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

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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.

June 27, 1986

Date

Chairperson, Graduate Committee

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June 27, 1986

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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.

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CHAPTER I

INTRODUCTION

Chickpea (<u>Cicer arietinum</u> 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 <u>Rhizobium</u> 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 Aschochyta 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 Rhizobium 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^{o}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^{o}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.