EFFECT OF POPULATION AND ROW SPACING ON LEAF AREA AND GRAIN YIELD OF SORGHUM

By

ERNESTO CARLOS BELTRAMINI

Ingeniero Agrónomo

Universidad de La República

Montevideo, Uruguay

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Thesis Approved:

Lavoy I. Croy
Thesis Adviser

Charles E. Denman

Dale E. Weibel

D. D. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Light, nutrients, and water may be considered as the most important environmental factors governing the yield of a given crop. An adequate amount of nutrients supplied as commercial fertilizers is common practice in modern agriculture. Irrigation may supply the water needed by crops, but this is not a widely used practice and actually most crops are grown under dryland conditions. The amount of light cannot be modified by man, and we can only attempt to intercept solar radiation in the most efficient manner. Therefore, planting patterns which make the best utilization of available water and light for a given particular condition will determine the ultimate yield.

The objectives of this research were to estimate the effect of stand density and row spacing on grain yield, leaf area, and plant morphology of an early sorghum hybrid NK 127 (Sorghum bicolor (L. Moench), under the environmental conditions found during the summer season 1973, at Perkins, Oklahoma.

CHAPTER II

REVIEW OF LITERATURE

Yield per unit area is the result of yield per plant times plant population. Considering grain yield (a product of the reproductive phase), increasing stand density increases grain yield up to a maximum at optimum populations and then decreases with further increments in the number of plants. At population densities above the optimum, any gain in total yield per hectare due to a higher number of plants may be offset by the decrease in the yield per plant.

Theoretical Considerations

Donald (10) stated that maximum yield per unit area is the result of the interaction of competition between plants and competition within plants. At low plant densities inter-plant competition is absent, each plant can grow at its potential rate and by the time of flowering each plant develops a large number of flower primordia. As growth proceeds, the plant cannot supply metabolites at the rate demanded by the large number of flowers and intraplant competition becomes operative, reducing the efficiency of seed production in the individual inflorescences. In moderately dense stands, the number of flower primordia developed by each plant is considerably reduced due to interplant competition and the plant can meet the demands for metabolites as intraplant competition takes place. In extremely dense stands both inter and intraplant competition are intense and the plant cannot supply enough metabolies even to the few flowers developed on each plant, and grains per plant and grain weight are reduced.

At populations which are optimum to obtain the highest yield per unit area, the yield per plant is lower than the yield per plant at lower stand densities. This indicates that plants growing at optimum populations do not produce their potential yield but are under such intense competition that the individual plants are, in quantitative terms, markedly subnormal. This agrees with Donald's statement (10) that "it is the community of suppressed plants which gives the greatest yield."

Effects of Planting Patterns on Sorghum Grain Yields

It is a common observation that widely spaced plants produce more grain per plant than those closely spaced. As the plant numbers increase, competition for the growth factors, either above or below the ground, becomes greater. Higher water and fertility levels may alleviate the struggle for plant food; and, higher plant populations can be grown. Work has been done under widely different conditions to determine what planting patterns will produce the greatest yield of grain per hectare for different crops. Results will be discussed by considering corn and sorghum crops.

Most investigations dealing with the problem of plant population and row spacing in grain sorghum conducted under conditions of abundant moisture supply have shown higher yields from narrow row spacings (1, 2, 5, 6, 14, 16, 22, 32, 34, 41), whereas under limited moisture supply, wider row spacing was preferable (2, 6). Changes in stand density may not have much effect on sorghum yield (14, 24, 25, 32, 34, 38, 41); however, under good growth conditions yield responses to higher populations were observed (6, 27, 39, 40, 46). It should be pointed out that in several experiments population and row spacing effects were confounded.

Grimes and Musick (14) working on Ulysses clay loam at Garden City, Kansas, reported that with two or more irrigations, sorghum growing in narrow rows produced considerably more grain than did sorghum in wider rows with identical plant populations. Populations, ranging from 138,264 to 553,056 plants per hectare in some instances, did not materially influence yields. However, a population approaching 246,900 plants per hectare, under optimum irrigation, produced maximum or near maximum yields in all years.

Porter et al. (32) observed that irrigated grain sorghum produced significantly higher yields at the 30 and 51 cm row spacings than at 76 and 102 cm spacings on the high fertilizer level. Planting rates had little influence on grain yields but the heavier planting rates produced the higher yields of forage.

Brown et al. (5) found that grain sorghum in the Piedmont produced significantly more grain and forage when planted in 51 than in 102 cm row spacings in 2 out of 3 years over all irrigation levels. In the third year 51 cm rows gave an increase over the 102 cm rows only when irrigated after available soil moisture had dropped to 10% in the top 60 cm of soil.

Robinson et al. (34) obtained a linear trend for increased yield in southern Minnesota, as rows narrowed from 102 to 25 cm. Two of the components of yield, seed per panicle and panicles per hectare tended to increase with the narrow row spacing, whereas the third component, seed weight tended to decrease. The population had little effect on yield.

Bielorai et al. (2) in the northern Negev, Israel, found wide (105 cm) spacing to be preferable when no irrigation was applied after sowing, however, in the medium and wet irrigation regimes, closer inter-row spacing resulted in higher yields.

Karchi and Rudich (19) studied the effects of population density and its distribution under dryland conditions in Israel. Highest grain yields of sorghum were obtained from 49,380 to 172,830 plants per hectare, especially when planted in narrower rows. Yield superiority was due primarily to increased number of heads per unit area, rather than to changes in head weight. Plant yields were inversely associated with the number of heads per unit area.

Brown and Shrader (6) worked at Hays, Kansas, under drouth conditions. Soil moisture levels were established prior to planting by applying water to wet the soil to field capacity to depths of 90, 150, and 210 cm. Optimum plant populations were higher when higher moisture levels were applied, varying from 37,035 to 222,210 plants per hectare for the lowest to the highest amount of water applied, respectively. The optimum row spacing was 51 cm except in a very dry year when wider spacings showed greater yields.

For several years Stickler and his associates reported results from sorghum population-spacing experiments conducted in Kansas. In 1960 Stickler and Laude (39) reported higher yields of grain sorghum with 192,582 than with 128,388 plants per hectare, and a significant population X row spacing interaction was noted. In 1961, Stickler et al. (40) analysed results from eight years of grain sorghum experiments where plant population and row spacing were confounded and obtained an average yield advantage of 28% for 51 over 102 cm rows. However, the analysis of other four-year tests, where both population and row spacing effects were evaluated, revealed an average yield advantage of only 6% for 51 over 102 cm rows, which indicates that most of the yield superiority of narrow rows in earlier tests was due to a higher plant population, since the number of plants per unit area in 51 cm rows was twice that in 102 cm rows. In 1964, Stickler (38) reported that sorghum seeding rates varied by 400% produced remarkably similar grain yields and in 1965, Stickler and Wearden (41) analysed 34 grain sorghum spacing experiments and concluded that yields from 51 cm rows exceeded those from 102 cm rows by 10% in eastern Kansas and by 7% in central Kansas. A remarkable constancy of grain yields from widely varying stand densities was found, and was explained by intercompensation among yield components, particularly heads per unit area and seeds per head.

Hittle et al. (16) in Illinois, reported that grain yield of sorghum growing in both 51 and 76 cm rows out-yielded 102 cm rows. In rate of planting experiments, plants spaced 8 cm apart in 102 cm rows gave higher yields than plants spaced 15, 23, and 31 cm.

Atkins et al. (1) at Ames, Iowa, evaluated the performance of two short-stature grain sorghum hybrids at two row spacings and four within-row plant populations. Both hybrids showed a grain yield advantage of 11% for 76 over 102 cm row spacing averaged over all within-row plant populations. The highest grain yield at each row spacing was produced by a within-row population of 5 plants/30.5 cm, and seeds per head and heads per plant decreased progressively as the within-row plant population increased from 4 to 8 plants/30.5 cm.

Mann (24) conducted experiments during a three-year period in southeastern Colorado in order to determine the effects of rate of seeding and row widths on grain sorghum grown under dryland conditions. Grain yields from 53 and 107 cm row spacings were not significantly different when the same amount of seed per unit area was planted, and the results suggested that to plant more than 4.5 kg/ha under those conditions would be a waste of seed. Low populations under dryland conditions were also suggested by Quinby et al. (33) in Texas, they stated that a stand thicker than 2 plants/30.5 cm in normal 91 to 107 cm rows may reduce yields in a dry year.

Tillering characteristics of different varieties may influence their response to plant population. Sieglinger (35) working at Woodward, Oklahoma, has shown that varieties that tillered profusely produced similar yields when within-row space varied from 15 to 76 cm. Conversely, genotypes that produced few tillers showed successive yield reductions when plant populations were decreased. Accordingly, Karper (20) observed that milo, a profusely tillering variety, yielded 21% more grain when planted from 46 to 91 cm apart in the row than when planted 8 to 23 cm. However, Kafir, a sparse tillering type, yielded 13% more grain when planted 8 to 23 cm apart in the row than when planted further than 46 cm apart.

Plant height as a factor affecting response of sorghum to row width and stand density was evaluated by Stickler and Younis (43) at Manhattan, Kansas. These workers compared isogenic lines differing by one gene (Dw3) and thus, height effect was determined within a common genetic background. Tall and short types averaged 145 and 94 cm, respectively. They found little evidence for a row width X plant height interaction, but plant height X stand density and plant height X variety interactions were significant. The short genotype performed better at high stand density (774 cm^2/plant), but the tall genotype was superior at lower populations (1,548 or 2,323 cm^2/plant). They suggested that the short form may better withstand effects of strong competition resulting from high planting rates.

The effect of plant density and growth duration on grain sorghum yield was studied by Blum (3) at Bet Dagan, Israel, under conditions of limited water supply. He found that the grain yield of the late maturing hybrid was highest under the low plant density and that of an early maturing hybrid was highest under the high density. The highest yield in the experiment was obtained with the earliest maturing hybrid planted at the heaviest plant population. All grain yield components were operative in the determination of inter-hybrid differences under moderate competition, and the superiority of the early maturing hybrid at the highest density was attained through its ability to maintain larger grains in spite of increased interplant competition for water.

Effect of Planting Patterns on Corn Grain Yields

Many yield comparisons between different corn planting patterns have been made, however, the superiority of any one planting pattern has not been clearly established. Dungan et al. (11) presented a review of corn spacing investigations and concluded that under general conditions it is better to underplant than overplant, and that uniform distribution of plants is apparently the best from the stand point of grain production under conditions of adequate moisture.

Olson (26) reported that in South Dakota, grain yield of corn decreased with increasing population in adverse soil-water seasons, and under more favorable growing seasons corn could not take advantage of the increased populations to increase grain production. In contrast to corn, sorghum yields remained constant in adverse years or increased significantly with increasing population during the better growing seasons.

Lutz et al. (23) in Virginia, and Hunter et al. (18) in Ontario, Canada, studied the performance of 10 late corn hybrids and 5 short season corn hybrids respectively, under varied plant populations and row widths. The general results were higher grain yields with higher populations and narrower row widths. Yao and Shaw (51) in Iowa, found a slight yield advantage for 53 cm corn rows over 107 cm rows, but the effect of population was reversed in the two years of study. Stickler (37) in Kansas, reported slightly higher yields from 50 cm than from 100 cm rows, and found 40,000 plants per hectare to yield better than 60,000 plants per hectare. Finally, Giesbrecht (13) in Manitoba, Canada, studied the effects of population and row spacing on the performance of four corn hybrids, and reported that changes in row spacing did not affect grain yield, but each increase in population increased grain production. Varieties were found to differ significantly in their yield response to higher stands, the later maturing, taller hybrids were adapted better to the competition in high populations than were the earlier hybrids.

Hoff and Mederski (17) theorized that an equidistant planting pattern may reduce competition between roots of adjacent plants for water and nutrients, and thereby increase grain yield. They tested two corn planting patterns - conventional 107 cm row spacing and equidistant planting at several plant populations. Equidistant spacing increased the mean yield of corn 345 kg/ha. The yield difference between the two planting systems was minimal at the low population levels but increased with increasing population.

Effects of Planting Patterns on Light Utilization

If the supply of water and nutrients is not a limiting factor to plant growth, the interception of light will be the factor determining yield. Williams et al. (47, 48, 49) stated that the amount of photosynthetically active radiation intercepted is a major determinant of corn growth rate during the vegetative phase, where nutrients and soil moisture are not limiting. They obtained a maximum growth rate of 52 g/m^2 per day with a very high population density during a pretasseling period of 12 days. This growth rate is one of the higher maximal rates recorded for terrestrial and for aquatic communities. The yield of grain, however, correlated well with crop growth rates up to an optimum population density (48,700 plants/hectare), but then decreased with density.

A commonly used index to estimate the light interception capacity of plant canopies is the leaf area index (LAI = area of leaf per unit area of ground). With plants like corn and sorghum high populations are needed to obtain a high enough LAI to intercept light efficiently at low levels of illumination. There is a limit, however, where further increases of LAI reduce the amount of light transmitted down into the canopy to extremely low levels of illumination.

Eik and Hanway (12) obtained a linear trend between grain yield of corn and LAI at silking time, but the linear relationship did not continue beyond the LAI value of 3.3. However, the manner of leaf display may affect the penetration of light into the foliage canopy and higher LAI for optimum growth can be obtained. Winter and Ohlrogge (50) evaluated the effect of leaf angles of the upper leaves on the grain yield of corn at varied LAI. They found that at low LAI (below 3 or 4), upright leaves tended to decrease grain yield, however, at high LAI (5 and above), upright leaves tended to increase grain yield. Pendleton et al. (29) reported that erect leaf hybrids produced 40% more grain than normal leaf type when compared in rows 51 cm wide at 59,304 plants per hectare. Results were not always consistent however, since Hicks and Stucker (15) found grain yield of corn and leaf angle to be negatively correlated at low populations, but the correlations approached zero as plant density increased (small angle characterizes uprightness).

Bowers et al. (4) working on sorghum found that row spacing was the only factor affecting the total net radiation absorbed by both plants and soil, but the division of this energy between crop and soil was only influenced by plant population. The greater the population the more the net radiation is absorbed by the crop than by the soil. It has been also suggested (22, 32, 40) that a more uniform distribution of plants at narrower row spacings results in more efficient use not only of solar energy, but also of nutrients and water, and consequently, in higher grain yields.

Effect of Planting Patterns on Water Use

The amount of evapotranspiration from any area is governed primarily by those factors affecting water and heat supply to soil and plant surfaces. Plant population may affect the total amount of water use only in the low range of stand densities, where the soil is partly covered, but once a complete canopy is obtained, further changes in density will produce little if any effect on evapotranspiration.

Tanner et al. (44) found that maximum evaporation in fully grown corn drilled in 102 cm rows may constitute 30 to 40% of the total evapotranspiration with a plant population of 32,097 plants per hectare, and only slightly less with 54,318 plants per hectare. Peters (30) reported that in the Midwest, where frequent summer showers occur, as much as 50% of the total water loss in a season can be accounted for by evaporation from the soil surface. Those high rates of water loss by evaporation could be reduced as suggested by Denmead et al (9) with closer rows. Since 102 cm spacings, either in hills or drilled rows, does not provide a complete crop cover, narrower rows will reduce the energy available for water evaporation from the soil surface, and thereby, a considerable increase in water-use efficiency could be obtained, at least under conditions in which the soil surface is frequently wet. Results which support this idea were reported by Stickler et al. (40) for sorghum where the rate of drying of the soil surface after rainfall decreased with narrower rows.

Timmons et al. (45) studied the effect of corn population on yield, water use, and water-use efficiency. They found that plant population did not affect total water use, so the water-use efficiency varied with yield. The dry matter yield and the efficiency of water used increased as population increased. Peters and Russell (31) stated that an increase in plant population will result in only a small increase in total water use but will result in a marked reduction of the water used per plant. This reduction may be physiologically important and could well account for the depressed yields often observed at high plant populations in corn.

Porter et al. (32) reported from sorghum experiments that row spacing and planting rate had little influence on the total water use, but plants at the narrower spacings tended to use water at a greater rate early in the season. The water-use efficiency decreased as row width increased from 51 to 76 - 102 cm.

Pendleton (28) in a review on this topic stated:

> "As research proceeds on this broad front, plant populations may continue to edge upward and planting patterns tend to become more equidistant. Such a spacing trend in humid regions may emcompass all crops as specialized machinery and chemical herbicides are further developed. While these changes will do little toward changing total water use, they will change water-use efficiency by subsequent yield increases."

Planting Pattern-Fertility Interactions

The optimum plant population for maximum yield is highly dependent on fertility level and vice-versa. The specific combination of fertility and population is dependent on climatic conditions, especially water supply.

Lang et al. (21) studied the response of nine corn hybrids to population rate and nitrogen level at Urbana, Illinois. Both population and nitrogen influenced yield, and a significant population by nitrogen interaction was observed such that the higher the population, the higher the nitrogen level required for maximum yield. Similar results were reported by Colyer and Kroth (7, 8) from the analysis of several year's data of corn experiments under varied conditions. Corn yields were higher under conditions of adequate moisture supply, and the higher the water availability the higher the population and nitrogen levels required for maximum yield.

Working on sorghum, Welch et al. (46) in Texas, reported marked nitrogen by population interaction effect on grain yields. With adequate nitrogen level, 148,140 plants per hectare produced higher yields than lower populations, and at this stand density, 56 kg/ha of nitrogen was sufficient for maximum yield in a dry year; however, with better moisture conditions, grain yields increased with increasing nitrogen through 112 kg/ha.

Painter and Leamer (27) at Tucumcari, New Mexico, found significant interactions between fertility and moisture and fertility and spacing. High moisture levels and closer row spacings favored larger grain yield responses of sorghum at the higher nitrogen rates. On the other hand, Nelson (25) in Washington, working with three sorghum varieties, Early Hegari, Martin, and Double Dwarf White Sooner under irrigation, found that the amount of nitrogen applied was the only variable that affected yield significantly. Plant populations for the three varieties varied considerably without affecting grain yield.

Other Important Facts Related to Planting Pattern

Plant population and/or row spacing often affect other things of agronomic interest in addition to yield (22, 24, 28, 36).

1) Maturity. Since tillers start after the main culm has already developed, lower stands that tiller more frequently mature later, and the moisture content of the grain is higher than in higher densities with less tillering.

2) Plant height. Increasing population increases plant height which is associated with lodging.

3) Weed control. Thick stands and narrow rows often show advantage in competition with weeds.

4) Soil protection. High populations and narrow rows produce a thicker and more uniform plant mass which reduce the rainfall impact on the soil structure in the surface layer. Prevention of wind erosion has also been pointed out.

CHAPTER III

MATERIALS AND METHODS

A sorghum hybrid OK 612 was planted on June 13, 1973, and plants emerged on June 17, 1973. Since the stand obtained was not uniform, and some areas showed a markedly greater growth rate, the whole experiment had to be replanted in a different place.

As planting date was late, an early sorghum hybrid NK 127 was planted on Teller loam soil, at Perkins, Oklahoma, on July 20, 1973, and plants emerged on July 24, 1973. Prior to planting, 224 kg/ha of 14-28-14 ($N-P_2O_5-K_2O$) was applied over the whole experiment. Sorghum was thickly planted in narrow (25 cm) rows, and rows were removed and thinned by hand to obtain the desired populations and row spacings when plants were 15 to 20 cm tall. Weeds were controlled by hand hoeing.

Variables were plant population (50,000, 100,000 and 200,000 plants per hectare) and row width (25, 50, 75, and 100 cm between rows). All combinations of three populations and four row spacing levels gave a factorial arrangement of twelve treatment combinations. A randomized block design with three replications was used. Each plot was 9 m long and 3 m wide. The number of rows per plot was not constant but varied with the row spacing of the treatment from three to twelve for row widths from 100 to 25 cm, respectively.

The grain was harvested by hand. Approximately 6 m^2 were harvested from each plot. The number of rows harvested varied with the row spacing from one to four for row spacings from 100 to 25 cm, respectively and the number of plants harvested per plot varied from about 30 to about 120 for populations from 50,000 to 200,000 plants per hectare.

Leaf area was estimated by leaf length X leaf width X 0.747 (42). Leaf length and leaf width of all live leaves of six plants per plot in all plots were measured and used to estimate leaf area per plant and to calculate leaf area index (LAI). Leaves were measured only once, at flowering.

Midge damage was observed, and grain yield was reduced, but since the damage was uniform over the whole experiment, treatment differences are assumed to be realistic.

Soil water content was measured during the last five weeks of the growing season. The measurements were made in two spacings (50 and 100 cm) at one population level (100,000 plants per hectare) in all three replications. The soil water content was recorded weekly, at 25 cm away from the row, every 15 cm down to a depth of approximately 130 cm, by using the neutron scattering moisture meter.

CHAPTER IV

RESULTS AND DISCUSSION

Water Availability

Table I shows the rainfall during the spring and summer seasons of 1973 and Table II shows the variation in soil water for two row spacings (50 and 100 cm) at 100,000 plants per hectare. The data indicates that the amount of water available to the crop was not a limiting factor and the conditions were favorable for sorghum growth. This is also shown in Table III where yields obtained with thick densities were high enough (over 3000 kg/ha) to indicate good growth conditions.

Effect of Planting Pattern on Grain Yield

Grain yield per unit area increased 990 kg/ha (45%) by increasing the number of plants per hectare from 50,000 to 200,000, and 454 kg/ha (18%) by narrowing rows from 100 to 50 cm.

Grain yield per plant decreased 27 grams (69%) when plant population increased from 50,000 to 200,000 plants per hectare, but increased 5 grams (19%) when rows were 50 instead of 100 cm apart.

In Tables IV and V the analyses of variance show that the effect of both population and spacing were statistically significant on either yield per unit area or per plant, but the interaction population X spacing did not meet the significance level in any case. The effect of plant population seems to be higher than the effect of spacing on either

TABLE I

PRECIPITATION DURING SPRING AND SUMMER 1973

	Rainfall (mm)	Normal (mm)	Departure from Normal
March	196.3	47.2	+149.1
April	87.4	72.6	+ 14.8
May	81.3	117.3	- 36.0
June	54.6	107.7	- 53.1
July	110.5	89.7	+ 20.8
August	54.9	81.5	- 26.6
September	315.2	85.9	+229.3
October	62.0	70.6	- 8.6

TABLE II

WATER IN THE SOIL[1]

Date	Row Spacing (cm)	75 cm depth (mm)	120 cm depth (mm)
9/15	50	159	251
	100	159	250
9/23	50	161	253
	100	161	254
9/29	50	198	291
	100	186	280
10/7	50	193	286
	100	187	280
10/17	50	203	297
	100	200	295

[1]Only 100,000 plants/ha population sampled.

TABLE III

SORGHUM GRAIN YIELDS

Population	Row Spacing	Grain Yield	Grain Yield
Plants/ha	cm	kg/ha[1]	gr/plant[1]
50,000	25	2008	40.16
50,000	50	2374	46.89
50,000	75	2293	44.30
50,000	100	2066	40.87
100,000	25	3053	30.99
100,000	50	3074	30.51
100,000	75	2822	28.06
100,000	100	2595	26.08
200,000	25	3251	16.58
200,000	50	3453	17.37
200,000	75	3125	16.46
200,000	100	2873	14.48

[1]Each value is an average of 3 replications.

TABLE IV

ANALYSIS OF VARIANCE OF SORGHUM GRAIN YIELD PER HECTARE

Source	df	M.S.	Cal. F	P>F
Replications	2	956795.26		
Population	2	3110333.08	62.187	0.0001
Row Spacing	3	312988.00	6.258	0.0034
Interaction	6	54115.19	1.082	0.4037
Error	22	50015.54		

ANALYSIS OF VARIANCE OF SORGHUM GRAIN YIELD PER PLANT

Source	df	M.S.	Cal. F	P>F
Replications	2	87.74130		
Population	2	2161.88196	176.89479	0.0001
Row Spacing	3	29.87868	3.82687	0.0236
Interaction	6	9.87146	1.26434	0.3132
Error	22	7.80759		

grain yield per unit area or per plant.

Grain Yield Per Unit Area

The variation of sorghum grain yield per hectare when changing population and row spacing is shown in Figure 1. The effects of the different levels of population and row spacing on grain yield per hectare were tested and the results are in Table VI.

Every increase in population increases the grain yield per hectare significantly. Row spacings from 25 to 75 cm did not affect yield significantly, but when 100 cm spacing between rows were used, yield decreased significantly.

Although population x row spacing interaction was not significant, there is a trend for narrow rows (50 cm) to be more important when higher populations are used. In this experiment, by narrowing rows from 100 to 50 cm, a yield increase of 308, 479, and 580 kg/ha was obtained from 50,000, 100,000, and 200,000 plants per hectare respectively, as can be computed from the values given in Table III.

The highest yield (3453 kg/ha) was obtained with 200,000 plants per hectare and 50 cm row spacing, and the lowest (2008 kg/ha) was obtained with 50,000 plants per hectare and 25 cm row spacing.

Grain Yield Per Plant

In Figure 2 is shown the relationship between grain yield per plant and population and row spacing. Results of the tests of the effect of population and row spacing levels are found in Table VII.

Every increase in population decreases the grain yield per plant significantly. The only row spacing which produced a significantly

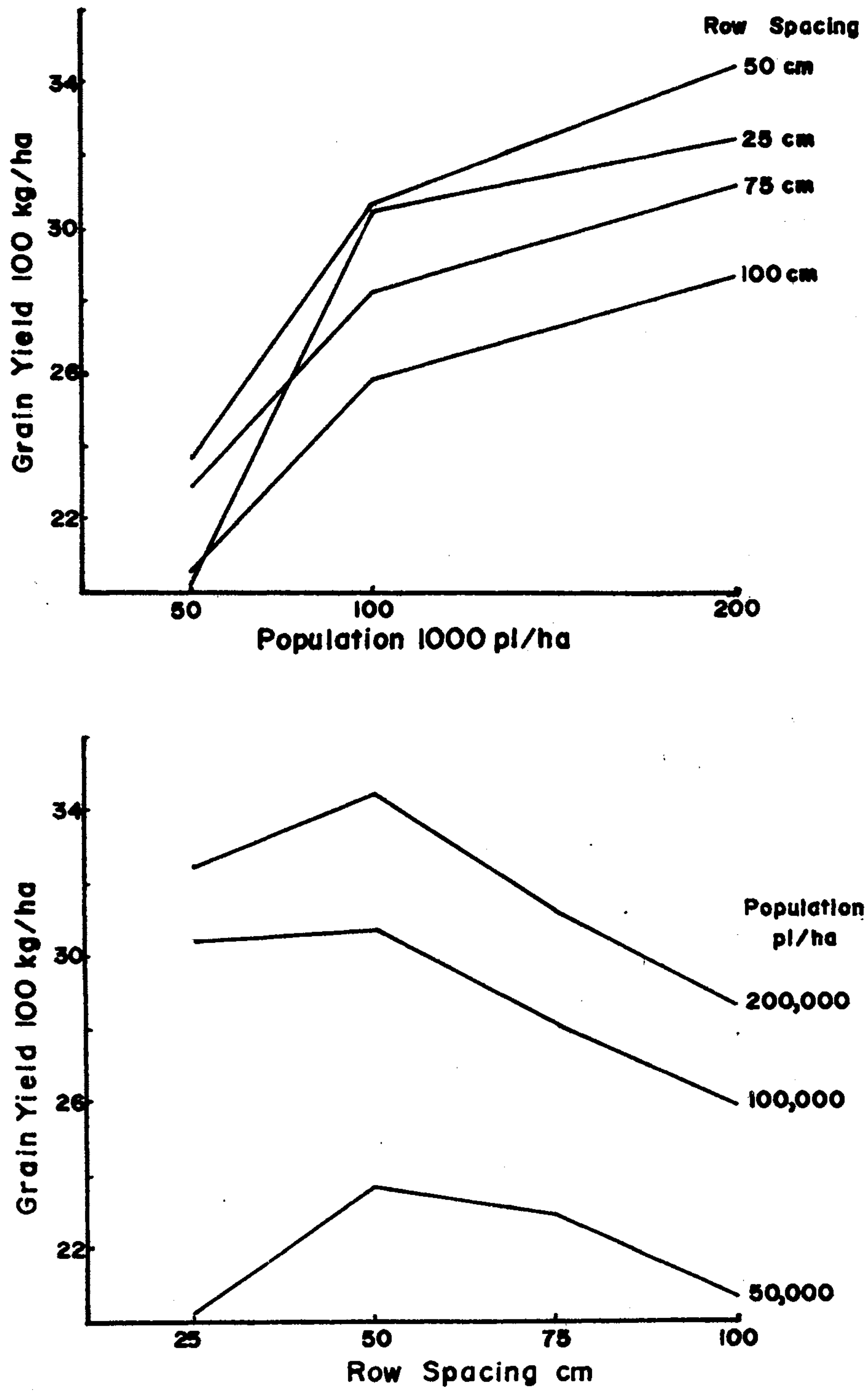


Figure 1. Sorghum Grain Yield Per Hectare at Different Populations and Row Spacings.

TABLE VI

THE EFFECT OF POPULATION AND ROW SPACING LEVELS ON SORGHUM GRAIN YIELD PER HECTARE

Population (pl/ha)	50,000		100,000	200,000
Grain Yield (kg/ha)[1]	2185		2886	3175 **
Row Spacing (cm)	100	75	25	50
Grain Yield (kg/ha)[2]	2512	2747	2770	2966 **

[1]Each value is an average of 12 observations.

[2]Each value is an average of 9 observations.

**Duncan's New Multiple Range Test at 5% level.

TABLE VII

THE EFFECT OF POPULATION AND ROW SPACING LEVELS ON SORGHUM GRAIN YIELD PER PLANT

Population (pl/ha)	200,000		100,000	50,000
Grain Yield (gr/pl)[1]	16.22		28.91	43.05 **
Row Spacing (cm)	100	25	75	50
Grain Yield (gr/pl)[2]	27.14	29.25	29.61	31.59 **

[1]Each value is an average of 12 observations.

[2]Each value is an average of 9 observations.

**Duncan's New Multiple Range Test at 5% level.

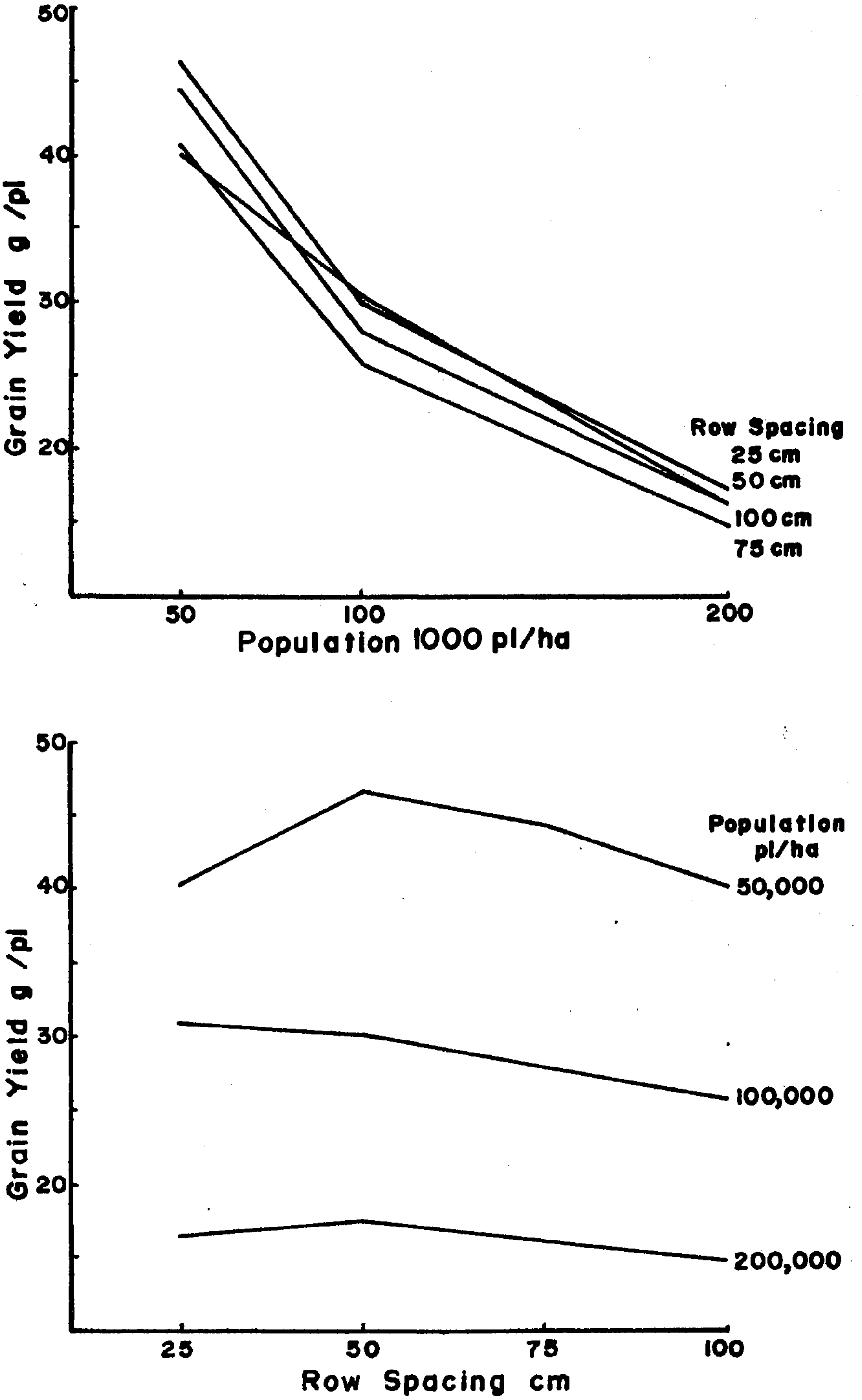


Figure 2. Sorghum Grain Yield Per Plant at Different Populations and Row Spacings.

lower grain yield per plant was 100 cm between rows, since 25, 50, and 75 cm row spacings did not affect yield per plant significantly.

Although population x row spacing interaction was not significant, the effect of row spacing seems to be smaller at high population levels than at lower populations.

The highest grain yield per plant in this experiment was obtained with 50,000 plants per hectare and 50 cm between rows, while the lowest was obtained with 200,000 plants per hectare and 100 cm between rows. The optimum grain yield per plant which occurred in relation with the highest grain yield per hectare was 17.37 grams and was obtained with 200,000 plants per hectare in rows 50 cm apart.

Effect of Planting Pattern on Leaf Area

The leaf area per plant and leaf area index (LAI = area of leaf per unit area of ground) obtained for each treatment in this experiment are shown in Table VIII. The analysis of variance of leaf area per plant and LAI are shown in Tables IX and X, respectively.

The effect of population was highly significant on both leaf area per plant and LAI. The effect of row spacing seems to be smaller and only significant on LAI at the 5 percent level; however, since population x row spacing interaction was significant in both cases, the effect of row spacing may be important depending on the population level being considered.

Leaf Area Per Plant

The relationship between leaf area per plant and population and row spacing is shown in Figure 3. Since the population x row spacing

TABLE VIII

SORGHUM LEAF AREA

Population	Row Spacing	Leaf Area	Leaf Area
Plants/ha	cm	cm^2/Plant	Index
50,000	25	2053[1]	1.027[1]
50,000	50	2179	1.089
50,000	75	2193	1.083
50,000	100	2145	1.072
100,000	25	2024	2.024
100,000	50	2039	2.039
100,000	75	1900	1.949
100,000	100	2011	2.011
200,000	25	1836	3.672
200,000	50	1796	3.592
200,000	75	1796	3.420
200,000	100	1557	3.113

[1]Each value is an average of 18 plants.

TABLE IX

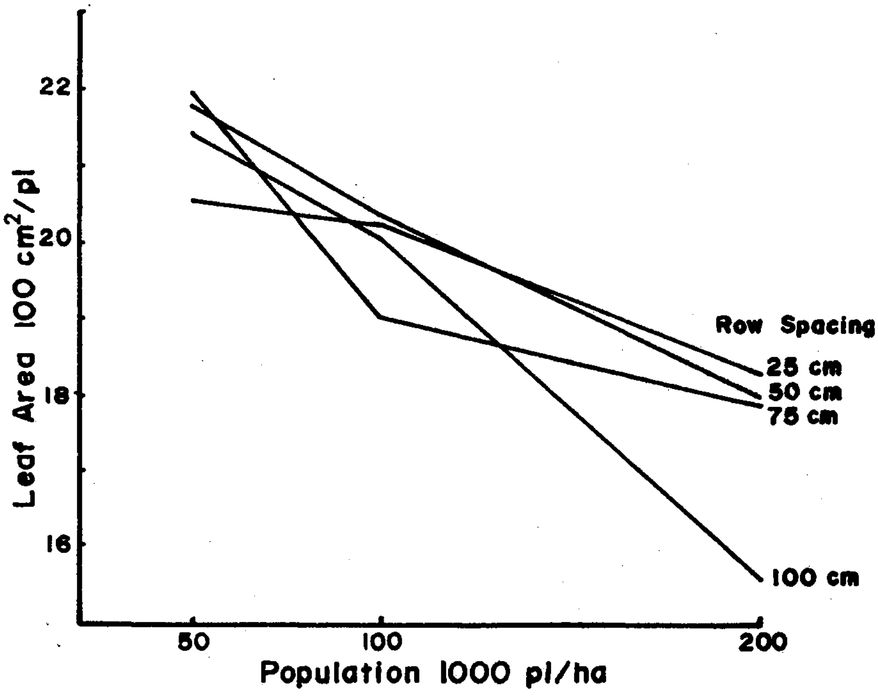
ANALYSIS OF VARIANCE OF SORGHUM LEAF AREA PER PLANT

Source	df	M.S.	Cal. F	P>F
Replications	2	773524.70		
Population	2	2884424.95	57.658	0.0001
Row Spacing	3	94230.84	1.884	0.1609
Interaction	6	26241.89	3.420	0.0154
Plants	180	41753.28	0.835	
Error	22	50026.10		

TABLE X

ANALYSIS OF VARIANCE OF SORGHUM LEAF AREA INDEX

Source	df	M.S.	Cal. F	P>F
Replications	2	1.47399		
Population	2	103.64202	856.020	0.0001
Row Spacing	3	0.38041	3.142	0.0450
Interaction	6	0.38209	3.156	0.0217
Plants	180	0.06406	0.529	
Error	22	0.12107		



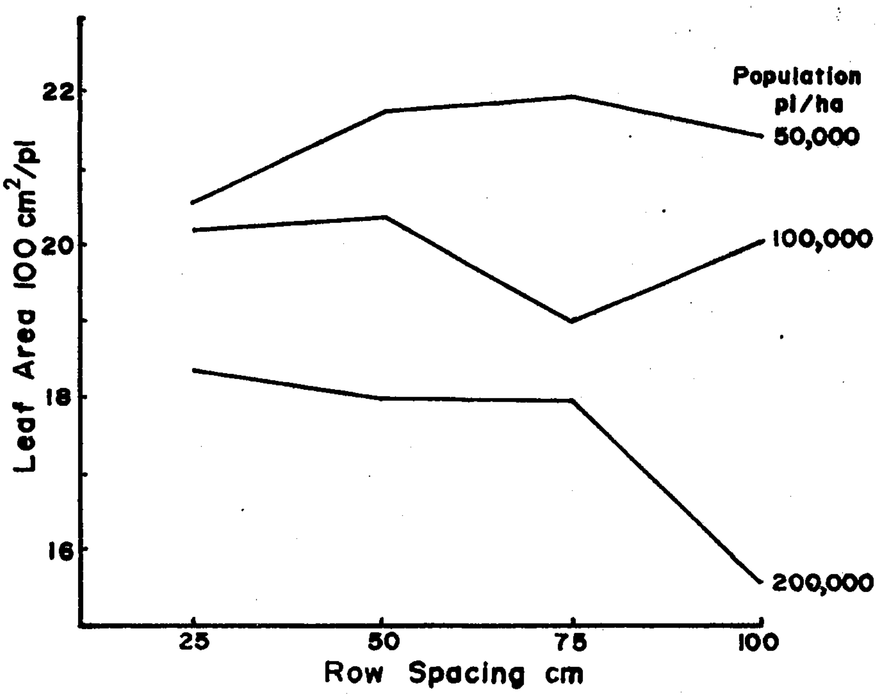


Figure 3. Sorghum Leaf Area Per Plant at Different Populations and Row Spacings.

interaction was significant, the effect of population was tested at every level of spacing, and the row spacing effect was tested at every level of population. Results are shown in Table XI.

Every increase in population decreased the leaf area per plant. Differences between 50,000 and 100,000 plants per hectare were not always significant, but 200,000 plants per hectare usually decreased significantly the leaf area per plant. When the row spacing effect was tested, the only significant difference was found at 200,000 plants per hectare where 100 cm between rows decreased significantly the leaf area per plant.

These results indicate that the main factor affecting leaf area per plant is population. Row spacing effect becomes important only when high stand densities are planted at wide row spacings.

Leaf Area Index

The variation of LAI with population and row spacing is shown in Figure 4. Population x row spacing interaction was found to be significant, so the population effect was tested at every level of row spacing and the row spacing effect was tested at every population level. Results are shown in Table XII.

Every increase in population increased the LAI at all levels of row spacing. The effect of spacing was significant only at the highest population level, where the widest spacing (100 cm) decreased the LAI.

The results indicate that population is mainly affecting the LAI. The effect of row spacing may become important only at high population levels and wide inter-row distances.

TABLE XI

THE EFFECT OF POPULATION AND ROW SPACING LEVELS ON SORGHUM LEAF AREA PER PLANT[1]

25 cm Row Spacing					
Population (pl/ha)	200,000	100,000		50,000	
Leaf Area (cm^2/pl)	1836	2024		2053	**
50 cm Row Spacing					
Population (pl/ha)	200,000	100,000		50,000	
Leaf Area (cm^2/pl)	1796	2039		2179	**
75 cm Row Spacing					
Population (pl/ha)	200,000	100,000		50,000	
Leaf Area (cm^2/pl)	1796	1900		2193	**
100 cm Row Spacing					
Population (pl/ha)	200,000	100,000		50,000	
Leaf Area (cm^2/pl)	1557	2011		2145	**
50,000 pl/ha Population					
Row Spacing (cm)	25	100	50	75	
Leaf Area (cm^2/pl)	2053	2145	2179	2193	**
100,000 pl/ha Population					
Row Spacing (cm)	75	100	25	50	
Leaf Area (cm^2/pl)	1900	2100	2024	2039	**
200,000 pl/ha Population					
Row Spacing (cm)	100	75	50	25	
Leaf Area (cm^2/pl)	1557	1796	1796	1836	**

[1]Each value is an average of 18 observations.

**Duncan's new Multiple Range Test at 5% level.

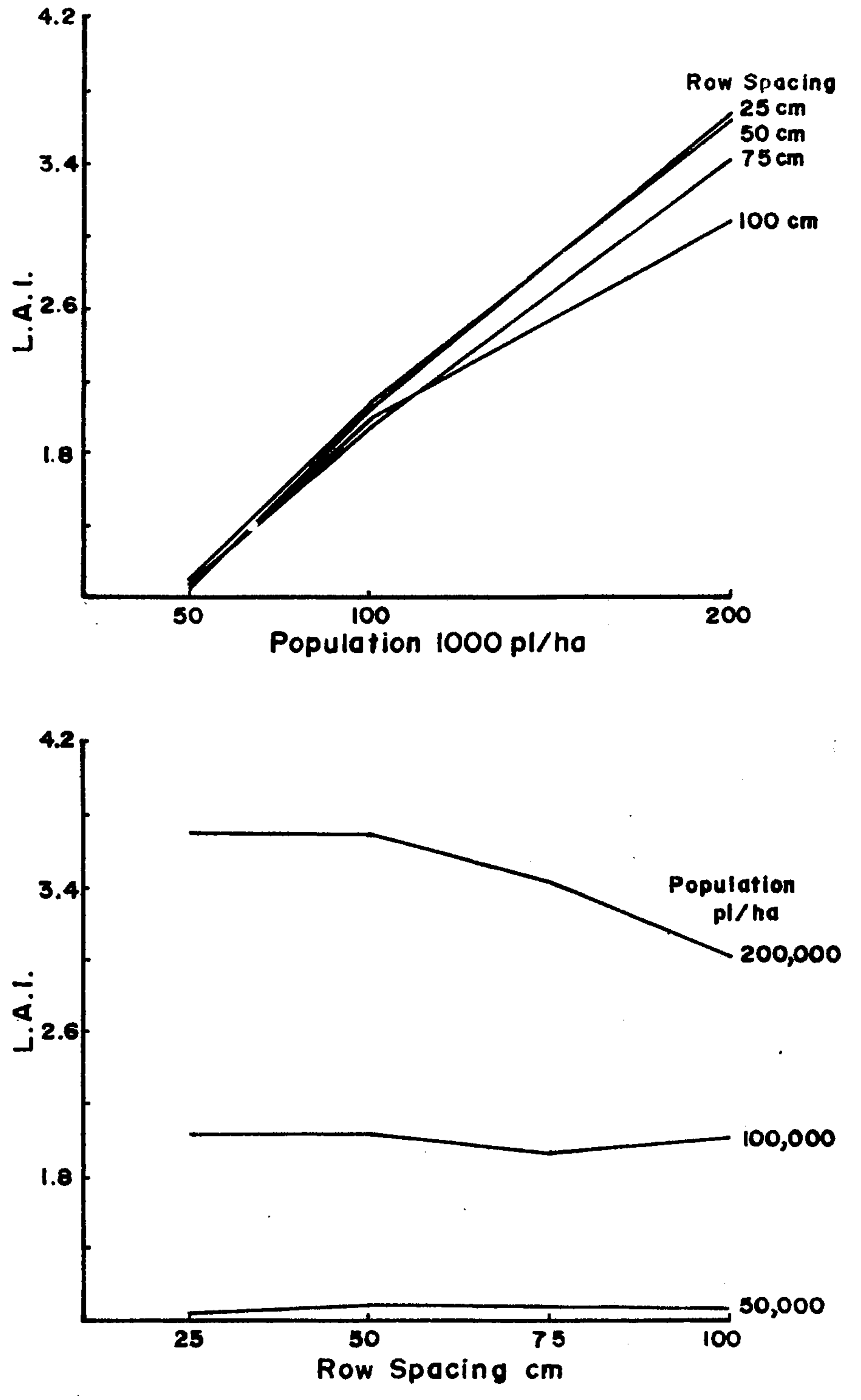


Figure 4. Sorghum Leaf Area Index at Different Populations and Row Spacings.

TABLE XII

THE EFFECT OF POPULATION AND ROW SPACING LEVELS ON SORGHUM LEAF AREA INDEX[1]

25 cm Row Spacing				
Population (pl/ha)	50,000	100,000	200,000	
Leaf Area Index	1.027	2.024	3.673	**
50 cm Row Spacing				
Population (pl/ha)	50,000	100,000	200,000	
Leaf Area Index	1.089	2.039	3.592	**
75 cm Row Spacing				
Population (pl/ha)	50,000	100,000	200,000	
Leaf Area Index	1.083	1.049	1.420	**
100 cm Row Spacing				
Population (pl/ha)	50,000	100,000	200,000	
Leaf Area Index	1.072	2.011	3.113	**

50,000 Pl/ha Population					
Row Spacing (cm)	25	100	75	50	
Leaf Area Index	1.027	1.073	1.083	1.089	**
100,000 pl/ha Population					
Row Spacing (cm)	75	100	25	50	
Leaf Area Index	1.949	2.011	2.024	2.039	**
200,000 pl/ha Population					
Row Spacing (cm)	100	75	50	25	
Leaf Area Index	3.113	3.420	3.592	3.672	**

[1]Each value is an average of 18 observations

**Duncan's New Multiple Range Test at 5% Level.

Partial Leaf Area

The effect of population and row spacing on leaf area and on accumulative LAI of the top six leaves was tested. Results are found in Tables XIII and XIV. In Figure 5 leaf area and accumulative LAI of the first six leaves are plotted for the highest and lowest populations and all spacings used in this experiment.

As population increases, the area of each of the top six leaves decreased, and the accumulative LAI increased. The effect of spacing was only significant on the area of the first three leaves, and only on LAI1 (flag leaf). Although population x row spacing interaction did not usually meet the significance level, there is a trend to decrease the leaf area of the first three or four leaves as rows get wider than 75 cm under high stand density (200,000 plants/ha), but this has not been observed at lower populations.

Correlations between partial and total LAI are given in Table XV. The correlation between LAI1 and total LAI is 0.906. Each extra leaf added improved the relationship between partial and total LAI, so that the correlation between LAI6, estimated from the top six leaves, and total LAI is 0.987. It shows a strong relationship between partial and total LAI, and suggests that with sorghum hybrids like the one used in this experiment, considerable effort could be saved by measuring only the flag leaf or a few leaves instead of all leaves to estimate LAI.

Leaf Area-Grain Yield Relationships

In Figure 6 all observations and treatment averages of grain yield per plant and grain yield per unit area were plotted against leaf area per plant and LAI, respectively.

TABLE XIII

LEAF AREA OF THE HIGHER SIX LEAVES

		Leaf 1		Leaf 2		Leaf 3	
Source	df[1]	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	7.46	0.0036	6.00	0.0084	10.65	0.0008
Row Spacing	3	4.29	0.0157	2.86	0.0591	4.03	0.0197
Interaction	6	1.98	0.1113	1.17	0.3598	1.46	0.2359
		Leaf 4		Leaf 5		Leaf 6	
Source	df	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	18.39	0.0001	14.90	0.0002	14.39	0.0002
Row Spacing	3	1.45	0.2552	1.25	0.3159	2.15	0.1220
Interaction	6	3.70	0.0108	2.43	0.0583	1.63	0.1866

[1]Error degrees of freedom = 22

TABLE XIV

ACCUMULATIVE LEAF AREA INDEX
OF THE HIGHER SIX LEAVES

		One Leaf		Two Leaves		Three Leaves	
Source	df[1]	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	102.99	0.0001	125.71	0.0001	175.69	0.0001
Row Spacing	3	3.31	0.0383	2.29	0.1053	2.14	0.1233
Interaction	6	2.09	0.0949	1.46	0.2368	1.35	0.2790
		Four Leaves		Five Leaves		Six Leaves	
Source	df	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	288.09	0.0001	490.73	0.0001	800.24	0.0001
Row Spacing	3	1.88	0.1623	1.77	0.1822	1.59	0.2183
Interaction	6	1.52	0.2163	1.68	0.1725	2.07	0.0983

[1]Error degrees of freedom = 22

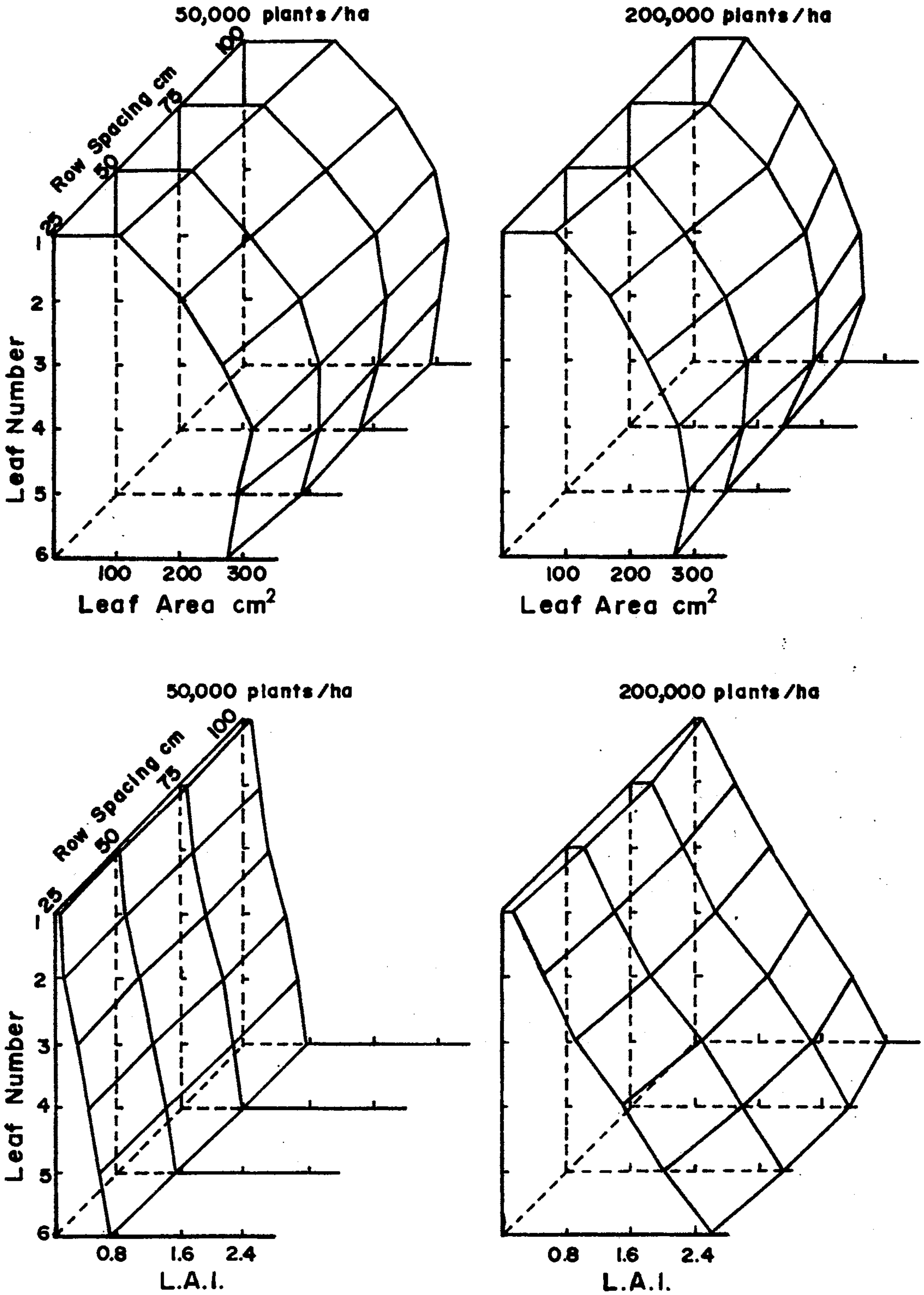


Figure 5. Leaf Area and Leaf Area Index Profile of Sorghum Canopy at Different Populations and Row Spacings.

TABLE XV

CORRELATIONS BETWEEN PARTIAL LAI AND TOTAL LAI

	LAI2	LAI3	LAI4	LAI5	LAI6	Total LAI
LAI1	0.994*	0.986	0.975	0.963	0.950	0.906
LAI2		0.997	0.990	0.980	0.969	0.931
LAI3			0.997	0.990	0.982	0.950
LAI4				0.998	0.993	0.968
LAI5					0.999	0.980
LAI6						0.987

*All correlations are significant at 0.0001 level.

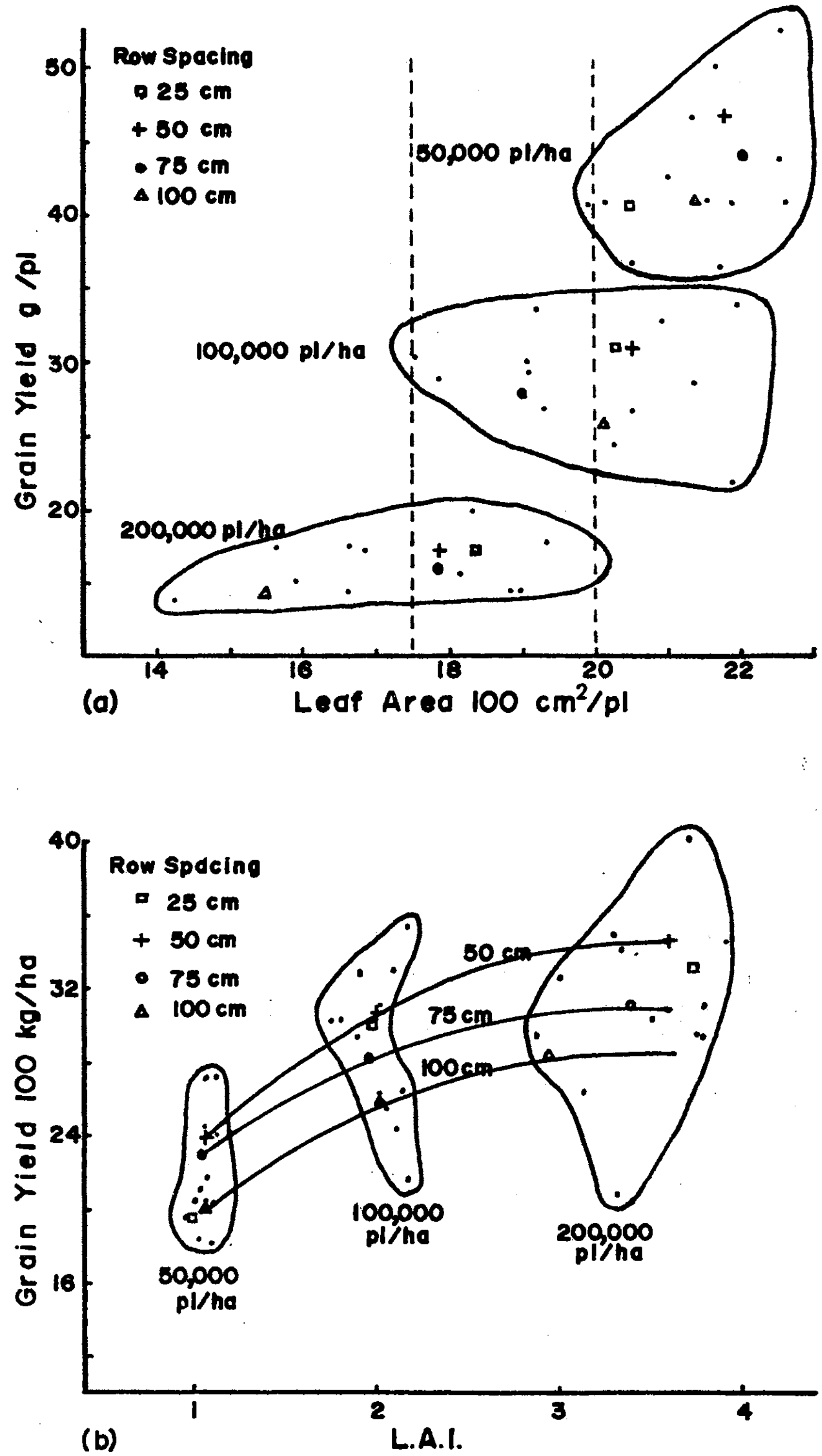


Figure 6. Variation of Sorghum Grain Yield Per Plant and Per Hectare with Leaf Area Per Plant and Leaf Area Index.

If population is ignored, there is a linear relationship between leaf area and grain yield per plant. However, when this relationship is considered within populations, leaf area and yield variations are not related. The results suggest that the efficiency of a given leaf area to produce grain depends on the population in which that particular plant is growing. In Figure 6a, it is observed that the amount of grain that a plant with a leaf area between 1750 and 2000 cm^2 can produce varies widely according to population. With that leaf area, about 16, 30 and 40 grams of grain per plant were produced from 200,000, 100,000, and 50,000 plants per hectare, respectively. However, although less efficient per unit leaf area, higher populations were able to produce higher grain yields per hectare. A population as high as 200,000 plants per hectare, with a leaf area and grain yield per plant as low as 1796 cm^2 and 17.37 grams respectively, was able to produce the highest grain yield per hectare.

As it is shown in Figure 6b, a quadratic type of relationship between grain yield per unit area and LAI was found when population was ignored. However, within populations, there is no relationship between grain yield per hectare and LAI. This is because population and LAI are very closely related since population is the main factor affecting LAI.

Either in narrow or wide rows, as population increases, LAI increases and grain yield increases, however, in narrow rows an extra yield increment is obtained over wide rows. This extra yield could be explained by the fact that narrow rows decrease interplant competition. At medium and low densities, the amount of water and nutrients was high enough to satisfy the crop demands, so that lower competition in narrow rows did not produce higher LAI, but the LAI produced was able to utilize light more efficiently giving higher yields. Nutrient supply, most likely nitrogen, may not have been enough to satisfy the demands of a high population (200,000 plants/ha), then the reduced competition in narrow rows made the crop able to produce higher LAI and as a consequence higher grain yield.

Effect of Planting Pattern on Plant Morphology

Plant height and average length and width of the top six leaves for every treatment are found in Table XVI. Analysis of variance of plant height is in Table XVII and the F values obtained from the analysis of variance of leaf length and width are shown in Tables XVIII and XIX.

Plant Height

Plant height was plotted against population and row spacing in Figure 7. The effects of population, row spacing, and population x row spacing interaction were highly significant on plant height. The effect of population at every level of spacing, and the effect of spacing at every level of population was tested, and the results are in Table XX. In narrow rows (25 cm) the differences in plant height at 50,000 and 100,000 plants per hectare was not significant; however, the highest population (200,000 plants/ha) tended to decrease plant height. The opposite effect of population was found at wider spacings since 200,000 plants per hectare increased significantly plant height at 50 and 75 cm row spacing. At the widest spacing (100 cm) every increase in population increased plant height significantly. The effect of row spacing was not significant on plant height at a low population level (50,000

TABLE XVI

SORGHUM PLANT CHARACTERISTICS

Population	Row Spacing	Leaf Length	Leaf Width	Plant Height
Plants/ha	cm	cm	cm	cm
50,000	25	44.1[1]	7.1[1]	87.6[2]
50,000	50	45.9	7.2	88.1
50,000	75	47.8	7.2	90.2
50,000	100	48.4	7.1	89.6
100,000	25	45.2	6.7	90.1
100,000	50	47.2	6.8	87.8
100,000	75	48.2	6.5	92.4
100,000	100	51.0	6.5	96.2
200,000	25	46.0	6.1	87.0
200,000	50	48.6	6.1	91.5
200,000	75	52.1	6.0	96.0
200,000	100	49.5	5.3	99.0

[1]Each value is an average of six higher leaves of 18 plants

[2]Each value is an average of 18 plants

TABLE XVII

ANALYSIS OF VARIANCE OF SORGHUM PLANT HEIGHT

Source	df	M.S.	Cal. F	P>F
Replications	2	220.214		
Population	2	376.056	21.435	0.0001
Row Spacing	3	538.758	30.709	0.0001
Interaction	6	107.957	6.153	0.0009
Plants	180	12.147	0.692	
Error	22	17.544		

TABLE XVIII

LEAF LENGTH OF THE HIGHER SIX LEAVES

		Leaf 1		Leaf 2		Leaf 3	
Source	df[1]	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	8.03	0.0027	1.37	0.2751	1.06	0.3645
Row Spacing	3	3.53	0.0310	2.43	0.0915	6.01	0.0040
Interaction	6	1.88	0.1302	0.74	0.6262	0.87	0.5364
		Leaf 4		Leaf 5		Leaf 6	
Source	df[1]	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	38.72	0.0001	70.59	0.0001	28.67	0.0001
Row Spacing	3	21.11	0.0001	20.56	0.0001	12.09	0.0002
Interaction	6	3.24	0.0193	1.58	0.1996	1.20	0.3410

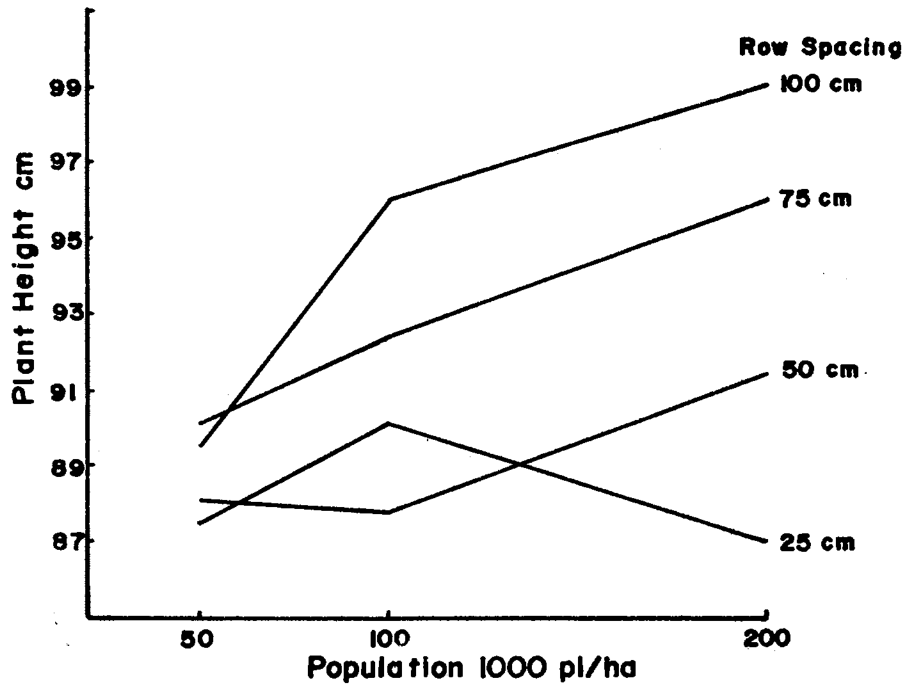
[1]Error degrees of freedom = 22

TABLE XIX

LEAF WIDTH OF THE HIGHER SIX LEAVES

		Leaf 1		Leaf 2		Leaf 3	
Source	df[1]	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	8.65	0.0020	30.85	0.0001	114.89	0.0001
Row Spacing	3	4.64	0.0117	2.21	0.1150	2.45	0.0895
Interaction	6	1.48	0.1719	1.83	0.1391	1.86	0.1325
		Leaf 4		Leaf 5		Leaf 6	
Source	df[1]	Cal. F	P>F	Cal. F	P>F	Cal. F	P>F
Population	2	169.62	0.0001	129.23	0.0001	83.00	0.0001
Row Spacing	3	10.80	0.0003	14.27	0.0001	17.28	0.0001
Interaction	6	2.33	0.0674	2.83	0.0338	2.87	0.0317

[1]Error degrees of freedom = 22



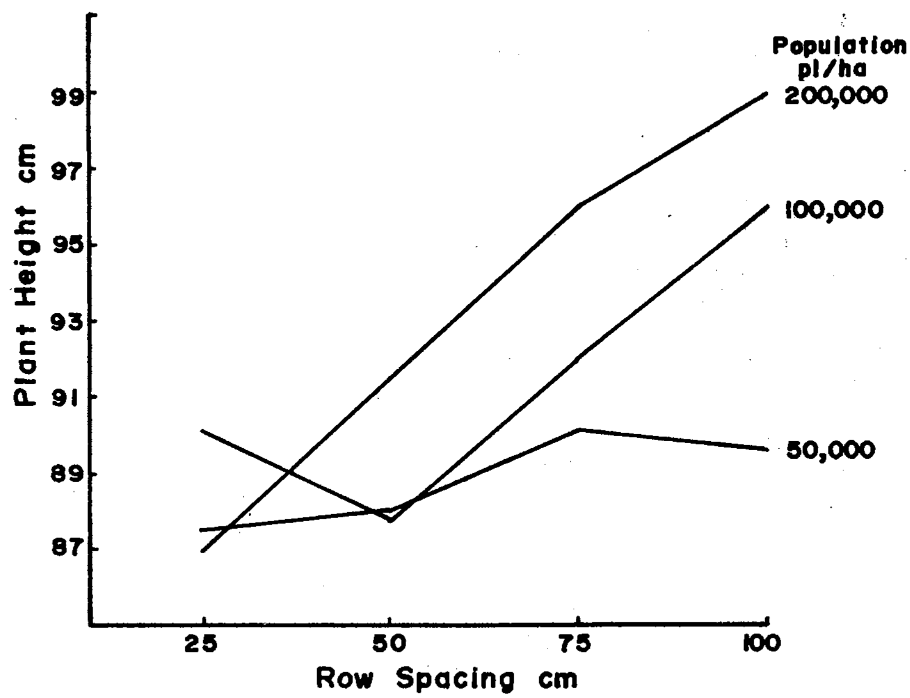


Figure 7. Sorghum Plant Height at Different Populations and Row Spacing.

TABLE XX

THE EFFECT OF POPULATION AND ROW SPACING LEVELS ON SORGHUM PLANT HEIGHT[1]

25 cm Row Spacing					
Population (pl/ha)	200,000	50,000		100,000	
Plant Height (cm)[1]	87.0	87.6		90.1	**
50 cm Row Spacing					
Population (pl/ha)	100,000	50,000		200,000	
Plant Height (cm)	87.8	88.1		91.5	**
75 cm Row Spacing					
Population (pl/ha)	50,000	100,000		200,000	
Plant Height (cm)	90.2	92.4		96.0	**
100 cm Row Spacing					
Population (pl/ha)	50,000	100,000		200,000	
Plant Height (cm)	89.6	96.2		99.0	**
50,000 pl/ha Population					
Row Spacing (cm)	25	50	100	75	
Plant Height (cm)	87.6	88.1	89.6	90.2	**
100,000 pl/ha Population					
Row Spacing (cm)	50	25	75	100	
Plant Height (cm)	87.8	90.1	92.4	96.2	**
200,000 pl/ha Population					
Row Spacing (cm)	25	50	75	100	
Plant Height (cm)	87.0	91.5	96.0	99.0	**

[1]Each value is an average of 18 plants.

**Duncan's New Multiple Range Test at 5% level.

plants/ha); however at higher population levels, wider rows tended to increase plant height such that at 200,000 plants per hectare, every increase in row spacing increased significantly plant height.

These results suggest that high population rates will produce taller plants, especially when they are planted in wide row spacings.

Leaf Length and Width

The variation of leaf length and width of the top six leaves with population and row spacing is shown in Figure 8 for all spacing and for the two extreme populations tested in this experiment. All leaf lengths were affected significantly by population except for the second and third leaves. The length of the first two leaves tended to decrease as population increased but the lower leaves became longer at higher populations. All leaf widths were affected significantly by population; and in fact as population increased, leaves tended to be narrower.

The effect of row spacing was significant on all leaf lengths except on the second leaf. As row spacing increased so did leaf length, except for the top four leaves at 200,000 plants per hectare where leaf length decreased at rows wider than 75 cm, although population x row spacing interactions were not significant. Leaf width was affected significantly by row spacing, except for the second and third leaves. The width of the first two leaves tended to increase with row spacing, with the only exception at 200,000 plants per hectare in 100 cm rows. The width of the lower leaves, on the other hand, tended to decrease with wider rows, particularly at high population levels.

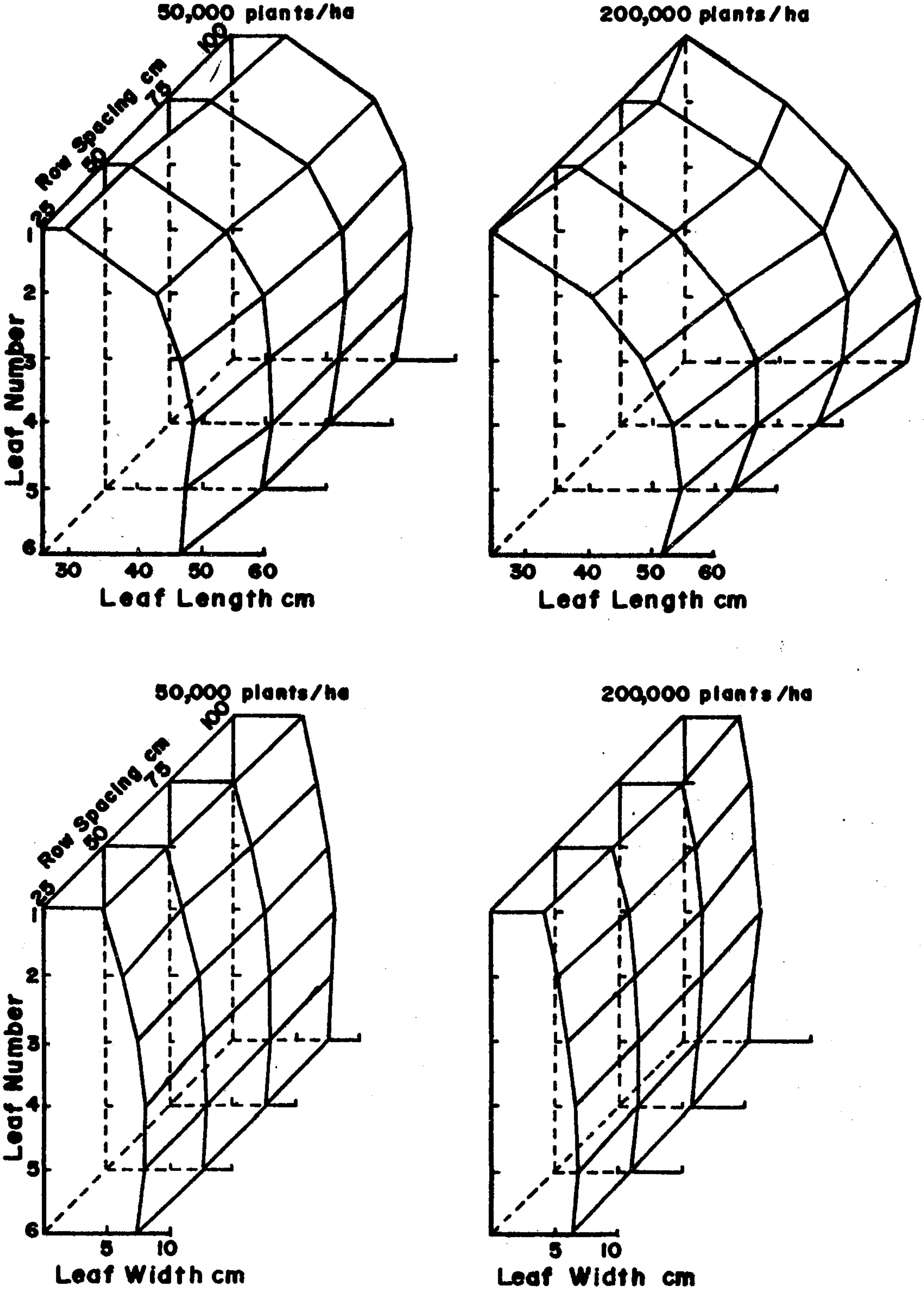


Figure 8. Leaf Length and Width Profile of Sorghum Plants at Different Populations and Row Spacings.

CHAPTER V

SUMMARY AND CONCLUSIONS

A field experiment on grain sorghum was conducted to study the influence of plant population and row spacing on grain yield, leaf area and plant morphology at Perkins, Oklahoma, in the summer season 1973.

The applied treatments were all combinations of three population levels (50,000, 100,000, and 200,000 plants per hectare) and four row spacings (25, 50, 75, and 100 cm between rows).

From the results of this study the following conclusions seem justifiable:

1. Both population and row spacing affected grain yield per hectare and per plant. The higher the population, the higher the grain yield per unit area and the lower the grain yield per plant. The greater the distance between rows (over 50 cm), the lower the grain yield per hectare and per plant. This effect was particularly significant at the widest distance between rows and highest population.
2. Both population and row spacing affected leaf area per plant and LAI. The higher the population, the lower the leaf area per plant and the higher the LAI. The effect of spacing was only significant at the highest population level in which the widest row spacing

(100 cm) decreased the leaf per plant and LAI.

3. High correlations have been observed between partial and total LAI. Considerable effort could be saved by measuring only a few leaves to estimate LAI.

4. The higher the population, the lower the efficiency of leaf area to produce grain. However, the population which caused the lowest leaf area efficiency produced the highest grain yield per hectare. Narrow rows (about 50 cm apart) increased the leaf area efficiency allowing a grain yield increment at any stand density.

5. The higher the population (at wide row spacings), and the wider the row spacing (at high populations), the taller the plants.

6. In general, as population and distance between rows increased, leaves tended to be longer and narrower. Exceptions to this may be found for the length of the upper two or three leaves.

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APPENDIX

TABLE XXI

ACTUAL POPULATIONS, GRAIN YIELDS PER HECTARE AND GRAIN YIELDS PER PLANT OF GRAIN SORGHUM

Rep.	Pop. pl/ha.	Row Spac. cm.	Plant Spac. cm.	Actual Pop. pl/ha.	Grain Yield kg/ha	Grain Yield gr/pl.
1	50,000	25	80	50,000	1843	36.86
1	50,000	50	40	50,000	2055	41.10
1	50,000	75	27	50,000	1814	36.28
1	50,000	100	20	53,333	2192	41.10
1	100,000	25	40	96,774	2561	26.46
1	100,000	50	20	93,333	2646	28.35
1	100,000	75	13	100,000	2419	24.19
1	100,000	100	10	98,333	2192	22.29
1	200,000	25	20	196,667	2872	14.61
1	200,000	50	10	200,000	2873	14.37
1	200,000	75	7	188,333	3100	16.46
1	200,000	100	5	175,000	2646	15.12
2	50,000	25	80	50,000	2126	42.52
2	50,000	50	40	51,667	2722	52.68
2	50,000	75	27	51,667	2722	52.68
2	50,000	100	20	50,000	2041	40.82
2	100,000	25	40	100,000	3326	33.26
2	100,000	50	20	103,333	3553	34.38
2	100,000	75	13	101.667	3024	29.74
2	100,000	100	10	100,000	2646	26.46
2	200,000	25	20	195,000	3478	17.84
2	200,000	50	10	198,333	4007	20.20
2	200,000	75	7	195,000	3024	15.51
2	200,000	100	5	211,667	3100	14.65
3	50,000	25	80	50,000	2055	41.10
3	50,000	50	40	50,000	2344	46.88
3	50,000	75	27	53,333	2344	43.95
3	50,000	100	20	48,333	1966	40.68
3	100,000	25	40	98,361	3272	33.27

TABLE XXI (CONTINUED)

Rep.	Pop. pl/ha.	Row Spac. cm.	Plant Spac. cm.	Actual Pop. pl/ha.	Grain Yield kg/ha	Grain Yield gr/pl.
3	100,000	50	20	105,000	3024	28.80
3	100,000	75	13	100,000	3024	30.24
3	100,000	100	10	100,000	2948	29.48
3	200,000	25	20	196,667	3402	17.30
3	200,000	50	10	198,333	3478	17.54
3	200,000	75	7	186,667	3251	17.42
3	200,000	100	5	210,000	2873	13.68

TABLE XXII

LEAF AREA INDEX, LEAF AREA PER PLANT AND PLANT HEIGHT OF GRAIN SORGHUM

Rep.	Pop. pl/ha.	Row Spac. cm	Plant Spac. cm	Leaf Area Index	Leaf Area cm^2/pl	Height cm
1	50,000	25	80	1.024	2047	84.2
1	50,000	50	40	1.074	2149	85.8
1	50,000	75	27	1.071	2169	87.5
1	50,000	100	20	1.092	2184	85.5
1	100,000	25	40	2.056	2056	88.3
1	100,000	50	20	2.133	2133	87.0
1	100,000	75	13	2.080	2028	97.2
1	100,000	100	10	2.184	2184	91.5
1	200,000	25	20	3.779	1890	85.8
1	200,000	50	10	3.787	1893	90.7
1	200,000	75	7	3.813	2002	97.3
1	200,000	100	5	3.170	1585	99.2
2	50,000	25	80	1.049	2098	88.2
2	50,000	50	40	1.128	2257	88.8
2	50,000	75	27	1.067	2161	90.5
2	50,000	100	20	1.131	2262	91.7
2	100,000	25	40	2.094	2094	89.7
2	100,000	50	20	2.195	2195	87.2
2	100,000	75	13	1.969	1920	91.8
2	100,000	100	10	1.938	1938	90.0
2	200,000	25	20	3.868	1934	86.3
2	200,000	50	10	3.664	1832	89.7
2	200,000	75	7	3.462	1817	94.7
2	200,000	100	5	3.330	1665	97.2
3	50,000	25	80	1.007	2014	90.3
3	50,000	50	40	1.065	2131	89.5
3	50,000	75	27	1.110	2248	92.5
3	50,000	100	20	0.994	1989	91.7
3	100,000	25	40	1.922	1922	92.3

TABLE XXII (CONTINUED)

Rep.	Pop. pl/ha.	Row Spac. cm.	Plant Spac. cm.	Leaf Area Index	Leaf Area cm^2/pl	Height cm
3	100,000	50	20	1.791	1791	89.3
3	100,000	75	13	1.799	1754	92.3
3	100,000	100	10	1.913	1913	99.2
3	200,000	25	20	3.369	1684	88.8
3	200,000	50	10	3.326	1663	94.2
3	200,000	75	7	2.986	1568	96.0
3	200,000	100	5	2.841	1420	100.7

VITA

Ernesto Carlos Beltramini

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF POPULATION AND ROW SPACING ON LEAF AREA AND GRAIN YIELD OF SORGHUM

Major Field: Agronomy

Biographical:

Personal Data: Born in Montevideo, Uruguay, April 16, 1945, the son of Juan and Olga Beltramini.

Education: Graduated from Instituto Alfredo Vázquez Acevedo, Montevideo, Uruguay in December, 1962; received the Ingeniero Agrónomo degree from the Facultad de Agronomía, Montevideo, Uruguay in April, 1970; completed the requirements for a Master of Science degree in July, 1974.

Professional Experience: Worked at the Department of Soil Science, Facultad de Agronomía, Montevideo, Uruguay from 1964 to 1966; 1967-1972 worked at the Department of Crop Science in the Experimental Station Dr. Mario A. Cassinoni, Paysandú, Uruguay.