Effect of moisture stress on nodulation, growth and yield of chickpea (Cicer arietinum L.)

by Kwang-Wook An

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

Abstract:
Chickpea (Cicer arietinum L.) is being investigated for rotation with cereals in the Northwestern United States. Chickpea is capable of a symbiotic relationship with Rhizobium bacteria that can convert atmospheric nitrogen to a usable plant form. Soil moisture stress limits chickpea production. The objective of this research was to determine the effect of soil moisture levels on nodulation, growth, and yield of chickpea. Field experiments were established in 1985. Main moisture treatments (zero, low, intermediate and high irrigation) were applied with a modified line-source sprinkler system. Subplots of four chickpea cultivars (ILC 591, UC-5, ILC 517, and Suratato) were evaluated for yield effects and irrigation by cultivar interactions.

The highest soil water depletion occurred at 0 to 20 cm as compared to the 20 to 40 cm depth for all cultivars. Days to flowering, plant height, biomass, shoot dry weight, seed yield, seed weight, harvest index, and nodule dry weight of all cultivars increased with increased ET. Days to flowering, plant height, shoot dry weight, and harvest index for all irrigation regimes were significant among cultivars. Plant biomass, seed yield, seed weight, and grain water use efficiency (WUE) had an irrigation by cultivar interaction. However, there was no significant difference in nodule dry weight due to cultivar or irrigation by cultivar interactions.

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APPROVAL

of a thesis submitted by

Kwang-Wook An

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Chickpea (Cicer arietinum L.) is being investigated for rotation with cereals in the Northwestern United States. Chickpea is capable of a symbiotic relationship with Rhizobium bacteria that can convert atmospheric nitrogen to a usable plant form. Soil moisture stress limits chickpea production. The objective of this research was to determine the effect of soil moisture levels on nodulation, growth, and yield of chickpea. Field experiments were established in 1985. Main moisture treatments (zero, low, intermediate and high irrigation) were applied with a modified line-source sprinkler system. Subplots of four chickpea cultivars (ILC 591, UC-5, ILC 517, and Suratato) were evaluated for yield effects and irrigation by cultivar interactions.

The highest soil water depletion occurred at 0 to 20 cm as compared to the 20 to 40 cm depth for all cultivars. Days to flowering, plant height, biomass, shoot dry weight, seed yield, seed weight, harvest index, and nodule dry weight of all cultivars increased with increased ET. Days to flowering, plant height, shoot dry weight, and harvest index for all irrigation regimes were significant among cultivars. Plant biomass, seed yield, seed weight, and grain water use efficiency (WUE) had an irrigation by cultivar interaction. However, there was no significant difference in nodule dry weight due to cultivar or irrigation by cultivar interactions.

CHAPTER I

INTRODUCTION

Chickpea (Cicer arietinum L.) is a cool-season food legume that is being investigated as an alternative crop in Montana. It may have potential as a rotational crop with cereals and may provide the same soil amendment benefits as dry pea and lentil.

Chickpea has low oil, high protein, and is popular for Oriental and Spanish cooking. It is commonly used as an "add on" in salads in the United States.

Chickpea fixes nitrogen through a symbiotic relationship with Rhizobium bacteria. Rhizobia convert atmospheric nitrogen (N_2) to a usable plant form. Chickpea is self-sufficient for nitrogen fixation in low NO_3^- soils. Consequently, chickpea may be used in some cropping systems to decrease the demand for nitrogen fertilizer.

Soil moisture stress is one of the most limiting factors affecting chickpea production. However, there is limited chickpea research on irrigation management and water requirements. This study was initiated to determine the effect of various soil moisture levels on nodulation, growth and yield of chickpea.

CHAPTER II

LITERATURE REVIEW

Chickpea (*Cicer arietinum* L.), also called gram, Bengal gram, garbanzo and Pois chiche, originated in Asia Minor with the earliest recording 5450 B.C. (Auckland and Singh, 1977). Approximately, 85% of the world production is from Southern Asia. The remaining acreage extends westward from Afghanistan, through Western Asia and the Mediterranean Basin, into Ethiopia and Eastern Africa, the Americas, and Australia (Smithson, 1983).

Chickpea is divided into two distinct types based on seed size and area of adaptation. The large-seeded "Kabuli" type is grown as a summer crop in the Mediterranean, Near East, and Central and South America. The fall planted, small-seeded "Desi" type is grown in India, Pakistan, and Ethiopia during the cool, dry season (Auckland and van der Maesen, 1980; Auckland and Singh, 1977; Ladizinsky and Alder, 1976).

Compared to other grain legumes produced in the world, chickpea rates second in area planted, and third in quantity harvested with nearly 8 million metric tons produced annually (Auckland and Singh, 1977). India accounts for nearly 75% of the total world production. Pakistan and Ethiopia produce approximately 14% of the world's crop. The remaining portion is produced mostly in the Middle East, Africa and Mexico (Auckland and van der Maesen, 1980; Auckland and Singh, 1977). The majority of production in India is still from ancient land-races, where chickpea is grown as a rainfed crop on poor fertility soil. The world's average unit production is very low at 700 Kg ha^{-1}. Production in India averages 690 Kg ha^{-1} while Egypt's irrigated production is 1,650 Kg ha^{-1} (Auckland and Singh, 1977).

Chickpea is a relatively new crop in many parts of Africa, Australia and the Americas. It has gained popularity in the United States, mostly for use in salads. Most of the 3,500 metric tons of chickpea produced in the United States is grown in California. The United States imports another 10,000 metric tons, much of which comes from Mexico. Mexico has recently encouraged a production shift from chickpea to pinto bean (*Phaseolus vulgaris* L.), thus decreasing the amount available for export (Auld et al., 1982). This reduction combined with the decreased production trends in California, may create new domestic markets.

Chickpea is a cool-season, deep-rooted, annual legume. Roots may penetrate to 180 cm with nodules developing on both the primary and secondary roots. Leaves are yellowish-green and covered with glandular hairs. Flowers are typically papilionaceous, solitary, and borne in axillary racemes, although some cultivars have two or three flowers per raceme (Auckland and van der Maesen, 1980).

"Kabuli" chickpea usually has white flowers and large leaflets. The "Desi" usually has purplish flowers and small leaflets. Chickpea is self-pollinated, although natural cross pollination by bees has been noted (Auckland and Singh, 1977).

Great diversity exists between cultivars for most agronomic traits. Height ranges from 20 to 100 cm, pods per plant range from 9 to 618, seed size varies from 1,500 to 16,500 seeds Kg^{-1}, and there may be 1 to 3 seeds per pod (Auckland and Singh, 1977). Seed color of the "Kabuli" type is cream to yellow. The "Desi" type has green, brown or black seeds. One pod per peduncle is most common, although the "double pod" characteristic may be present (Bahl and Gowda, 1975; Govil et al., 1980).

Chickpea is considered a long-day plant, but may flower under all types of photoperiods. A diurnal sequence of cool night and warm day temperatures is optimal for crop growth and yield. Optimum day/night temperatures for chickpea production range from 21 to 27^{o}C during the day and from 18 to 21^{o}C at night. Soil temperature for germination should exceed 5^{o}C and preferably be above 15^{o}C. Optimum precipitation for chickpea is approximately 635 to 762 mm annually (Muehlbauer et al., 1982).

The most important yield component is pod number per plant, which is closely correlated with the number of secondary branches (Katiyar and Singh, 1979; Ladizinsky and Adler, 1976; Mehra and Ramanujam, 1979). Seed size has a major effect on yield (Singh and Auckland, 1975). One hundred seed weight has a significant negative correlation with both the number of seeds per pod and pods per plant. The small seeded varieties generally have higher yield potential, but the opposite has been reported in some cases (Pinthus et al., 1973).

Seed yield in grain legumes depends upon both the vegetative and reproductive components which are markedly affected by environmental factors (Summerfield and Minchin, 1976). Chickpea is grown in a tremendous variety of environments ranging from the Tropic of Cancer to 40^{o}N (Sinha, 1977; Summerfield et al., 1979).

The rate and duration of chickpea growth are greatly influenced by climatic conditions, especially temperature, which exerts a strong influence on cultivar adaptation in different regions. Crops generally mature 110 days after planting in a warm environment and within 160 days in a cool environment (Summerfield et al., 1979). Early cultivars are well adapted at Hyderabad India (17^{o}N), where winters are short (Saxena and Sheldrake, 1979). However, production is restricted to late cultivars at Hissar (29^{o}N), where winters are prolonged. Growing season at

Hissar is double that of Hyderabad. Additionally, dry matter productivity per day is higher at Hissar. Harvest indices (HI) are higher at Hyderabad than at Hissar as a consequence of greater vegetative growth at the latter location.

Chickpea is moderately frost tolerant. Young seedlings can withstand temperatures as cold as $-13^{o}C$ (FAO, 1959; Koinov, 1968; Whyte et al., 1953). In the Mediterranean region, winter planting has recently become feasible following the selection of lines that are more resistant to <u>Aschochyta</u> blight (Keatinge and Cooper, 1983). The advantages of winter planting are (1) higher yields resulting from better moisture availability and a longer growing season, and (2) the opportunity to extend chickpea cultivars to areas of lower rainfall than is required with spring-planted conditions (Singh and Hawtin, 1979).

Soil moisture stress may enhance early senescence and maturation of chickpea. Chickpea senescence in India coincided with water depletion in the upper soil profile (Saxena and Sheldrake, 1979). This suggested that soil moisture is an important factor in triggering senescence.

Utilization of reduced branching chickpea may offer a way to increase yields by suppressing early depletion of stored soil moisture. Islam and Sedgley (1981) found evidence for this in field experiments with spring wheat.

Variation in branching in chickpea cultivars has been reported (Singh and Tuwafe, 1981).

Several hypotheses have been suggested for the effect of water stress on nitrogen fixation. Sprent (1976) identified two water stress effects: (1) depressed O_2 uptake inhibits oxidative phosphorylation which produces ATP and $NADPH_2$ required for the metabolic reduction of NO_3^- to NH_3 and (2) water stress affects membrane characteristics which in turn affect the function of the membrane bound enzyme essential for N_2 fixation. Effects of moderate stress may be overcome by increasing the O_2 concentrations.

Low soil moisture in rainfed situations may restrict the formation and function of nodules (Sinha, 1977). Pate et al. (1969) suggested that limitations in water supply to the nodule may affect nodule activity by restricting fixation products which may accumulate in inhibitory concentrations. Sprent (1971) observed a close link between nitrogen-fixing and respiratory activities. However, other researchers reported that inhibition of shoot photosynthesis accounts for the inhibition of nodule acetylene-reduction at low water potentials (Finn and Brun, 1979; Huang et al., 1975a; Huang et al., 1975b).

Some effects of water stress may be directly related to the multiplication and movement of <u>Rhizobium</u> in the soil. Shimshi et al. (1967) found that 3 to 4 cm placement of inoculum in the soil gave the best nodulation for peanut. They also concluded that Rhizobium multiply rapidly following irrigation, and migrate in the soil when sufficient moisture is available. Soil water tensions of -0.8 Mpa reduced the movement of Rhizobium trifolii, and migration cessation occurred when water-filled soil pores became discontinuous (Hamdi, 1970).

Chickpea has been reported to obtain moisture down to a 180 cm depth and grow well without supplemental irrigation if either pre-plant soil moisture or rainfall is adequate (Sandhu et al., 1978). Non-irrigated chickpea may extract water at deep soil depths. However, fully irrigated chickpea usually does not deplete soil moisture below 127 cm. Water stress beyond -0.5 Mpa is reported to be detrimental to seedling chickpea emergence and growth of the radicle and plumule (Sandhu et al., 1978; Sharma, 1985). Saxena and Yadav (1975) reported a positive response to irrigation in areas where winter rainfall was negligible. Irrigated plants maintained a higher leaf water potential, greater leaf area index, and longer leaf area duration. Singh et al. (1982) showed that irrigation 45 days after planting significantly increased chickpea grain yield. Two irrigations, one during vegetative growth and the other during pod fill generally gave the best yield response in India (Saxena and Yadav, 1975; Sharma et al., 1974). The greatest yield increase in northern India was 32 percent. The average water use by chickpea at Dehradun, India ranged from 110 to 210 mm and the yields varied from 900 to 1800 Kg ha^{-1} (Singh and Bhushan, 1979). A water use efficiency of 8.1 Kg grain $mm^{-1}ha^{-1}$ has been reported for rainfed chickpea receiving irrigation 31 to 43 days after planting (Sardar Singh and Saxena, unpublished). Conversely, plants receiving frequent irrigations (31, 43, 65 and 92 days after planting) had a lower water use efficiency of 7.8 Kg grain $mm^{-1}ha^{-1}$.

CHAPTER III

MATERIALS AND METHODS

Effects of moisture level on growth and yield of chickpea (*Cicer arietinum* L.) were evaluated in field experiments in 1985 at the Wytanna Ranch near Manhattan, Montana. Four "Kabuli" chickpea cultivars (ILC 591, UC-5, ILC 517, and Suratato) were evaluated under four irrigation regimes.

Site Description

The soil was a Manhattan sandy loam (coarse-loamy, mixed, Typic Calciborolls). Composite soil samples were taken on 18 May 1985 at depths of 0 to 30, 30 to 60, and 60 to 120 cm to determine initial soil fertility. Samples were oven-dried at 80^{o} in a forced-air oven for 48 hours and analyzed by standard soil test methods in the Montana State University Soil and Plant Testing Laboratory. The analysis indicated the presence of 26, 169, 2,977, and 198 Kg ha^{-1}, respectively of N, P, K, and $SO_4^{=}$. The soil had an electrical conductivity (EC) of 0.35 mmhos, medium effervescence, organic matter content of 1.14%, and pH's of 8.6, 8.7, and 8.9 at depths of 0 to 30, 30 to 60, and 60 to 120 cm, respectively. Bulk densities at depths of 0 to 30, 30 to 60 and 60 to 120 cm were 0.87, 1.01, and 1.23 Mg m^{-3}, respectively. The area was previously cropped to barley.

Experimental Design

A modified randomized complete block, split-block design with six replication was utilized. Four main treatments (2.5 x 4.8 m) of increasing moisture (zero, low, intermediate, and high irrigation) were applied. Main plot irrigation treatments were fixed due to the limits of the line-source system, and could not be tested statistically by analysis of variance (ANOVA) (Hanks et al., 1980). However, cultivars were randomized to afford a valid statistical test to evaluate cultivar yield differences and irrigation by cultivar interactions. Moisture data were analyzed by linear regression as described by Hanks et al. (1980).

Planting

Seed were planted 16 May 1985 in eight-row plots with a cone planter. Rows were 30 cm apart with 20 seed m^{-1}. Commercial granular Rhizobium inoculum from the Nitragin Co. was applied to the seed prior to planting.

Meteorological Observations

Growing season precipitation, temperature, and humidity were measured daily with standard weather instruments.

These measurements are shown in Appendix, Table 3 and summarized in Table 1. Evaporation was recorded daily by by measuring the water loss from pans (No. 1 wash tubs) similar to the procedure described by Bauder et al. (1982). Cumulative evaporation from the pan is a good estimate of crop water use (Bauder et al., 1982).

Table 1. Weekly Environmental Data for Chickpea Moisture Stress Experiment at the Wytanna Ranch near Manhattan, MT, in 1985.

		Temperature			Humidity	
Week	Precip	Mean High	Mean Low	Mean Mean	Mean High	Mean Low
	mm	------------C---------			------%------	
5/16-5/18	0.0	20	2	11	59	25
5/19-5/25	27.0	25	6	16	67	24
5/26-6/ 1	22.0	17	8	12	71	37
6/ 2-6/ 8	2.2	23	9	16	68	34
6/ 9-6/15	0.0	23	5	14	64	23
6/16-6/22	0.0	27	6	17	62	22
6/23-6/29	4.0	22	5	14	68	31
6/30-7/ 6	0.0	33	9	21	70	26
7/ 7-7/13	4.4	30	11	20	74	34
7/14-7/20	0.0	28	10	19	76	32
7/21-7/27	0.0	31	10	20	75	29
7/28-8/ 3	20.0	22	8	15	77	46
8/ 4-8/10	12.5	26	6	16	76	29
8/11-8/17	3.2	17	1	10	76	38
8/18-8/20	11.5	25	2	14	76	26
5/16-8/20	106.8	25	7	16	71	30

Irrigation System

Moisture treatments were applied with a line-source sprinkler irrigation system similar to the one described by Hanks et al. (1976). A Model 25 sprinkler with 4 mm nozzles (Rain Bird Sprinkler Manufacturing Company of Glendora, California) was used. Sprinklers were operated at 379.5 kPa giving a wetted radius of 15 m and a discharge rate of 0.34 l s^{-1} per sprinkler head. Sprinklers were placed on 2.5 x 60 cm risers spaced 4.6 m apart on 5 cm diameter aluminum pipe with hook and latch couplings.

Plots were irrigated after approximately 6.5 cm of water was lost from the evaporation container. Irrigation was applied when the wind speed was less than 2.4 m s^{-1} to control drift, and at successive intervals to reduce runoff. Plastic collection cups were placed within each plot at canopy level to monitor the amount of applied water.

Soil Moisture Determination

Neutron probe access tubes (160 psi PVC pipe with an inside diameter of 40 mm) were placed in the center of each plot. Soil moisture measurements were taken with a neutron probe (Campbell, Model 503DR Hydroprobe) at depths of 20, 40, 60, 80, 100, 120, and 140 cm. Initial probe readings were taken after planting and at 14 day intervals.

Additionally, measurements were taken prior to and 24 hours after each irrigation. Irrigations were applied at 37 and 48 days after planting.

Data at specific time periods for ET, irrigation and rainfall levels are given in Appendix, Tables 4 and 5 and summarized in Table 2. Seasonal irrigation regimes and corresponding ET values were used to regress all soil and plant growth parameters. Seasonal ET was determined for each irrigation regime by the following equation: ET = soil moisture content at planting + precipitation + irrigation - soil moisture content at harvest.

Growth and Yield Measurements

Stand counts were taken from the center two rows of each plot on 19 June 1985, and at harvest from a 2 m^2 area in the center of each plot.

Plant height was measured 15 days after emergence and at 14 day intervals until harvest. Date of first bloom was recorded for each plot.

Plots were harvested from 1 August to 20 August when approximately 60% of the leaves turned yellow. Nodule dry weight was based on a sample of 12 plants per plot. Plants were randomly selected, dried at 80°C for 24 hours, and weighed. Shoot and seed dry weight were taken from a 2 m^2 area in the center of each plot at harvest. Plant material was dried at 80°C with a forced-air oven for 48 hours and weighed to determine dry matter per plant. Seeds were removed from the pods with a Vogel rubber-roller thresher.

Plant biomass, harvest index (expressed as the ratio of seed yield to above-ground plant biomass) and grain and biomass WUE (expressed as yield $mm^{-1}ha^{-1}$ of ET) were determined.

Table 2. Irrigation Regimes for Chickpea Moisture Stress Experiment at the Wytanna Ranch, Manhattan, MT, in 1985.

Cultivar	Irrigation Regime	Total Water Applied (precip.+irrigation)	Seasonal ET
		mm	
ILC 591	Zero	67	123
	Low	95	154
	Intermediate	190	245
	High	253	309
UC-5	Zero	67	118
	Low	95	156
	Intermediate	190	249
	High	253	309
ILC-517	Zero	67	122
	Low	95	157
	Intermediate	190	245
	High	253	307
Suratato	Zero	67	125
	Low	95	164
	Intermediate	190	249
	High	253	309

Statistical Methods

The MSUSTAT computer program developed by Richard E. Lund was used for all statistical analyses. Main plot effects were analyzed by linear regression. Subplot and the main plot by subplot interaction effects were analyzed by ANOVA.

CHAPTER IV

RESULTS AND DISCUSSION

Environments

The maximum temperature ranged from 9 to 37^{o}C while the minimum temperature ranged from -4 to 15^{o}C (Appendix, Table 3). The maximum temperature was equal to or above 30^{o}C for 24 days and the minimum temperature was equal to or below 0^{o}C for 3 days. Total precipitation for the crop growing season was 106.8 mm. Most of the precipitation occurred before 8 June or after 28 July in the growing season. Growing season length was 97 days.

Evapotranspiration

Evapotranspiration (ET) expressing water use by a crop is a measure of crop transpiration plus soil surface evaporation. There was a good relationship between ET and applied water (precipitation and irrigation) at four irrigation regimes with r^2 =0.99 (Fig. 1). ET increased 146% between the zero and high irrigation regime.

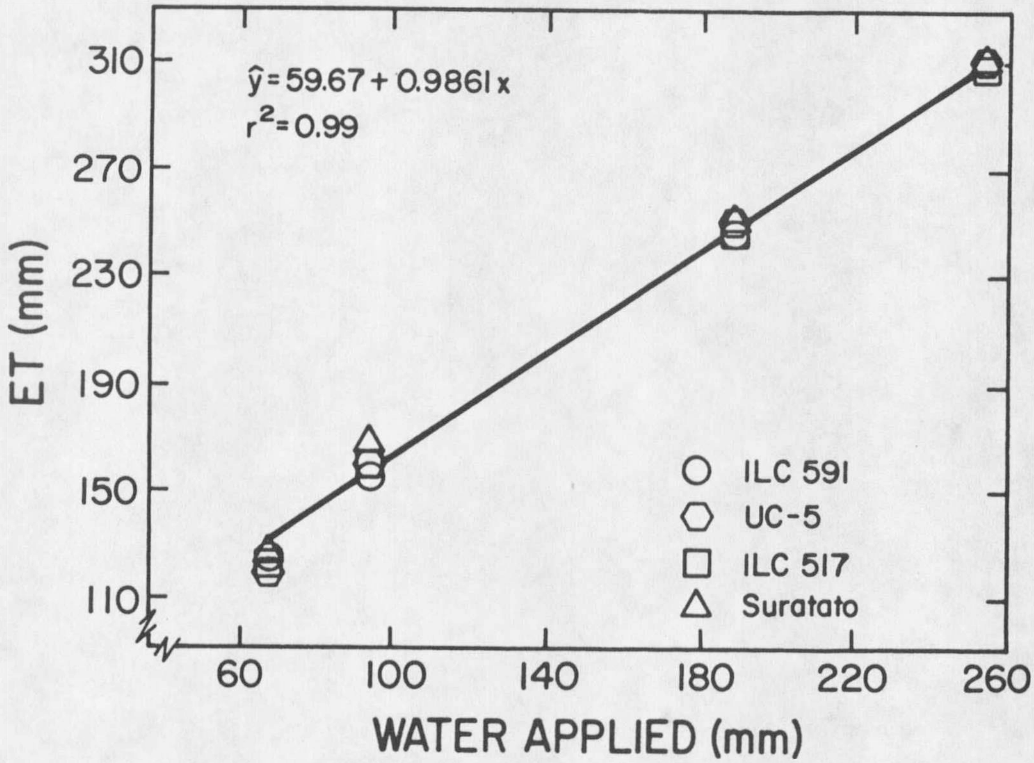

Figure 1. Relationship of Seasonal Evapotranspiration (ET) to Water Applied at Four Irrigation Levels (zero, low, intermediate, and high) to Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

<u>Plant Available Water</u>

Plant available water for each cultivar at emergence to a depth of 140 cm was approximately 7.8 cm (Fig. 2, 3, 4, 5). Available water in the 0 to 20 cm depth for the four irrigation treatments declined immediately after emergence. However, available water in the intermediate

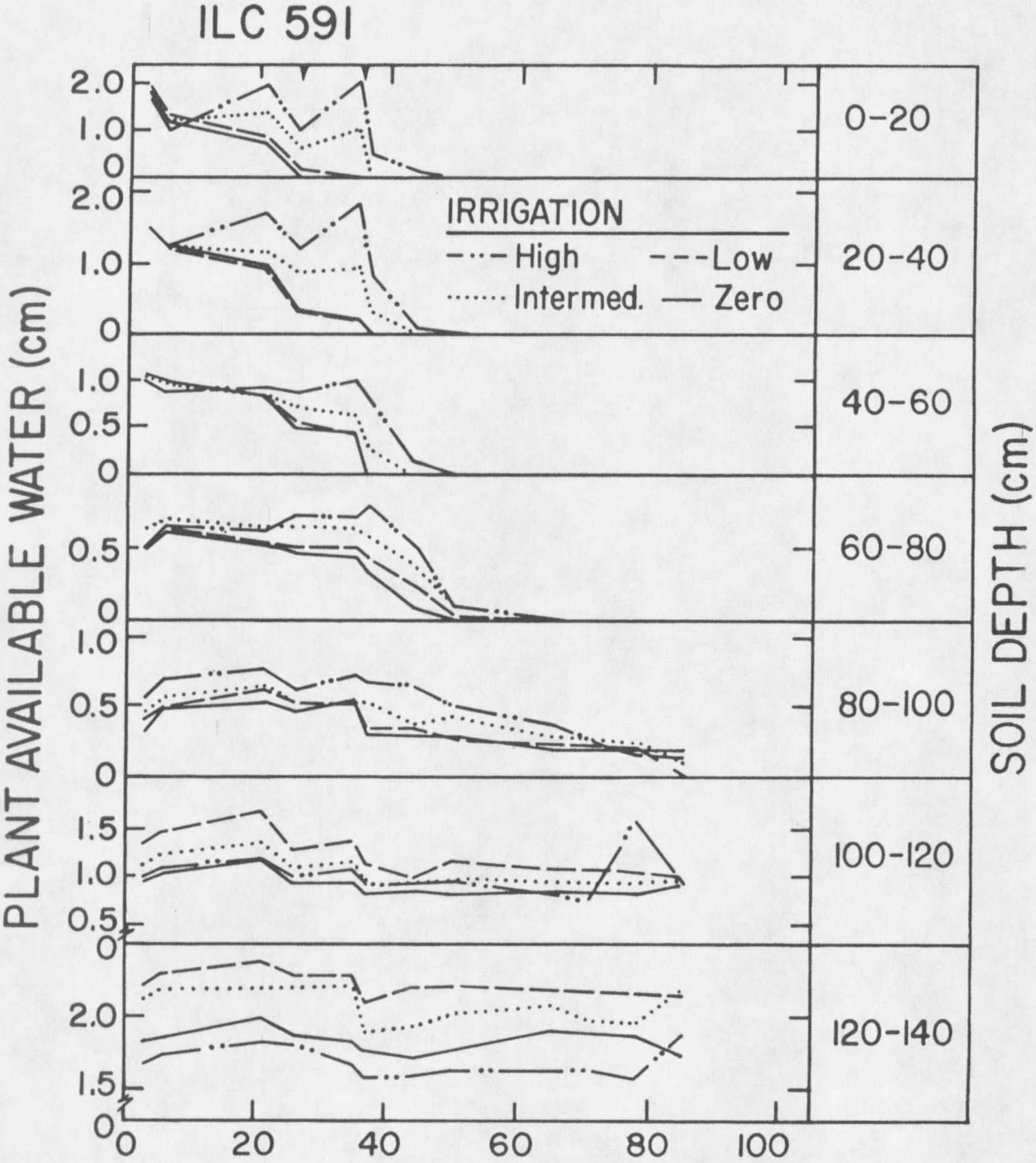

Figure 2. The Effect of Chickpea 'ILC 591' on Plant Available Water from Emergence to Harvest at the Wytanna Ranch, Manhattan, MT, in 1985. Arrows indicate time of irrigation.

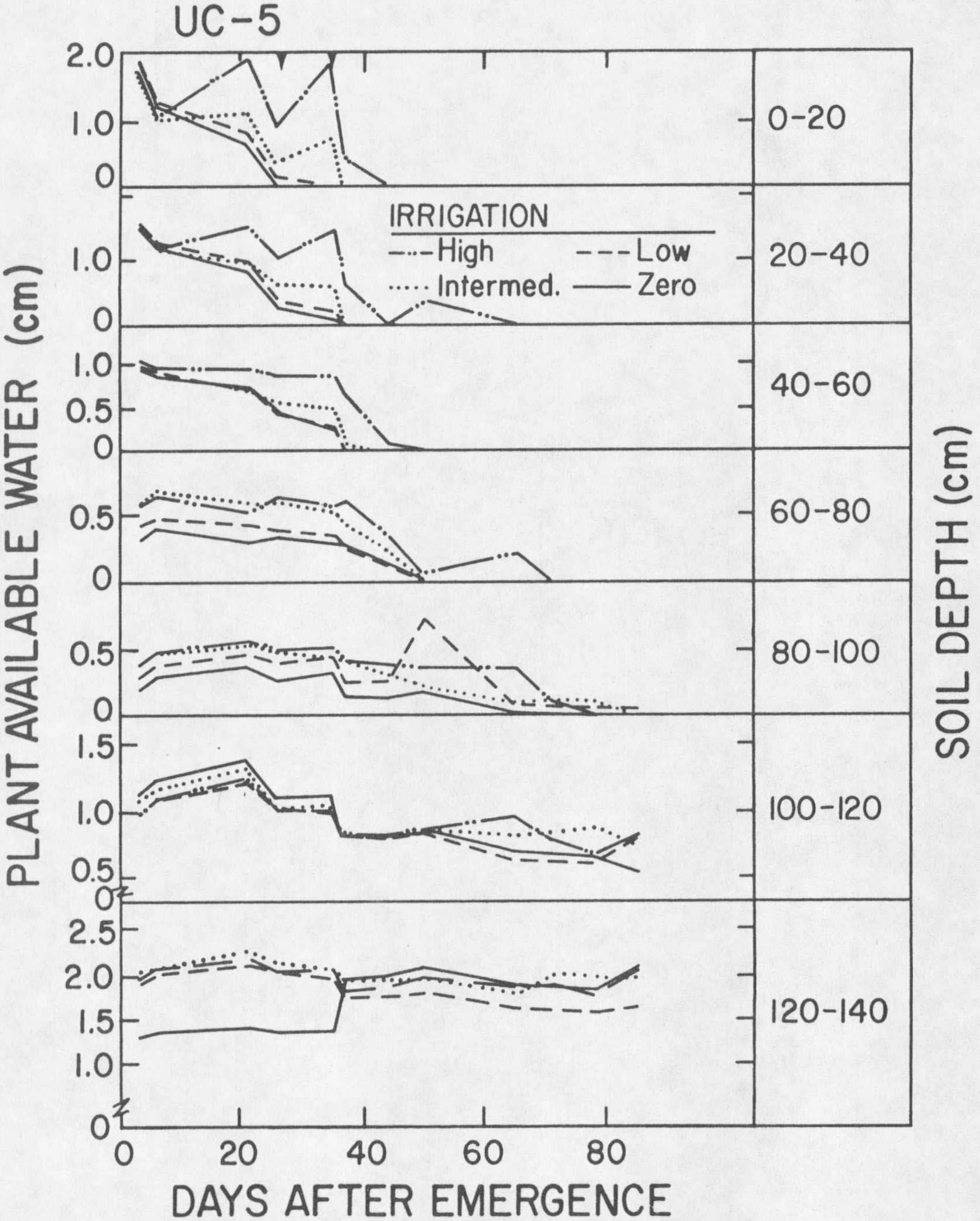

Figure 3. The Effect of Chickpea 'UC-5' on Plant Available Water from Emergence to Harvest at the Wytanna Ranch, Manhattan, MT, in 1985. Arrows indicate time of irrigation.

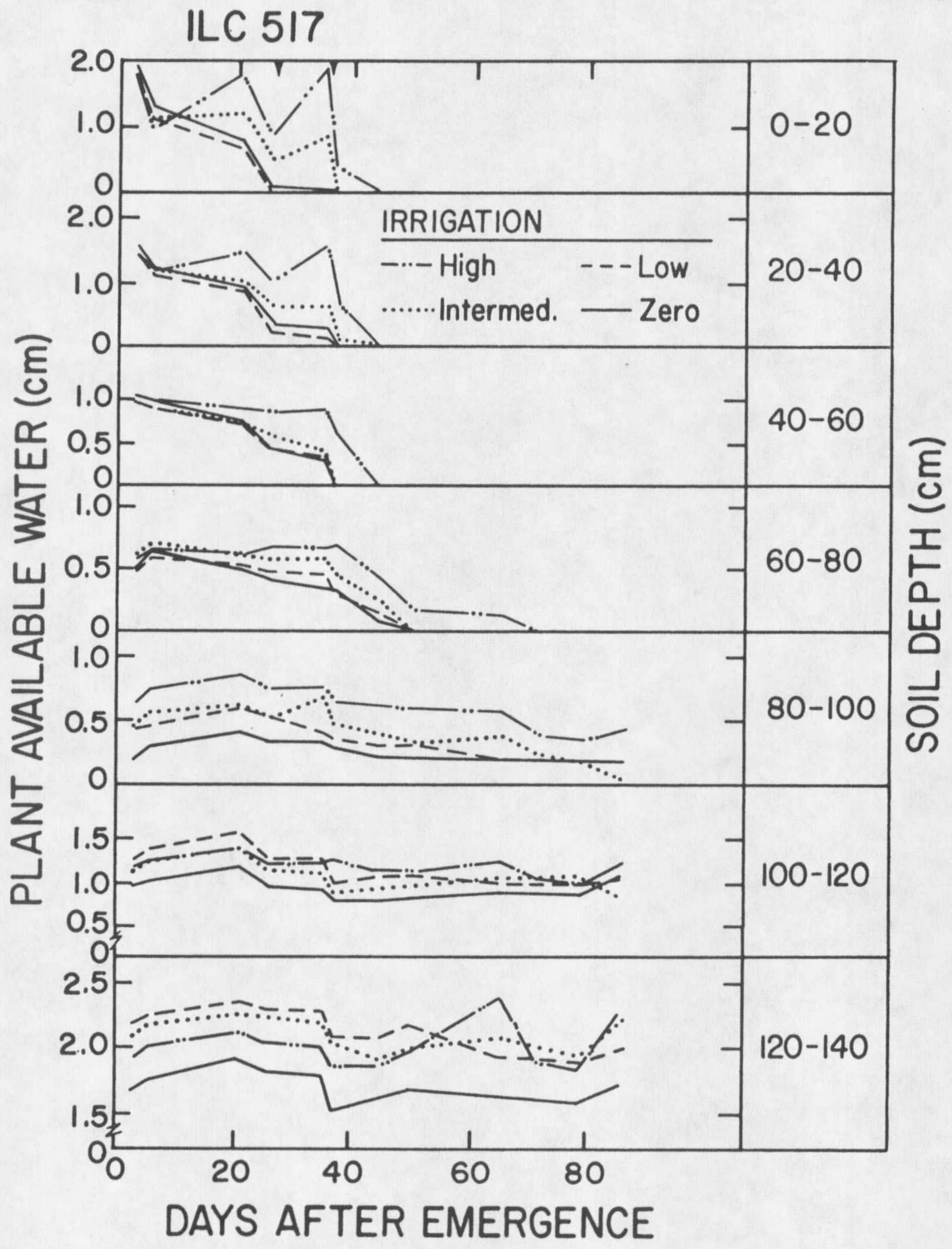

Figure 4. The Effect of Chickpea 'ILC 517' on Plant Available Water from Emergence to Harvest at the Wytanna Ranch, Manhattan, MT, in 1985. Arrows indicate time of irrigation.

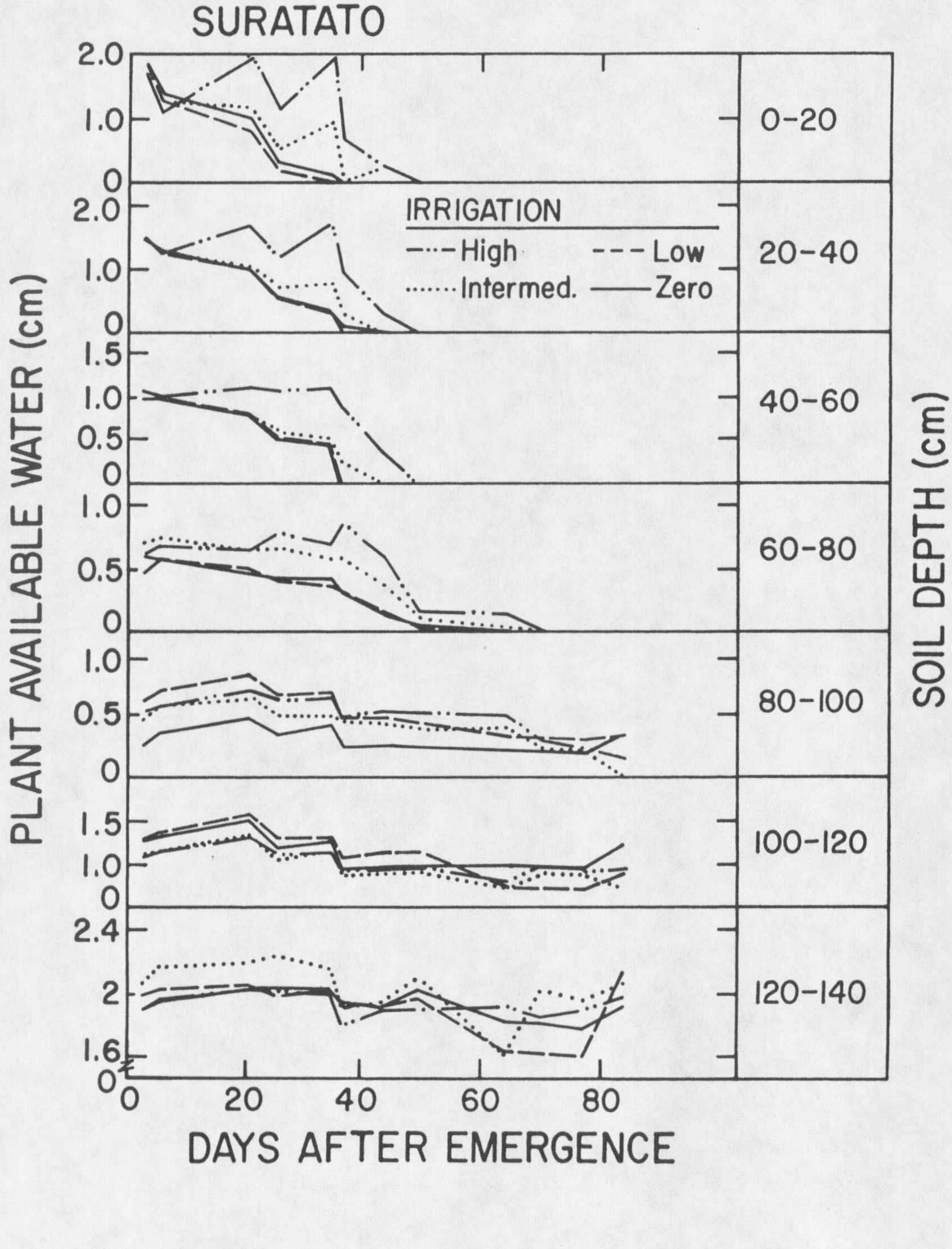

Figure 5. The Effect of Chickpea 'Suratato' on Plant Available Water from Emergence to Harvest at the Wytanna Ranch, Manhattan, MT, in 1985. Arrows indicate time of irrigation.

and high irrigation treatments was replenished to varying degrees with rainfall and irrigation.

Marked differences in plant available water occurred among the four chickpea cultivars at the four irrigation regimes, especially late in the season. Available water for 'ILC 591', 'UC-5', 'ILC 517', and 'Suratato' in the 0 to 20 cm depth for the zero irrigation treatments was depleted 26, 26, 35, and 37 days after emergence, respectively. However, available water for all cultivars in the 20 to 40 cm depth was depleted 37 days after emergence. Variable depletion levels are primarily attributed to differential root densities among cultivars. Subramanialyer and Saxena (1975) reported that the upper 30 cm of the soil profile is the most important absorption area for chickpea since 40 to 50% of the extractable roots were found in the top 10 cm of the soil.

Days to Flowering

Analysis of variance indicates a significant difference in days to flowering among cultivars. However, there was no significant irrigation by cultivar interaction. Cultivar 'ILC 591' consistently bloomed later than the other three cultivars at the zero, low, and intermediate irrigation regimes (Fig. 6). First bloom for all the cultivars was delayed approximately two days between the low and high irrigation regimes. These data indicate that increased soil moisture increased vegetative growth with subsequent delayed flowering.

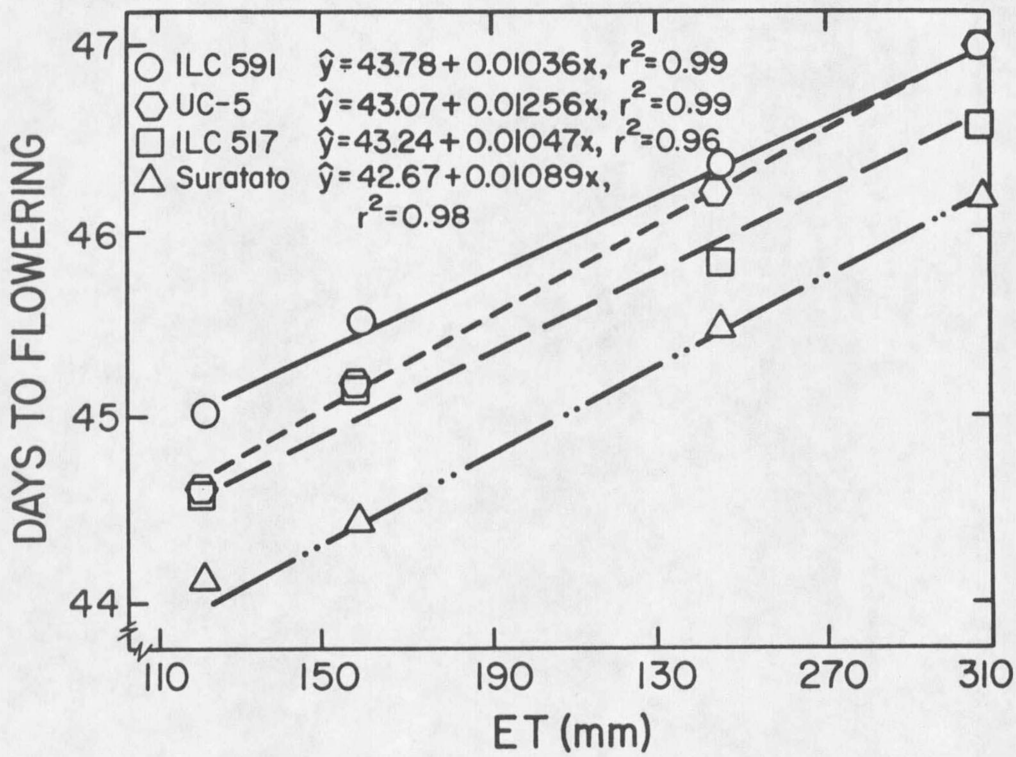

Figure 6. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Days to Flowering of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

Plant Height

Cultivars were significantly different for plant height at 15, 29, 38, 45, 55, and 63 days after emergence (Fig. 7). Irrigation had the greatest effect on cultivar height during the intermediate growth and development stages. Cultivar height is important due to lodging potential, harvestability, and cultural management.

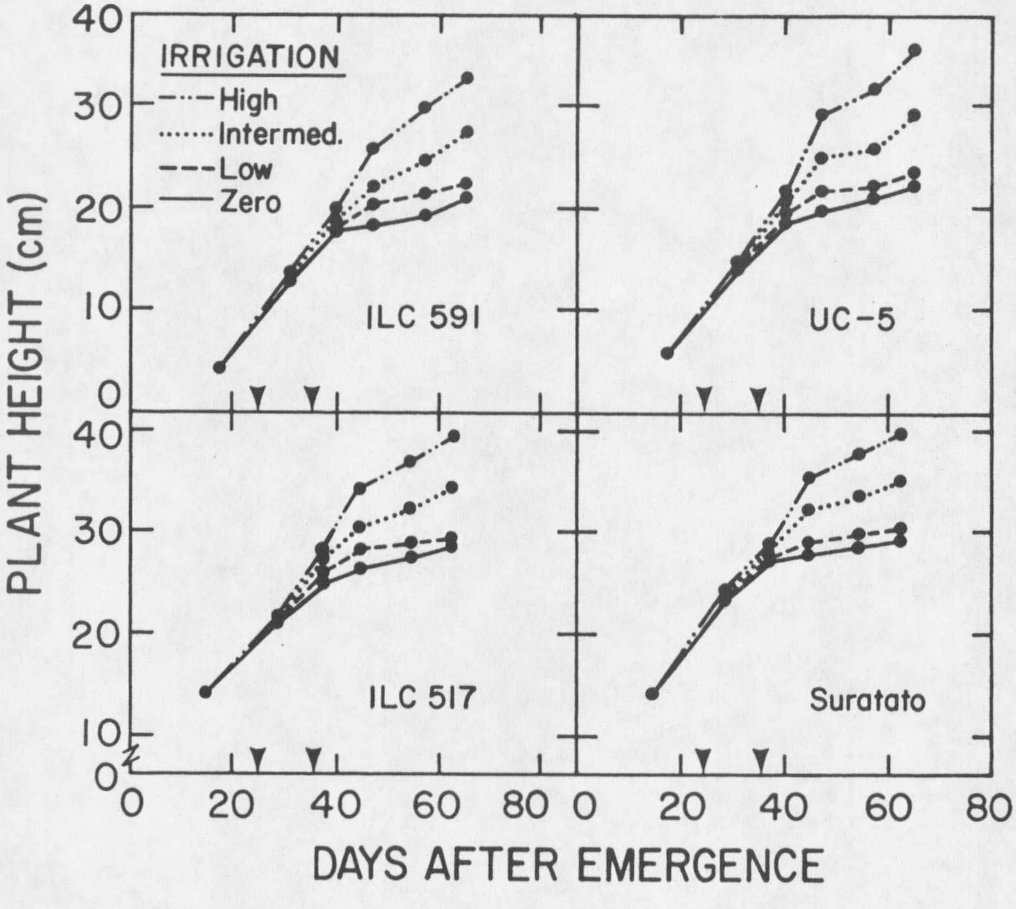

Figure 7. The Effect of Time and Four Irrigation Levels on Plant Height of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985. Arrows indicate time of irrigation.

There was a significant difference in plant height at harvest due to cultivar even though the irrigation by cultivar interaction was non-significant. Cultivar 'UC-5' had the highest increase (61%) in plant height with increased ET levels while cultivar 'Suratato' had the lowest increase (49%) (Fig. 8). Manning et al. (1977) and Miller et al. (1977) reported that plant height had a positive relationship with increased water application in pea. These data indicate that irrigation management is important in controlling vegetative growth of chickpea.

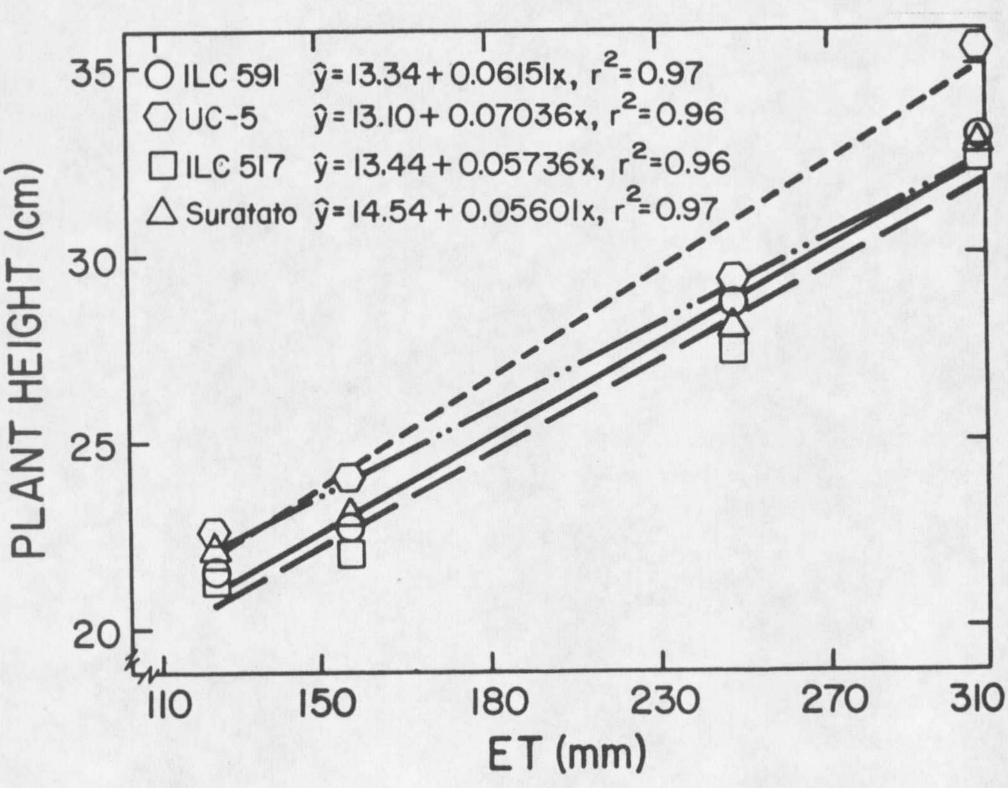

Figure 8. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Plant Height of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

Biomass

Cultivars were significantly different for plant biomass and there was an irrigation by cultivar interaction. Cultivar 'ILC 591' had the lowest and highest biomass response at the zero (ET = 122 mm) and high irrigation regimes (ET = 309 mm), respectively (Fig. 9). The high irrigation treatment increased the biomass of cultivar 'ILC 591' 133% as compared to the zero irrigation treatment.

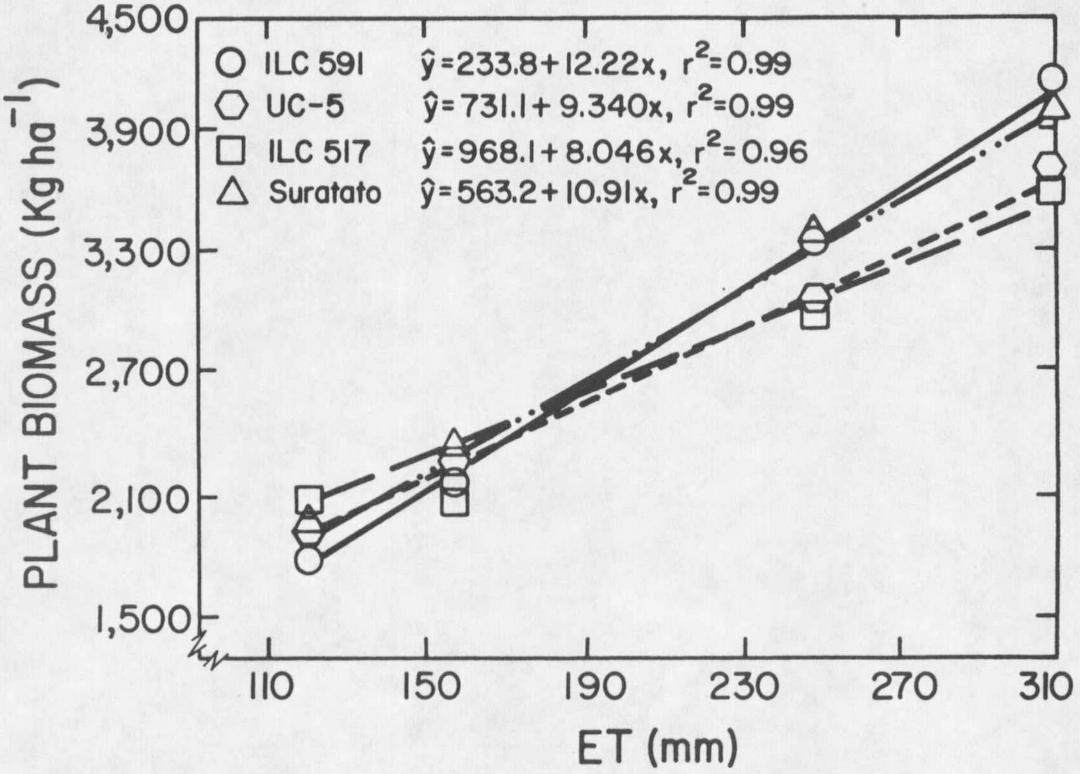

Figure 9. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Plant Biomass of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

Shoot Dry Weight

Cultivars were significantly different in shoot dry weight. However, there was no irrigation by cultivar intéraction. Cultivar 'Suratato' had the highest shoot dry weight response to increased ET for the zero, intermediate, and high irrigation regimes (Fig. 10). 'ILC 517' had consistently lower shoot dry weight at the low, intermediate, and high ET levels. Shoot dry weight of cultivar 'ILC 591', 'UC-5', 'ILC 517', and 'Suratato' at harvest increased 87, 73, 68, and 95%, respectively with increased ET.

Seed Yield

Cultivar seed yield was significant and there was a signifiant irrigation by cultivar interaction. Cultivar 'ILC 591' had the lowest seed yield response at the zero irrigation level and the highest increase as ET increased (225%) (Fig. 11). Seed yield of 'ILC 517' was higher than all the other cultivars at the zero and low irrigation levels. These results suggest that cultivar 'ILC 517' may have a higher production potential under drought conditions.

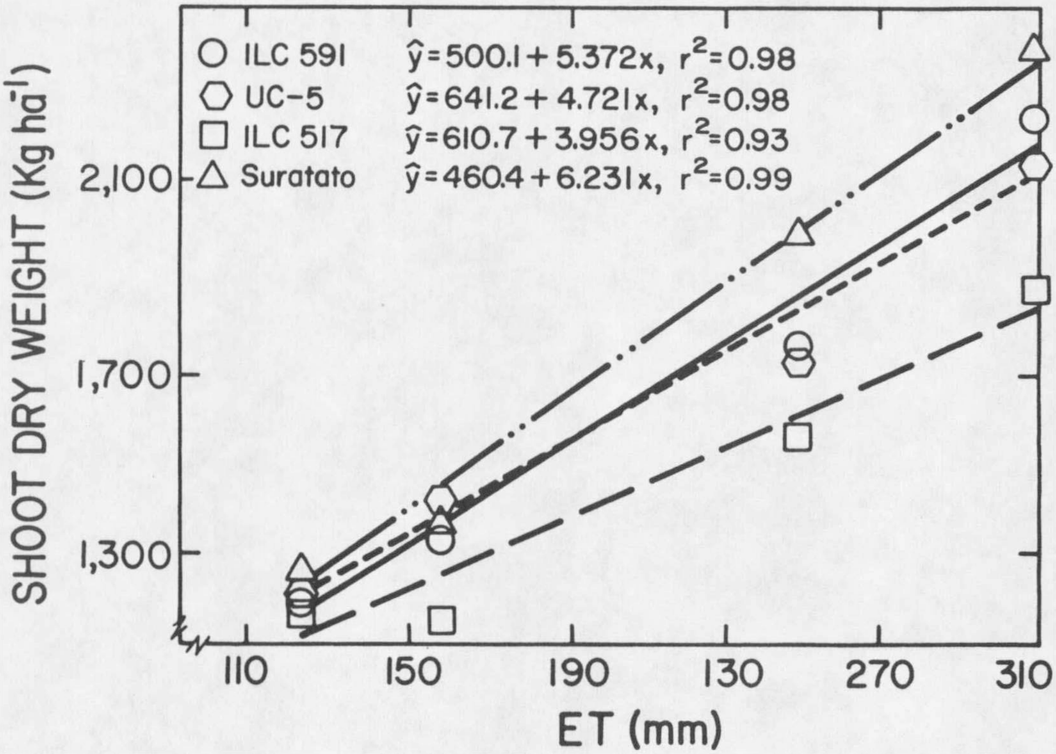

Figure 10. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Shoot Dry Weight of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

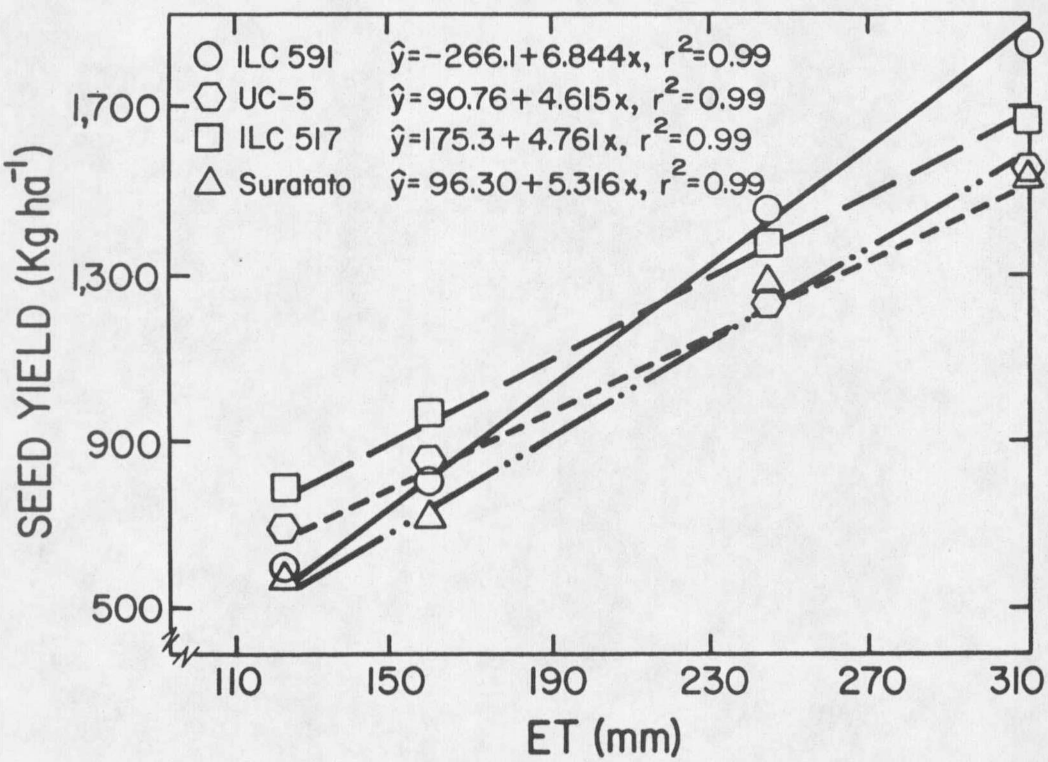

Figure 11. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Seed Yield of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

Seed Weight

Chickpea market quality and price is based upon seed size, with the larger seeds receiving a premium. There was a significant difference in 1,000 seed weight due to cultivar and an irrigation by cultivar interaction. 'Suratato' and 'UC-5' cultivars had higher 1,000 seed weight than 'ILC 591' and 'ILC 517' for all irrigation regimes (Fig. 12). 'Suratato' and 'UC-5' 1,000 seed weight increased with increased irrigation at a greater rate than the other two cultivars. Seed weight of 'Suratato' and 'UC-5' increased 21% and 17% from the zero to high irrigation regimes, respectively. These data suggest that irrigation management may be used to maximize market quality of chickpea.

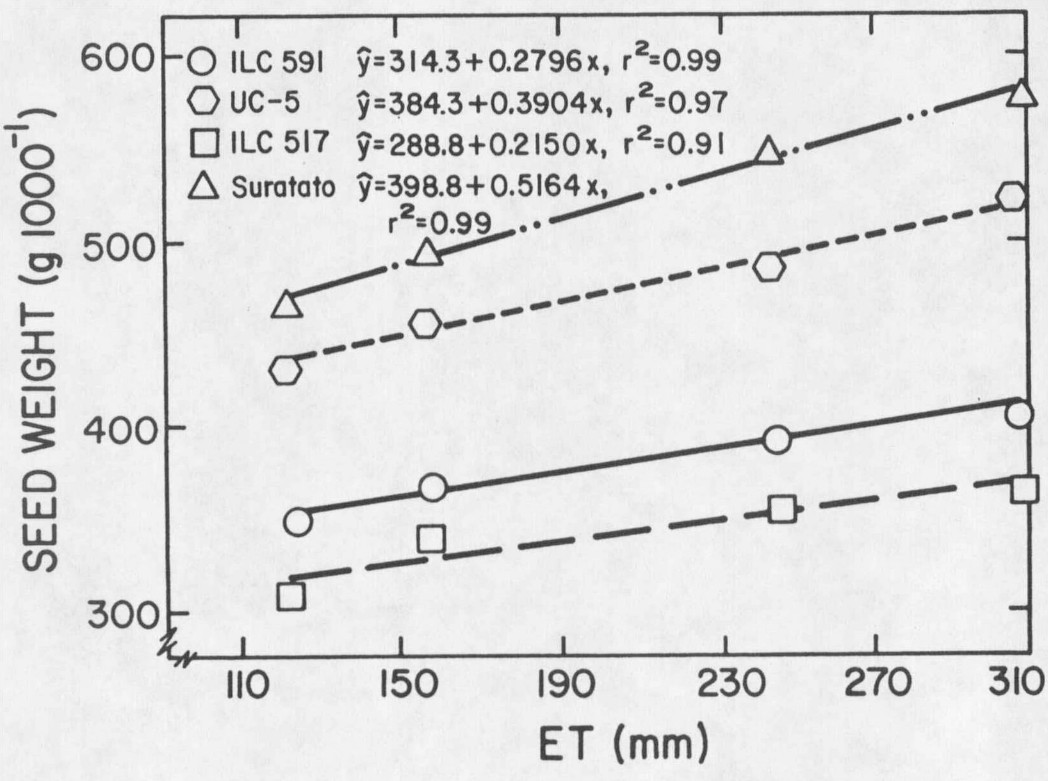

Figure 12. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on 1,000 Seed Weight of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

WUE

There was no significant difference in biomass water use efficiency (WUE) due to cultivar and irrigation by cultivar interaction. However, there was a significant difference in grain WUE due to cultivar and an irrigation by cultivar interaction. Grain WUE of 'ILC 591' and 'Suratato' increased with increased ET (Fig. 13). Additional water evapotranspired was efficiently converted into increased seed production. Grain WUE's of 'ILC 591' and 'Suratato' increased 26% and 12%, respectively. 'ILC 517' and 'UC-5' WUE decreased with increased ET indicating that additional soil moisture was not used efficiently . WUE is suggested as a good tool for characterizing moisture conservation models.

Harvest Index

The analysis of variance indicated that harvest index (HI) was significantly different among cultivars. Harvest index for all cultivars increased with increased ET (Fig. 14). 'ILC 591' and 'Suratato' cultivars had a higher increase in HI than the other two cultivars. These data support the conclusion that the additional water evapotranspired for 'ILC 591' and 'Suratato' was more efficiently utilized in increased seed production.

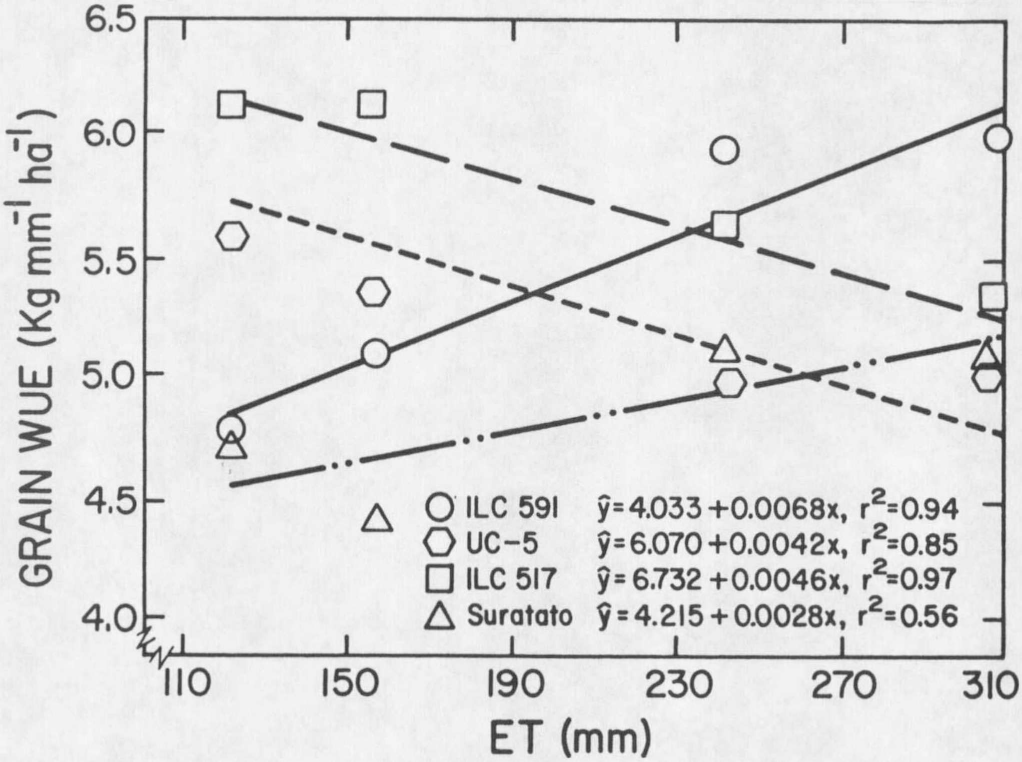

Figure 13. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Grain Water Use Efficiency (WUE) of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

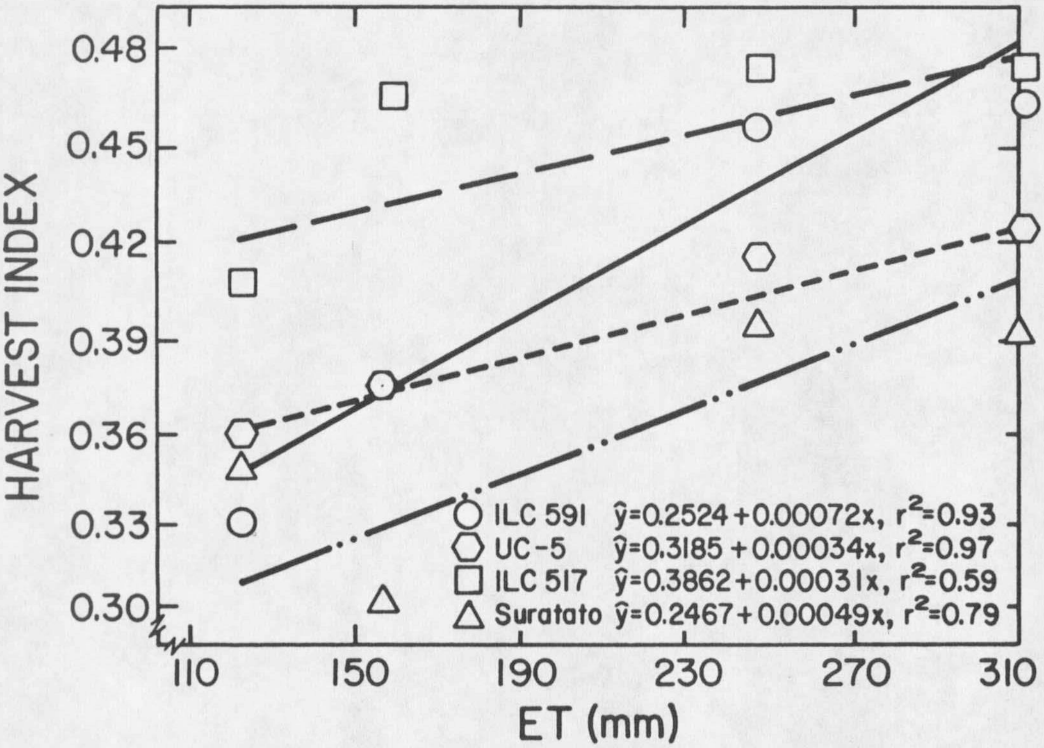

Figure 14. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Harvest Index (HI) of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985.

Nodule Dry Weight

There was no significant difference in nodule dry weight among cultivars. Overall nodule weight increased 437% with increases in ET (Fig. 15). These data agree with reports from Pate et al. (1969) and Sinha (1977) that low soil moisture may restrict the formation and function of nodules. Further research is warranted involving the effect of soil moisture stress on N_2-fixation efficiency.

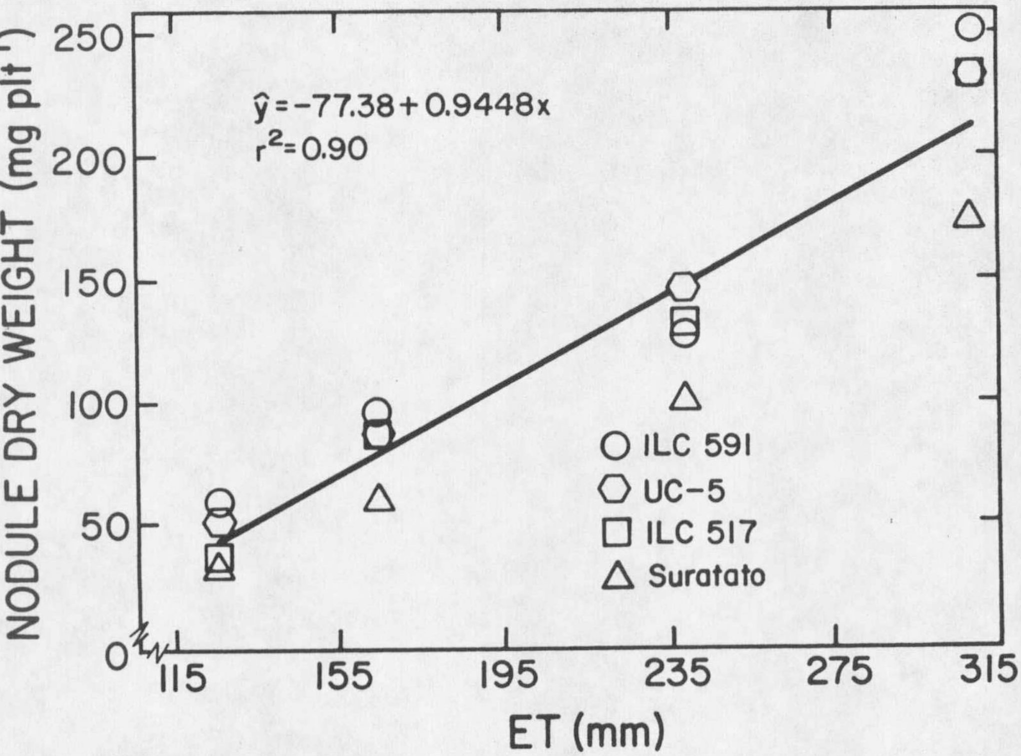

Figure 15. The Effect of Four Seasonal Evapotranspiration (ET) Levels of Zero, Low, Intermediate and High Irrigation Regimes on Nodule Dry Weight of Four Chickpea Cultivars at the Wytanna Ranch, Manhattan, MT, in 1985. Means represent the average of 36 plants.

CHAPTER V

SUMMARY AND CONCLUSIONS

Four chickpea cultivars and four irrigation regimes resulted in differences in soil plant available water. All cultivars showed less soil water depletion at 20 to 40 cm, compared with 0 to 20 cm depth. This supports the previous reports that the upper 30 cm of the soil profile is the most important absorption area for chickpea.

There was a significant difference in plant height, days to flowering, plant biomass, shoot dry weight, seed yield, seed weight, harvest index, and grain WUE due to cultivar. All plant parameters except grain WUE increased with increased ET. There was also a significant irrigation by cultivar interaction for plant biomass, seed yield, seed weight, and grain WUE.

Cultivar 'ILC 591' consistently bloomed later than the other three cultivars at the four irrigation regimes. Additionally, 'ILC 591' exhibited a greater plant height response to time and increasing irrigation levels. Grain WUE and harvest index of cultivar 'ILC 591' increased with increased ET. This was related to the higher increase in plant biomass and seed yield, compared with the other three cultivars.

Chickpea is relatively self-sufficient in N_2-fixation if environmental conditions are favorable. There was no significant difference due to cultivar and cultivar by irrigation interaction for nodule dry weight. However, nodule dry weight increased with increased ET.

These data indicate that irrigation management is extremely important in chickpea seed production and quality. Further research is warranted involving irrigation timing and rate of application.

LITERATURE CITED

LITERATURE CITED

Auckland, A. K., and L. J. G. van der Maeson. 1980. Chickpea. pp. 249-258. In W. R. Fehr, and H. H. Hadley (eds.) Hybridization of crop plants. American Soc. of Agron. and Crop Sci. Soc. of America, Madison, WI.

Auckland, A. K., and K. B. Singh. 1977. The exploitation of natural genetic variability for the improvement of chickpea (Cicer arietinum L.). pp. 83-94. In A. Muhammed, R. Aksel, and R. C. von Borstel (eds.) Genetic Diversity in Plants. Plenum Press, New York.

Auld, D. L., R. H. Callihan, G. A. Murray, L. E. O'Keeffe, and B. L. Bettis. 1982. Garbanzo beans-a potential new pulse crop for Idaho. Uni. of Idaho Exp. Stn. Bull. No. 615.

Bahl, P. N., and C. L. L. Gowda. 1975. Pod setting in crosses of Bengal gram. Ind. J. Genet. 35:13-16.

Bauder, J. W., L. D. King, and G. L. Westesen. 1982. Scheduling irrigation with evaporation pans. Cooperative Extension Service, Montana State University. Bozeman, MT. Bull. No. 1262.

FAO (Food and Agriculture Organization of the United Nations). 1959. pp. 78-87. In Tabulated information on tropical and sub-tropical grain legumes. Food and Agriculture Organization of the United Nations, Rome.

Finn, G. A., and W. A. Brun. 1979. Water stress effects on CO_2 assimilation, photosynthate partitioning, stomatal resistance, and nodule activity in soybean. Crop Science. 20:431-434.

Hanks, R. J., J. Keller, V. P. Rasmussen, and G. D. Wilson. 1976. Line source sprinkler for continuous variable irrigation-crop production studies. Soil Sci. Soc. Am. Journal. 40(3):426-429.

Hanks, R. J., D. V. Sisson, R. L. Hurst, and K. G. Hubbard. 1980. Statistical analysis of results from irrigation experiments using the line-source sprinkler system. Soil Sci. Soc. Am. Journal. 44(4):886-887.

Govil, J. N., B. R. Murty, and B. S. Rana. 1980. Components of Productivity in relationship to geographical distribution in chickpea. Ind. J. Genet. 40:515-527.

Hamdi, Y. A. 1970. Soil water tension and the movement of rhizobia. Soil/Biol. and Biochem. 3:121-126.

Huang, C., J. S. Boyer, and L. N. Vanderhoet. 1975a. Acetylene reduction (nitrogen fixation) and metabolic activities of soybean having various leaf and nodule water potentials. Plant Physiol. 56:222-227.

Huang, C., J. S. Boyer, and L. N. Vanderhoet. 1975b. Limitation of acetylene reduction (nitrogen fixation) by photosynthesis in soybean having low water potentials. Plant Physiol. 56:228-232.

Islam, T. M. T., and R. H. Sedgley. 1981. Evidence for a 'uniculum effect' in spring wheat (Triticum aestivum L.) in a mediterranean environment. Euphytica. 30:277-282.

Katiyar, R. P., and S. P. Singh. 1979. Genetic architecture of yield and its components in chickpea. Ind. J. Genet. 39:146-149.

Keatinge, J. D. H., and P. J. M. Cooper. 1983. Kabuli chickpea as a winter-sown crop in northern Syria: moisture relations and crop productivity. J. Agric. Sci. Camb. 100:667-680.

Koinov, G. 1968. Optimum sowing rates for chickpea (In Bulgarian). Nauchni Trudone. Vissh Selskostoopanski Institute Vasil Kolarov. 17:65-69.

Ladizinsky, G., and A. Adler. 1976. The origin of chickpea (Cicer arietinum L.). Euphytica. 25:211-217.

Manning, C. E., D. G. Miller, and I. D. Teare. 1977. Effect of moisture stress on leaf anatomy and water-use efficiency of peas. J. Amer. Soc. Hort. Sci. 102:756-760.

Mehra, R. B., and S. Ramanujam. 1979. Adaptation in segregating populations of Bengal gram. Indian J. Genet. 39:492-500.

Miller, D. G., C. E. Manning, and I. D. Teare. 1977. Effects of soil water levels on components of growth and yield in peas. J. Amer. Soc. Hort. Sci. 102(3):349-351.

Muehlbauer, F. J., R. W. Short, W. J. Kaiser, D. F. Bezdicek, K. J. Morrison, and D. F. Swan. 1982. Description and culture of chickpeas. Washington State University Coooperative Extension. Pullman, Washington. Bull. No. 1112.

Pate, J. S., B. E. S. Gunning, and L. G. Baiarty. 1969. Ultrastructure and functioning of the transport system of a leguminous root nodule. Planta. 85:11-34.

Pinthus, M. J., A. Bar-am, and A. Muhasen. 1973. Environmental and genetic factors affecting seed size and grading of chickpeas (Cicer arietinum. L.), Israel J. Agric. Res. 23(2):59-67.

Sandhu, B. S., S. S. Parihar, K. L. Khera, and K. S. Sandhu. 1978. Scheduling irrigation to chickpea. Indian J. Agric. Sci. 48(8):486-492.

Saxena, M. C., and D. S. Yadav. 1975. Some agronomic considerations of pigeonpeas and chickpeas. pp. 31-61. In Proceedings of the International Workshop on Grain Legumes. ICRISAT, Hyderabad.

Saxena, N. P., and A. R. Sheldrake. 1979. Physiology of growth, development, and yield of chickpea in India. pp. 106-120. In Proceedings of the International Workshop on Chickpea Improvement. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad.

Sharma, H. C., Tejsingh, and D. S. R. Mohan. 1974. Response of gram varieties to irrigation. Haryana Agricultural University Journal of Research. 4(4):255-260.

Sharma, R. A. 1985. Influence of drought stress on the emergence and growth of chickpea seedlings. International Chickpea Newsletter. 12:15-16.

Shimshi, D., J. Schiffmann, Y. Kost, H. Bielorai, and Y. Alper. 1967. Effect of soil moisture regime on nodulation of inoculated peanuts. Agron. J. 59:397-400.

Singh, G., and L. S. Bhushan. 1979. Water use, water use efficiency and yield of dry land chickpea as influenced by P-fertilization and stored soil water and crop season rainfall. Agricultural water management. 2:299-305.

Singh, H. B., A. Rahman, and M. C. Saxena. 1982. Responses of chickpea to rhizobia inoculation, nitrogen, and phosphorus under different irrigation regimes. International Chickpea Newsletter. 6:26-27.

Singh, K. B., and A. K. Auckland. 1975. Chickpea breeding at ICRISAT. pp. 3-17. In Proceedings of the International Workshop on Grain Legumes. ICRISAT, Hyderabad.

Singh, K. B., and G. C. Hawtin. 1979. Winter planting. International Chickpea Newsletter. 1:4.

Singh, K. B. and S. Tuwafe. 1981. The collection, evaluation, and maintenance of Kabuli chickpea germplasm at ICARDA. International Chickpea Newsletter. 4:2-4.

Sinha, S. K. 1977. Food legumes: distribution, adaptability and biology of yield. FAO Plant Production and Protection Paper 3. Food and Agriculture Organization of the United Nations, Rome.

Smithson, J. B. 1983. ICRISAT's Research on Chickpea. pp. 20-23. In Grain legumes in Asia, Summary Proceedings of the Consultative Group Meeting for Asian Regional Research on Grain Legumes, 1983. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad.

Sprent, J. I. 1971. The effects of water stress on nitrogen-fixing root nodules 1. Effects on the physiology of detached soybean nodules. New Phys. 70:9-17.

Sprent, J. I. 1976. Water deficits and nitrogen-fixing nodules. pp. 291-315. In T. T. Kozlowski (ed.) Water deficits and plant growth. Academic Press Inc., New York, New York.

Subramanialyer, P. R. V., and M. C. Saxena. 1975. Preliminary studies on root distribution pattern of some gram varieties. Journal of Nuclear Agriculture and Biology. 4(2):46-48.

Summerfield, R. J., and F. R. Minchin. 1976. An integrated strategy for daylength and temperature-sensitive screening of potentially tropic-adapted soybeans. pp. 186-191. In R. M. Goodman (ed.) Expanding the use of soybeans in Asia and Oceania. INTSOY, Illinois.

Summerfield, R. J., F. R. Minchin, E. H. Roberts, and P. Hadley. 1979. Effects of daylength, day and night temperature on growth, reproductive development and seed yield of chickpea (*Cicer arietinum* L.). University of Reading-ICRISAT. Internal Communication No. 2.

Whyte, R. O., G. Nilsson-leissner, and H. C. Trumble. 1953. Legumes in Agriculture. Food and Agriculture Organization of The United Nations. Agricultural Study Number 21, FAO, Rome.

APPENDIX

Table 3. Daily Environmental Data for Chickpea Moisture Stress Experiment at the Wytanna Ranch, Manhattan, MT, in 1985.

		Temperature			Humidity	
Date	Precip.	High	Low	Mean	High	Low
	mm	----------C----------			-----%-----	
5/16	0.0	18	1	10	50	28
5/17	0.0	18	1	10	64	31
5/18	0.0	23	3	13	64	16
5/19	0.0	24	4	14	62	17
5/20	0.0	23	6	15	66	26
5/21	0.0	26	6	16	67	19
5/22	0.0	26	8	17	67	20
5/23	0.0	27	7	17	66	23
5/24	9.0	27	8	18	68	22
5/25	18.0	22	6	14	70	39
5/26	22.0	16	9	13	74	50
5/27	0.0	19	8	14	76	37
5/28	0.0	19	4	12	74	31
5/29	0.0	19	4	12	70	31
5/30	0.0	11	1	6	66	42
5/31	0.0	20	5	13	68	21
		-----------------	-----------------	means	-----------------	-----------------
May totals	49.0	21	5	13	67	28
6/1	0.0	12	9	11	70	47
6/2	0.0	17	7	12	70	46
6/3	0.0	17	6	12	72	34
6/4	2.0	22	9	16	74	49
6/5	0.2	26	7	17	74	36
6/6	0.0	29	8	19	73	28
6/7	0.0	31	15	23	50	20
6/8	0.0	21	9	15	62	23
6/9	0.0	20	4	12	58	20
6/10	0.0	20	2	11	50	20
6/11	0.0	19	3	11	68	26
6/12	0.0	26	3	15	68	17
6/13	0.0	24	8	16	68	26
6/14	0.0	24	7	16	68	31
6/15	0.0	27	6	17	68	22
6/16	0.0	24	7	16	55	24
6/17	0.0	24	7	16	50	27

Table 3. Continued

Date	Precip.	Temperature High	Temperature Low	Temperature Mean	Humidity High	Humidity Low
	mm	---------C---------			-----%-----	
6/18	0.0	24	4	14	68	23
6/19	0.0	32	6	19	64	17
6/20	0.0	29	9	19	66	20
6/21	0.0	28	6	17	68	26
6/22	0.0	29	4	17	66	16
6/23	0.0	32	8	20	69	16
6/24	4.0	9	5	7	72	48
6/25	0.0	11	6	9	66	42
6/26	0.0	19	0	10	68	26
6/27	0.0	25	1	13	71	24
6/28	0.0	29	8	19	64	30
6/29	0.0	30	10	20	68	30
6/30	0.0	31	8	20	67	19
		-----------------means-----------------				
June totals	6.2	24	6	15	66	28
7/1	0.0	32	5	19	66	34
7/2	0.0	32	9	21	72	32
7/3	0.0	37	9	23	74	22
7/4	0.0	33	9	21	72	28
7/5	0.0	34	10	22	70	18
7/6	0.0	33	10	22	68	27
7/7	3.0	32	13	23	74	36
7/8	0.0	30	9	20	74	31
7/9	0.0	31	9	20	71	28
7/10	0.0	32	11	22	70	32
7/11	1.0	28	14	21	80	42
7/12	0.2	27	10	19	74	50
7/13	0.2	28	8	18	73	20
7/14	0.0	26	11	19	70	13
7/15	0.0	30	11	21	69	31
7/16	0.0	28	10	19	78	38
7/17	0.0	23	10	17	80	48
7/18	0.0	25	10	18	82	40
7/19	0.0	30	9	20	78	30
7/20	0.0	32	9	21	77	25
7/21	0.0	33	12	23	76	20
7/22	0.0	33	11	22	76	26
7/23	0.0	26	14	20	74	43
7/24	0.0	28	7	18	79	28

Table 3. Continued

Date	Precip.	Temperature High	Temperature Low	Temperature Mean	Humidity High	Humidity Low
	mm	C			%	
7/25	0.0	30	4	17	75	30
7/26	0.0	32	6	19	76	26
7/27	0.0	32	13	23	68	27
7/28	0.0	29	9	19	59	36
7/29	4.0	14	10	12	80	80
7/30	2.0	17	6	12	80	58
7/31	2.0	24	7	16	80	40
		means				
July totals	12.4	29	10	20	74	34
8/1	0.0	30	8	19	79	17
8/2	2.0	19	11	15	78	45
8/3	10.0	22	8	15	80	43
8/4	0.0	27	6	17	79	22
8/5	2.0	33	8	21	79	48
8/6	0.0	27	4	16	81	30
8/7	0.0	31	6	19	78	20
8/8	0.0	20	11	16	71	28
8/9	0.0	23	2	13	72	22
8/10	10.5	21	2	12	72	31
8/11	0.0	12	5	9	75	62
8/12	2.0	15	4	10	76	43
8/13	0.2	16	3	10	80	38
8/14	0.0	18	-3	8	77	32
8/15	0.0	23	3	13	75	21
8/16	1.0	13	2	8	75	44
8/17	0.0	21	-4	9	74	27
8/18	0.0	27	2	15	75	24
8/19	11.5	24	3	14	76	30
8/20	0.0	25	2	14	77	23
		means				
August totals	39.2	22	4	13	76	33
		means				
Growing season totals (97 days)	106.8	25	7	16	71	30

Table 4. Water Budget (Evapotranspiration) of Four Irrigation Regimes for Chickpea Moisture Stress Experiment at the Wytanna Ranch, Manhattan, MT in 1985.

		Irrigation Regime											
Cultivar	Time Period	11	12	13	14	21	22	23	24	31	32	33	34
		mm											
ILC-591	May 16-June 21	44	45	43	43	46	43	42	46	44	49	46	44
	June 22-July 2	29	40	69	79	36	44	72	86	36	48	75	85
	July 3-Aug 20	47	64	121	185	46	67	123	176	43	65	124	175
		120	149	233	307	128	154	237	308	123	162	245	304
UC-5	May 16-June 21	44	46	45	44	42	44	46	47	49	46	47	47
	June 22-July 2	31	46	68	78	36	39	76	91	33	43	72	89
	July 3-Aug 20	45	70	121	186	39	80	121	178	43	58	112	172
		120	162	234	308	117	163	243	316	125	147	231	308
ILC-517	May 16-June 21	44	50	44	44	47	50	44	46	48	45	46	44
	June 22-July 2	33	43	76	82	34	44	75	91	37	46	75	88
	July 3-Aug 20	50	68	119	186	36	74	118	175	46	71	107	166
		127	161	239	312	117	168	237	312	131	162	228	298
Suratato	May 16-June 21	41	46	46	45	42	52	46	47	46	54	47	44
	June 22-July 2	31	45	75	82	33	41	76	90	34	56	74	78
	July 3-Aug 20	49	89	123	185	51	70	115	174	47	85	112	180
		121	180	244	312	126	163	237	311	127	195	233	302

*First number indicates replication. Second number indicates irrigation level (1 = zero irrigation, 2 = low irrigation, 3 = intermediate irrigation, 4 = high irrigation.)

Table 4. Continued

Cultivar	Time Period	41	42	43	44	51	52	53	54	61	62	63	64
		Irrigation Regime											
		mm											
ILC-591	May 16-June 21	52	52	47	48	44	46	42	45	40	36	42	43
	June 22-July 2	31	45	58	71	30	44	54	78	22	45	61	76
	July 3-Aug 20	35	59	150	192	58	65	53	187	54	66	148	192
		118	156	255	311	132	155	249	310	116	147	251	311
UC-5	May 16-June 21	55	46	59	38	44	47	51	44	44	45	45	45
	June 22-July 2	31	42	63	77	26	47	61	75	28	40	69	85
	July 3-Aug 20	45	61	151	195	15	58	145	187	58	80	139	185
		131	149	273	310	85	152	257	306	130	165	253	315
ILC-517	May 16-June 21	50	54	53	38	44	45	36	47	42	42	48	46
	June 22-July 2	35	45	61	80	27	40	61	79	26	40	64	80
	July 3-Aug 20	34	63	147	185	44	55	152	180	55	62	141	187
		119	162	261	303	115	140	249	306	123	144	253	313
Suratato	May 16-June 21	51	53	51	41	39	43	36	45	39	48	43	45
	June 22-July 2	22	39	60	67	17	42	68	71	31	42	62	74
	July 3-Aug 20	56	60	156	197	50	45	156	189	69	76	145	198
		129	152	267	305	106	130	260	305	139	166	250	317

*First number indicates replication. Second number indicates irrigation level (1 = zero irrigation, 2 = low irrigation, 3 = intermediate irrigation, 4 = high irrigation.)

Table 5. Water Budget (Irrigation, Rainfall) for the Four Irrigation Regimes for Chickpea Moisture Stress Experiment at the Wytanna Ranch, Manhattan, MT, in 1985.

	Irrigation Regime											
Time Period	11	12	13	14	21	22	23	24	31	32	33	34
Irrigation (mm)												
May 16-June 21	0	14	48	76	0	14	48	76	0	14	48	76
June 22-July 2	0	14	48	76	0	14	48	76	0	14	48	76
July 3-August 20	0	0	0	0	0	0	0	0	0	0	0	0
	0	28	96	152	0	28	96	152	0	28	96	152
Rainfall (mm)												
May 16-June 21	51	51	51	51	51	51	51	51	51	51	51	51
June 22-July 2	4	4	4	4	4	4	4	4	4	4	4	4
July 3-August 20	52	52	52	52	52	52	52	52	52	52	52	52
	107	107	107	107	107	107	107	107	107	107	107	107

*First number indicates replication. Second number indicates irrigation level (1 = zero irrigation, 2 = low irrigation, 3 = intermediate irrigation, 4 = high irrigation).

Table 5. Continued

Time Period	Irrigation Regime											
	41	42	43	44	51	52	53	54	61	62	63	64
Irrigation (mm)												
May 16-June 21	0	14	48	76	0	14	48	76	0	14	48	76
June 22-July 2	0	14	48	76	0	14	48	76	0	14	48	76
July 3-August 20	0	0	0	0	0	0	0	0	0	0	0	0
	0	28	96	152	0	28	96	152	0	28	96	152
Rainfall (mm)												
May 16-June 21	51	51	51	51	51	51	51	51	51	51	51	51
June 22-July 2	4	4	4	4	4	4	4	4	4	4	4	4
July 3-August 20	52	52	52	52	52	52	52	52	52	52	52	52
	107	107	107	107	107	107	107	107	107	107	107	107

*First number indicates replication. Second number indicates irrigation level (1 = zero irrigation, 2 = low irrigation, 3 = intermediate irrigation, 4 = high irrigation).

Table 6. Significance Table of the Cultivar and Irrigation by Cultivar Interaction for each Parameter Measured at the Wytanna Ranch, Manhattan, MT, in 1985.

Parameter	Days after Emergence	Significance C	I x C
Plant height			
	15	*	NS
	29	*	NS
	38	*	NS
	45	*	NS
	55	*	NS
	63	*	NS
Days to flowering	33-63	*	NS
Plant biomass	++ 68-86	*	*
Shoot dry weight	68-86	*	NS
Seed yield	68-86	*	*
Seed wt. 1,000	68-86	*	*
Harvest index	68-86	*	NS
Biomass WUE	68-86	NS	NS
Grain WUE	68-86	*	*
Nodule dry weight	68-86	NS	NS

++Harvest; *significant @ .05 level.