EFFECT OF IRRIGATION SCHEDULE AND PLANT POPULATION ON GRAIN YIELD AND OTHER CHARACTERISTICS OF GRAIN SORGHUM

by

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ABSTRACT

This study was carried out at the Agricultural Research and Education Center of the American University of Beirut to determine the effect of various irrigation schedules and plant populations on the performance of Early Hegari sorghum. The characters studied were grain and stover yield, number of days to heading, plant height, number of heads per plant, head size, weight of 1,000 kernels, and protein percentage. Plant populations were 13,333, 8,888 and 6,666 plants per dunum and irrigation schedules were weekly furrow irrigation, weekly furrow up to heading followed by biweekly irrigation, and biweekly furrow irrigation up to heading followed by weekly irrigation.

A plant population of 13,333 plants per dunum produced higher grain and stover yields, taller plants, advanced the date of heading by one day and made more efficient use of irrigation water. In contrast the number of heads per plant, thickness of stem, protein percentage, head size and 1,000 kernel weight were significantly greater from a population of 8,888 plants per dunum.

The weekly irrigated plots produced more grain and stover, taller and thinner plants, more heads per

plant, and heavier heads and seeds than did plots which received irrigation at biweekly intervals either before or after the heading stage. The plants irrigated at biweekly intervals after heading made more efficient use of the water and contained a higher percentage of protein than did those irrigated weekly.

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INTRODUCTION

Sorghum (*Sorghum vulgare*, Pers.) ranks third, next to wheat and rice, among the world food crops. About 75 per cent of the world sorghum production is used as human food while the remainder is used as feed for cattle, poultry, swine, and horses. As a feed, it contains twelve per cent protein, three per cent fat, and seventy per cent carbohydrates (1) and compares favourably with corn.

Although sorghum is a drought resistant crop and yields fairly well under limited moisture conditions, it can not be grown profitably without irrigation in the arid and semiarid regions.

The Beqa'a area of Lebanon receives an insignificant amount of rainfall during the normal growing period and therefore sorghum has to depend mainly upon irrigation. Under such conditions, knowledge about the inter-relation of irrigation intervals and plant populations is of paramount importance for maximum grain production and efficient water utilization. However, in areas where the distribution of irrigation water is by fixed rotation, farmers have no power to modify the irrigation interval. They might adopt schedules in which some irrigations are not utilized for a particular crop but used for another.

Based on the water holding capacity of soil, climatic conditions and nature of the main crops grown, the usual irrigation interval at the Agricultural Research and Education Center is one week. It was planned to study the effects of increasing this irrigation interval from one week to two weeks for parts of the growth period. The two extensions considered were based on the assumption that the period from planting to heading is not as critical regarding soil moisture stress as the period after heading.

A plant population of 8,888 plants per dunum has proved optimum under weekly irrigation for the variety Early Hegari at the Agricultural Research and Education Center (35). Therefore, three population levels viz 13,333, 8,888 and 6,666 plants per dunum were included in the trial in order to determine the possibilities of better grain and stover yields under each irrigation schedule. In addition the effect on number of days to heading, thickness of stem, plant height, number of heads per plant, weight of 1,000 kernels, protein content, stomatal opening and water use efficiency were studied.

REVIEW OF LITERATURE

Profitable yields of grain sorghum depend to a considerable extent upon good cultural practices. Among the basic cultural practices, irrigation intervals and plant populations play important roles in determining the yield. It is the purpose of this section to review the available literature pertaining to the effect of irrigation and plant population on the yield and other characteristics of grain sorghum.

GRAIN YIELD

1. Population influence:

Painter and Leamer (27) observed that maximum yields were obtained when grain sorghum was planted four inches apart within the rows on soils of higher fertility. On soils of medium fertility no significant difference in yield was observed, when plants were spaced at four or nine inches within the rows. According to Thurman and Staten (41) Laude and Wilkins reported an increase of 25 per cent in grain yield from 20-inch spaced rows over 40-inch spaced rows of dwarf grain sorghum in an experiment conducted at Kansas for nine years. Porter *et al.* (29) showed that when fertility was not the limiting factor, sorghum planted in narrow rows of 12 and 20 inches gave significantly higher yields when compared to 30 and 40-inch row widths. When fertility was the limiting factor wider row spacings gave higher yields than did narrow rows. Kurtkoti and Divekar (21) found that drilling the seed at four pounds per acre in rows 24 inches apart, instead of the usual 15 inches, yielded 31 per cent increase of grain.

Herbert (17) conducted a grain sorghum cultural experiment with two common varieties; Martin and Early Hegari. He used three seeding rates of 2, 4 and 6 pounds of seed per acre in two row widths of 21 and 42 inches. Although results were not significant at the 5 per cent level, the highest yield was obtained from Early Hegari seeded at four pounds per acre in 21 inch rows. There was significant difference in yield in favour of 21 inch rows over 42 inch rows. Stinson (40) similarly showed that the varieties Westland and Golly grain sorghums yielded about 10 bushels per acre more at 20-inch than at 40-inch row spacings. This was observed when the crop was sown after fallow, but when the crop followed winter wheat, the difference was reduced to 5 bushels per acre. Grimes and Musick (14) conducted an experiment to determine the proper plant spacing for obtaining maximum yield under irrigated conditions. An area of 50-60 square inches per plant, which corresponds to a population of about 100,000 plants per acre, was considered most desirable for getting higher yields. When the plant population level was dropped below 50,000 plants per acre, yield was reduced considerably. Stickler _et al_. (38) reported a similar effect of plant population on yield of grain sorghum. Significantly higher yields were obtained with an area of 60 and 80 square inches per plant than with 40, 120 and 160.

Rautou (32) conducted a grain sorghum cultural experiment in 1960, under irrigated conditions with two hybrids:Rs 590 and Wheatland x Red line - 60, and established 4, 8, 12 and 16 plants per square meter. Significantly higher yields were obtained with 8, 12 and 16 plants per square meter than with four plants. Bordade (3) at Amravati in India found that wider row spacings gave higher yields than did narrow spacings when plant to plant spacings within the rows were kept the same. Norman and Hsi (26) reported that an increase in plant population but with constant row width resulted in higher yield.

2. Irrigation influences:

Paschal and Evans (28) mentioned that on soils of high fertility grain sorghum spaced four and nine inches apart within the rows gave higher yields under high moisture level (eight irrigations) than under low moisture level (five irrigations). Furthermore, close spacings gave higher yields than did wider spacings under both levels of irrigation. Brown and Shrader (6) reported that grain yield averaged 11.4, 23.6 and 40.6 bushels per acre on plots which were wetted at planting to the depth of three, five and seven feet respectively.

Hughes <u>et al</u>. (19) reported that water stress at any stage of development reduces the grain yield. This effect was more pronounced when the moisture stress was imposed during early bloom and soft dough stages and the reduction in yield observed was 48 and 25 per cent respectively. According to Denmead and Shaw (11) Miller and Duley stated that when moisture stress treatments were imposed during the late vegetative stage, grain yield was reduced by 35 per cent. When stress was imposed during silking stage, it lowered yield by 43 per cent. Webster (42) studied the effect of within row spacings of four and six inches on the yield of grain sorghum planted in 20-inch rows and in a soil wetted to a depth of at least six feet at planting time. Five to six inches of water were applied just before heading. Significantly higher yields were obtained from the plants spaced at four inches. Grimes and Musick (14) showed that with a plant population of 112,000 plants per acre, yields of

31.5, 41.4 and 46.2 bushels per acre were obtained from 7, 14 and 28 inch rows respectively with preplanting irrigation only. With one additional irrigation applied when the plants were 12 inches high, increases over the preplant irrigation were 70.8, 43.3 and 25.8 bushels per acre respectively for the three row spacings studied. Rao (31) studied the effect of various nitrogen levels (30, 60 and 90 lbs of nitrogen per acre) on the yield of grain sorghum under various irrigation intervals. He reported that irrigating at three week intervals was almost as good as irrigating at weekly intervals, and hence, appears beneficial since it reduces the irrigation costs. Irrigations contributed to a 14-15 per cent increase in 1,000 seed weight; manuring alone had no effect on seed weight. Capstick _et al_. (9) showed that application of 90 pounds of nitrogen per acre gave 4,149 pounds of grain per acre under non-irrigated conditions but when irrigation water was made available, the yield was as high as 5,022 pounds of grain per acre. Ross and Bieberly (34) recommended thick planting to get higher yields under irrigated conditions. The factors responsible for higher yields in narrow rows were uniform plant spacings, more efficient use of water, soil nutrients and light and reduced evaporation from the soil.

Gonzale _et al_. (13) conducted an experiment for three years under Lamao conditions using 0, 0.72, 1.44, 2.88, 4.32 and 5.76 centimeters as weekly irrigation treatments for eleven weeks, the first irrigation commencing one week after seedling emergence. Irrigation applications ranging from 1.44 to 4.32 centimeters at weekly intervals resulted in higher grain yields. Musick et al. (23) reported that grain yields were curvilinearly related to the soil moisture availability as controlled by number of irrigations. Maximum yield of about 8,500 pounds per acre was obtained with the adapted hybrid under high level of irrigation (four irrigations) whereas maximum yield from non-irrigated plots was 3,000 pounds per acre.

Bond et al. (2) emphasized that grain yields were markedly increased with increasing amount of soil moisture at seeding time. Generally more grain per acre was produced at the lower moisture level with 40-inch rows than with 20-inch rows. However, 20-inch rows produced greater yield at higher moisture contents.

Protein percentage

Limited data are available on the effect of plant population and irrigation on the protein content of grain sorghum. Stickler and Pauli (39) mentioned that protein percentage in grain decreased with increased plant density and narrow rows. Nelson (25) and Siddiq (35), on the contrary, reported that plant and row spacing did not effect the protein content of the grain.

Quinby and Marion (30) found that sorghum grown on irrigated plots contained a lower percentage of protein as compared to the non-irrigated. Stephens _et al._ cited by Boyd _et al._ (4), showed that when grain sorghum was grown with a water table 36, 24 and 12 inches deep the protein content was eight, six and three per cent respectively.

Number of days to heading

Painter and Leamer (27) reported that sorghum plants headed earlier when planted under a combination of low moisture content and narrow spacing. Siddiq (35) observed that heading of sorghum was influenced slightly by plantings made in 50 and 75 centimeter rows. Heading was delayed by half a day when planted in wider rows. The significant interaction of varieties x spacing within the rows showed that varieties generally headed earlier when planted at 5 centimeters spacing as compared to 10 or 15 centimeters. Maun (22) reported similar effects of spacing on number of days to heading. Sorghum headed one day earlier when planted in 50 centimeter rows than when planted in 75 centimeter rows.

Thickness of stem

Broadhead *et al.* (5) reported that the size of the stem was influenced by plant density. The stem circumference was smaller when the plants were spaced four inches apart in the rows and increased with increased spacing within the rows. Maun (22) concluded that plants growing in rows 50 centimeters apart had significantly greater stalk circumferences than did those growing in 75-centimeter rows. Choudhry (10) showed that irrigation resulted in thinner stems. The average thickness of the stem was 1.30 inches for the check but in the case of more frequent irrigation it was reduced to 1.15 inches.

Heads per plant

Porter *et al.* (29) expressed the tillering of the sorghum plants on the basis of number of heads per acre at different planting rates and row spacings. It was found that at the same plant population, tillering was not affected by changing the distance between rows from 20 to 30 inches. Grimes and Musick (14) found that tillering was influenced by the thickness of the plants in the rows and total area per plant. Tillering was reduced when row width was increased and plant population held the same. Hendry (16) reported that when sorghum plants are spaced closely, they stool less and produce smaller and erect heads but ripen uniformly. Siddiq (35) concluded that an increase in the number of heads per plant was obtained with the increase of row width or reduction of stand of sorghum within the row. Burnside et al. (7) stated that the number of tillers produced per plant was increased with an increase of area available to each plant.

Plant height and stover yield

Ross and Webster (33) found that when moisture or soil fertility was not the limiting factor, plants grow taller when sown thickly. When the soil was poor or there was a deficiency of moisture, thick planting produced stunted and smaller plants. Stickler and Laude (37) reported that plant population influenced the plant height. Plants were taller as the area per plant was decreased. This was due to the effect of light on elongation of internodes. Porter et al. (29) on the other hand showed that wider row spacings produced the taller plants. Plant height was 4.2 feet in case of 40 inch rows and when the row width was 12 inches, the plant height was reduced to 3.8 feet. Stickler et al. (38) reported that the plant height increased with decrease in per plant area. This was attributed to the competition for light. Plants were taller when they were planted thickly in 10 and 20-inch rows than in wider rows of 30 and 40 inches.

Quinby and Marion (30) observed that stover yield was higher under irrigated conditions than on dryland. Kurtkoti and Divekar (21) claimed that on soil of higher fertility 21 per cent increase in fodder yield was achieved by increasing the row spacing. Brown and Shrader (6) and Porter _et al_. (29) also reported similar results. They found that forage production was increased as plant population per acre was increased. Bond _et al_. (2) mentioned that lower moisture levels, high seeding rates and narrow spacings increased the stover yield but reduced the grain yield. Siddiq (35) reported that sorghum planted five centimeters apart in the rows produced the taller plant, but the plant height did not differ significantly between the 10 or 15 centimeters spacings. Stover yield of sorghum increased with thickness of stand.

Head size and seed weight

Grimes and Musick (14) conducted an experiment for seven years with different plant populations and plant spacings to study their effect on head size of grain sorghum. They concluded that head size was related to the area provided to each plant. The quantity of grain produced per head was greater in 28-inch spaced rows with

12-inch spaced plants than 7-inch spaced rows with plants spaced four inches apart. When the same area per plant was maintained by increasing row width and reducing the distance between the plants, no significant difference in head weight was observed, indicating that plant area determines head weight. Burnside *et al.* (7) found that on plants growing in wider rows both head weight and weight of 1,000 kernels were significantly greater than were the heads of plants in narrow row spacings. Rautou (32) observed that the number of tillers per plant and head size decreased as the number of plants per square meter increased. Similar results were reported by Ross and Webster (33). Stickler and Laude (37) on the other hand reported that head size was not influenced by the row spacings or by plant density.

Water use efficiency

Painter and Leamer (27) reported that irrigated grain sorghum grown in 12 or 20-inch rows produced significantly higher grain yields and produced more grain per inch of water used than in 30 or 40-inch rows. This was attributed to a more uniform spacing of plants, which resulted in more efficient use of moisture, nutrients and solar energy.

Musick *et al.* (24) showed that irrigation treatments that produced maximum or near maximum yield did not necessarily give maximum water use efficiency. The maximum efficiency occurred on a treatment in which yields were 84.5 per cent of maximum. This is due to the fact that grain sorghum has considerable tolerance to moisture stress, and under soil moisture conditions that include short periods of limited moisture availability and moisture stress, seasonal evapotranspiration decreases more rapidly than do grain yields.

Stomatal opening

According to Halevy (15) stomatal opening behaviour as an indicator of moisture stress was first studied by Loftfield, in 1921. Later, in 1941, Oppenheimer and Elge developed a practical technique. The infiltration method was used for determining the degree of stomatal opening as an indicator for the irrigation of orange trees. They used kerosene oil and determined the degree of stomatal opening by noting the time elapsed from the time of application to the starting of absorption.

Glover (12) reported that maize stomata were markedly affected by severe drought lasting about a week or more. Under these condition, even on application of water, the stomata do not recover their apparent pattern of normal behaviour. However, the leaves regain their turgidity and seem normal. On the other hand sorghum stomata recovered well from severe drought lasting for fourteen days. Their recovery followed fairly closely behind the restoration of turgidity to the leaves.

Halevy (15) studied moisture relations in gladiolus. A series of eleven liquids which were mixtures of kerosene and medicinal paraffin oil in various viscosities were used for determining the degree of stomatal opening. These mixtures were applied to the median portion of the leaves. The grade which was absorbed and changed the colour of leaf from green to dark green within five seconds was taken as representative of the degree of stomatal opening. On the basis of this study, it was reported that when a mixture of 65 per cent kerosene and 35 per cent paraffin oil was not absorbed within five seconds, irrigation was necessary. Khan (20) concluded that when the leaves of sugarbeets did not absorb a mixture of 70 per cent paraffin and 30 per cent kerosene during the first half of the growing period, and a mixture of 60 per cent paraffin and 40 per cent kerosene during the second half, the plants start wilting. Bybordi (8) recommended that corn and potatoes should be irrigated when the leaves of the plants no longer absorb grades 10 (10 per cent paraffin and 90 per cent kerosene) and 7

(40 per cent paraffin and 60 per cent kerosene) respectively.

MATERIALS AND METHODS

This study was carried out during 1964, at the Agricultural Research and Education Center in the Beqa'a. The area is characterised by a frost free period extending from May to November with rainless summer months. The soil is high in clay, low in organic matter, nitrogen and phosphorous, is well drained and with a pH of about 8 (43).

Twenty kilograms of P_2O_5 per dunum[x] as superphosphate and twelve kilograms of nitrogen per dunum as ammonium sulphate nitrate were broadcast and disced into the soil prior to planting. The experiment was laid out in a split plot design replicated three times. The main treatments were the irrigation schedules with plant population as subplots superimposed on each of the main treatments. The details of the treatments are as follows:

Irrigations

All plots were sprinkle irrigated for five weeks, after which the following schedule was followed:

I_1 (Check) weekly furrow irrigations throughout the whole growing period.

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[x] dunum is a 1,000 m^2.

I_2 Weekly furrow irrigations up to heading followed by biweekly irrigations.

I_3 Biweekly irrigations up to heading followed by weekly irrigations.

Populations

A constant row spacing of 75 centimeters was maintained. The following populations were achieved by using within row spacings of 10, 15 and 20 centimeters:

High	13,333 plants per dunum
Medium (check)	8,888 plants per dunum
Low	6,666 plants per dunum

Cultural operations

The planting was done with a V-belt hand drill on May 5th, 1964, when soil and air temperatures were suitable for germination of seed. All plots were planted thickly and later, when plants were about four to six centimeters in height, were thinned by hand to the required plant population. The plot unit consisted of four rows each seven meters in length. The furrow irrigation treatments commenced on June 15 and continued up to September 28, 1964 and thus the total number of irrigations applied were as follows:

For I_1 16 irrigations excluding sprinkler irrigation.

I_2 11 irrigations excluding sprinkler irrigation.

I_3 13 " " " "

The amount of water applied by the sprinkler was the same in all treatments and was measured to be 1.5 inches of water per irrigation. The amount of water applied per irrigation by the furrow method was measured by the bucket method twice. Before heading stage, it was found to be 1.75 inches for the weekly irrigated plots and 1.95 inches for the biweekly ones. After heading it was 1.95 and 2.25 inches respectively. The total amounts of water applied in each case were as follows:

Method of irrigation

Irrigation treatment	Sprinkler	Furrow Before heading	 After heading	Total
I_1	(1.5 x 4)	(1.75 x 7)	(1.95 x 9)	36.20 inches
I_2	(1.5 x 4)	(1.75 x 7)	(4 x 2.25)	27.25 "
I_3	(1.5 x 4)	(1.95 x 4)	(1.95 x 9)	31.25 "

Hand weeding was done regularly until the boot stage, when the sorghum plants were able to supress the weeds by competition.

The plot area was sprayed twice with Metasystox for the control of leaf hopper and aphids.

Stomatal opening

A series of 11 liquids were used for measuring the stomatal opening. These liquids were mixtures of kerosene and medicinal paraffin oil, (Table 1) from grade I (pure liquid paraffin, highest viscosity, 6.16 compared to water) to grade 11 (pure kerosene, lowest viscosity, 0.613 compared to water). The grades between these differed from each other by steps of 10 per cent by volume (15).

Table 1. Oil mixtures (paraffin + kerosene) used for determining degree of stomatal opening of grain sorghum in 1964, in the Beqa'a, Lebanon.

Grade	Paraffin per cent	Kerosene per cent
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50
7	40	60
8	30	70
9	20	80
10	10	90
11	0	100

These mixtures were applied to the median portion of well developed leaves for determining the degree of stomatal opening. The grade of oil, which was absorbed within five seconds, after application to the lower surface of the leaves was taken as representative of the degree of stomatal opening. The readings were taken on five plants at weekly intervals, just prior to irrigation.

Data were recorded on date of heading, heads per plant, plant height, 1,000 kernel weight, grain and stover yields.

For obtaining yield data five meters of the two central rows of each plot were harvested. The outer rows and one meter at each end served as border rows. The plants harvested from each plot were placed into sacks, dried for two weeks and thrashed separately with a nursery thresher.

For the calculation of stover yield, a representative sample was taken from each plot and air-dried for a period of 40 days.

Duplicate chemical determinations for nitrogen contents were made on each sample according to the modified Kjeldahl method, as specified in the Association of Official Agricultural Chemists, Official Method of Analysis (18).

Statistical analysis of data were made by methods appropriate to the design as described by Snedecor (36). Analysis of variance and the "T"-test, were used to calculate the difference between the treatments and their interactions.

RESULTS AND DISCUSSION

This experiment was conducted at the Agricultural Research and Education Center in the Beqa'a during the year 1964 to study the effect of various irrigation schedules and plant populations on the grain yield and other agronomic characteristics of sorghum. Data regarding grain yield, stover yield, number of days to heading, thickness of stem, number of heads per plant, plant height, head size, weight of 1,000 kernels, protein content, water use efficiency and stomatal opening are reported in Tables 2 to 12.

Grain yield

The data for grain yield as influenced by the various plant populations and irrigation treatments are reported in Table 2. It is evident that the medium plant population gave significantly lower yield than did the high plant population, but when compared to the low plant population the yield was significantly higher. In general, the yield increases with increase in stand per unit area. A plant population of 13,333 plants per dunum seems to be the optimum for obtaining higher yields under the prevailing conditions. These results are in agreement with those obtained by Grimes and Musick (14) who reported that when plant population was dropped below 12,500 plants per dunum, yield was reduced considerably.

Grain yield also differed significantly because of the changes in the irrigation schedules. Plots receiving irrigation regularly at weekly intervals from planting to maturity gave significantly higher grain yields than did plots that received irrigations at biweekly intervals after heading stage. When the check treatment i.e. irrigation at weekly intervals was compared with biweekly irrigation interval up to heading followed by weekly irrigation, there were no significant differences in the yield. These results emphasize that moisture stress prior to the heading stage has no detrimental effect on grain yields. The water saved by irrigating at biweekly intervals prior to heading can be used for raising other crops without any reduction in the grain yields. These results are in agreement with those obtained by Hughes et al. (19), who reported that when moisture stress was imposed during heading and soft dough stages, reduction in grain yield was 48 and 25 per cent respectively.

The interaction between irrigation interval and plant population was found to be significant. The check treatment, i.e. the combination of 8,888 plants per

Table 2. Effect of irrigation schedule and plant population on yield of grain sorghum in kilograms per dunum in 1964, in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	812.2	737.8	684.2	744.7
I_2	697.8	663.1	621.2	660.7
I_3	737.5	717.3	689.4	714.7
Population mean	749.2	706.1	664.9	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	30.42	50.45
Population	18.10	25.30
Irrigation x population	31.27	-

Analysis of Variance

Source	D.F.	M.S.
Replication	2	1,668.71
Irrigation	2	16,180.53^{xx}
Error "a"	4	541.15
Population	2	15,924.39^{xx}
Irrigation x population	4	1281.92^{x}
Error "b"	12	309.21

^{x} Denotes F values significant at the 5% level.

^{xx} Denotes F values significant at the 1% level.

dunum with weekly irrigation (I_1) gave significantly higher yields than did the low plant population at all the three levels of irrigation, though the reduction in grain yield was more pronounced in the case of the I_2 treatment. When the check treatment is compared with the high plant population it is noticed that the check gave a significantly lower yield than did 13,333 plants per dunum in combination with the I_1 treatment. A population of 13,333 plants per dunum with biweekly irrigation after heading gave a significantly lower yield than did the check, but when compared to the high plant population x I_3, there were no significant differences. A similar trend was observed in the case of the I_2 and I_3 treatments in combination with the medium plant population.

Stover yield

There was a significant difference in the sorghum forage yield due to variations in plant populations. (Table 3). The medium plant population gave a significantly higher forage yield than did the lower plant population but when compared to the higher plant population it was lower, indicating that the stand per unit area is the factor that determines the forage yield. These results are in agreement with those reported by Brown and Shrader (6) and Porter et al. (29). Both obtained higher stover yield with higher plant population.

Forage yields were found to differ significantly under the various irrigation treatments. The regular weekly irrigation gave higher yields than the treatments where water was applied at biweekly intervals either before or after the heading stage. These results are in close agreement with the well known fact that production is closely associated with water availability. The maximum plant growth and development are responsible for the higher stover yield under weekly irrigation interval. Similar results have been reported by Quinby and Marion (30), Bond *et al*. (2), and Choudhry (10).

Number of days to heading

The data reported in Table 4 indicate the number of days from planting to heading. An inspection of the means reveals that heading of sorghum was delayed with a decrease in plant population. When compared to the medium plant population the date of heading was delayed by about one day in the case of low plant population, but was earlier by about one and half days in the case of high plant population. These results are in confirmity with those obtained by Siddiq (35) and Maun (22). They reported that heading was delayed by thinner stands. The heading of sorghum was also influenced by irrigation schedules. Heading of sorghum was earlier by one day on

Table 3. Effect of irrigation schedule and plant population on the stover yield of grain sorghum (in tons per dunum) in 1964, in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum			Irrigation mean
	13,333	8,888	6,666	
I_1	1.00	0.98	0.95	0.98
I_2	0.96	0.91	0.89	0.92
I_3	0.89	0.89	0.86	0.88
Population mean	0.95	0.93	0.90	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	0.02	0.04
Population	0.02	0.03

Analysis of Variance

Source	D.F.	M.S.
Replication	2	0.00005
Irrigation	2	0.02115[xx]
Error "a"	4	0.00027
Population	2	0.01115[xx]
Irrigation x population	4	0.00165
Error "b"	12	0.00054

[xx] Denotes F values significant at 1% level.

Table 4. Effect of irrigation schedule and plant population on number of days to heading of grain sorghum in 1964, in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	87.3	89.0	89.1	88.5
I_2	86.6	89.0	89.6	88.4
I_3	87.0	86.7	88.3	87.3
Population mean	86.9	88.2	89.0	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	1.1	1.7
Population	0.8	1.1

Analysis of Variance

Source	D.F.	M.S.
Replication	2	0.64
Irrigation	2	4.59^{x}
Error "a"	4	0.65
Population	2	11.15^{xx}
Irrigation x population	4	1.45
Error "b"	12	0.56

[x] Denotes F values significant at the 5% level.

[xx] Denotes F values significant at the 1% level.

the plots that received irrigation at biweekly intervals up to heading stage, whereas the plots which were irrigated at weekly intervals prior to heading showed no significant differences in the number of days from planting to heading. These results are in agreement with those obtained by Painter and Leamer (28) who concluded that the heading date was advanced by a combination of low moisture contents and narrow spacings.

Thickness of stem

The data regarding the effect of irrigation schedules and plant populations on thickness of stem, recorded at maturity, are presented in Table 5. It is evident from the data that the medium plant population produced significantly thicker stems than did the high plant population, but thinner stems than those of the low plant population. The possible explanation for this can be that when plants are closely spaced, they grow erect and taller, resulting in the stems becoming thinner than those of widely spaced plants. These results are in agreement with those obtained by Broadhead et al. (5).

The thickness of stems was significantly affected by the variation in irrigation schedules. From the data presented in Table 5, it is noticed that the thickest stems were produced under the biweekly irrigation treatment up to

Table 5. Effect of irrigation schedule and plant population on the thickness of plant in centimeters in 1964 in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	1.59	1.69	1.79	1.69
I_2	1.49	1.71	1.80	1.67
I_3	1.66	1.76	1.92	1.78
Population mean	1.58	1.72	1.84	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	0.06	0.10
Population	0.05	0.08

Analysis of Variance

Source	D.F.	M.S.
Replication	2	0.002
Irrigation	2	0.029^{x}
Error "a"	4	0.003
Population	2	0.141^{xx}
Irrigation x population	4	0.005
Error "b"	12	0.003

^{x} Denotes F values significant at the 5% level.
^{xx} Denotes F values significant at the 1% level.

heading and thinnest stems when the irrigation water was applied at weekly intervals up to heading stage. A possible explanation for the thinner stems under weekly irrigation intervals up to heading may be that the plants grow taller under weekly irrigation intervals and so were thinner than those where the interval was biweekly. These results are in agreement with those reported by Choudhry (10).

Heads per plant

The number of heads per plant counted at the time of harvesting are recorded in Table 6. It is obvious that the number of heads per plant increased with decrease of stand per unit area. The capacity of the plant to produce more than one head is due to the fact, that it takes advantage of more space, nutrients and moisture available in the soil. These results are in agreement with those reported by Grimes and Musick (14) and Burnside *et al*. (7).

It is also observed that plots which received irrigation at weekly intervals produced a greater number of heads per plant than did those which were irrigated at biweekly intervals either before or after heading stage. It is interesting to note that the number of heads per plant appeared to be the contributing factor toward

Table 6. Effect of irrigation schedule and plant population on number of heads per plant in grain sorghum in 1964 in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	1.95	2.55	2.86	2.45
I_2	1.64	2.03	2.29	1.99
I_3	1.80	2.41	2.66	2.29
Population mean	1.79	2.33	2.60	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	0.08	0.14
Population	0.08	0.12

Analysis of Variance

Source	D.F.	M.S.
Replication	2	0.0122
Irrigation	2	0.4208^{xx}
Error "a"	4	0.0041
Population	2	1.2715^{xx}
Irrigation x population	4	0.0124
Error "b"	12	0.0068

^{xx} Denotes F values significant at the 1% level.

increased grain yield. The irrigation treatment which produced, the lower number of heads per plant was also low in grain yield.

Plant height

The average height obtained by measuring 5 plants from each plot, was recorded at the time of harvest. The data are given in Table 7. The analysis of variance reveals that there were significant differences in plant height due to variations in plant populations. The plants attained greater height under the high plant population, while they were smaller under the low plant population in comparison to the medium plant population. The reason for the plants growing taller under high plant population may be attributed to the competition for light. It is interesting to note that the plant population which produced the taller plants gave higher yields of forage. These results are in agreement with those obtained by Stickler and Laude (37), Stickler et al. (38) and Siddiq (35), they reported that plants were taller when the area per plant was decreased and this was because of the effect of light on the elongation of internodes.

An inspection of the data also indicates that the plots which were irrigated at weekly intervals throughout the growing period produced the tallest plants whereas

Table 7. Effect of irrigation schedule and plant population on plant height in centimeters in 1964 in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	155.0	146.9	138.8	146.9
I_2	142.7	138.0	135.5	138.7
I_3	146.6	139.0	128.2	137.9
Population mean	148.1	141.3	134.2	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	3.2	5.3
Population	4.3	6.0

Analysis of Variance

Source	D.F.	M.S.
Replication	2	1.0500
Irrigation	2	220.9541[xx]
Error "a"	4	5.9925
Population	2	435.4908[xx]
Irrigation x population	4	28.2713
Error "b"	12	17.3567

[xx] Denotes F values significant at the 1% level.

the plots receiving irrigations at biweekly intervals either before or after heading produced the shortest plants. These results are in confirmity with the findings of Ross and Webster (34) who reported that when moisture or soil fertility was not the limiting factor, plants grow taller when sown thick.

Head size (ear weight)

The data regarding the influence of irrigation schedule and plant population on the head size, recorded by weighing 10 ears at the time of threshing are reported in Table 8. It is noticed from the data that the ear weight was influenced considerably by the variation in plant density. Medium plant population produced ears that were of significantly heavier weight as compared with high plant population and this increase in head size was significant at the one per cent level. On the other hand when compared with low plant population, the ear weight was significantly lower. These results are in agreement with those obtained by Grimes and Musick (14) and Rautou (32). They found that the number of tillers per plant and head size decreased where the plants were thickly spaced.

Head size differed significantly under the various irrigation treatments. Plots that received irrigation at

Table 8. Effect of irrigation schedule and plant population on head size in grams of grain sorghum in 1964 in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	36.6	38.6	43.6	39.6
I_2	33.2	37.4	39.4	36.6
I_3	33.4	38.8	43.4	38.5
Population mean	34.4	38.3	42.2	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	0.30	0.51
Population	0.37	0.52
Irrigation x population	0.65	0.92

Analysis of Variance

Source	D.F.	M.S.
Replication	2	0.3004
Irrigation	2	24.0026^{xx}
Error "a"	4	0.0520
Population	2	145.2970^{xx}
Population x irrigation	4	5.1804^{xx}
Error "b"	12	0.1359

^{xx} Denotes F values significant at the 1% level.

weekly intervals produced significantly heavier heads, than did those receiving irrigations at biweekly intervals. The reduction in head size was more drastic in the case of I_2 treatment, suggesting that development of heads is associated with water availability and biweekly irrigation after heading stage is not desirable for maximum grain yield.

The interaction between irrigation interval and plant population was found to be significant. The check treatment i.e. 8,888 plants per dunum in combination with weekly irrigation intervals produced ears of significantly heavier weights than did high plant population at all the three levels of irrigation. But the head size was significantly lower when compared to low population at I_1 and I_3 treatments.

1,000 Kernel weight

The weight of 1,000 kernels as affected by variations in plant populations and irrigation schedules is presented in Table 9. It is noticed that the plant population affected the kernel weight significantly. The seed weight increased with the decrease in number of plants per unit area. The possible explanation for this can be more sunlight and nutrient availability per plant. These results are in conformity with those obtained by Burnside

Table 9. Effect of irrigation schedule and plant population on the weight of 1,000 kernels in grams of grain sorghum in 1964, in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	20.7	22.6	22.7	22.0
I_2	19.3	21.8	22.0	21.0
I_3	20.2	21.8	22.5	21.5
Population mean	20.1	22.1	22.4	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	0.11	0.18
Population	0.52	0.73

Analysis of Variance

Source	D.F.	M.S.
Replication	2	0.205
Irrigation	2	2.155[xx]
Error "a"	4	0.007
Population	2	14.620[xx]
Irrigation x population	4	0.117
Error "b"	12	0.255

[xx] Denotes F values significant at the 1% level.

et al. (7) who got more weight per 1,000 kernels from wider row spacings than from narrow ones.

The differences in seed weight due to variations in irrigation schedule were highly significant. The weekly irrigation intervals produced 1,000 kernels of 22.0 grams compared to 21.0 and 21.5 grams for I_2 and I_3 respectively. These results indicate that biweekly irrigation intervals after heading interfere with proper development of the grains and ultimately affect the yield.

Protein percentage

The results of the analysis for protein percentage in the grain are summarized in Table 10. From the data shown in Table 10 it is evident that protein content differed significantly between plant populations. The low plant population produced the highest percentage of protein, while the high population gave a lower percentage than did the medium one. (check treatment). These results are in conformity with findings of Stickler and Laude (37) who reported that protein percentage in grain decreased with increased plant density and narrow rows.

The protein percentage of the grain was markedly influenced by the various irrigation treatments. The plots that received irrigation at two week intervals after

Table 10. Effect of irrigation schedule and plant population on protein percentage of grain sorghum in 1964, in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	6.24	6.47	6.84	6.52
I_2	6.71	7.06	7.57	7.11
I_3	6.35	6.52	6.95	6.60
Population mean	6.43	6.68	7.12	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	0.42	0.69
Population	0.25	0.35

Analysis of Variance

Source	D.F.	M.S.
Replication	2	0.13
Irrigation	2	0.92[x]
Error "a"	4	0.10
Population	2	1.09[xx]
Irrigation x population	4	0.02
Error "b"	12	0.06

[x] Denotes F values significant at the 5% level.

[xx] Denotes F values significant at the 1% level.

heading produced significantly greater percentage of protein. The smallest percentage of protein was obtained from the plots that received irrigation at weekly intervals after heading. The possible explanation for this can be that nitrogen uptake appears to be independent of water supply, so that since the yield increases with increasing water supply, the nitrogen content of the grain decreases. These results are in agreement with those obtained by Quinby and Marion (30).

Water use efficiency

Water use efficiency is defined as the weight of grain produced per unit depth of irrigation water applied during the growing period and may be expressed as kilograms per inch. The data regarding the influence of irrigation schedules and plant populations on water use efficiency are presented in Table 11. It is seen that maximum water use efficiency occurred under high plant population and minimum efficiency under low population. It was 23.8, 22.4 and 21.3 kilograms for every inch of water used for high, medium and low plant populations respectively. This more efficient use of water under high plant population may be attributed to uniform spacing of plants which resulted in more efficient use of moisture, nutrients and solar energy. These results are in

Table 11. Effect of irrigation schedule and plant population on water use efficiency of grain sorghum (in kg per inch of water used) in 1964, in the Beqa'a, Lebanon.

Irrigation	Plant population per dunum 13,333	8,888	6,666	Irrigation mean
I_1	22.4	20.3	18.9	20.5
I_2	25.6	24.3	22.8	24.2
I_3	23.6	22.6	22.1	22.8
Population mean	23.8	22.4	21.3	

L. S. D.

	At 5 per cent	At 1 per cent
Irrigation	0.7	1.3
Population	0.2	0.3
Irrigation x population	0.4	0.6

Analysis of Variance

Source	D.F.	M.S.
Replication	2	1.8100
Irrigation	2	31.0977^{xx}
Error "a"	4	0.3294
Population	2	15.6700^{xx}
Irrigation x population	4	0.8011^{xx}
Error "b"	12	0.0507

^{xx} Denotes F values significant at the 1% level.

agreement with those reported by Painter and Leamer (27).

The water was used more efficiently for grain production on the plots that received irrigations at bi-weekly intervals after heading where it was 24.2 kilograms per inch of water used in comparison to 20.5 kilograms in case of the check treatment where water was applied at weekly intervals throughout the growing period. This may be because grain sorghum has considerable tolerance to moisture stress and the additional irrigations caused water use to increase at a faster rate than increase in grain yields. The results obtained are in agreement with the findings of Musick et al. (24).

The interactions between irrigation intervals and plant populations were found to be significant. Check treatment, i.e. 8,888 plants per dunum in combination with weekly irrigation interval was significantly lower in efficient utilization of water than all other treatments except 6,666 plants per dunum receiving weekly irrigation throughout the whole growing period.

Stomatal opening

The degree of stomatal opening was determined at weekly intervals just prior to irrigation by noting the most viscous grade of oil which was absorbed by the leaves within five seconds. The data regarding the influence of various irrigation schedules and plant populations on the degree of stomatal opening are presented in Table 12 and in Figures 1 and 2. It is evident from the data presented in the table that in case of weekly irrigation (I_1) the leaves absorbed a lower grade of mixture during the growth period, but a higher grade of mixture as the crop advanced toward maturity.

In the case of I_2, there was a gradual increase in the grade of mixture absorbed up to heading, but when the irrigation interval was changed from one week to two weeks, the grade of mixture absorbed one week after irrigation was lower than that recorded two weeks after irrigation. In the case of I_3, where the irrigation interval up to heading was biweekly, the grade of mixture absorbed a week after irrigation was lower than the grade absorbed two weeks after irrigation. After the heading stage when the irrigation interval was reduced to one week, the leaves absorbed lower grades. The explanation for this can be that when water was applied at biweekly intervals prior to heading, the plants were stunted in growth, and on changing the irrigation interval from two weeks to one, the plants re-started their growth and thus absorbed the lower grade.

As far as plant population is concerned, it is observed that a higher grade of mixture was absorbed in the case

Table 12. Effect of various irrigation schedule and plant population on degree of stomatal opening of grain sorghum.

	Grade of oil absorbed on														
Irrigation	23/6	30/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9
I_1	3.3	3.6	3.8	4.5	5.1	5.7	6.2	6.4	6.6	6.9	7.0	7.1	7.3	7.6	7.5
I_2	3.4	3.6	4.1	4.9	5.4	6.1	6.6	7.2	6.9	7.5	7.4	7.9	7.7	8.1	7.7
I_3	4.2	5.1	4.7	5.8	5.6	6.1	5.8	6.0	6.1	6.2	6.6	6.7	6.8	7.2	7.6
Plant population	23/6	30/6	6/7	13/7	20/7	27/7	3/8	10/8	17/8	24/8	31/8	7/9	14/9	21/9	28/9
High	4.4	5.0	5.3	5.7	6.0	6.5	6.8	7.0	7.1	7.3	7.3	7.7	7.7	8.1	7.8
Medium	3.5	4.0	4.6	5.0	5.3	5.8	6.3	6.6	6.8	7.0	7.1	7.3	7.4	7.6	7.5
Low	3.4	3.5	3.8	4.4	4.8	5.6	6.1	6.4	6.6	6.8	6.8	7.1	7.1	7.3	7.1

of the high population and a lower grade of mixture in the case of low population in comparison to the medium plant population. This may be because under low plant populations the stomata remain open for a relatively long time and thus absorb lower grade, whereas in high plant populations, there is more evapotranspiration which results in rapid closure of stomata and ultimately the absorption of a higher grade of mixture.

In general, it can be said that as the soil moisture status is lowered due to increases in the irrigation interval or increases in plant population, the stomatal aperture is narrowed. However, this is not consistant and can not be used as an indication for the necessity of irrigation.

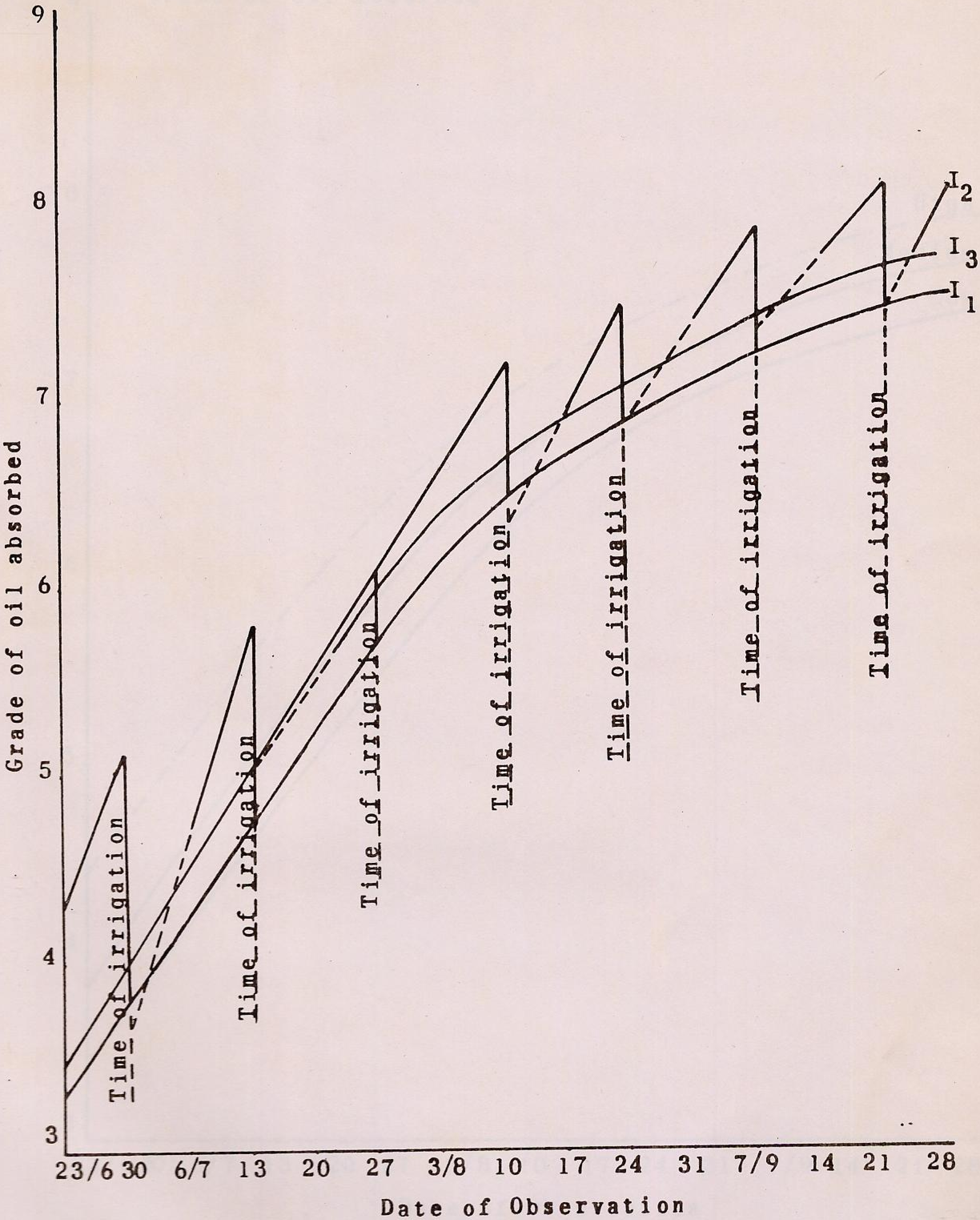

Figure 1. Relationship between grade of oil absorbed and various irrigation schedules.

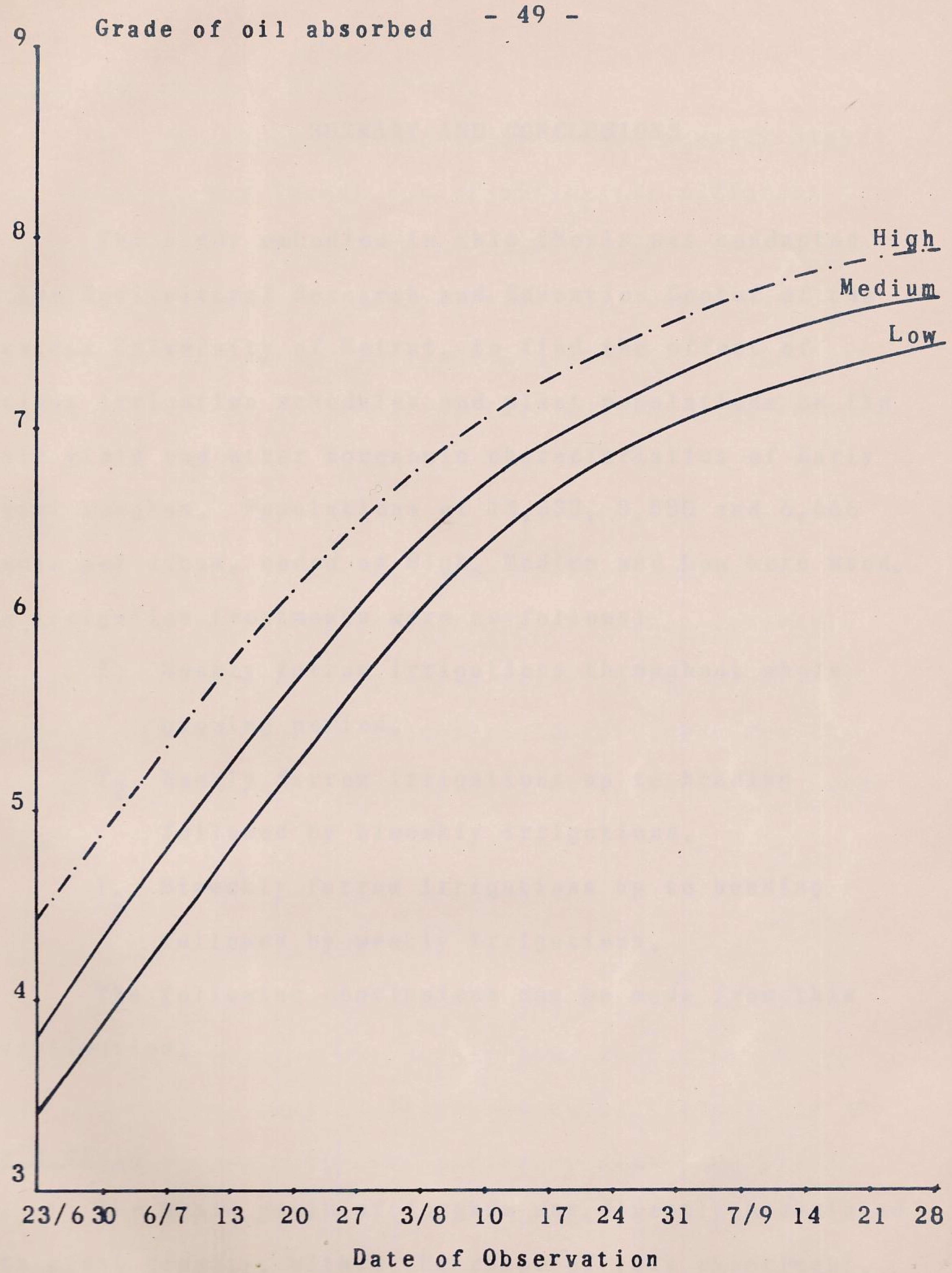

Figure 2. Relationship between grade of oil absorbed and various plant populations.

SUMMARY AND CONCLUSIONS

The study embodied in this thesis was conducted at the Agricultural Research and Education Center of the American University of Beirut, to find the effect of various irrigation schedules and plant populations on the grain yield and other agronomic characteristics of Early Hegari sorghum. Populations of 13,333, 8,888 and 6,666 plants per dunum, coded as High, Medium and Low were used. The irrigation treatments were as follows:

- I_1 Weekly furrow irrigations throughout whole growing period.
- I_2 Weekly furrow irrigations up to heading followed by biweekly irrigations.
- I_3 Biweekly furrow irrigations up to heading followed by weekly irrigations.

The following conclusions can be made from this investigation.

Grain yield

The grain yield of sorghum was directly associated with plant density, within the range of this experiment. The high population gave higher yields than did the low population. A population of 13,333 plants per dunum seems optimum for maximum grain yield.

I_1 i.e. check treatment gave significantly higher yield than I_2, but it was not significantly different from I_3. By applying irrigations at biweekly intervals prior to heading followed by weekly irrigation, water can be saved without any detrimental effect on yields, and this saved water can be utilized for raising some other crops.

Stover yield

The stover yield increased with thickness of stand. Plots receiving irrigations at weekly intervals regularly throughout the growing season gave the highest stover yield, the lowest stover yield resulted from the plots where the irrigation interval prior to heading was biweekly.

Number of days to heading

Heading date was advanced one day by high plant population and delayed one day by low population as compared with the check. Plots receiving irrigations at biweekly intervals prior to heading reached the heading stage earlier by one day than did those receiving irrigation at weekly intervals.

Thickness of stem

The thickness of stem was greatly influenced by plant population. Plots with high population contained plants with thinner stems while the reverse was true for the plots with low populations.

Plots that received irrigation at biweekly intervals prior to heading produced thicker stemmed plants.

Heads per plant

An increase in the number of heads per plant resulted from the reduction of stand of sorghum per unit area. A greater number of heads per plant was obtained from plots that received irrigation at weekly intervals throughout the growing period.

Plant height

Plots with high populations produced the tallest plants whereas plots with low populations produced the shortest plants. Plots that received irrigation at weekly intervals produced taller plants than did those where the irrigation interval was biweekly during the vegetative or after heading stage.

Head size and weight of 1,000 kernels

The head size and weight of 1,000 kernels were higher from the widely spaced plants than from the plants spaced closer together. The weekly irrigated plants produced heavier heads and seeds than did those receiving irrigation at biweekly intervals after heading.

Protein percentage

Protein percentage was greatly influenced by various populations. Low plant populations produced grains with highest percentage of protein, whereas the high population contained grains with lowest protein percentage.

The grains from the plants that received irrigation at weekly intervals after heading contained a lower percentage of protein than did those which were irrigated at biweekly intervals.

Water use efficiency

Maximum water use efficiency occurred in high plant populations and decreased with reduction of stand per unit area. The plots that received irrigation at biweekly intervals after heading used water more efficiently than did those receiving irrigation at weekly intervals after heading.

Stomatal opening

Longer irrigation intervals and an increase in plant population caused the narrowing of the stomatal aperture due to lower moisture status and thus favoured the absorption of lower grade of mixture.

General conclusion

It is evident that under the condition of this study that 13,333 plants per dunum produced the best yields of grain and forage. Application of irrigation water at biweekly intervals up to heading followed by weekly irrigation is as good as application of water at weekly intervals throughout the growing period.

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