis. The average yield was 5390 kg/ha, which was very close to the yield for the winter barley at Clovis. Again, however, the data at Artesia were determined from flood irrigated lysimeters. Consequently, the yield and the location where the E/E_o ratios were determined and the method of irrigation should be considered when using these crop ratios for a given location and irrigation system. The E/E_o ratios, of course, are dependent on yield. Table 8 presents the linear relationship between E/E_o ratios and yield for the three methods of computing E for both spring and winter barley. Although the equations relating yield to E/E_o ratios represent only a single year's data, this should result in reasonable estimates of E/E_o ratios for a given yield level if the soil evaporation component is the same as that in the sprinkler-line-source experiment. Kallsen et al. (1982) found differences over the years in the crop E/E_o ratios and the water-production functions due to differences in soil evaporation caused by a different number and amount of irrigations, and a different L at the time of the irrigation or rainfall event. As stated

Table 8. The linear relationship between E/E_o ratios and barley yield for Penman's, Pan, and Blaney-Criddle methods of calculating E_o.

Method Calculating E_o	Equation[1]	Coefficient of Determination r^2
	Spring Barley	
Penman	$\frac{E}{E_o} = 0.25 + 0.000086\ Y(kg/ha)$	0.85
Pan	$\frac{E}{E_o} = 0.25 + 0.000086\ Y(kg/ha)$	0.85
Blaney-Criddle	$\frac{E}{E_o} = 0.36 + 0.00013\ Y(kg/ha)$	0.85
	Winter Barley	
Penman	$\frac{E}{E_o} = 0.18 + 0.000018\ Y(kg/ha)$	0.93
Pan	$\frac{E}{E_o} = 0.21 + 0.000038\ Y(kg/ha)$	0.93
Blaney-Criddle	$\frac{E}{E_o} = 0.28 + 0.00051\ Y(kg/ha)$	0.93

[1] Based on plots receiving 168 kg N/ha.

Table 9. A chronology of phenological events for spring barley at the sprinkler line in Clovis, New Mexico.

Date	Julian Date	G*	Event
01/14/81	14		Planted and Irrigated
02/23/81	54	176	Emergence (50%)
03/12/81	71	247	First Tiller Appears Leaves 1-3 at Max. Size
03/18/81	77	275	Wind Damage
03/30/81	89	361	Third Tiller Appears Leaves 1-5 at Max. Size
04/16/81	106	513	Beginning of Stem Elongation Average No. Tillers/Plant = 3
04/29/81	119	667	Stem Elongation (50%)
05/01/81	121	698	Floral Initiation (Main Shoot)
05/08/81	128	790	First Node Appears
05/13/81	133	841	Second Node Appears
05/20/81	140	910	Boot Swelling, Third Node Appears
05/25/81	145	279	Awn Emergence
06/01/81	152	1075	Head Emergence
06/09/81	160	1201	Anthesis (± 2 days)
06/12/81			
06/19/81	166	1306	Milk Stage
06/19/81	170	1366	Beginning of Soft Dough Stage
06/26/81	177	1497	All Plants in Soft Dough
06/30/81	181	1566	Beginning of Hard Dough
07/06/81	187	1675	All Plants in Hard Dough

* Growing Degree Days

Table 10. A chronology of phenological events for winter barley at the sprinkler line in Clovis, New Mexico.

Date	Julian Date	G*	Events
10/14/81	287	0	Planted and Irrigated
10/27/81	300	92	Emergence 50 Percent
11/03/81	307	141	Leaf 1 Maximum Size
11/11/81	11	473	Leaf 2 Maximum Size
05/03/82	123	1102	Beginning of Heading
05/10/82	130	1169	Head Emergence 50 Percent
06/21/82	172	1736	Greater than 50 Percent, Still in Soft Dough

* Growing Degree Days

earlier, future work needs to include the measurement or estimation of soil evaporation so that the relationship between transpiration and yield can be determined.

Physiological events of barley and G, calculated using Equation 2, for barley located at the sprinkler line, are presented in Tables 9 and 10. It took 1,497 G for the spring barley plant to get to the soft dough stage, and 1,736 G for the winter barley to reach the same development stage. Because of a large amount of variability in plant density (Table 11), no conclusion about the effect of moisture stress on the number of tillers of spring barley can be made. The total biomass in g/m^2 and L (Table 11) decreased as the plant underwent moisture stress conditions and seasonal evapotranspiration decreased. Maximum leaf area provides a means of evaluating photosynthesis and yield potential. Maximum L and yield decreased under moisture stress and are related by Equation 3.

$$Y = -3439 + 1564L \tag{3}$$

where

Y = Yield kg/ha
L = Leaf area index on 6/8/81
$r^2 = 0.91$

Equation 3 includes only the plot receiving 168 k/ha of nitrogen. Appendix B presents several growth parameters for spring barley measured at maturity from a hand harvested small plot, 0.5 m^2. The

Table 11. The change in biomass, plant density (P), and leaf-area-index (L), for spring barley throughout the growing season for two levels of nitrogen application.

Applied N in Plot	Subplot Dist. from Line	Date 098 (4/08/81) Days since planting/84			Date 118 (4/28/81) Days since planting/104				Date 139 (5/19/81) Days since planting/125			Date 158 (6/08/81) Days since planting/144			Date 173 (6/23/81) Days since planting/159		
		Density P/m^2*	g/m^2#	L	Density P/m^2	g/m^2	% Leaves	L	Density P/m^2	g/m^2	L	Density P/m^2	g/m^2	L	Density P/m^2	g/m^2	L
kg/ha	m																
168	1.5	64	2	.04	194	151	52	2.93	152	306	3.55	170	656	3.61	94	540	0.75
	2.5	70	4	.07	106	73	55	1.41	160	264	3.28	136	669	3.51	72	742	1.01
	6.6	62	2	.04	112	71	56	1.39	188	351	4.38	160	652	3.49	98	602	0.85
	10.7	98	5	.09	90	53	61	1.03	152	197	2.69	162	540	3.17	88	471	0.69
	14.7	86	3	.05	166	138	61	2.61	124	211	2.87	126	429	2.71	96	440	0.55
56	1.5	80	2	.04	86	62	62	1.26	148	182	2.52	120	550	2.97	118	818	1.01
	2.5	132	3	.07	68	47	62	0.90	116	161	2.24	128	530	2.86	72	545	0.75
	6.6	150	5	.09	92	56	62	1.07	130	217	3.03	98	370	2.18	74	575	1.04
	10.7	82	2	.05	112	79	59	1.54	160	225	3.00	110	423	3.35	102	606	0.84
	14.7	88	5	.09	96	86	52	1.67	116	190	2.24	76	250	1.66	66	255	0.41

* Plants per m^2.

\# Dry weight near 0 percent moisture.

information represents only a single sample without repetitive measurements. Measurements were not made on the physiological development of the winter barley in 1982 due to the limitation of resources.

WHEAT EXPERIMENT RESULTS

The wheat plot planted in 1980 which received zero nitrogen, had green-bug damage to the extent that no useful data were acquired from the plot. The grain yield, biomass yield, and harvest ratio determined from the plot receiving 112 kgN/ha and the wheat data from 1982 are presented in Table 12. In 1982 the variability in the data prevented the interpolation of the E data between measured plots where yield but not E was measured. The grain yield data in 1982 are from large plots that were harvested with a combine. The biomass data in 1982 represents small plots (0.25 m^2), which tend to overestimate biomass, and so resulted in a low computed harvest ratio for the 1982 wheat crop.

Table 13 presents the linear regression of grain and biomass yield, versus evapotranspiration. The grain water-production functions are statistically ($P \leq 0.05$) the same and can be combined. The biomass water-production functions are statistically ($P \leq 0.05$) different because the biomass in 1982 was harvested from small plots. The plot of the combined grain water-production function is presented in Figure 3 along with data from Yuma, Arizona, presented by Heady (1978). The two water-production functions are statistically different but have the same intercepts. When the functions were normalized by dividing the data by the maximum yield and maximum E, they were statistically ($P \leq 0.05$) the same (Figure 4).

Table 14 presents the E, yield and E/E_o ratios for the highest, middle, and lowest measured seasonal evapotranspiration of winter wheat averaged over two years. Data from lysimeter studies at Clovis,

Table 12. Grain yield, biomass yield, harvest ratio, and seasonal evapotranspiration (E) of wheat at Clovis, New Mexico.

Subplot Distance from Line	E	Grain Yield at 14 Percent Moisture	Biomass Yield at 0 Percent Moisture *	Harvest Ratio Grain/Biomass
m	cm	kg/ha	kg/ha	
		Year 1981		
14.7	28.5	1204	2420	.43
13.7	29.2	1169	2481	.41
12.7	30.3	1268	2707	.40
11.7	31.9	1688	3428	.42
10.7	33.7	1692	3845	.38
9.7	38.0	2168	4426	.42
8.6	42.2	2196	4927	.38
7.6	44.5	2558	5380	.41
6.6	46.8	2612	5488	.41
5.6	49.4	2593	5259	.42
4.6	52.0	3173	6512	.42
3.5	54.0	2845	5657	.43
2.5	55.8	2718	5457	.43
1.5	56.7	3384	6675	.44
0.5	57.7	2898	6072	.41
0.5	55.2	3025	6034	.43
1.5	52.8	3374	6458	.45
2.5	51.2	2486	5354	.40
3.5	49.7	2697	5378	.43
4.6	47.7	2271	4969	.39
5.6	45.7	2227	4474	.43
6.6	41.0	1595	3479	.39
7.6	36.4	1641	3123	.45
8.6	34.6	1363	2754	.43
9.7	32.8	1325	2518	.45
10.7	32.6	1388	2766	.43
11.7	32.4	891	1777	.43
		Year 1982		
14.7	38.2	1037	5315	.16
12.7	37.5	1758	5388	.28
10.7	38.0	2165	4822	.38
8.7	46.0	1831	5348	.29
6.6	48.0	2610	7959	.28
4.6	55.4	2874	10352	.24
2.5	61.2	3714	12142	.26
0.5	61.5	4041	12792	.27
1.5	61.2	3616	10670	.29
3.5	55.0	4026	8023	.43
5.6	49.8	3320	7302	.39
7.6	42.6	2521	7716	.28
9.7	38.5	1860	5881	.27
11.7	36.1	1696	4457	.33
13.7	38.0	1214	5318	.20

* 1982 biomass determined from a 0.25 m^2 plot replicated twice.

Table 13. Grain and biomass water-production functions for wheat at Clovis, New Mexico.

Water Production Function	Equation Number	Equation	Coefficient of Determination
		Year 1981	
Grain at 14% Moisture	1	Y(kg/ha) = -916 + 71.6 E(cm)a[1]	0.88
Biomass at 0% Moisture	2	Y(kg/ha) = -1718 + 142.93 E(cm)b	0.87
		Year 1982	
Grain at 14% Moisture	3	Y(kg/ha) = -1893 + 94.3 E(cm)a	0.82
Biomass at 0% Moisture	4	Y(kg/ha) = -5027 + 267.2 E(cm)c	0.88
		Combined Data 1981-1982	
Grain at 14% Moisture		Y(kg/ha) = -1261 + 80.1 E(cm)	0.84

[1] Equations followed by the same letter are statistically $(P \leq 0.05)$ the same.

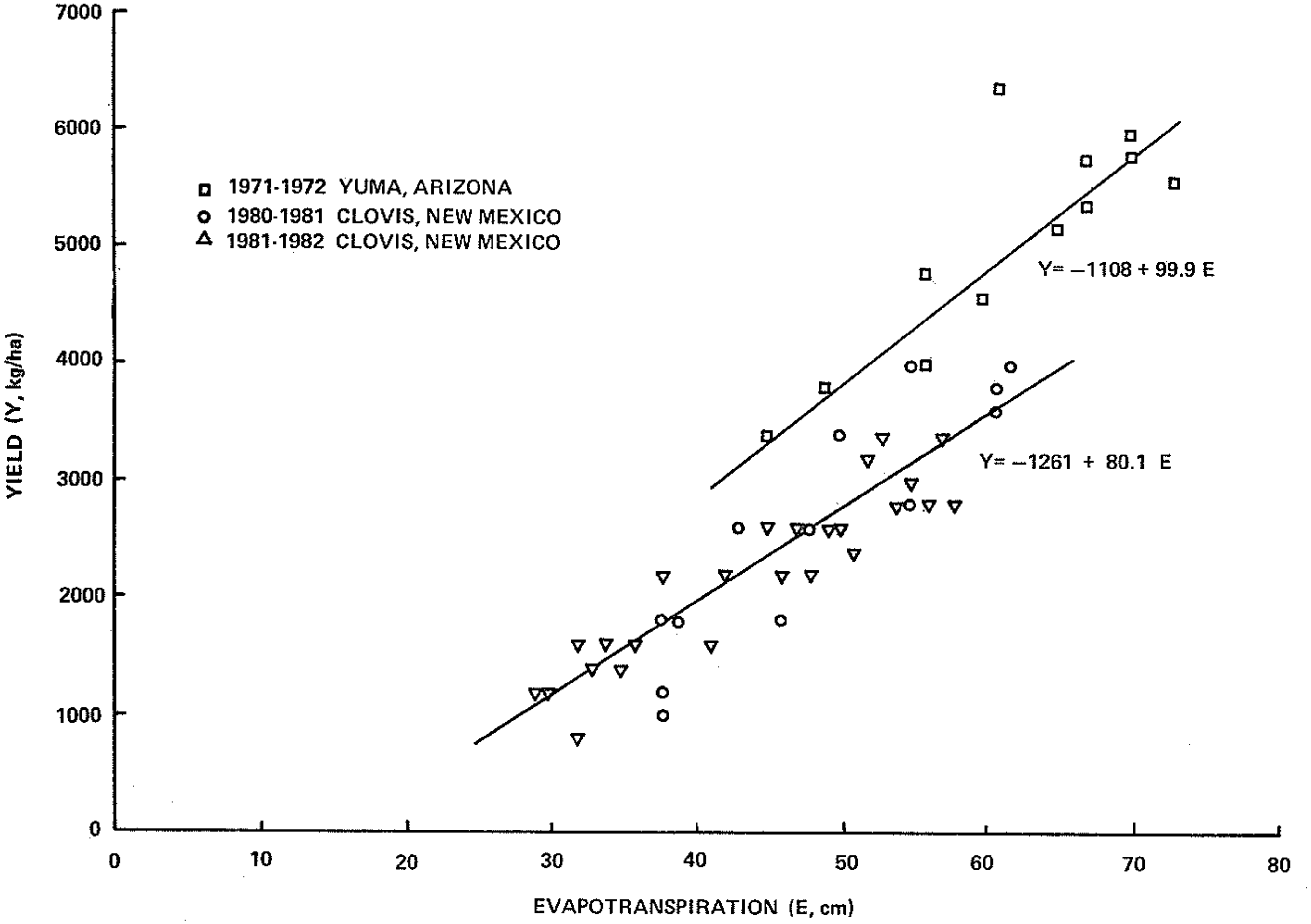

Figure 3. Yield of wheat at Clovis, New Mexico, and Yuma, Arizona, as related to evapotranspiration.

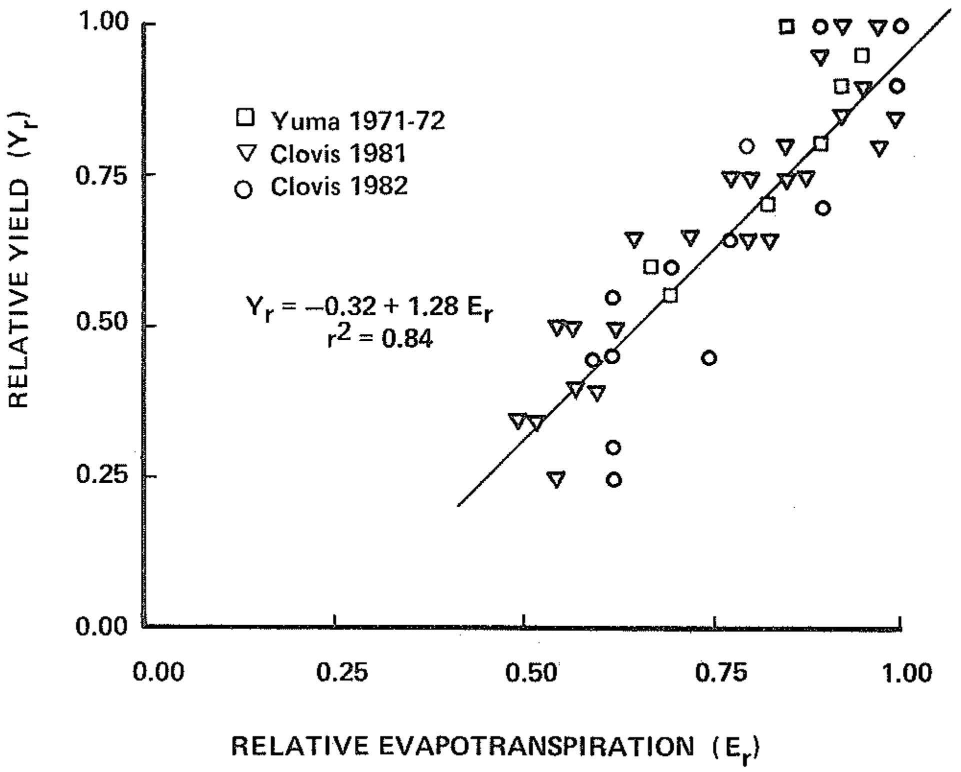

Figure 4. The relationship of relative yield of wheat at Yuma, Arizona, and Clovis, New Mexico, compared to seasonal relative evapotranspiration.

Table 14. Seasonal evapotranspiration (E), yield, and E/E_o ratios for the highest, middle, and lowest measured seasonal E of winter wheat.

		E/E_o Ratio		
E Level	Yield	Penman Method*	Pan Method*	Blaney-Criddle Method*
	kg/ha			
28.5	1204	0.19	0.20	0.31
44.5	2558	0.30	0.30	0.48
61.5	4041	0.40	0.40	0.66

* Winter wheat E_o: 1980-1981/1981-1982 = Penman (150.9/149.3)cm, Pan (146.6/131.6)cm, Blaney-Criddle (88.2/97.6)cm. The average value of two years used in E/E_o ratio computations.

New Mexico (Sammis et al., 1979), had resulted in a ratio of E/E_o, using the Penman method, of 0.69 with a yield of 2793 kg/ha. The E_o measured at Clovis during the 1976-1977 study and the 1981-1982 study was 150 cm. This ratio of E/E_o is considerably higher than the 0.3 ratio calculated from the sprinkler-line-source experiment presented in Table 14. However, the wheat was planted at the end of August in 1976 and 1977 instead of October and the plots were flood irrigated instead of sprinkler irrigated. The resulting seasonal E for winter wheat from the lysimeter studies was 103.7 cm, which is considerably larger than the E measured from the sprinkler-line-source. This increase was due to a longer growing season and possibly additional soil evaporation losses from frequent irrigations in the early part of the growing season. Table 15 presents the linear function relating yield to E/E_o. The seasonal ratios increase with yield and the equations can be used to compute E/E_o for a selected yield from 1000 kg/ha to 4000 kg/ha.

Tables 16 and 17 present the physiological chronology of wheat development located at the sprinkler line. It required 2,700 G to bring wheat to the hard dough stage in 1980-1981, and only 2,539 G to bring the plant to the same development stage in 1981-1982. Increases in both total dry weight (g/m^2) and dry weight (g) per plant (Tables 18 and 19, and Figures 5 and 6) are affected by moisture stress. Because the plants were growing on a full water supply at planting time in a clay loam soil, a differentiation of growth due to moisture stress did not occur until 160 days after planting, when stem elongation started. At that time, the growth at irrigation level 9,

Table 15. The linear relationship between E/E_o ratios and winter wheat yield for Penman, Pan, and Blaney-Criddle methods of calculating E_o.

Method Calculating E_o	Equation	Coefficient of Determination
Penman	$E/E_o = 0.15 + 0.000065\ Y$	0.84
Pan	$E/E_o = 0.16 + 0.000070\ Y$	0.84
Blaney-Criddle	$E/E_o = 0.23 + 0.000105\ Y$	0.84

Table 16. A chronology of phenological events for wheat at the sprinkler line in Clovis, New Mexico, 1980-1981.

Date	Julian Date	G*	Event
10/14/80	288		Planted and Irrigated
10/23/80	297	116	Emergence of Shoot 1 (Leaf #1)
10/31/80	305	178	Leaf #1 at Max. Size
10/31/80	305	178	Emergence of Shoot 2 (Leaf #2)
11/07/80	312	271	Leaf #2 at Max. Size
11/07/80	312	271	Emergence of Leaf #3
11/11/80	316	330	Leaf #3 at Max. Size
11/11/80	316	330	Emergence of Leaf #4
11/11/80	316	330	First Tiller Appears
11/13/80	318	357	Emergence of Leaf #5
11/20/80	325	360	Second Tiller Appears
12/13/80	348	473	Leaf #4 at Max. Size
12/25/80	360	550	Substantial Insect Damage
01/11/81	011	644	
02/10/81	041	751	Cold Wind Damage (note climatological data)
02/24/81	055	859	Third Tiller Appears
03/18/81	007	1014	Stem Elongation
03/24/81	083	1066	Floral Initiation (main shoot, estimated)
04/16/81	106	1360	Second Node Visible
04/16/81	106	1360	Much Variation in No. of Tillers Visible Range 3-8.
04/20/81	110	1421	Aug. No. Tillers/Plant = 3.4
04/22/81	112	1453	Third Node Visible
05/04/81	124	1678	Heads Visible (greater than 50%)
05/08/81	128	1749	Fourth Node Visible
05/18/81	138	1901	Anthesis
05/27/81	147	2064	Milk Stage
06/14/81	165	2461	Soft Dough Stage, Maturity
06/24/81	175	2700	Hard Dough

*Growing Degree Days

Table 17. A chronology of phenological events for wheat at the sprinkler line. Clovis, New Mexico, 1981-1982.

Date	Julian Date	G#	Event*
10/14/81	287		Planted and irrigated
10/20/81	293	91	Beginning of emergence
10/27/81	300	148	Emergence (greater than 50%)
11/02/81	306	217	Leaf #1 at max. size
11/10/81	314	295	Leaf #2 at max. size
12/07/81	341	543	Leaf #4 at max. size
12/07/81	341	593	Mean no. shoots/plant = 3.2
01/28/82	28	782	Mean no. shoots/plant = 7.0
02/24/82	55	910	Mean no. shoots/plant = 8.3
03/02/82	61	942	*Floral initiation
03/08/82	67	972	Mean no. shoots/plant = 9.1
03/12/82	71	1021	*Definite double ridges-beginning of early floral growth
03/12/82	71	1021	Beginning of stem elongation
03/23/82	82	1134	Pseudostem erection (greater than 50%)
03/30/82	89	1183	Awns under development
05/04/82	124	1605	Awns visible (greater than 50%)
05/10/82	130	1681	Head emergence (greater than 50%)
05/12/82	132	1715	Anthesis (greater than 50%)
05/18/82	138	1809	Milk stage (beginning)
06/09/82	160	2236	50% milk, 50% dough
06/17/82	168	2399	Full soft dough
06/24/82	175	2539	Hard dough

Growing Degree Days

* According to Ahrens, J.F. and W.E. Loomis. 1963. Floral Induction and Development in Winter Wheat. Crop Sci., 3(6):463-466.

Table 18. Increase in total dry weight/plant and m^2 of wheat during the growing season for 1980-1981.

Irrigation Level	Subplot Distance from Line	Date 12/01/80	 12/20/80	 02/28/81	 03/16/81	 04/20/81	 05/08/81	 05/27/81	 06/23/81	Grain Yield
		Days Since Planting 48	 67	 133	 153	 188	 206	 225	 252	
	m	g/Plant								kg/ha
1	14.7	0.042	0.046	0.070	0.111	0.84	1.68	2.81	3.98	1204
3	10.7	0.042	0.046	0.070	0.154	0.63	1.83	2.90	5.23	1692
5	6.6	0.042	0.046	0.070	0.099	0.82	2.49	3.86	8.66	2612
7	2.5	0.042	0.046	0.070	0.093	0.70	2.19	3.69	5.60	2718
9	1.5	0.042	0.046	0.070	0.105	0.87	2.01	4.06	10.46	3374
Mean		0.042	0.046	0.070	0.112	0.71	2.04	3.46	6.78	
		Total Dry Weight g/m^2								
1	14.7	5.25	6.33	6.78	8.86	65.6	174.7	320.1	374.0	1204
3	10.7	5.25	6.33	6.78	21.83	83.6	241.2	307.1	418.0	1692
5	6.6	5.25	6.33	6.78	7.29	91.9	288.9	448.1	710.0	2612
7	2.5	5.25	6.33	6.78	6.68	84.0	301.7	553.3	694.0	2718
9	1.5	5.25	6.33	6.78	7.18	149.3	297.5	657.3	962.0	3374
Mean		5.25	6.33	6.78	12.96	118.6	326.0	571.5	789.5	

Table 19. Increase in total dry weight/plant and m^2 of wheat during the growing season for 1981-1982.

Irrigation Level	Subplot Distance from Line	Date												Grain Yield
		1981	1982											
		12/07	01/28	02/24	03/08	03/17	03/30	04/15	04/29	05/11	05/28	06/05	06/17	
		Days Since Planting												
		54	106	133	145	154	167	183	197	209	226	234	246	
	m	g/Plant												kg/ha
9	1.5	0.067	0.23	0.31	0.37	0.51	0.95	2.23	4.77	7.17	12.65	15.98	19.27	3616
11	5.6	0.079	0.19	0.27	0.35	0.48	0.67	1.73	3.19	4.77	7.57	8.86	9.53	3320
13	9.7	0.060	0.22	0.23	0.31	0.47	0.86	1.55	2.55	4.35	6.79	9.10	6.51	1860
15	13.7	0.056	0.21	0.26	0.43	0.49	0.65	1.14	2.26	3.42	4.89	5.31	3.39	1214
Mean		0.065	0.21	0.27	0.36	0.49	0.78	1.66	3.26	4.93	7.98	9.81	9.68	
LSD (0.05)		0.02	0.13	0.11	0.16	0.20	0.42	0.35	1.89	2.34	2.21	3.45	4.13	
		Total Dry Weight g/m^2												
9	1.5	5.82	16.60	22.31	32.96	49.00	78.36	159.73	334.4	531.4	858.5	1075.6	1385.2	3616
11	5.6	8.29	17.55	28.11	26.85	43.48	63.16	179.91	349.3	315.5	622.7	651.2	819.2	3320
13	9.7	4.33	14.63	23.92	32.84	36.76	68.77	132.08	193.2	278.8	437.6	542.0	547.2	1860
15	13.7	6.91	20.59	28.24	43.42	42.92	67.90	121.03	200.0	320.8	430.1	521.2	380.8	1214
Mean		6.34	17.34	25.64	34.02	43.03	69.54	148.19	264.22	361.62	587.22	697.5	783.1	
LSD (0.05)		5.08	8.23	13.05	14.7	19.1	25.2	51.7	94.8	149.1	212.9	138.3	261.8	

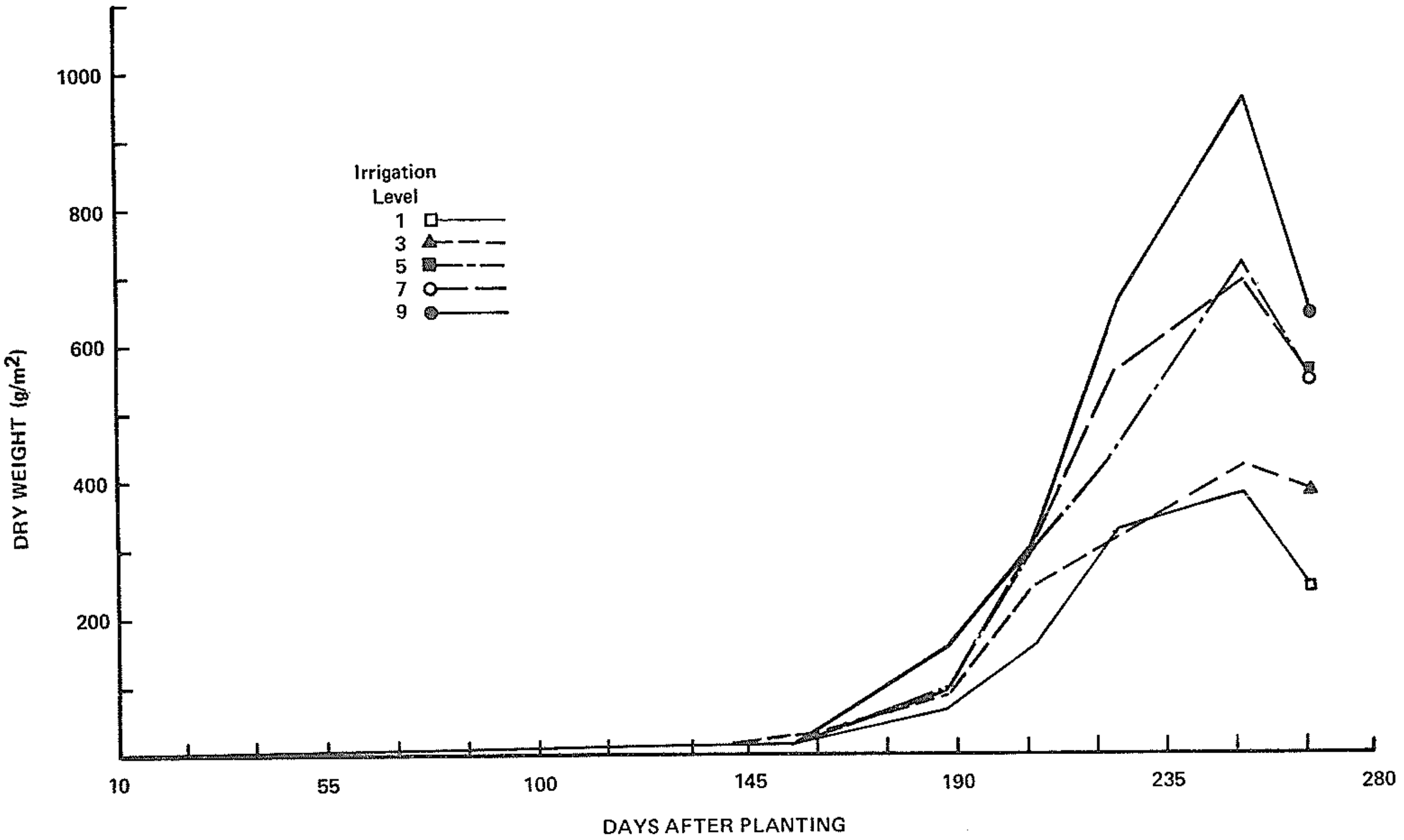

Figure 5. Change in dry weight g/m^2 of wheat during the 1980-1981 growing season.

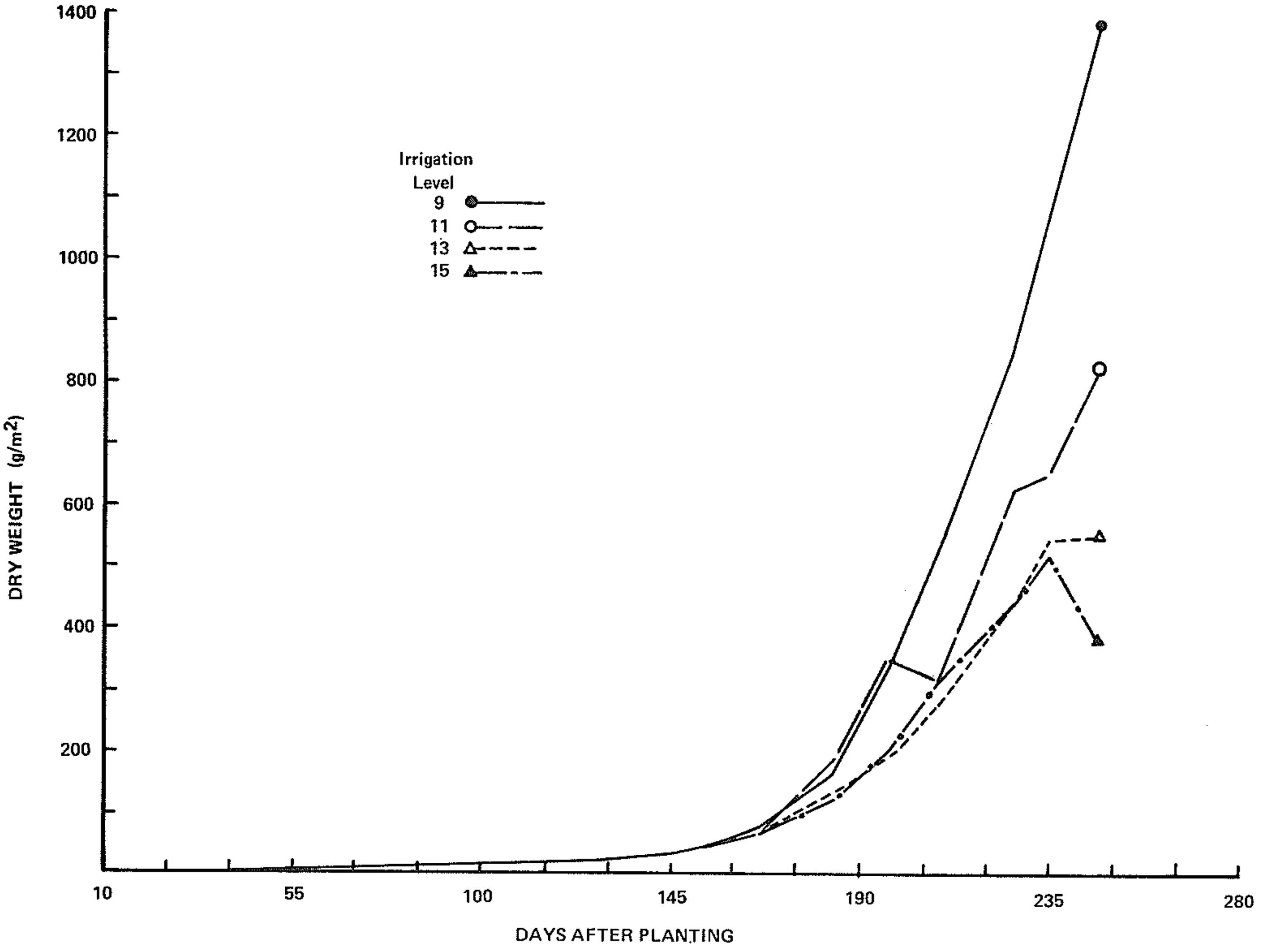

Figure 6. Change in dry weight g/m^2 of wheat during the 1981-1982 growing season.

located adjacent to the sprinkler line, showed a greater increase than that at irrigation level 1 or 15, located on the edge of the sprinkler line plot. However, the growth does not statistically ($P \leq 0.05$) become different until 180 days after planting and then the differences are only statistically detectable between the irrigation level at the sprinkler line and the edge of the field.

A high linear correlation exists ($r^2 = 0.88$) between final biomass (kg/ha) and grain yield (kg/ha) (Table 12). When final biomass in g/plant (Tables 18 and 19) is correlated to grain yield (kg/ha), the linear correlation drops ($r^2 = 0.67$) due to the high variability in the number of plants/m^2. This is derived by dividing the total plant weight/m^2 by the weight/plant.

The growth differential also can be seen when L is plotted versus time (Figures 7, 8 and Table 20). Again, there is no differentiation in L until after 160 days of growth. At the stage of maximum leaf area, L provides a means of evaluating photosynthetic and yield potential. The decrease in L and grain yield under moisture stress is related by Equation 4:

$$y = -1099 + 3320L - 619L^2 \qquad (4)$$

$$r^2 = 0.76$$

where:

y = grain yield (kg/ha)

L = Leaf-Area-Index

Similar results were reported by Black and Aase (1982) showing a decrease in L and yield caused by nitrogen and moisture stress.

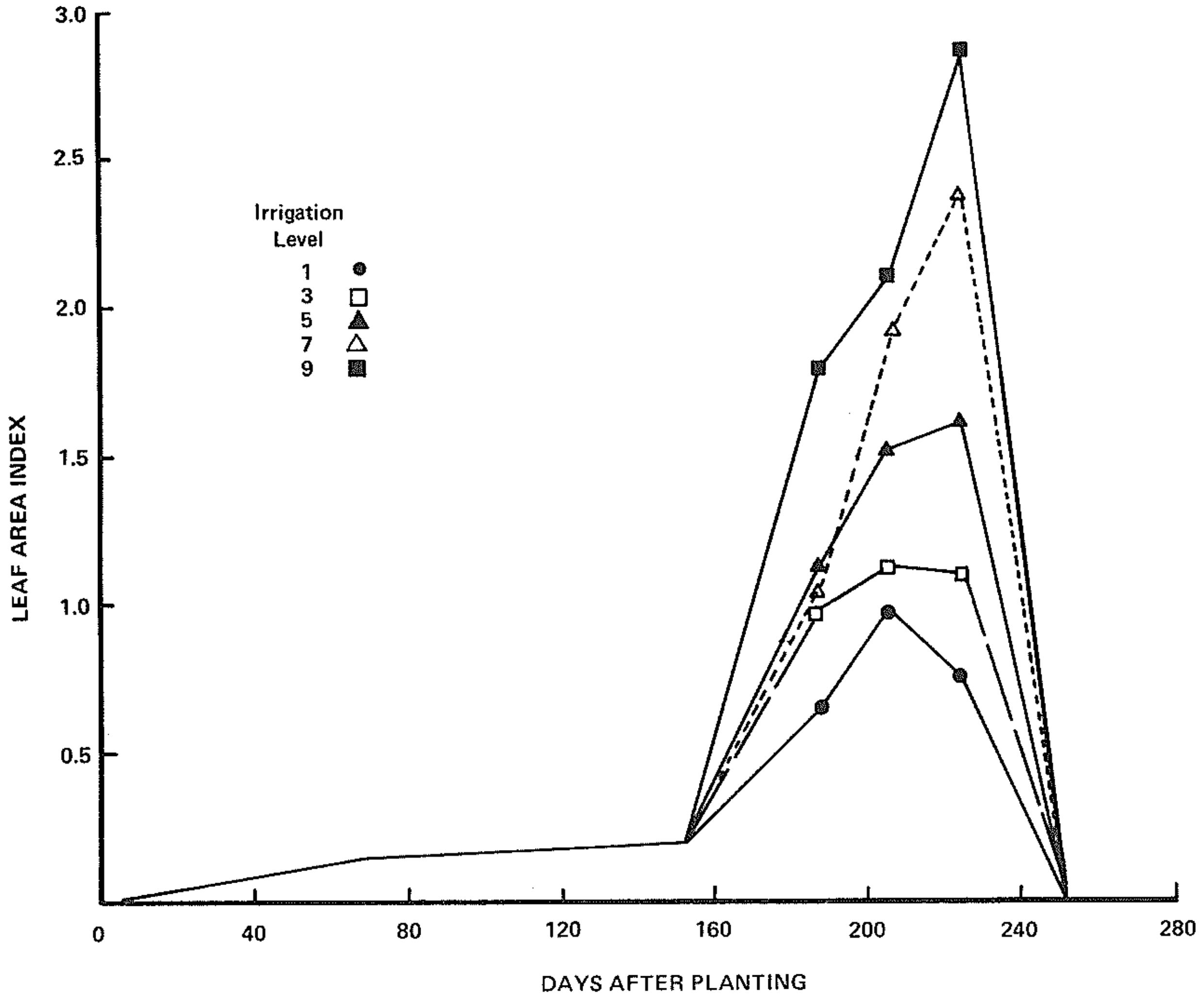

Figure 7. Change in leaf-area-index of wheat for five irrigation levels during the 1980-1981 growing season.

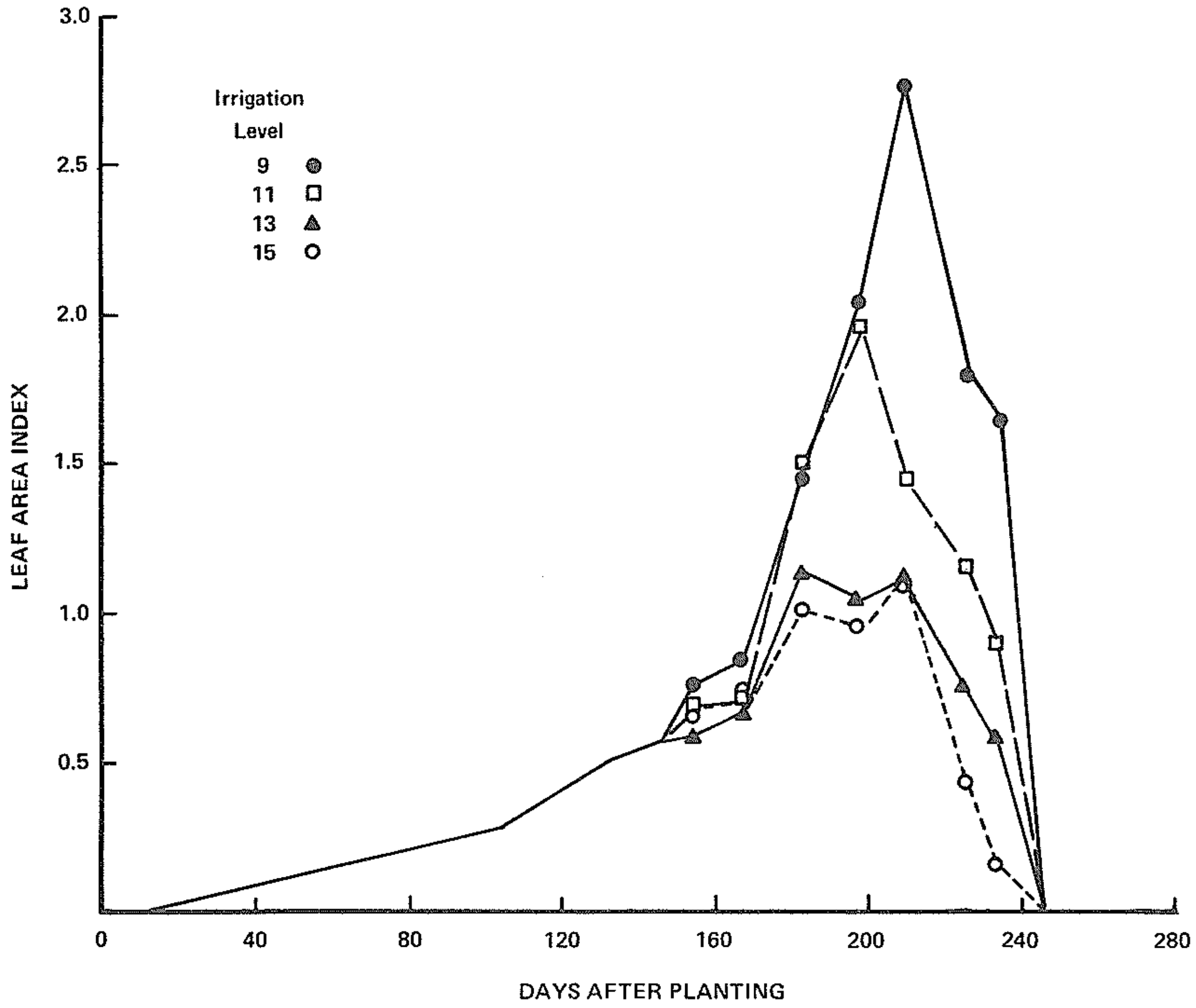

Figure 8. Change in leaf-area-index of wheat for four irrigation levels during the 1981-1982 growing season.

Table 20. Plant height (H) and leaf-area-index (L) during the growing season at various irrigation levels for Clovis wheat, 1980-1981 and 1981-1982.

Irrigation Level	Date: 12/21		3/20		4/20		5/08		5/18*	
	Days After Planting: 68		157		188		206		216	
	H cm	L	H cm	L	H cm	L	H cm	L	H cm	L
					1980-1981					
1	14	0.10	20.0	0.2	29.70	0.66	40.4	0.98	50.40	0.76
3	14	0.10	20.0	0.2	31.00	0.98	48.8	1.13	56.20	1.11
5	14	0.10	20.0	0.2	31.00	1.14	52.9	1.52	73.20	1.61
7	14	0.10	20.0	0.2	38.80	1.06	52.9	1.92	69.70	2.40
9	14	0.10	20.0	0.2	37.60	1.80	49.8	2.12	71.40	2.84
Mean	14	0.10	20.0	0.2	33.50	1.13	49.0	1.53	64.20	1.74
LSD (0.05)	--	----	----	---	3.93	----	6.75	----	5.76	----

*Anthesis occurred 5/18/81. Measurement taken on 6/23/82.

Irrigation Level	Date: 12/07		1/28		2/24		3/08		3/17		3/30	
	Days After Planting: 54		106		133		145		154		167	
	H cm	L	H cm	L	H cm	L	H cm	L	H cm	L	H cm	L
					1981-1982							
9	8.10	0.12	8.40	0.28	11.00	0.44	13.30	0.55	16.50	0.77	23.40	0.84
11	8.10	0.18	8.40	0.29	10.90	0.56	11.50	0.45	15.70	0.69	20.60	0.68
13	8.10	0.09	8.40	0.24	10.30	0.47	11.60	0.55	14.70	0.58	20.90	0.66
15	8.10	0.15	8.40	0.34	12.20	0.56	13.80	0.73	15.70	0.68	18.69	0.71
Mean	8.10	0.14	8.40	0.29	11.10	0.51	12.60	0.57	15.70	0.68	20.90	0.72
LSD (0.05)	----	0.14	----	0.14	0.77	0.26	0.98	0.25	1.01	0.30	1.66	0.31

Irrigation Level	Date: 4/15		4/29		5/11		5/28		6/05		6/17	
	Days After Planting: 183		197		209		226		234		246	
	H cm	L	H cm	L	H cm	L	H cm	L	H cm	L	H cm·	L
9	32.80	1.46	49.00	2.05	60.90	2.77	79.40	1.81	78.70	1.65	77.20	---
11	33.00	1.51	45.00	1.97	52.10	1.45	67.90	1.16	63.40	0.89	64.20	---
13	30.30	1.15	38.20	1.05	46.90	1.12	56.70	0.75	56.20	0.58	51.00	---
15	28.40	1.02	36.20	0.94	49.30	1.12	52.60	0.43	54.10	0.16	46.20	---
Mean	31.10	1.29	42.10	1.50	52.30	1.62	64.10	1.04	63.10	0.82	59.60	---
LSD (0.05)	2.80	0.55	3.07	0.56	4.27	0.56	2.58	0.35	3.05	0.29	2.26	---

Wheat also does not start to show a differentiation in E at different irrigation levels until elongation of the stem starts to occur in April (Tables 21 and 22). The differentiation in height of wheat plants at the end of April can be used to monitor E if the proper amount of water has been applied during April. By continually monitoring the plant height in May, the farmer will know if growth is on course in terms of the amount of water applied to obtain the desired E and yield. An example of how plant height can be used to monitor E and yield follows:

> Figure 9 is used to determine how high the plants should be if moisture stress is not occurring. For the variety grown, if a 75 percent relative yield (y_r) is desired at the end of the growing season, Figure 4 is used to determine the relative seasonal evapotranspiration (E_r), in this case 0.83. The seasonal distribution of this amount of E can be obtained from Tables 21 and 22. There is a slight difference in the relative evapotranspiration from planting to anthesis (E_{ra}) and the relative E for the season (E_{rs}) is indicated by Equation 5:
>
> $$E_{ra} = 0.01 + 0.99\ E_{rs} \qquad (5)$$
>
> $$r^2 = 0.96$$
>
> The difference between E_{ra} and E_{rs} is small enough that the two can be considered the same and used interchangeably. Consequently, from Figure 10, the associated relative plant height (H_r) during April and May should be 0.89 of the maximum height (Figure 9) in

Table 21. Evapotranspiration (E) for Clovis wheat, 1980-1981.

Irrigation Level	1		3		5		7		9	
Seasonal Relative E	0.54		0.64		0.88		1.05		1.00	
Relative Grain Yield	0.35		0.50		0.77		0.80		1.00	
	E	E_a*	E	E_a*	E	E_a*	E	E_a*	E	E_a*
Dates	cm		cm		cm		cm		cm	
10/14/80-11/12/80	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90
11/12/80-01/23/81	0.10	4.00	0.50	4.40	-0.10	3.80	1.40	5.30	0.80	4.70
01/23/81-02/16/81	0.53	4.53	2.01	6.41	2.29	6.09	3.40	8.70	2.16	6.86
02/16/81-03/17/81	3.58	8.11	3.23	9.64	3.89	9.98	4.06	12.76	4.47	11.33
03/17/81-04/01/81	1.17	9.28	1.52	11.16	9.97	10.95	1.19	13.95	2.18	13.51
04/01/81-04/27/81	6.99	16.27	6.83	17.99	10.21	21.16	11.25	25.20	10.95	24.46
04/27/81-05/19/81	6.30	22.57	7.62	25.61	11.15	32.31	12.62	37.82	11.35	35.81
05/19/81-06/11/81	5.51	28.08	6.55	32.16	11.20	43.51	12.27	50.09	11.46	47.27
06/11/81-06/23/81	0.46	28.54	1.57	33.73	3.28	46.79	5.66	55.75	5.56	52.83

* Accumulative daily E.

Table 22. Evapotranspiration (E) for Clovis wheat, 1981-1982.

Irrigation Level	9		11		13		15	
Seasonal Relative E	1		0.81		0.63		0.62	
Relative Grain Yield	1		0.92		0.51		0.34	
	E	E_a*	E	E_a*	E	E_a*	E	E_a*
Dates	cm		cm		cm		cm	
10/14/81-11/11/81	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90
11/11/81-12/08/81	1.96	5.86	1.19	5.09	1.47	5.37	1.14	5.04
12/08/81-01/15/82	0.79	6.65	0.69	5.78	1.30	6.67	0.03	5.07
01/15/82-02/18/82	1.68	8.33	1.27	7.05	1.14	7.81	1.24	6.31
02/18/82-03/09/82	2.62	10.95	2.13	9.18	1.63	9.44	1.37	7.68
03/09/82-03/23/82	2.24	13.19	1.88	11.06	1.47	10.91	2.39	10.07
03/28/82-04/16/82	6.74	19.93	4.85	15.91	3.45	14.36	4.14	14.21
04/16/82-05/04/82	4.67	24.60	2.44	18.35	4.72	19.08	2.92	17.13
05/04/82-05/20/82	8.86	33.46	9.98	28.33	5.03	24.11	5.59	22.72
05/20/82-06/03/82	12.24	45.70	9.42	37.75	2.64	26.75	5.49	28.21
06/03/82-07/13/82	15.52	61.22	12.09	49.84	11.76	38.51	9.80	38.01

* Accumulative daily E.

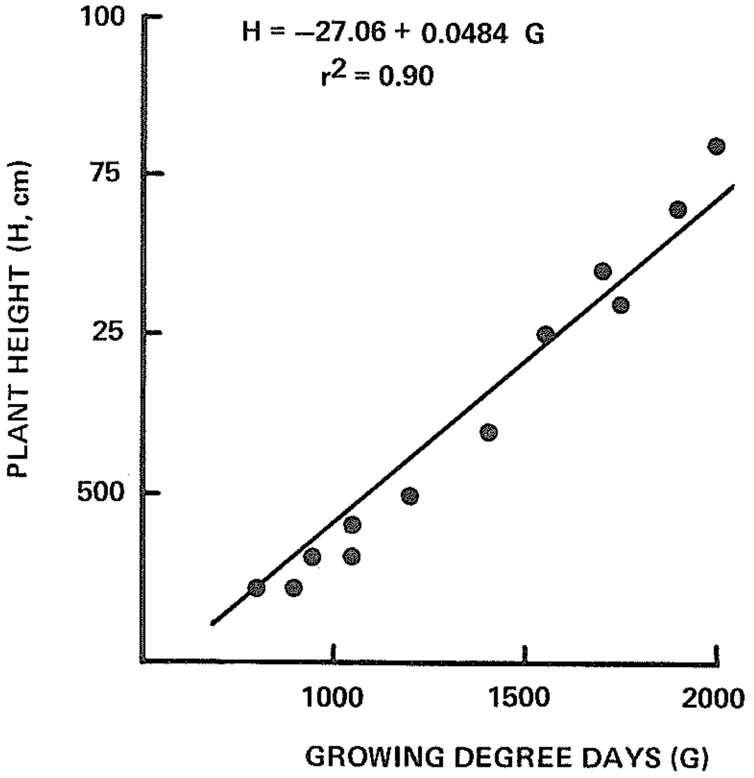

Figure 9. Wheat height as a function of growing degree days under nonmoisture stress conditions during 1980–1981 and 1981–1982 at Clovis, New Mexico.

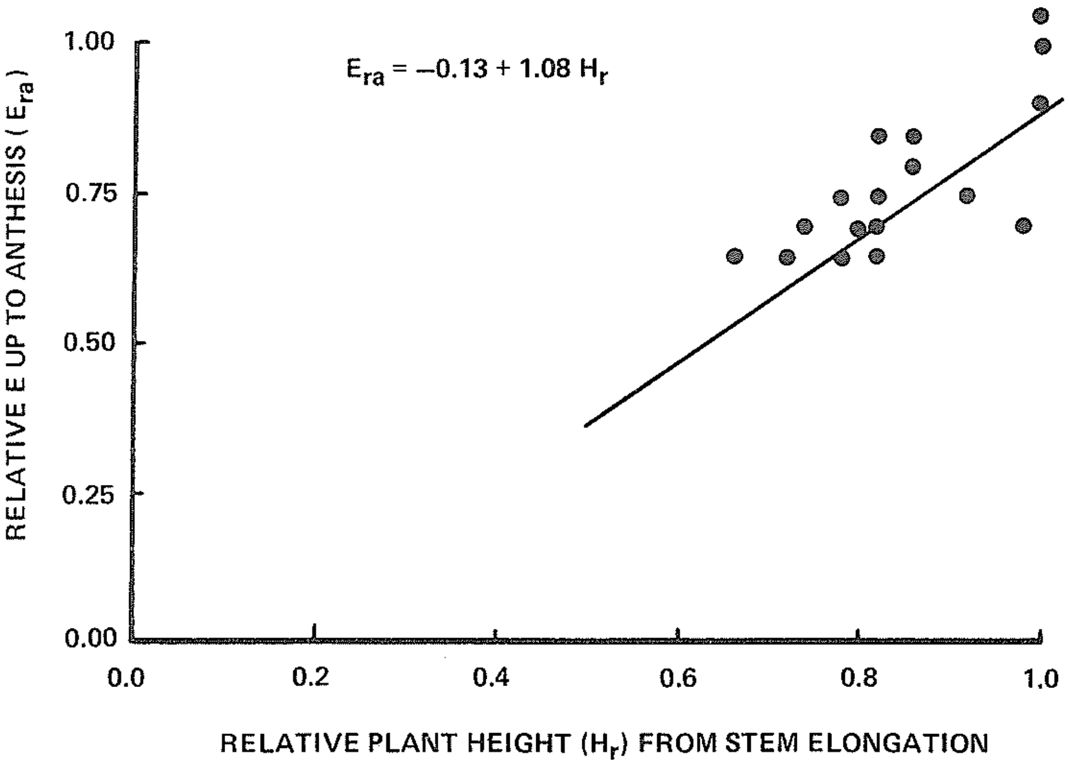

Figure 10. The relationship between relative E up to anthesis, and relative plant height of winter wheat during 1980-1981 and 1981-1982 growing season.

order to achieve 75 percent of the maximum yield or 83 percent of relative E for the season and up to anthesis.

Wheat physiological development also was affected by moisture stress. Wheat plants under severe moisture stress matured at a faster rate than plants under nonmoisture stress conditions. Beginning of head emergence occured 5-6 days earlier at irrigation levels 1 and 15 than at irrigation level 9 (Table 23). Soft dough occurred 12-15 days earlier under moisture stress conditions. The hard dough stage was reached 11-12 days earlier.

Plant density measurement during the growing season showed no statistical difference ($P \leq 0.05$) between irrigation levels. The mean plant density was 117 plant/m^2 with a variation coefficient of 0.02 in 1980-1981 and 88 plant/m^2 with a variation coefficient of 0.17 in 1981-1982.

Table 24 presents the changes in live shoots/m^2 over the growing season. Again, as would be expected, there is an increase in the number of live shoots/m^2 as the irrigation level increases. However, in 1982 the number of live shoots/m^2 was not statistically greater ($P \leq 0.05$) under nonmoisture stress conditions until the end of May, when there was a drop in the number of live shoots under the moisture stress conditions. The number of live shoots/m^2 during the milk stage is linearly related to yield ($r^2 = 0.74$ [Table 25]). The linear correlation drops ($r^2 = 0.52$) if the number of live shoots in the hard dough stage are correlated to yield. Increase in the number of heads is correlated with the number of live shoots and also increases over time as irrigation levels increase (Table 26). The number of heads/m^2 is

Table 23. Wheat growth variation in time of physiological development between irrigation levels.

Irrigation Level	Begin Head Emerge. Date	>50% Head Emerge. Date	Begin Milk Stage	Begin Soft Dough	Begin Hard Dough	All Grain Hard Dough
			1980-1981			
1	4/25/81	5/01/81	*	6/01/81	6/10/81	6/12/81
3	4/27/81	5/02/81	*	6/01/81	6/10/81	6/12/81
5	5/01/81	5/04/81	*	6/09/81	6/15/81	6/12/81
7	5/01/81	5/04/81	*	6/12/81	6/19/81	6/23/81
9	5/01/81	5/04/81	*	6/12/81	6/19/81	6/24/81
			1981-1982	Full Soft Dough		
9	5/03/82	5/20/82	*	6/17/82	6/21/82	6/28/82#
11	5/01/82	5/08/82	*	6/14/82	6/17/82#	6/25/82#
13	4/30/82	5/04/82	*	6/11/82	6/15/82#	6/22/82
15	4/29/82	5/02/82	*	6/02/82	6/09/82	6/17/82

* Exact dates undetermined, all plants in milk by 5/27/81 and 5/18/82.

\# Estimates.

Table 24. Change in number of live shoots per square meter over the growing season at various irrigation levels for Clovis wheat, 1980-1981 and 1981-1982.

Irrigation Level	Date			
	04/20	05/08	05/27	06/23*
	Days After Planting			
	188	206	225	252
	Live Shoots/m^2			
	1980-1981			
1	200	266	242	184
3	380	294	266	180
5	386	350	318	280
7	410	388	452	274
9	558	476	504	396
Mean	387	354	332	263

Irrigation Level	Date											
	12/07	01/28	02/24	03/08	03/17	03/30	04/15	04/29	05/11	05/28	06/05	06/17
	Days After Planting											
	54	106	133	145	154	167	183	197	209	226	234	246
	Live Shoots/m^2											
	1981-1982											
9	290	664	723	810	767	726	583	620	568	523	561	692
11	367	568	825	654	706	667	746	724	385	439	372	440
13	212	549	801	902	626	705	611	504	365	365	319	352
15	363	644	781	1000	745	765	657	504	447	348	393	328
Mean	308	606	783	842	711	717	649	588	441	418	411	453
LSD (0.05)	276	268	272	298	229	276	218	183	166	121	124	172

* Only those shoots containing heads.

Table 25. Linear regression estimates and coefficient of determination (r^2) for the relationships between grain yield and other plant physiological characteristics of winter wheat (Y = grain yield kg/ha).

Regression			Intercept	Slope	r^2
Y	vs	Heads/m^2	-450	8.90	0.52
Y	vs	Live shoots/m^2 milk stage	665	7.98	0.74
Y	vs	Live shoots/m^2 hard dough stage	887	4.35	0.52
Y	vs	Dry head weight g/m^2 hard dough stage	587	4.45	0.80
Y	vs	Head weight g	-1090	2367	0.97
Y	vs	Grains/head on main shoot	-2041	133	0.90
Y	vs	Grain weight/ head g	1243	3146	0.94
Y	vs	Head length cm	6373	1006	0.98
Y	vs	Spikelets/head	-5982	579	0.93
Y	vs	Heads/plant	556	346	0.63

Table 26. Increase in number of heads (h) per square meter over the growing season (after head emergence) for Clovis wheat, 1980-1981 and 1981-1982.

Irrigation Level	Date		
	5/08/81	5/27/81	6/23/81
	Days After Planting		
	206	225	252
	h/m^2		
1	104	212	184
3	154	228	180
5	178	254	280
7	84	342	274
9	60	352	396
Mean	116	278	263

Irrigation Level	Date			
	5/11/82	5/28/82	6/05/82	6/17/82
	Days After Planting			
	209	226	234	246
	h/m^2			
9	212	443	511	692
11	184	386	353	438
13	181	311	308	350
15	282	339	393	329
Mean	215	369	391	452
LSD (0.05)	139	131	116	171

Table 27. Change in dry head weight per square meter during the growing season for Clovis wheat, 1980-1981 and 1981-1982.

Irrigation Level	Date 5/08/81 Days After Planting 206	 5/27/81 225	 6/23/81 253
	g/m^2		
1	30.4	130.2	222.0
3	51.2	103.5	244.0
5	54.5	142.2	410.0
7	26.3	141.8	398.0
9	17.4	177.7	510.0
Mean	36.0	139.1	356.8

Irrigation Level	Date 5/11/82 Days After Planting 209	 5/28/82 226	 6/05/82 234	 6/17/82 246
	g/m^2			
9	86.95	272.56	449.24	817.30
11	59.96	236.26	321.99	502.34
13	53.41	176.68	293.32	338.56
15	82.35	212.85	334.57	227.24
Mean	70.66	224.58	349.78	471.35
LSD (0.05)	42.82	90.38	71.51	175.38

linearly correlated to yield, but the coefficient of determination was only 0.52, (Table 25). Table 27 presents the change in dry head weight g/m^2 during the growing season. As would be expected, head weight increases over time until the hard dough stage and as the plants receive higher irrigation levels. Dry head weight (g/m^2) in the hard dough stage, is also linearly related to yield ($r^2 = 0.80$ [Table 25]). Black (1982) found a higher linear correlation ($r^2 = 0.86$) between $heads/m^2$ and yield for treatments receiving different levels of N fertilizer and moisture due to rainfall. However, in this experiment, moisture stress appeared to affect the head weight (g/m^2) more than number of $heads/m^2$ because tillers were formed during the early growing season when the plants have a soil moisture reservoir to draw from.

Moisture stress also decreases grain weight per head, number of grains per head, head length, number of spikelets per head and total number of heads per plant (Table 28). The decrease was statistically different ($P \leq 0.05$) between individual irrigation levels having E differences of 10 cm. Campbell and Davidson (1979) also reported a decrease in the number of spikelets per head with moisture stress. These plant parameters also are linearly correlated with yield, having a coefficient of determination higher than 0.9, except for the total number of heads per plant which had a determination coefficient of 0.63 (Table 25).

Campbell and Davidson (1979), Robins and Domingo (1962) and Sosulski et al. (1966) reported that the number of grains per head and the weight of the grain was positively correlated to yield.

Table 28. The effect of moisture stress on wheat head weight, grain weight, and number for Clovis wheat, 1982.

Irrigation Level	Head Weight 1/	Number Grains/Head 2/	Grain Weight/Head 3/	Head Length 4/
	g		g	cm
9	2.00	42	1.49	10.1
11	1.79	38	1.44	9.4
13	1.36	33	1.11	8.2
15	0.92	23	0.72	7.6
Mean	1.52	34	1.19	8.8
LSD (P ≤0.05)	0.21	6	0.26	0.5

Irrigation Level	Number Spikelets/Head 5/	Total No. Heads/Plant 6/	Yield
			kg/ha
9	17.0	9.4	3616
11	15.3	5.0	3320
13	13.7	4.9	1860
15	12.6	3.2	1214
Mean	14.6	5.6	
LSD (P ≤0.05)	0.9	1.2	

1/ Based on random samples of *main shoot heads*.

2/ Based on random samples of *main shoot heads*.

3/ Sample size 50.

4/ Sample size 8.

5/ Sample size 20.

6/ Sample size 8.

The percentage of biomass material represented by leaf, stem, and head compared to the harvested biomass does not change until moisture stress occurs 160 days after planting. The leaves are affected by moisture stress more than the stem and the leaf/stem ratio decreases under moisture stress (Tables 29 and 30).

Waldren and Flowerday (1979) reported that leaves plus culms represented 55 percent of the total biomass under nonmoisture stress conditions when the leaves reached maximum size. Leaves plus stems were 50 percent of the total biomass when leaf size was maximum for both the stress and nonstress moisture conditions at Clovis in 1980-1981 (Figure 11). In 1982, the total leaves plus stem represented 32 percent of total biomass at maximum leaf size under nonmoisture stress conditions and 63 percent of the total under moisture stress conditions at irrigation level 15 (Figure 12). In both years, anthesis occured earlier under moisture stress conditions and the head weight represented a greater percent of the total weight earlier in the growing season for the moisture stressed plants.

Yield data were collected by hand-thrashing small plots and machine-thrashing large plot areas in 1981. The machine-thrashed data in 1981 (Table 31), represents a reduction in harvested material of about 23 percent compared to the hand-thrashed data.

In 1982, the grain yield was collected using a combine. The machine was set to harvest grain at yields represented by irrigation level 5. This caused a substantial loss, 48 percent on the high yield plots compared to that harvested by hand. However, the small plots tend to overestimate yields and combine losses. Grain yield losses may have been higher than normal, but they were probably closer to field harvest conditions than the hand-harvested data.

Table 29. Percentage of total dry plant weight at harvest represented by leaf (LF), stem (ST), head (HD), and leaf to stem ratios (LF/ST), for Clovis wheat season, 1980-1981.

	Date																		
	1980	1981																	
	12/01	12/20	02/28	03/16	04/20			05/08				05/27				06/23			
Irrigation Level	%Leaf	%Leaf	%Leaf	%Leaf	%LF	%ST	LF/ST	%LF	%ST	%HD	LF/ST	%LF	%ST	%HD	LF/ST	%LF	%ST	%HD	LF/ST
1	1	2	2	2	9	8	1.13	15	23	8	0.68	13	37	35	0.34	11	46	43	0.23
3	1	2	2	2	12	8	1.50	16	29	12	0.54	15	34	24	0.42	11	47	42	0.23
5	1	1	1	1	8	5	1.84	13	20	7	0.62	13	30	20	0.43	10	48	42	0.21
9	1	1	1	1	8	7	1.22	13	16	2	0.82	17	33	18	0.52	10	52	38	0.19

Table 30. Percentage of total dry plant weight at harvest represented by leaf (LF), stem (ST), head (HD), and leaf to stem ratio (LF/ST), for Clovis wheat season, 1981-1982.

	Date									
	1980	1981								
	12/07	01/28	02/24	03/08	03/17			03/30		
Irrigation Level	%Leaf	%Leaf	%Leaf	%Leaf	%LF[1]	%ST	LF/ST	%LF	%ST	LF/ST[2]
9	1	1	2	2	3	1	3.6	4	2	2.7
11	1	2	3	3	4	1	3.6	5	2	2.4
13	1	3	4	6	5	1	3.6	8	4	1.9
15	1	5	7	11	8	2	3.6	10	8	1.3
Mean	1	3	4	5	5	1	3.6	7	4	2.1
LSD (0.05)	0.8	1	5	4	2	0.5		4	3	

	Date																				
	1982																				
	04/15			04/29			05/11				05/28				06/05				06/17[3]	
Irrigation Level	%LF	%ST	LF/ST	%LF	%ST	LF/ST	%LF	%ST	%HD	LF/ST	%LF	%ST	%HD	LF/ST	%LF	%ST	%HD	LF/ST	%Straw	%Head
9	6	5	1.25	9	15	0.56	11	21	6	0.49	9	33	19	.27	8	37	32	0.22	41	59
11	12	10	1.13	14	28	0.49	9	22	7	0.43	10	37	29	.26	7	32	39	0.22	39	61
13	13	12	1.08	11	24	0.46	11	30	10	0.36	9	38	32	.24	7	38	53	0.19	38	62
15	15	17	0.92	14	37	0.39	16	47	22	0.33	7	49	56	.16	3	46	57	0.06	41	59
Mean	12	11	1.09	12	26	0.48	12	30	11	0.40	9	39	34	.23	6	38	46	0.17	40	60
LSD (0.05)	4	4		4	4		5	13	6		3	14	15		3	9	12		11	21

[1] %LF, %ST, %HD, are representative of percentage of leaf, stem, and head.

[2] LF/ST is representative of leaf/stem ratio.

[3] Actual dry grain weight was found to be 75 percent of the head weight on 06/17/82.

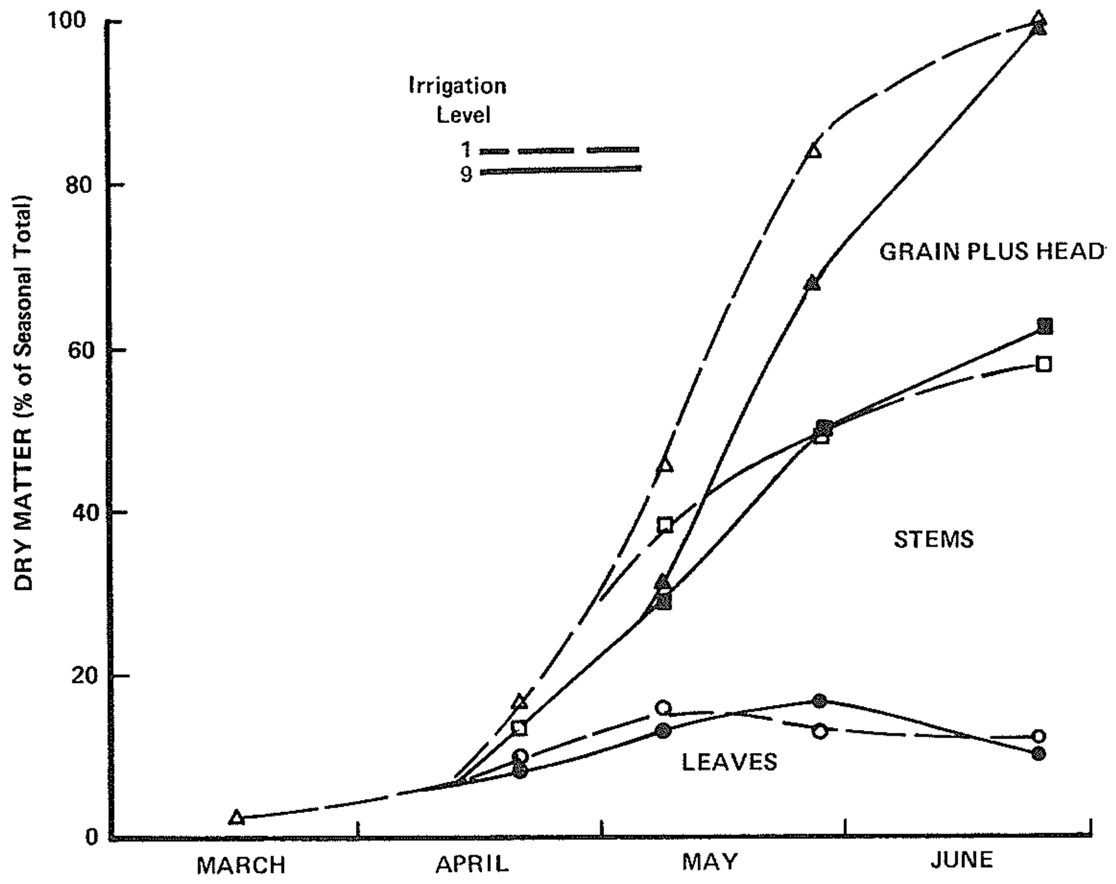

Figure 11. Distribution of dry matter in various parts of winter wheat during the 1980-1981 growing season.

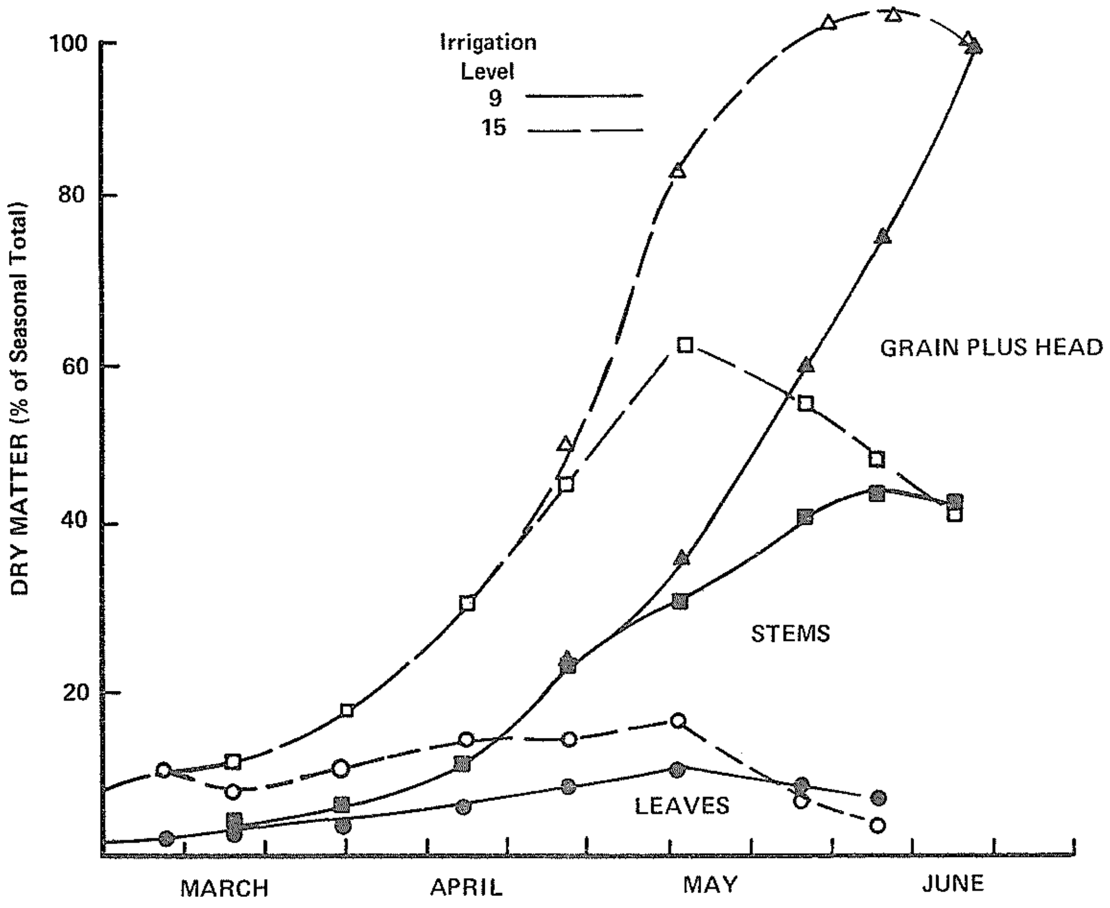

Figure 12. Distribution of dry matter in various parts of winter wheat during the 1981-1982 growing season.

Table 31. Comparisons of grain yield calculated using biomass data versus yields derived from machine harvest data, for Clovis wheat, 1980-1981 and 1981-1982.

Irrigation Level	Grain Hand-Thrashed	Grain Machine-Thrashed
	kg/ha	kg/ha
	1980-1981	
1	1871	1204
2	1771	1268
3	2057	1692
4	3844	2196
5	3457	2612
6	3288	3173
7	3355	2718
8	3237	2898
9	4299	3374

Machine Harvest = 12.6 + 0.77 Hand Harvest $r^2 = 0.76$.

Irrigation Level	Grain Hand-Thrashed	Grain Machine-Thrashed
	kg/ha	kg/ha
	1981-1982	
1	2922	1315
2	2833	1856
3	2589	2773
4	2968	2227
5	4152	2725
6	5506	3007
7	6404	3605
8	6411	3854
9	5695	3616
10	4128	4026
11	3964	3320
12	4268	2521
13	3287	1860
14	2454	1696
15	2911	1214

Machine-Harvest = 550 + 0.52 (Hand-Harvest) $r^2 = 0.59$.

Linear regression forced through 0.

Machine-Harvest = 22.17 + 0.63 (Hand-Harvest).

SUMMARY AND CONCLUSIONS

The water-production functions were statistically ($P \leq 0.05$) different for winter and spring barley under different fertilizer levels. However, expressing the data in terms of relative yield and relative evapotranspiration produced a common water-production function. The grain water-production functions for winter wheat under non-nitrogen stress conditions were the same over the years. Leaf-area-index, grain weight, number of grains per head, number of heads per meter squared, and other physiological parameters of wheat and barley were affected by moisture stress conditions, and many of the physiological parameters could be used to estimate the resulting yield in kg/ha. Future work should include the separation of evapotranspiration into its components, soil evaporation, and transpiration. The separation would help determine the relationship between transpiration and yield, which should be consistent over the years and possibly under different nitrogen fertilizer levels. Expressing the water-production function in terms of relative yield and relative E tends to mask differences in the soil evaporation component which, also will vary under different irrigation systems and fertilizer applications.

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APPENDIX A

Grain yield, biomass yield, harvest ratio, and water-production functions for barley in 1981 at Clovis, New Mexico.

Table A1 . Grain yield, biomass yield, harvest ratio, and seasonal evapotranspiration (E) of barley at Clovis, New Mexico. For plot receiving 168 kg N/ha in 1981.

Subplot Distance from Line	E	Grain Yield at 14 Percent Moisture*	Biomass Yield at 0 Percent Moisture	Harvest Ratio Grain/Biomass
m	cm	kg/ha	kg/ha	
14.70	35.8	855	2900	.25
13.70	35.9	974	3383	.25
12.70	35.9	843	3082	.24
11.70	36.0	1033	3115	.29
10.70	38.0	1134	3378	.29
9.70	40.0	1489	4069	.31
8.60	41.7	1518	3984	.33
7.60	43.4	2148	5053	.37
6.60	45.1	1840	4470	.35
5.60	46.8	2113	5042	.36
4.60	48.7	2344	5179	.39
3.60	50.5	2588	6056	.37
2.50	51.4	2131	4897	.37
1.50	52.2	2517	5526	.39
0.50	52.3	1487	4707	.27
0.50	52.4	1702	4394	.33
1.50	53.6	2317	5288	.38
2.50	54.7	2044	4740	.37
3.60	56.1	2102	4871	.37
4.60	57.6	2510	5277	.41
5.60	55.6	2448	5057	.42
6.60	53.6	1920	4348	.38
7.60	50.2	1636	4047	.35
8.60	46.9	1289	3325	.33
9.70	45.6	1660	4330	.33
10.70	44.3	1432	3598	.34
11.70	44.4	1082	3118	.30
12.70	44.6	1021	3158	.28
13.70	40.4	855	3017	.24
14.70	36.3	1005	3320	.26

* Yields are low due to hail damage before harvest and climate conditions not suitable for growing spring barley.

Table A2 . Grain yield, biomass yield, harvest ratio, an seasonal evapotranspiration (E) of barley at Clovis, New Mexico. For plot receiving 56 kg N/ha in 1981.

Subplot Distance from Line	E	Grain Yield at 14 Percent Moisture	Biomass Yield at 0 Percent Moisture	Harvest Ratio Grain/Biomass
m	cm	kg/ha	kg/ha	
14.7	32.7	963	3822	.22
13.7	32.9	1014	4143	.21
12.7	33.0	1082	4166	.22
11.7	33.2	1264	4717	.23
10.7	34.0	1149	4304	.23
9.7	34.8	1217	4103	.26
8.6	35.9	1238	4090	.26
7.6	37.0	1609	4791	.29
6.6	40.8	1580	4778	.28
5.6	44.6	1675	4428	.33
4.6	45.3	1562	4510	.30
3.6	46.1	1553	4431	.30
2.5	46.4	1748	4728	.32
1.5	46.7	1638	4583	.31
0.5	50.0	1775	4567	.33
0.5	53.2	2011	5856	.30
1.5	50.2	2128	5545	.33
2.5	47.2	2246	5912	.33
3.6	47.8	2321	5535	.36
4.6	44.4	2058	5478	.32
5.6	41.8	2151	5505	.34
6.6	39.3	2095	5467	.33
7.6	39.7	1897	4900	.33
8.6	40.1	1704	5023	.29
9.7	39.4	1762	4924	.31
10.7	38.6	1235	4167	.25
11.7	36.5	1198	4086	.25
12.7	34.5	1059	3554	.26
13.7	34.4	973	3470	.24
14.7	34.4	813	2723	.26

Table A3. Unaveraged grain and biomass water-production functions and harvest ratios for spring barley, computed using measured evapotranspiration (E) at Clovis, New Mexico, for 1981.

Applied Nitrogen in Plot	Equation Number	Equation	Coefficient of Determination
kg/ha		Grain at 14 percent Moisture Content	
56	1	Y(kg/ha) = -728.41 + 56.45 E(cm)a[1/]	0.62
168	2	Y(kg/ha) = -1427.10 + 66.81 E(cm)a	0.65
		Biomass at 0 percent Moisture Content	
56	3	Y(kg/ha) = 1274.93 + 82.28 E(cm)b[1/]	0.45
168	4	Y(kg/ha) = -365.88 + 99.08 E(cm)b	0.58
		Harvest Ratio (H_r) (grain/biomass)	
56	5	H(kg/ha) = 0.062 + 0.006 E(cm)a[2/]	0.65
168	6	H(kg/ha) = 0.044 + 0.006 E(cm)a	0.66

[1/] Slope is the same, intercept is different.

[2/] Slope and intercept are the same.

APPENDIX B

Growth parameters under moisture stress conditions of barley at harvest time in 1981.

Table B1. Several growth parameters of barley (v. Schuyler) measured at maturity under varying levels of evapotranspiration at two fertilizer levels.

Station No. & Distance from Line	ET	Total Dry Weight Biomass	Total Dry Weight Harvest	Dry Grain Weight Biomass	Dry Grain Weight Harvest	Harvest Ratios Biomass	Harvest Ratios Harvest	Total Dry Weight Per Plant Biomass	Total Dry Weight Per Plant Harvest	Number of Live Head Bearing Shoots	Average No. Heads/Plant
m	cm	m²		g/m²				gms		m²	
45-14.7	33.0	440	272	218	70	0.50	0.26	4.58	3.09	192	2.0
43-10.7	37.1	471	417	228	106	0.48	0.25	5.53	4.74	218	2.5
41- 6.6	39.5	602	547	308	180	0.51	0.33	6.14	6.21	222	2.3
37- 1.5	46.3	540	458	272	141	0.50	0.31	5.74	5.20	236	2.5
39- 2.5	47.0	742	591	396	193	0.53	0.33	10.31	6.72	286	4.0
60-14.7	36.5	255	332	110	86	0.43	0.26	3.86	2.89	114	1.7
58-10.7	43.0	606	360	284	123	0.47	0.34	5.94	6.89	258	2.5
52- 1.5	51.3	818	553	408	217	0.50	0.39	6.93	9.30	362	3.1
56- 6.6	51.5	575	435	268	165	0.47	0.38	7.77	6.53	236	3.2
54- 2.5	52.9	545	474	262	176	0.48	0.37	7.57	6.19	226	3.1

Station No. & Distance from Line	Average Grain Weight Head	Average No. of Grains Per Head	Average No. of Grains Per Plant	Nodes Per Head	Grains Per Row	Average Plant Height	Maximum Measured Leaf Areas LAI	Maximum Measured Leaf Areas Square cm Per Plant
m	g					cm		
45-14.7	1.14	71	142	11.8	6.0	51.0	2.87	231.4
43-10.7	1.04	60	150	9.9	6.0	53.9	3.17	195.6
41- 6.6	1.36	67	154	11.1	6.0	60.9	4.38	232.8
37- 1.5	1.15	60	150	9.9	6.0	58.4	3.61	233.5
39- 2.5	1.37	60	240	9.9	6.0	60.1	3.51	258.5
60-14.7	0.97	54	92	9.0	6.0	46.5	2.74	218.9
58-10.7	1.12	70	175	11.6	6.0	53.9	3.35	304.7
52- 1.5	1.13	70	217	11.7	6.0	62.7	2.97	247.8
56- 6.6	1.14	68	218	11.3	6.0	63.2	3.03	233.2
54- 2.5	1.17	75	233	12.5	6.0	65.0	2.86	223.4