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Effects of soil moisture stress and inter-plot competition on grain yield and other agronomic characteristics of sorghum and pearl millet

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EFFECTS OF SOIL MOISTURE STRESS AND INTER-PLOT COMPETITION ON GRAIN YIELD AND OTHER AGRONOMIC CHARACTERISTICS OF SORGHUM AND PEARL MILLET

by

Azizur Rahman

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

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12 Dec. 1989
Date

DEDICATION

I dedicate this thesis
to my wife (Nitu) and
my daughter (Esha)

ACKNOWLEDGMENT

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ABSTRACT

Sorghum (Sorghum bicolor L., Moench) and pearl millet (Pennisetum americanum L., Leeke) were intercropped under soil moisture non-stress and stress at Marana, Arizona during summer 1987. Effects of soil moisture stress and inter-row competition between sorghum and pearl millet on grain yield, 50% bloom, plant height, head length, head exsertion, 1000 grain weight, and number of effective tillers were evaluated.

Interplot competition significantly reduced grain yield and head exsertion of pearl millet. In sorghum, only plant height was significantly different due to competition. Agronomic characters were significantly different due to the effect of soil moisture stress except head length in pearl millet and head length, 1000 seed weight, and number of effective tillers in sorghum.

Sorghum growing in a neighbor plot greatly suppressed millet grain yield under soil moisture stress. Relative yield total of the cereals under intercrop was less than unity under soil moisture stress.

CHAPTER 1

INTRODUCTION

Growing two or more crops simultaneously under similar field management practices in alternating rows or sets of rows in a unit piece of land is intercropping (Zandstra, 1979). Intercropping may provide greater relative yield advantages for grain and/or dry matter production as compared to the cultivation of crops separately (sole crop or monocrop). When crops with varying growth habits are intercropped, plant nutrients in different soil layers are better utilized and light energy is more effectively intercepted (Liebman,1986). It is generally believed that subsistence farmers often have better assurance of a crop harvest with intercropping when sudden outbreaks of pests or other economic situations cause a particular crop to be unprofitable. According to Lynam et al.(1987), risk reduction is the primary goal of intercropping in subsistence farming with crop yield as the secondary objective.

The normal growth and development of a crop is likely to vary under intercropping. This variation is primarily due to the inter-plot competition for growth resources such as soil moisture, light, and nutrients by the intercrop companion crop. According to Willey (1979b), inter-species competition and complementarity may result in a greater dry matter or grain yield advantage in intercropping. Willey (1979a) categorized intercrop competition and complementarity in terms of: mutual inhibition - where actual yield of each species is less than expected; mutual cooperation - where the yield of each species is greater than expected; and compensation - where one species yields less than expected and the other more.

Sorghum (Sorghum bicolor L., Moench) and pearl millet (Pennisetum americanum L., Leeke) together occupy more than 100 million hectares of the world's cropland, from which about 100 million tons of grain are produced. Semi-arid tropic (SAT) countries have more than two-thirds of the world's harvested area of sorghum and millet but they contribute only about half of the world's total production (Ryan and Oppen, 1984). Intercropping of two cereals like sorghum and pearl millet is common in regions of Tanzania, and other arid and semi-arid parts of the world (Mitawa and Francis, 1985). Because of their drought tolerant characteristics, sorghum and pearl millet play an important role in farmers' cropping systems.

As compared to sorghum, pearl millet is more productive in areas where soil structure is relatively light or sandy and water availability is inadequate. Generally, millet is considered more efficient in its utilization of moisture and has a higher level of heat tolerance than sorghum and maize (_Zea_ _mays_ L.) (Rachie and Majmudar, 1980). By choosing suitable special arrangements of component crop rows, intercrop advantages may be increased (Waghmare et al., 1982). In order to understand the intercrop compatibility of sorghum and pearl millet in a certain agro-ecological environment, basic interactions of resource competition of the two species should first be known. This research is designed mainly to observe the effect of inter-row (inter-plot) competition as influenced by soil moisture treatments on the agronomic productivity of sorghum and pearl millet.

The objectives of the research are: 1) to evaluate the effect of inter-plot competition on intra-row performance of sorghum and pearl millet at different levels of soil moisture, and 2) to evaluate biological efficiencies for grain yield, and neighbor-row competition patterns of intercrop treatments under soil moisture non-stress and stress.

CHAPTER 2

LITERATURE REVIEW

Agronomic performance of a crop under intercropping largely depends on the interaction of the associated plant species and their immediate environment. There is competition among crop species in the utilization of resources below-ground as well as above-ground. Horwith (1985) observed that when the distance between plants in intercropping decreases to some critical point, they begin to compete for at least some of their resources.

2.1 Competition and resource utilization

Most cereals have similar rooting patterns and nutrient requirements therefore the potential for complementary effects of cereal-cereal intercrop with respect to below-ground resources is less than with unlike species (Rao, 1986). However, he reported that where large temporal differences exist among cereals, the intercrop components may complement each other over time to produce higher yields than sole cropping.

Willey and Reddy (1981), observed the below-ground interactions of pearl millet and groundnut (*Arachis hypogaea*) and reported that the interactions played a role in determining the competitive balance and final yield proportions of the two crops. In their below-ground partitioning experiment they found that the reduced millet growth and increased groundnut growth was primarily because pearl millet could not utilize below-ground resources from the groundnut planting zone.

Increased plant density of beans (Phaseolus sp.) and maize (Zea mays, L.) in a bean/maize intercrop experiment revealed that, as competition increased due to higher maize or bean density, there was a decreasing effect of each additional plant on per-plant bean yield. There was less effect of adding bean plants in intercropping than in monocropping on bean yield per plant. Reductions in bean yield per plant were not proportional to the added competition from either maize or beans, and thus beans under competition make more efficient use of scarce growth resources (Francis et al., 1982).

Putnam et al.(1985), used competitive-ratio to quantify the changes in relative competitive abilities of corn and soybean (Glycine max) under different arrangements of intercrops. They reported that the competitive ratio is the ratio of the gain or loss of dry matter of one crop in competition with the gain or loss of dry matter of the other crop and compared them with their respective sole crop. Corn was found more competitive and soybean less among all intercrop combinations studied, and the competitive-ratio for corn increased with an increase in corn population density. Corn and soybean crops competed less with each other for available resources in a corn-corn-soybean-soybean inter-row combination. The competitive ratio of corn was increased by increasing the proportion of corn in a corn-corn-soybean combination.

Nadar (1982) reported that the competition between intercrop components can be expected to be greater if the plant population per unit area is relatively high. In a maize/bean intercrop experiment he found that with a 50% of sole crop bean plant population intercropped with maize, bean yields were equivalent to those under normal density of beans as a sole crop.

2.2 Moisture stress

A crop plant becomes stressed when availability of soil moisture is inadequate for its normal growth and development. Crop management techniques generally play a major role in improving crop productivity where the soil moisture is very limiting.

Natarajan and Willey (1986) suggested that if the total populations in the intercrops are higher than in the sole crop then, under water stress, intercropping yield could well be less than sole crop yields because of increased competition for moisture. They studied nine cropping systems involving inter-row arrangements of sorghum-millet, sorghum-groundnut, and millet-groundnut under water stress and non stress situations and compared them with their respective sole crops. The dry matter yield advantages of intercropping compared with sole cropping ranged from 8 to 30% for the millet-groundnut system, 0 to 19% for the sorghum-groundnut system, and 5 to 15% for the millet-sorghum system. Soil moisture stress did not produce consistent effects on the dry matter advantages of the intercrop components. For grain yields, however, all of the intercropping treatments showed some increase in relative yield under moisture stress because of higher harvest indices in intercropping than in sole cropping.

Harris and Natarajan (1987), examined the performance of sorghum in droughted and well-irrigated situations cultivated under monocrop and intercrop with groundnut. The results of the 2:1 ratio of groundnut and sorghum replacement series intercrop (row by row substitution) experiment suggested that, as compared to solecrop, intercrop sorghum gave a 93% yield advantage in the droughted treatment and 38% in the well-watered treatment. Groundnut in the droughted environment had a filled-pod weight per unit row of 81% higher than in sole cropping. Similar results were reported by Willey (1983) who used sorghum-groundnut intercropping with five irrigation regimes ranging from severely stressed to a well-watered treatment. The 2:1 ratio groundnut:sorghum intercrop treatment, over the 3-year period, from the average of five irrigation regimes gave yield advantages ranging from 14 to 109%.

In another experiment on moisture availability and yield advantages, Natarajan and Willey (1982) tested, in addition to monocrop, 1 row millet to 2 rows groundnut, 1 row sorghum to 2 rows groundnut, and 1 row millet to 1 row sorghum. The three combinations gave significant advantages over monocropping ranging from 20 to 25% in the stress treatment but little or no advantage in the no-stress treatments. Based on the yield of the individual crop components it is evident that in the no-stress situations the balance of competition favored the dominant component. It is also evident from the 3 year's data from the three experiments that the effects of moisture stress are very complex and they vary with crop combination and row arrangement within a combination.

2.3 Planting arrangements and schedules

Field planting arrangements and planting times are areas of crop management within the control of most growers in most crop growing environments. One can change and modify the planting date considering the prevailing climatic condition and other resource allocations, can alter plant density and planting arrangement (geometry), and choose a planting method that best fits the locally available expertise and farmers' objectives. Suitable implementation of these management practices can add yield advantages without adding much to the cost of production.

The number of plants per unit area (plant population) determines the size of the area available to the individual plant. The distribution pattern of the plants over the ground (spatial arrangement) determines the shape of the plant over the area available to the individual plant (Steiner, 1982). In terms of plant population pressure on resources, Willey (1979b) stated that a single plant of one crop is seldom directly comparable to a single plant of another crop. Considering the complexity of intercrop plant population, he suggested to use sole crop equivalent plant density in intercropping on a per unit area basis.

For long season crops with an initial slow growth rate, solar energy utilization can be optimized by interplanting a quick maturing crop. For crops with a fast initial growing rate such as pearl millet, cowpea or mungbean, staggering the time of planting avoids mutual competition. Changing the plant geometry may avoid shading. Keeping the plant population constant and altering row orientation for paired or trebled row plantings offers more space for accommodating the companion crops (Rajat de and Singh, 1979). Similar types of information were found by Shelke and Krishnamoorthy (1978). According to their investigation, 3 rows pearl millet and 1 row legume intercrop gave increased total yield per unit land area compared to 2 rows pearl millet and 1 row of legume.

Cereal-legume intercropping of cowpea (Vigna unguiculata)-maize and soybean-maize were studied by May and Misangu (1982) using variable planting arrangements. In the alternate hill arrangement, cereal and legumes were alternately arranged within the same row maintaining the total plant population the same as in any sole crop. In the additive arrangement, a legume plant was added in each hill of normally populated maize. The alternate-hill arrangement created more plant spacing but, the grain yield per unit area and relative yield totals were not superior as compared to the same hill planting arrangements. The change from monoculture to an intercrop system significantly lowered the yield of each component in the cereal legume intercrops but did not significantly affect the number of harvestable plants/plot/species or the relative yield total. In a cereal-cereal intercropping of maize and sorghum, Ogkwaro (1983), observed that maize always out-yielded sorghum when maize was planted with sorghum in the same hill, or in alternate hills, or in alternate rows.

Singh (1981), compared different inter-row plantings of sorghum and bean with variable row spacing under irrigated and rainfed conditions. A 30cm spaced pair of sorghum rows, with a 60cm space between the pairs where beans were interplanted, did not reduce sorghum yield when compared to 45cm uniform row spacing of sorghum sole crop. The space created by a paired-row pattern in 30/60cm arrangement enhanced the intercropped legume yield. Waghmare et al.(1982), found that planting sorghum in paired rows (30/90cm) with two rows of intercropped legume at the 90cm spacing produced greater yields of sorghum than sorghum monocrop. The spacing between the two sorghum rows within a pair was 30cm, and between the two pairs was 90cm in the 30/90cm arrangement where legumes were interplanted. The average grain yields of green-gram (Phaseolus aureus), groundnut, and grain and fodder cowpea were higher in the 30/90cm planting arrangement. This was attributed to reduction in intra-row competition as the plant density was equal in all planting patterns.

Baker (1981) reported that farmers in Northern Nigeria make efficient use of plant growth resources by adjusting the planting schedule. In an alternate row arrangement of millet and sorghum intercrop, farmers obtain maximum advantage by sowing millet very early with the first rains and the sorghum was intersown later when the rains become more reliable. Farmers in such situations used low plant populations of a short-season millet grown on early and unreliable rainfall, followed by a full stand when long season sorghum is intersown, and leaving a low population of sorghum, after the millet has been harvested, to mature on stored moisture at the end of the season.

Adjustment of the planting schedule in a cereal-legume intercrop influenced the interspecific competition of cereal and legume components. Nnko and Doto (1982), reported the influence of planting schedule and cropping systems on the response of soybean grain yield. Soybean when interplanted 1 or 2 weeks earlier than intercropped millet produced lower grain yield than when intercropped with maize in the same planting schedule. The reduced soybean yield from soybean-cereal intercrop treatment as compared to soybean monocrop yield was due to the delay in soybean sowing time.

In an additive and replacement intercropping of green-gram/bulrush millet, May (1982) reported that the green-gram planted 1 to 2 weeks before bulrush millet in either intercropping system increased the proportion of legume grain yield. The relative yield total of the grain harvest was sensitive to different types of intercrops. The land equivalent ratios (LER) were varied between the planting arrangements but not to the planting schedules. The LER in an additive arrangement was 1.02 and in replacement arrangement 1.44. Green gram was more competitive than bulrush millet at the seedling stage, but was overpowered in the later growth stages.

2.4 Pests

It has already been found by researchers that the growing of crops under intercrop systems greatly suppresses weed populations, and reduces insect and disease incidence (Liebman, 1986). Willey (1983) stated that weed suppression is dependent on the competitive abilities and plant population of the component crop as compared to the weed. When total plant population in the intercrop is relatively similar to sole crop levels, weed suppression is likely to be similar in both systems, but this can vary. Based on a comparative study referred from Kasasian (1971), Mugabe et al.(1982) concluded that some crops are capable of outcompeting weeds. According to them, bulrush millet found to suffer very little from weed competition, whereas sorghum did not compete well with weeds. Mugabe et al. further reported that bullrush millet, under monoculture or when intercropped with legumes, was the best crop for suppressing weed growth and minimizing grain yield reduction as compared to the response of maize or sorghum.

The severity of powdery mildew (*Erysiphae polygoni*) was significantly higher in green-gram under monoculture than when green-gram was intercropped with either sorghum or bulrush millet. This was because, rows of green-gram were alternated with rows of sorghum or bulrush millet, which could make the transfer of inoculum much more difficult than in monocropped green-gram, due to the filtering effect created by separating the two rows of green-gram by rows of cereal. Wind velocities were reduced under intercropping thus reducing the spread at which pathogen propagules spread (Keswani and Mreta, 1982).

Lepidopterous stalk-borers can cause less damage to sorghum when interplanted with millet because of the inability of <u>Busseola</u> <u>fusca</u> adults to effectively utilize millet for oviposition which reduces larval infestation of sorghum stems. The best intercrop combination suggested was millet interplanted with sorghum in alternate stands within the same row (Adesiyun, 1983).

According to Amoako-Atta and Omoto (1983), relative yield advantages of a cropping system declined significantly as a result of the fluctuations of bio-mass yield and plant population due to pest attack. The LER observed was 1.45 in the maize-cowpea-sorghum inter-row arrangement, 1.3 in the sorghum-cowpea arrangement, and the lowest, 0.89, in the maize-sorghum arrangement. The significant yield loss in the maize-sorghum system occured primarily due to stem-borer causing 'dead heart' which reduced plant populations per unit area within the two cereal combinations. Ogwaro (1983), observed less stem-borer infestation in maize than in sorghum but when maize was intercropped with sorghum stem-borer infestation in intercropped maize was much higher than in maize sole crop.

2.5 Yield stability and economic advantage

Research findings very often provide information about higher economic return and increased productivity from intercropping systems but what most of the subsistence farmers mainly care about is the assurance of a crop harvest. Intercropping in that respect appeared to be very effective. Willey (1983), reported on the superiority of intercropping systems based on the survey of 94 experiments on sorghum/pigeonpea cultivated over a wide range of semi-arid tropic environments in India. Survey information indicated that for any required level of net monetary returns intercropping failed less often than either sole crop. For example, if failure is taken as a return less than 1000 Indian Rupees per hectare, sole pigeonpea failed 1 year in 5, sorghum 1 year in 8, but intercropping only 1 year in 36. Further calculation showed that if a farmer were to divide his land between the two sole crops to give the same average yield proportions as in intercropping, failure would be 1 year in 12.

CHAPTER 3

MATERIALS AND METHODS

This experiment was conducted during the summer of 1987 at the University of Arizona Marana Agricultural Center.

3.1 Soil

The soil type of the experimental site was a Pima Clay Loam, which is classified as a fine-silty, mixed thermic family of Typic Torrifluvents. The surface soil is a dark grayish brown clay loam. The soil is slightly heavy and the water holding capacity is good. The pH and organic matter content in the upper 50cm were approximately 7.8 and 1.0, respectively (Post et al., 1978).

3.2 Seed bed preparation

Cotton was the previously cultivated crop in this experiment area. The land was pre-irrigated, plowed, and listed into raised beds for seed planting and irrigation water control. The ridges (beds) and furrows were constructed in a north-south direction with the spacing of 1.02m between the center of two beds. Irrigation water was applied when required from an irrigation water ditch along the south end of the field through siphon tubes into each furrow being irrigated. The water in the irrigation ditch came from a well with a known output. The size and number of siphon tubes along with time of water application were used to calculate the amount of water applied to the plot being irrigated. All the fertilizers used in this experiment were applied by broadcast application during seed bed preparation. The amounts were 93 kg N and 60 kg P_2O_5 ha^{-1}, respectively.

3.3 Crop establishment and plant population

Seeds were sown in rows in the middle of the ridge. Sowing started on 19 May and completed on 20 May 1987. Seeding rates for sorghum and pearl millet were 208,000 and 270,000 seeds ha^{-1}, respectively. Plants were thinned at about two weeks after sowing to maintain a plant population of 120,000 plants ha^{-1} in sorghum and 80,000 plants ha^{-1} in pearl millet, uniform between the two water treatments.

3.4 Pest management

The chemical herbicide 'Atrazine' was applied at the rate 1.68 kg active ingredient per hectare to the soil as a pre-plant application to control broadleaf types of weeds. Insect and disease problems were not serious and did not require any control.

3.5 Major climatic data

After the initial vegetative growth, the rest of the crop growing period was very hot and dry. About 2 weeks after planting, the average daily maximum temperature remained mostly above $40^{0}C$ up to about 100 days (Fig.1). The total rainfall in Marana during 1987 was 230mm of which about 112mm was received during the crop growing period of mid-May to mid-October (Fig.1).

3.6 Treatments

The treatment combinations studied in the experiment are described in Tables 1 and 2. Seven different inter-row planting configurations of sorghum and pearl millet, presented in Table 1, were tested under soil moisture non-stress and stress. An initial preplant irrigation of 329mm water was applied to both irrigation treatments. Following planting, the moisture non-stressed treatments were irrigated as needed by plant observation which included five post plant irrigations. The moisture stress treatments only received two post plant irrigations. The total amount of water received through rainfall and irrigation by each soil moisture treatment is presented in Table 3.

Seven different inter-row combinations of sorghum and pearl millet were studied to evaluate the interspecific (between row) competition of the two crops. The seven

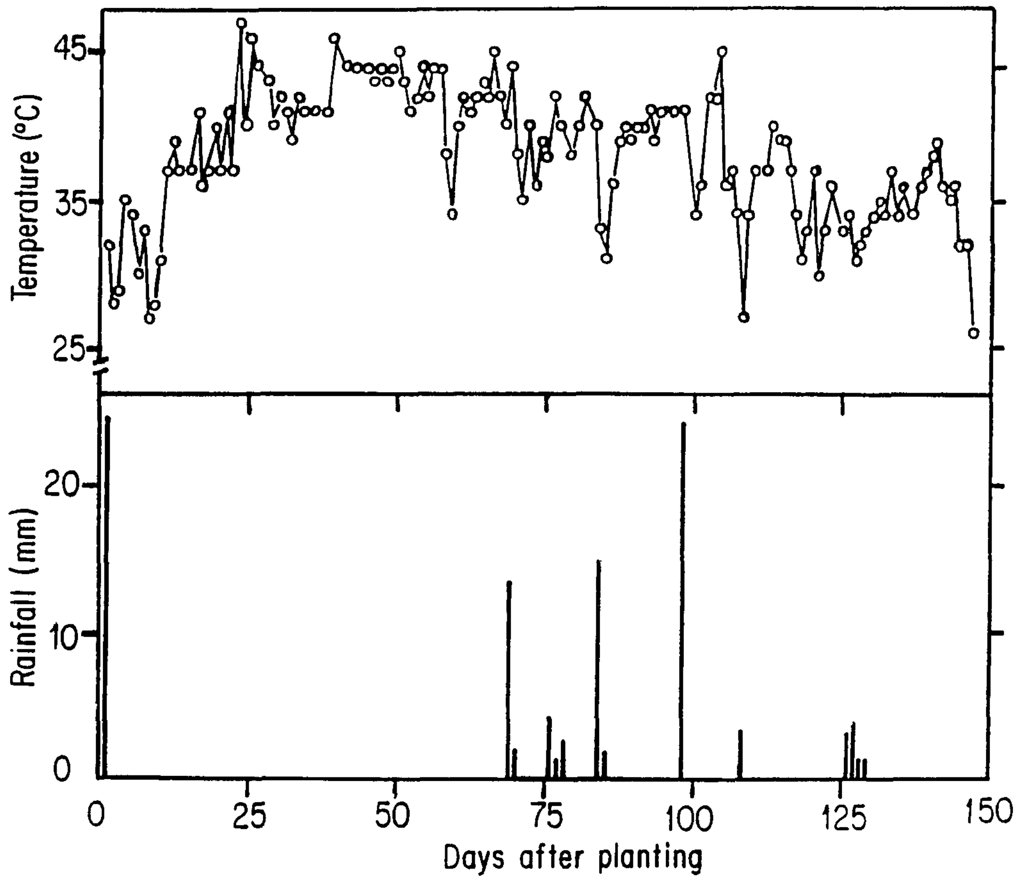

Fig. 1 Daily rainfall and maximum temperature during crop growing period

Table 1. Main treatments to compare inter-row competition of sorghum and pearl millet under different planting arrangements.

Treatment	Cropping systems	Inter-row arrangement
1	9 rows of sorghum (sole crop)	S-S-S-S-S-S-S-S-S*
2	9 rows of millet (sole crop)	M-M-M-M-M-M-M-M-M
3	3 rows of sorghum bordered by 6 rows of millet	M-M-M-S-S-S-M-M-M
4	3 rows of millet bordered by 6 rows of sorghum	S-S-S-M-M-M-S-S-S
5	1 row of millet bordered by millet and sorghum	S-S-S-S-M-M-M-M-M
6	1 row of sorghum bordered by millet rows	M-M-M-M-S-M-M-M-M
7	1 row of millet bordered by sorghum rows	S-S-S-S-M-S-S-S-S

* M and S represents pearl millet and sorghum, respectively

Table 2. Final grain harvest rows, revised treatment number, and center row (underlined) for evaluation of inter-row competition of sorghum and pearl millet.

Treatment	Harvest rows	Treatment	Harvest rows
1S	S-S-<u>S</u>-S-S*	1M	M-M-<u>M</u>-M-M
2S	M-M-S-<u>S</u>-S-M-M	2M	S-S-M-<u>M</u>-M-S-S
3S	S-S-<u>S</u>-M-M-M	3M	S-S-S-<u>M</u>-M-M
4S	M-M-<u>S</u>-M-M	4M	S-S-<u>M</u>-S-S

* M and S represents pearl millet and sorghum, respectively

Table 3. Amounts of rainfall and irrigation water received during crop growing period by soil moisture non-stress and stress treatments

Month	Date	Precipitation (mm)	Irrigation (mm) non-stress	Irrigation (mm) stress
May	6,7,8 *	----	329	329
	7	1.3	---	---
	11	1.3	---	---
	15	7.6	---	---
	21	24.4	---	---
June	11	----	123	---
	16	----	---	196
	26	----	78	---
July	7	----	58	---
	20	----	59	---
	27	13.2	---	---
	28	2.0	---	---
	30	----	---	57
August	3	5.1	---	---
	4	1.3	---	---
	5	2.8	---	---
	11	14.7	---	---
	12	1.8	---	---
	13	----	45	---
	25	24.1	---	---
September	4	3.3	---	---
	22	3.1	---	---
	23	3.8	---	---
	24	1.3	---	---
	25	1.3	---	---
Total		112.4	692	582

* Pre-plant irrigation

treatment combinations described in Table 1 were further grouped into eight treatments as described in Table 2. This reorganization was done for better presentation and interpretation of the inter-row plot competition effects. The Treatments 1S, 2S, 3S, and 4S were sorghum-based, while 1M, 2M, 3M, and 4M were millet-based.

3.7 Crop varieties

The sorghum and pearl millet genotypes used in the experiment were sorghum (*Sorghum bicolor* L., Moench) genotype 'Funks G522 DR', which is a commercial hybrid, and the pearl millet (*Pennisetum americanum* L., Leeke), genotype 'A81-1056X78-7088', a hybrid. These two genotypes possesed similar maturity and plant height characteristics.

3.8 Experimental design and field layout

The treatment combinations were laid out in a split-plot experimental design. The treatments were replicated four times. Soil moisture non-stress and soil moisture stress treatments were randomly assigned to the main plot, while the inter-row combination treatments were randomly assigned in the sub-plot. Each of the seven inter-row combinations was planted in a 9-row plot. Each row was 7.62m long and the rows were spaced 1.02m apart.

3.9 Grain harvest

The sorghum and pearl millet grains were harvested mechanically between 5 to 15 October 1987 by a two-row self propelled plot combine one row at a time. Each of the 7.62m long plots (rows) were harvested for grain yield.

3.10 Data collection

Most of the agronomic data other than grain yield, for sorghum and pearl millet were collected from the center row of each inter-row combination treatment. Grain yield data were collected from both the center and other rows of the inter-row combinations. The sole crop grain yield was averaged from the sole crop harvest rows.

3.10.1 Days to 50% bloom

The 50% bloom date of sorghum and pearl millet were monitored regularly. The time separating pearl millet female (stigma) and male (anther) flower 50% emergence; and the 50% sorghum flower bloom were recorded.

3.10.2 Plant height

At maturity, plant heights were measured from the base of the stem at the soil level to the highest point which usually refers to the tip of the head. For intercrop, height were measured from the center rows, and for sole crop, averaged from entire harvest row plants.

3.10.3 Head length

Head lengths of sorghum and pearl millet were taken from representative heads of each treatment. For sorghum, measurements were taken from 10 contiguous heads from a representative plot row. In the case of pearl millet, the sampling area was from a 61cm representative section of the plot row.

3.10.4 Head exsertion

The length of the peduncle above the upper leaf collar, which is referred to as head exsertion, was measured from the center row of each inter-row treatment. The peduncle length was recorded from the same head used for head length measurement as indicated in the preceding paragraph.

3.10.5 1000 seed weight

200 seeds were randomly collected from the harvested seed lot and were weighed and multiplied by 5 to obtain the 1000 seed weight.

3.10.6 Grain yield

Unlike other agronomic characters, grain yield data were collected separately from each inter-row combination and converted to kg/ha. The sorghum and pearl millet sole crop grain yield data were recorded from the sole crop treatment rows and converted to kg/ha.

3.11 Evaluation of the effect of inter-row competition

Grain yield of sorghum and pearl millet in intercrop combinations were compared with their respective sole crop under soil moisture non-stress and stress. Neighbor-row response was measured from individual intercrop plot row yield. The combined grain yield responses of each individual inter-row combination (biological efficiency of an intercrop treatment) was evaluated from relative grain yield total of sorghum and pearl millet using the formula of land equivalent ratio (LER) reported by Willey (1979a).

$$\text{LER} = \frac{\text{sorghum yield in intercrop}}{\text{sorghum yield in sole crop}} + \frac{\text{millet yield in intercrop}}{\text{millet yield in sole crop}}$$

A partial grain yield LER for each of the intercrop component was obtained by deviding intercrop component yield by their respective sole crop yield, and the LER for a intercrop treatment was obtained simply by adding the two partial LER values of the intercrop components.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Agronomic Characteristics

4.1.1 Days to 50% bloom

The soil moisture stress and non-stress treatments did not produce any significant differences in 50% bloom of sorghum (Table 4). The moisture treatments, however, resulted in significant differences in 50% bloom of both male and female flowers of pearl millet, Table 4. The female flowers in pearl millet required 63.3 days to 50% bloom under soil moisture stress conditions which is about 9% higher than the 59.5 days required under soil moisture non-stress. The pearl millet male flower bloom followed the same pattern as observed in the female flower. The 50% bloom of pearl millet male flower needed 65.8 days which is 2 days longer than under the non-stress growing condition (Table 4). Thus, both male and female flowering of pearl millet were delayed by about 4 days under the moisture stress treatment. A similar result was reported by Bidinger et al. (1987). According to their observation, pearl millet flowering was delayed by about 6 days under mid-season moisture stress, mid-season moisture stress was

Table 4. The effect of soil moisture non-stress and stress on the number days to 50% bloom of sorghum and pearl millet in sole crop

	50% bloom (days)					
			Pearl millet sole crop			
Soil moisture treatment	Sorghum sole crop	%diff. due to stress	Female flower	%diff. due to stress	Male flower	%diff. due to stress
Non-stress	73.0		59.5 a*		63.8 a	
Stress	72.8.	-0.3	63.3 b	+9.3	65.8 b	+3.1
	CV = 2.1		CV = 1.4		CV = 1.2	

* Means followed by a common letter are not significantly different at 5% level.

imposed by withholding irrigation for 5 weeks, before flowering.

The 50% flowering of sorghum observed under sole crop and under inter-row planting arrangements revealed no significant difference in their time to 50% bloom in either soil moisture treatment (Table 5). The trend however, indicated that sorghum flowering was slightly delayed when sorghum was interplanted with millet at different inter-row arrangements. The maximum delay observed under soil moisture non-stress and stress treatments were 2.1 and 1.0%, respectively. The pearl millet female and male flower 50%

flowering due to the competition of inter-row arrangements was arithmetically slightly advanced in either soil moisture treatment. The effect of inter-row planting arrangements on millet flowering, under soil moisture stress, produced a contrasting response. Millet flowering in such situation was delayed in all inter-row planting combinations and the delay was maximum (2.7%) in intercrop Treatment 4M (SS<u>M</u>SS) where one row of millet was bordered by sorghum rows. Some of the differences, though were not significant in either soil moisture treatment, were probably due to the competitive interactions of sorghum and pearl millet during the flowering period. Since large temporal differences in resource acquisition are present among cereals under intercrop (Rao, 1986), the slight shift of flowering dates observed in sorghum and millet in this experiment were probably due to the differences in competitive interactions and resource utilization by the two crops.

Table 5. The effect of inter-row competition (planting arrangements) on days to 50% bloom of sorghum and pearl millet under soil moisture non-stress and stress.

	Days to 50% Bloom (day)			
Inter-row planting arrangements	soil moisture non-stress	%diff. from sole crop	soil moisture stress	%diff. from sole crop
Effect on sorghum				
1S. S-S-S-S-S-S-S**	73.0		72.8	
2S. M-M-S-S-S-M-M	73.8	+1.0	73.0	+0.3
3S. S-S-S-S-M-M-M	74.5	+2.1	73.5	+1.0
4S. M-M-M-S-M-M-M	74.0	+1.4	73.3	+0.7
CV = 1.2				
Effect on millet (female flower bloom)				
1M. M-M-M-M-M-M-M	59.5		63.3	
2M. S-S-M-M-M-S-S	58.8	-1.3	63.5	+0.4
3M. S-S-S-M-M-M-M	59.5	0.0	63.8	+0.8
4M. S-S-S-M-S-S-S	59.3	-0.4	64.8	+2.4
CV = 1.3				
Effect on millet (male flower bloom)				
1M. M-M-M-M-M-M-M	63.8		65.8	
2M. S-S-M-M-M-S-S	63.0	-1.2	66.0	+0.4
3M. S-S-S-M-M-M-M	63.8	0.0	66.8	+1.5
4M. S-S-S-M-S-S-S	63.5	-0.4	67.5	+2.7
CV = 1.2				

* Means followed by a common letter are not significantly different at 5% level

** S=sorghum and M=pearl millet row, respectively.

4.1.2 Plant height

Soil moisture stress caused significant reductions in sorghum and pearl millet plant heights compared to moisture non-stress (Table 6). The average plant height of sorghum sole crop was 114.5cm in soil moisture non-stress condition, with a significant 21% shorter plant height (90.5cm) under soil moisture stress. The plant heights showed a similar significant response in pearl millet, where the height was 15.5% shorter under soil moisture stress than the height of 127.8cm observed under the soil moisture non-stress treatment (Table 6). A similar result was reported by Gregory and Squire (1979). They observed a significant

Table 6. The effect of soil moisture non-stress and stress on plant height of sorghum and pearl millet sole crop

	Plant height (cm)			
Soil moisture treatment	Sorghum sole crop	%diff due to stress	Millet sole crop	%diff due to stress
Non-stress	114.5 a*		127.8 a	
Stress	90.5 b	-21.0	108.0 b	-15.5
	CV = 6.8		CV = 4.9	

* Means followed by a common letter are not significantly different at 5% level.

increase in pearl millet plant height under irrigation reatment.

Sorghum plant height under soil moisture non-stress did not differ significantly among inter-row combinations compared to the sole crop except Treatment 3S (SSSSMMM). Plant height in Treatment 3S was significantly reduced by 2.8%. Sorghum plant heights under soil moisture stress in intercrop Treatments 2S and 4S were significantly higher (about 5%) than the plant heights observed in sole crop and intercrop Treatment 3S (Table 7).

Pearl millet plant heights were not statistically different from their sole crops in both moisture treatments due to the presence of sorghum in the inter-row arrangement. However, the plant height of pearl millet growing next to sorghum showed a trend towards being shorter compared to the sole crop, particularly in the moisture stress treatment. The plant height of pearl millet among inter-row combinations under soil moisture stress was lowest (99cm) in Treatment 4M (SSMSS) which is about 9% shorter than the plant height (108cm) observed in millet sole crop (Treatment 1M), Table 7.

Soil moisture stress treatment consistently reduced sorghum and millet plant height which reconfirmed the common believe that retarded plant growth and development is one of the many effects of water stress on plants. The water stress effects on pearl millet plant height were reported by Gregory and Squire (1979), and Mahalakshmi and Bidinger (1985). The later authors observed 35cm reduction of pearl millet plant height under soil moisture stress compared to 139cm plant height observed under control. The plant height of sorghum was significantly influenced due to the effect of inter-row planting arrangements. This increased plant height probably could be translated as increased growth and development that a sorghum plant attained from the growing environment in inter-row planting arrangements with millet. Thus, most of the inter-row planting systems in this experiment provided some added advantage to sorghum at the expense of a slightly negative effect on millet in either soil moisture treatents.

Table 7. The effect of inter-row competition (planting arrangements) on plant height of sorghum and pearl millet under soil moisture non-stress and stress

	Plant height (cm)			
Inter-row plating arrangements	soil moisture non-stress	%diff. from sole crop	soil moisture stress	%diff. from sole crop
Effect on sorghum				
1S. S-S-S-S-S-S-S**	114.5 a*		90.5 b	
2S. M-M-S-S-S-M-M	116.8 a	+2.0	95.0 a	+5.0
3S. S-S-S-S-M-M-M	111.3 b	-2.8	90.5 b	0.0
4S. M-M-M-S-M-M-M	115.3 a	+0.7	94.8 a	+4.7
CV = 2.4				
Effect on millet				
1M. M-M-M-M-M-M-M	127.8		108.0	
2M. S-S-M-M-M-S-S	125.5	-1.8	107.5	-0.5
3M. S-S-S-M-M-M-M	123.0	-3.8	103.0	-4.6
4M. S-S-S-M-S-S-S	126.8	-0.8	98.8	-8.6
CV = 4.4				

* Means followed by a common letter are not significantly different at 5% level

** S=sorghum and M=pearl millet row, respectively.

4.1.3 Head length

The head length of sorghum observed in sole crop under soil moisture non-stress was 25cm, Table 8. This length was significantly reduced about 20% under moisture stress. Pearl millet head lengths, on the other hand, was not statistically different from sole crop under soil moisture stress (Table 8).

The planting arrangement of one row of sorghum bordered by a sorghum row on one side and a millet row on the other (Treatment 3S) resulted in the arithmetically longest sorghum heads (27.2cm) among all inter-row planting arrangements under soil moisture non-stress (Table 9).

Table 8. The effect of soil moisture non-stress and stress on head length of sorghum and pearl millet in sole crop

	Head Length (cm)			
Soil moisture treatment	Sorghum sole crop	%diff due to stress	Millet sole crop	%diff due to stress
Non-stress	25.0 a*		18.2	
Stress	20.0 b	-19.8	18.1	-0.2
	CV = 5.5		CV = 10.1	

* Treatment means followed by same letter are not significantly different at LSD(5%).

Sorghum head lengths among all four planting arrangements under soil moisture non-stress and under soil moisture stress were not significantly different within soil moisture treatments. The arithmetic longest head length (22.6cm) was observed in Treatment 2S (MMSSSMM).

The head length of pearl millet did not differ statistically either by soil moisture treatment or by inter-row competition with sorghum (Table 9). The shortest pearl millet head length, 15.9cm was observed in Treatment 4M, where a single row of millet was bordered by sorghum rows (SSMSS) (Table 9). Although not statistically different, this would tend to indicate the presence of added competition for millet when subjected to being grown between rows of sorghum. Chigwe (1984) did not observe any significant differences in sorghum head length under wet and dry conditions, but he used a different genotype.

Table 9. The effect of inter-row competition (planting arrangements) on head length of sorghum and pearl millet under soil moisture non-stress and stress

Inter-row planting arrangements	Head Length (cm)			
	soil moisture non-stress	%diff. from sole crop	soil moisture stress	%diff. from sole crop
Effect on sorghum				
1S. S-S-S-<u>S</u>-S-S-S**	25.0		20.0	
2S. M-M-S-<u>S</u>-S-M-M	24.4	-0.7	22.6	+12.8
3S. S-S-S-<u>S</u>-M-M-M	27.2	+9.0	21.1	+ 5.4
4S. M-M-M-<u>S</u>-M-M-M	24.9	-0.2	21.8	+ 8.4
CV = 6.0				
Effect on millet				
1M. M-M-M-<u>M</u>-M-M-M	18.2		18.1	
2M. S-S-M-<u>M</u>-M-S-S	17.8	-1.9	17.0	- 6.5
3M. S-S-S-<u>M</u>-M-M-M	18.0	-0.8	16.4	- 9.5
4M. S-S-S-<u>M</u>-S-S-S	18.8	+3.6	15.9	-12.4
CV = 5.4				

* Means followed by a common letter are not significantly different at 5% level

** S=sorghum and M=pearl millet row, respectively.

4.1.4 Head exsertion

The sorghum head exsertion (amount of peduncle above the upper leaf collar) in sole crop under soil moisture non-stress was 7.1cm. This exsertion was significantly reduced to zero under soil moisture stress (Table 10). But Chigwe (1984) in his experiment observed no significant difference in sorghum head exsertion between his soil moisture non-stress and stress treatments. Pearl millet sole crop head exsertion in this experiment was significantly reduced by about 68% under soil moisture stress from the exsertion of 5.9cm observed under soil moisture non-stress (Table 10).

Sorghum head exsertions was increased non-significantly

Table 10. The effect of soil moisture non-stress and stress on head exsertion of sorghum and pearl millet in sole crop

	Head Exsertion (cm)			
Soil moisture treatment	Sorghum	%diff due to stress	Millet	%diff due to stress
Non-stress	7.1 a*		5.9 a	
Stress	0.0 b	-100.0	1.9 b	-68.0
	CV = 31.2		CV = 59.0	

* Treatment means followed by same letter are not significantly different at 5% level.

in all inter-row planting arrangements with pearl millet in both levels of soil moisture. Under soil moisture non-stress, the highest amount of head exsertion, 9.9cm, was observed in Treatment 4S (MMSMM), which was 38% longer than the 7.1cm found in the sole crop. The sorghum sole crop heads under soil moisture stress had no exsertion above the upper leaf collar of the plant. The average peduncle length was zero. But, the head exsertions under intercrop arrangements were in the range of 1.6 to 3.30cm depending on the type of inter-row combination. None of these differences though were statistically significant (Table 11) probably due to the extreme variability of head exsertion among plants in a treatment.

Reduced head exsertion in sorghum is an indication of increased moisture stress. Thus, the increased head exsertion of sorghum when in competition with millet under soil moisture stress indicated a reduction in moisture stress on sorghum at the expense of the millet.

Head exsertions in pearl millet differed significantly due to the effect of inter-row planting arrangements in both levels of soil moisture. The head exsertion under soil moisture non-stress was highest (5.9cm) in sole crop and lowest (4.2cm) in Treatment 4M (SSMSS). Under soil moisture stress, millet sole crop (Treatment 1M), and the arrangement SSMMM (Treatment 3M) produced highest head exsertion. The inter-row arrangement 2M (SSMMMSS) and 4M (SSMSS) produced 74% and 66% shorter head exsertion, respectively than the exsertion of 1.9cm observed in sole crop (Table 11).

Table 11. The effect of inter-row competition (planting arrangements) on the amount of head exsertion in sorghum and pearl millet

	Head Exsertion (cm)			
Inter-row planting arrangements	soil moisture non-stress	%diff. from sole crop	soil moisture stress	%diff. from sole crop
Effect on sorghum				
1S. S-S-S-S-S-S-S**	7.1		0.0	
2S. M-M-S-S-S-M-M	7.7	+ 8.0	3.3	+330.0
3S. S-S-S-S-M-M-M	8.5	+19.2	1.6	+155.0
4S. M-M-M-S-M-M-M	9.9	+38.2	3.2	+315.0
CV = 21.7				
Effect on millet				
1M. M-M-M-M-M-M-M	5.9 a		1.9 a	
2M. S-S-M-M-M-S-S	4.4 b	+26.6	0.5 b	-73.7
3M. S-S-S-M-M-M-M	5.1 ab	-14.3	2.3 a	+20.0
4M. S-S-S-M-S-S-S	4.2 b	-29.5	0.6 b	-66.3
CV = 23.4				

* Means followed by a common letter are not significantly different at 5% level

** S=sorghum and M=pearl millet row, respectively.

4.1.5 Number of Effective Tillers

The average number of effective (head bearing) tillers per plant in sorghum were not significantly different between the two moisture treatments in sole crop (Table 12). In pearl millet, however, the soil moisture stress treatment caused a significant reduction (about 62%) in the number of effective tillers per plant than the number 7.4 observed in soil moisture non-stress in sole crop (Table 12).

The inter-row competition of sorghum and pearl millet under different planting arrangements did not produce any statistically significant differences in the number of

Table 12. The effect of soil moisture non-stress and stress on the number of effective tillers per plant in sorghum and pearl millet in sole crop

	Effective Tillers per Plant (no.)			
Soil moisture treatment	Sorghum sole crop	%diff due to stress	Millet sole crop	%diff due to stress
Non-stress	1.24		7.35 a*	
Stress	1.20	-3.2	2.80 b	-61.9
	CV = 19.9		CV = 16.3	

* Means followed by a common letter are not significantly different at at 5% level.

effective tillers per plant in either of the soil moisture treatments (Table 13).

Table 13. The effect of inter-row competition (planting arrangements) on the number of effective tillers per plant of sorghum and pearl millet

Inter-row planting arrangements	Effective Tiller per Plant (no.)			
	soil moisture non-stress	%diff. from sole crop	soil moisture stress	%diff. from sole crop
Effect on sorghum				
1S. S-S-S-<u>S</u>-S-S-S**	1.24		1.20	
2S. M-M-S-<u>S</u>-S-M-M	1.22	-1.6	1.14	-5.0
3S. S-S-S-<u>S</u>-M-M-M	1.29	+4.0	1.20	0.0
4S. M-M-M-<u>S</u>-M-M-M	1.32	+6.5	1.19	-0.8
CV = 16.3				
Effect on millet				
1M. M-M-M-<u>M</u>-M-M-M	7.35		2.80	
2M. S-S-M-<u>M</u>-M-S-S	8.09	+10.1	2.80	0.0
3M. S-S-S-<u>M</u>-M-M-M	7.95	+ 8.2	2.48	-11.4
4M. S-S-S-<u>M</u>-S-S-S	8.38	+14.0	2.28	-18.6
CV = 12.5				

* Means followed by a common letter are not significantly different at at 5% level

** S=sorghum and M=pearl millet row, respectively.

4.1.6 1000 seed weight

The 1000 seed weight of both sorghum and pearl millet in sole crop were significantly reduced due to the effect of soil moisture stress. The weight of 1000 sorghum seeds under soil moisture non-stress was 21.6g and the weight was reduced to 16.2g by the moisture stress treatment. The millet seed weight under moisture non-stress and stress were 13.0g and 11.0g, respectively (Table 14). Similar types of responses were observed by Mahalakshmi and Bidinger (1985). They reported that pearl millet individual grain weight was reduced primarily due to the effect of post anthesis moisture stress. Seed weight loss observed in this

Table 14. The effect of soil moisture non-stress and stress on 1000 seed weight of sorghum and pearl millet in sole crop

	1000 Seed Weight (g)			
Soil moisture treatment	Sorghum sole crop	%diff due to stress	Millet sole crop	%diff due to stress
Non-stress	21.6 a*		13.0 a*	
Stress	16.2 b	-25.0	11.0 b	-15.4
	CV = 14.4		CV = 11.5	

* Means followed by a common letter are not significantly different at at 5% level

experiment seemed to be associated with both pre and post-anthesis moisture stress.

None of the inter-row competition of sorghum and pearl millet significantly changed the 1000 seed weight of these two cereals as compared to their respective sole crop seed weight. The pearl millet 1000 seed weight was arithmetically but not statistically reduced when millet was grown as a single row with sorghum under moisture stress in Treatment 4M (Table 15). The effect of inter-row competition between sorghum and cowpea under special planting arrangement increased sorghum 1000 seed weight from 25.4g in the sole crop to 27.0g under special arrangement with cowpea (Wagmare et al.,1982).

Reduced seed weight in sorghum under soil moisture stress from a soil moisture non-stress condition is an indication of increased moisture stress. Therefore, the tendency for increased seed weight of sorghum when in competition with millet with both crops under soil moisture stress indicates that sorghum is able to reduce its soil moisture stress at the expense of millet.

Table 15. The effect of inter-row competition (planting arrangements) on 1000 seed weight of sorghum and pearl millet

Inter-row planting arrangements	1000 Seed Weight (g) soil moisture non-stress	%diff. from sole crop	soil moisture stress	%diff. from sole crop
Effect on sorghum				
1S. S-S-S-S-S-S-S**	21.6		16.2	
2S. M-M-S-S-S-M-M	20.9	-3.2	19.4	+19.9
3S. S-S-S-S-M-M-M	22.9	+6.1	19.0	+17.5
4S. M-M-M-S-M-M-M	21.1	-2.3	18.6	+15.3
CV = 11.4				
Effect on millet				
1M. M-M-M-M-M-M-M	13.0		11.0	
2M. S-S-M-M-M-S-S	12.5	-3.8	10.6	- 3.5
3M. S-S-S-M-M-M-M	12.2	-5.9	11.0	0.0
4M. S-S-S-M-S-S-S	12.5	-4.0	8.2	-25.0
CV = 12.7				

* Means followed by a common letter are not significantly different at 5% level

** S=sorghum and M=pearl millet row, respectively.

4.1.7 Grain Yield

Like most other agronomic characters, grain yield of sorghum and pearl millet were also greatly influenced by differential soil moisture. Soil moisture non-stress almost doubled sorghum grain yield compared to the yield obtained under soil moisture stress (Table 16). The grain yield of pearl millet under soil moisture non-stress was even higher with the moisture stress treatment resulting in a 76% yield decrease (Table 16). Natarajan and Willey (1986) observed significant grain yield loss in millet and sorghum due to the effect of soil moisture stress. They imposed soil moisture stress at different growth stages of the cereals.

Table 16. The effect of soil moisture non-stress and stress on grain yield of sorghum and pearl millet in sole crop

	Grain Yield (kg ha^{-1})			
Soil moisture treatment	Sorghum sole crop	%diff due to stress	Millet sole crop	%diff due to stress
Non-stress	4160 a*		2201 a*	
Stress	2191 b	-47.0	533 b	-75.8
	CV = 5.1		CV = 29.5	

* Means followed by a common letter are not significantly different at 5% level

The variations in sorghum grain yield due to the effect of inter-row combinations were not significant for either of the soil moisture treatments. But sorghum showed a trend for higher yields in the inter-row combinations with millet under the soil moisture stress condition (Table 17).

The grain yield of pearl millet was significantly reduced under the influence of inter-row competition with sorghum in both soil moisture levels (Table 17). The pearl millet sole crop grain yield under soil moisture non-stress was 2201 kg ha^{-1}, and under inter-row planting arrangements with sorghum, grain yield decreased by 12 and 15.8%, respectively with Treatments 3M and 4M which had more competition from adjacent sorghum rows. Pearl millet yield loss under inter-row competition was greater under the soil moisture stress condition. The greatest yield reduction, as compared to sole crop, was about 69% observed in Treatment 4M, where a single row of millet was bordered by sorghum rows. The yield loss due to inter-row competition of sorghum in Treatments 2M and 3M were 33.4 and 43.2%, respectively which were not statistically different than when millet was grown as a sole crop (Table 17).

Table 17. The effect of inter-row competition (planting arrangements) on grain yield of sorghum and pearl millet

Inter-row planting arrangements	Grain Yield (kg ha^{-1}) soil moisture non-stress	%diff. from sole crop	soil moisture stress	%diff. from sole crop
Effect on sorghum				
1S. S-S-S-S-S-S-S**	4160		2191	
2S. M-M-S-S-S-M-M	4139	- 0.5	2512	+14.7
3S. S-S-S-S-M-M-M	4662	+12.1	2700	+23.2
4S. M-M-M-S-M-M-M	4294	+ 3.2	2490	+13.6
CV = 12.3				
Effect on millet				
1M. M-M-M-M-M-M-M	2201 ab		533 a	
2M. S-S-M-M-M-S-S	2294 a	+ 4.2	355 ab	-33.4
3M. S-S-S-M-M-M-M	1936 bc	-12.0	303 ab	-43.2
4M. S-S-S-M-S-S-S	1854 c	-15.8	166 b	-68.9
CV = 15.7				

* Means followed by a common letter are not significantly different at 5% level

** S=sorghum and M=pearl millet row, respectively.

4.2 <u>Neighbor Row Competition</u>

The below-ground resource competition between sorghum and pearl millet neighbor rows were evaluated from the intercrop grain yield of Treatment 2S, 2M, 3S, 3M, 4S, and 4M.

In Treatment 2S, under soil moisture non-stress condition, the sorghum neighbor row adjacent to millet gained 531 kg ha^{-1} grain yield, relative to sole crop this gain was 13%. The loss incurred by millet neighbor row in that treatment was 116 kg ha^{-1} and in relative scale this loss was only 5% of the millet sole crop. Under soil moisture stress, sorghum neighbor row adjacent to millet gained relatively higher amount of grain both actual (615 kg ha^{-1}) and in relative scale (28%), the loss incurred by the millet in that situation was 47 kg ha^{-1} which was 9% less than sole crop millet yield (Fig.2, Table 18).

The millet row adjacent to sorghum in Treatment 2M, as compared to sole crop, lost about 172 kg ha^{-1} of grain yield which was 32% less than sole crop relative yield. Sorghum neighbor in that situation gained only 8% relative yield and actual of 172 kg ha^{-1} under moisture stress (Fig. 2, Table 19). Under non-stress, both components produced slightly negative yield.

Under moisture non-stress conditions, pearl millet grain yield adjacent to sorghum row in Treatment 3S and 3M

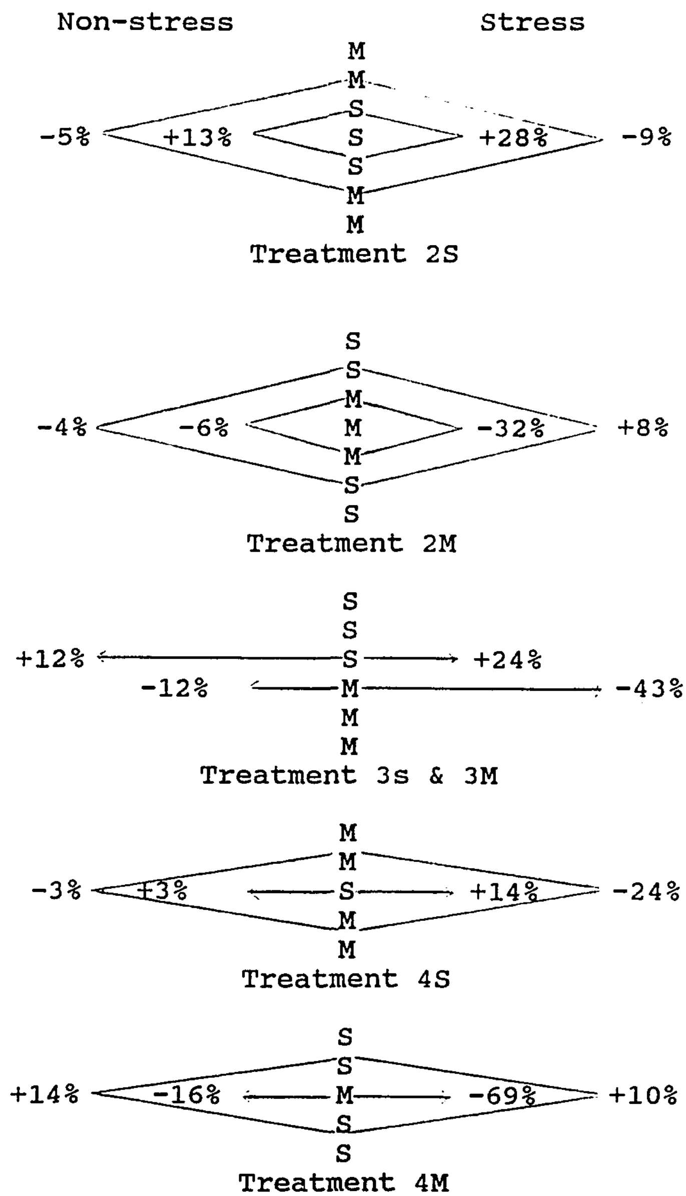

Fig. 2 Neighbor row competition in sorghum-millet intercrop treatments under soil moisture non-stress and stress, competition measured in terms of percent increase (+) or decrease (-) in grain yield from respective sole crop, sorghum (S) and pearl millet (M)

was reduced by 165kg ha^{-1}, in relative scale this reduction was 12% than millet sole crop. This loss was very well balanced by 12% relative yield gain by sorghum, and the actual yield of 502 kg ha^{-1} (Fig.2, Table 20). Under soil moisture stress, pearl millet neighbor row lost about 230 kg ha^{-1} grain grain, in relative term this amount seems high (43%), the sorghum neighbor row in that situation although gained about 516 kg ha^{-1} but in relative scale this gain was only 24%.

The yield loss suffered by millet neighbor row and gained by sorghum neighbor in Treatments 4S and 4M planting arrangements under soil moisture non-stress condition were mutually compensated in relative scale by the both components. Under soil moisture stress, the neighbor row of sorghum in Treatment 4S gained 14% grain yield relative to sole crop and actual of 299 kg ha^{-1}, neighbor millet row on the other hand suffered higher relative yield loss (24%), an actual of 128 kg ha^{-1} (Fig.2, Table 21). The biggest relative yield loss suffered by any pearl millet neighbor row among the treatment combinations studied was 69% and actual of 366 kg ha^{-1}, in treatment 4M, under moisture stress treatment. Although sorghum neighbor row in that situation recovered 217kg ha^{-1} yield but this gain in relative scale was only 10% (Fig.2, Table 22).

Based on the above competition patterns, it can be stated that sorghum as a neighbor row in an intercrop situation dominated over the pearl millet at both levels of soil moisture. The amount of loss suffered by a pearl millet neighbor row was recovered by sorghum neighbor rows under soil moisture non-stress condition. But under stress condition, the pearl millet neighbor row suffered greater amount of yield loss in most cases. The neighbor sorghum row in that situation failed to compensate the loss incurred by millet. Thus, this particular sorghum genotype at this Marana field condition found to be a better competitor than the pearl millet in terms grain yield productivity. Under conditions of moisture stress, sorghum was not able to compensate the loss suffered by the neighbor pearl millet, however.

4.3 Multi-row Competition

4.3.1 Millet-Millet-Sorghum-Sorghum-Sorghum-Millet-Millet

Treatment 2S - Sorghum and pearl millet in this planting arrangement produced a higher amount of grain yield in both levels of soil moisture. In this 3:4 ratio of sorghum and pearl millet intercrop treatment, the pearl millet row as an immediate neighbor to the sorghum suffered some degree of yield loss. These losses were about 9 (47 kg ha^{-1}) and 5% (116 kg ha^{-1}) in stress and non-stress conditions, respectively. The neighbor and next neighbor rows of sorghum gained about 28 (615 kg ha^{-1}) and 15% (322 kg ha^{-1}) of the grain yield, respectively in the moisture stress treatment. Under the soil moisture non-stress condition, the yield gained by sorghum was 13% (531 kg ha^{-1}) in the immediate neighbor row. The combined yield advantage of this treatment was 6% (LER=1.06) under non-stress treatment and 15% (LER=1.15) under stress treatment (Fig 3 and Table 18).

The competition pattern between the two crops in this treatment was mutually cooperative, which means the component crops not only balanced the utilization of soil moisture resources, but also helped each other to attain some added yield advantage. The two outer millet rows in the both sides of the three sorghum rows were bordered by a matching crop i.e. millet, thus the differential neighbor

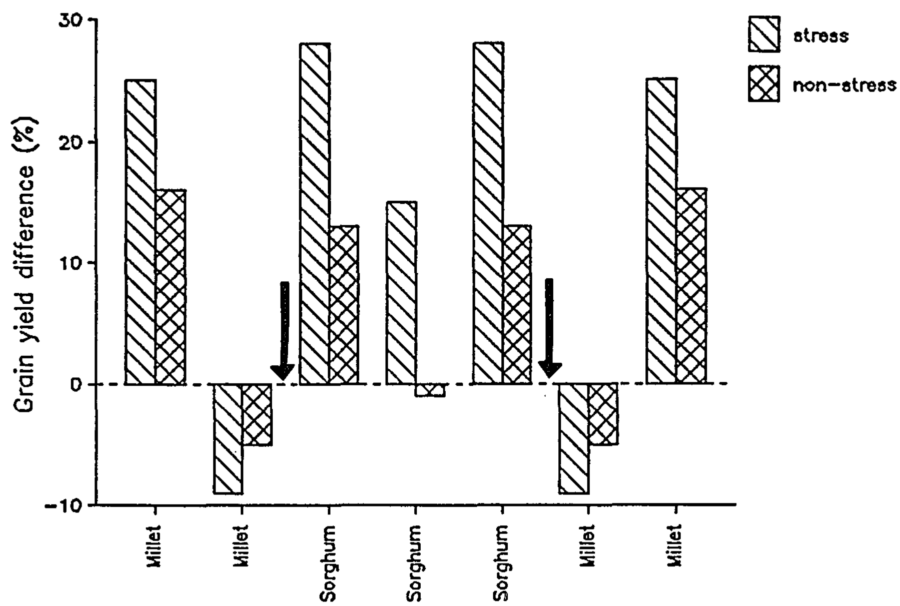

Fig. 3 Percent grain yield difference from respective sole crop of sorghum and pearl millet in intercrop Treatment 2S as influenced by neighbor-row competition under soil moisture non-stress and stress, down-ward arrow indicates interface point.

Table 18. Grain yield response of sorghum and pearl millet intercrop rows in Treatment 2S (MMSSSMM) relative to their respective sole crop yield under soil moisture non-stress and stress conditions

Soil moisture levels	Inter-row planting arrangement	Sole crop row-plot yield (kg ha^{-1})	Intercrop row-plot yield (kg ha^{-1})	Relative yield difference (kg ha^{-1})	(%)
NON-STRESS					
	Millet	2201	2553	+352	+16
	Millet	2201	2085	-116	- 5
	Sorghum	4160	4691	+531	+13
	Sorghum	4160	4139	- 21	- 1
	Sorghum	4160	4691	+531	+13
	Millet	2201	2085	-116	- 5
	Millet	2201	2553	+352	+16
	LER=1.06				
STRESS					
	Millet	533	668	+135	+25
	Millet	533	486	- 47	- 9
	Sorghum	2191	2806	+615	+28
	Sorghum	2191	2513	+322	+15
	Sorghum	2191	2806	+615	+28
	Millet	533	486	- 47	- 9
	Millet	533	668	+135	+25
	LER=1.15				

row competition observed in this treatment could be attributed to the influence of the sorghum component.

4.3.2 Sorghum-Sorghum-Millet-Millet-Millet-Sorghum-Sorghum

Treatment 2M - Three rows of pearl millet bordered by sorghum rows in this 3:4 ratio of millet sorghum intercrop treatment produced an overall loss in both of the soil moisture treatment. The pearl millet neighbor and second neighbor row in this treatment was heavily suppressed by neighbor sorghum rows particularly under soil moisture stress. Millet neighbor and next neighbor row lost about 32 (169 kg ha^{-1}) and 34% (179 kg ha^{-1}) relative grain yield, respectively. Sorghum neighbor rows in that situation gained about 8% (182 kg ha^{-1}) and next neighbor only less than a percent (3 kg ha^{-1}), respectively. The poor mutual compensation by the sorghum component crop rows in this moisture stress treatment led to a 11% decrease in combined relative grain yield (LER=0.89). The combined yield loss was only 4% (LER=0.96) under non-stress soil moisture (Fig.4 and Table 19).

The grain yield of the three millet rows at the center of this intercrop treatment were greatly suppressed from both sides by the neighbor sorghum rows. Sorghum, although dominated pearl millet in both moisture levels, still failed to maximize its production up to the level even equal to the

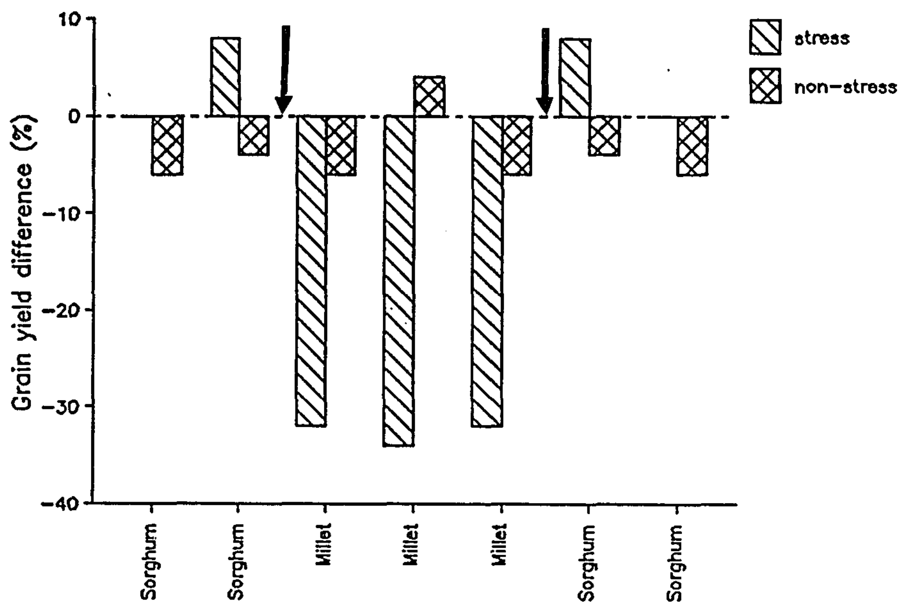

Fig. 4 Percent grain yield difference from respective sole crop of sorghum and pearl millet in intercrop Treatment 2M as influenced by neighbor-row competition under soil moisture non-stress and stress, down-ward arrow indicates interface point.

Table 19. Grain yield response of sorghum and pearl millet intercrop rows in Treatment 2M (SSMMMSS) relative to their respective sole crop yield under soil moisture non-stress and stress conditions

Soil moisture levels	Inter-row planting arrangement	Sole crop row-plot yield (kg ha^{-1})	Intercrop row-plot yield (kg ha^{-1})	Relative yield difference (kg ha^{-1})	Relative yield difference (%)
NON-STRESS					
	Sorghum	4160	3915	-246	- 6
	Sorghum	4160	4014	-146	- 4
	Millet	2201	2071	-131	- 6
	Millet	2201	2295	+ 94	+ 4
	Millet	2201	2071	-131	- 6
	Sorghum	4160	4104	-146	- 4
	Sorghum	4160	3915	-246	- 6
	LER=0.96				
STRESS					
	Sorghum	2191	2194	+ 3	0
	Sorghum	2191	2373	+182	+ 8
	Millet	533	364	-169	-32
	Millet	533	354	-179	-34
	Millet	533	364	-169	-32
	Sorghum	2191	2373	+182	+ 8
	Sorghum	2191	2194	+ 3	0
	LER=0.89				

amount lost by millet component, particularly under soil moisture stress.

4.3.3 Sorghum-Sorghum-Sorghum-Millet-Millet-Millet

Treatment 3S and 3M - The pearl millet neighbor and second neighbor row in this Treatment 3S and 3M suffered comparatively greater yield loss, 43 (230 kg ha^{-1}) and 10% (51 kg ha^{-1}), respectively in non-irrigated conditions, and the only substantial recovery of 24% (516 kg ha^{-1}) was attained by the immediate neighbor sorghum row. The combined relative yield total of the treatment was 97% of the sole crop (LER=0.97) under moisture stress treatment. Under soil moisture non-stress, the neighbor millet row next to sorghum lost about 12% (165 kg ha^{-1}) of its grain yield. The neighbor sorghum row increased its grain yield by an equal 12% but an actual of 502 kg ha^{-1}. The combined grain yield of the intercrop components under soil moisture non-stress was almost equal to the sole crop yield (LER=0.99) (Fig.5 and Table 20).

The resource use efficiency, as indicated by grain yield in this treatment found to be mutually compensated by sorghum and millet component crops in both soil moisture levels.

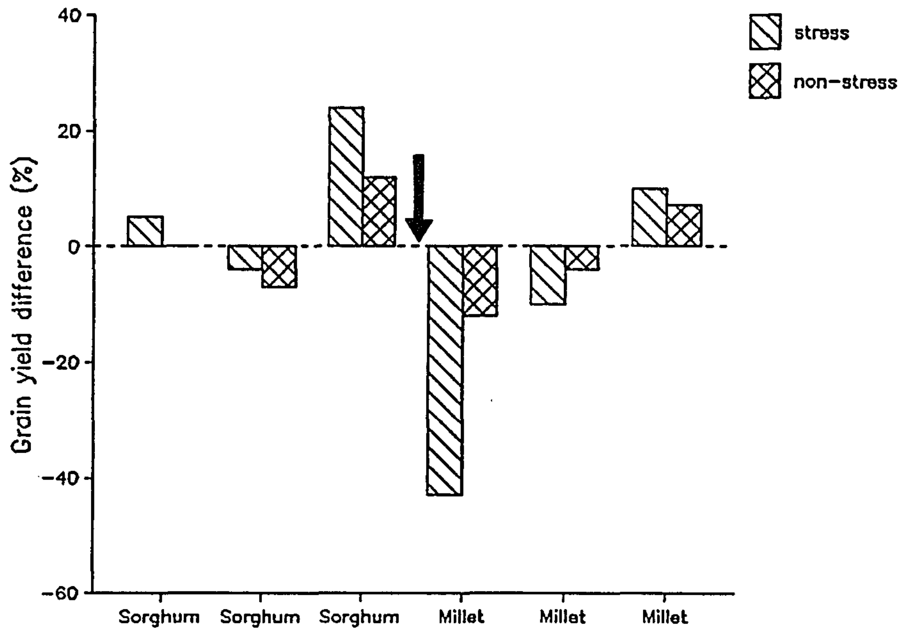

Fig. 5 Percent grain yield difference from respective sole crop of sorghum and pearl millet in intercrop Treatment 3S & 3M influenced by neighbor-row competition under soil moisture non-stress and stress, down-ward arrow indicates interface point.

Table 20. Grain yield response of sorghum and pearl millet intercrop rows in Treatment 3S&3M (SSSMMM) relative to their respective sole crop yield under soil moisture non-stress and stress conditions

Soil moisture levels	Inter-row planting arrangement	Sole crop row-plot yield (kg ha^{-1})	Intercrop row-plot yield (kg ha^{-1})	Relative yield difference (kg ha^{-1})	(%)
NON-STRESS					
	Sorghum	4160	4160	0	0
	Sorghum	4160	3856	-304	- 7
	Sorghum	4160	4662	+502	+12
	Millet	2201	1936	-165	-12
	Millet	2201	2118	- 83	- 4
	Millet	2201	2347	+146	+ 7
	LER=0.99				
STRESS					
	Sorghum	2191	2300	+109	+ 5
	Sorghum	2191	2102	- 89	- 4
	Sorghum	2191	2707	+516	+24
	Millet	533	303	-230	-43
	Millet	533	482	- 51	-10
	Millet	533	587	+ 54	+10
	LER=0.97				

4.3.4 Millet-Millet-Sorghum-Millet-Millet

Treatment 4S - The grain yield of a single row of sorghum at the center of the pearl millet rows in this Treatment 4S was increased by about 14% (299 kg ha^{-1}) under soil moisture non-stress. The pearl millet neighbor and next neighbor rows in the treatment experienced relatively greater percent yield loss, a 24% (128 kg ha^{-1}) and a 11% (58 kg ha^{-1}). The combined grain yield of this treatment under soil moisture stress was 11% less than sole crops (LER=0.89). Under soil moisture non-stress, a single row of sorghum neighbor gained 3% of its yield, the equal percent of yield loss was observed by a millet neighbor row. The gain and loss in grain for the sorghum and millet were actually 134 (kg ha^{-1}) and 70 (kg ha^{-1}) respectively. The combined relative yield (LER=1.0) under soil moisture non-stress in this 4:1 ratio of millet sorghum intercrop treatment was same as that could be expected from any of the sole crop (Fig.6 and Table 21).

Sorghum under soil moisture stress condition was capable of depressing the neighbor millet grain yield by a great percent but was unable to compensate that loss by an equal amount of grain yield.

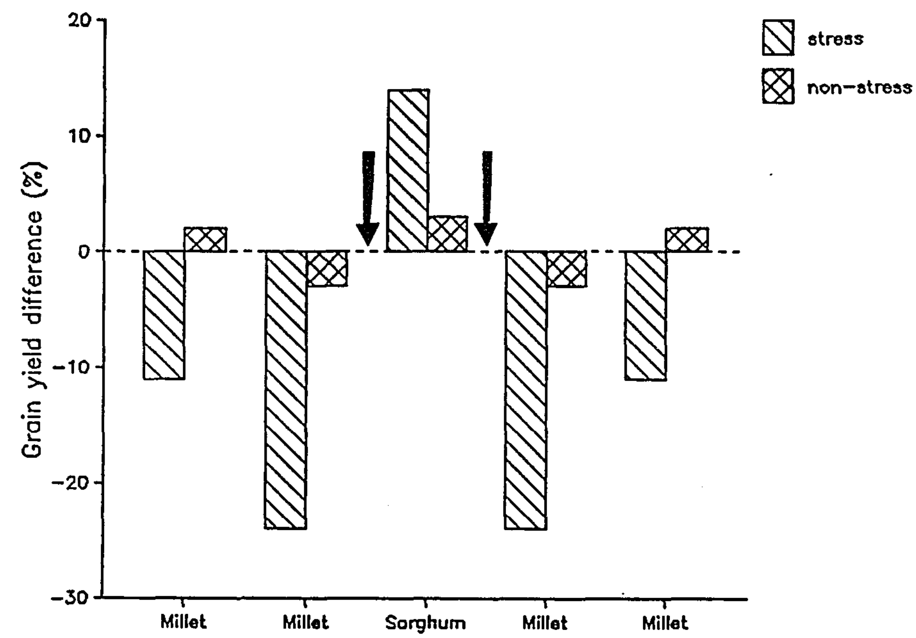

Fig. 6 Percent grain yield difference from respective sole crop of sorghum and pearl millet in intercrop Treatment 4S influenced by neighbor-row competition under soil moisture non-stress and stress, down-ward arrow indicates interface point.

Table 21. Grain yield response of sorghum and pearl millet intercrop rows in Treatment 4S (MMSMM) relative to their respective sole crop yield under soil moisture non-stress and stress conditions

Soil moisture levels	Inter-row planting arrangement	Sole crop row-plot yield (kg ha^{-1})	Intercrop row-plot yield (kg ha^{-1})	Relative yield difference (kg ha^{-1})	Relative yield difference (%)
NON-STRESS					
	Millet	2201	2251	+ 50	+ 2
	Millet	2201	2131	- 70	- 3
	Sorghum	4160	4294	+134	+ 3
	Millet	2201	2131	- 70	- 3
	Millet	2201	2251	+ 50	+ 2
	LER=1.00				
STRESS					
	Millet	533	476	- 58	-11
	Millet	533	405	-128	-24
	Sorghum	2191	2490	+299	+14
	Millet	533	405	-128	-24
	Millet	533	476	- 58	-11
	LER=0.89				

4.3.5 Sorghum-Sorghum-Millet-Sorghum-Sorghum

Treatment 4M - In this 4:1 ratio of sorghum pearl millet intercrop, the grain yield of a single row of millet under soil moisture stress was reduced by as much as 69% (366 kg ha^{-1}) with sorghum as a neighbor row in both sides. The yield advantage of the neighbor sorghum row was 10% (217 kg ha^{-1}). The combined relative yield of the treatment was 90% of the sole crop (LER=0.90). Under non-stress soil moisture, the neighbor and next neighbor row of sorghum increased their grain yield by 14 (567 kg ha^{-1}) and 8% (330 kg ha^{-1}), respectively compensated for the 6% (347 kg h^{-1}) loss incurred by the millet row. As a result, the intercrop rows added a 6% additional grain on the top of the sole crop equivalent yield (LER=1.06) (Fig.7 and Table 22).

Based on the inter-row competition and mutual compensation pattern in this treatment, it was observed that the component crops were able to compensate and complement each other well enough when water was not limiting.

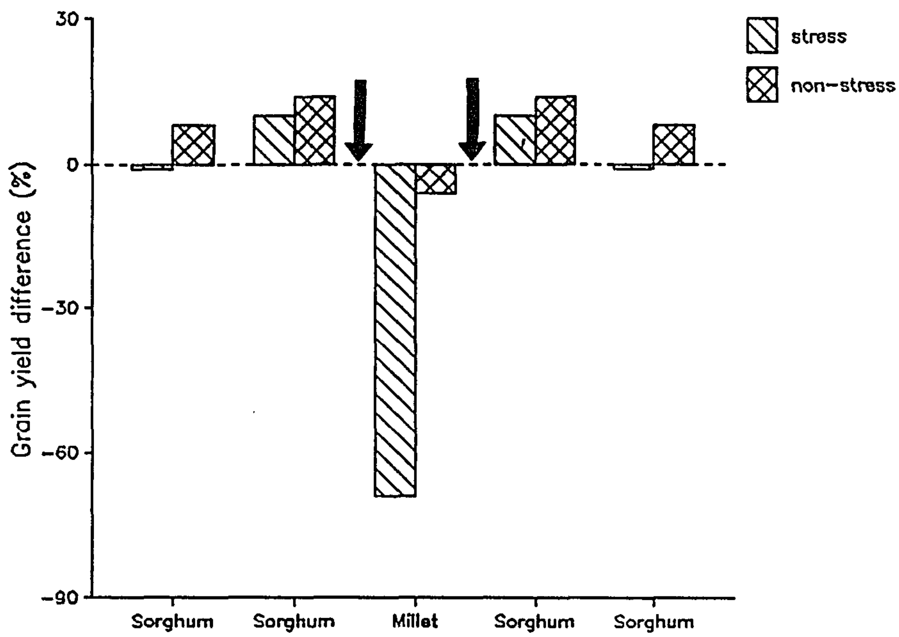

Fig. 7 Percent grain yield difference from respective sole crop of sorghum and pearl millet in intercrop Treatment 4M influenced by neighbor-row competition under soil moisture non-stress and stress, down-ward arrow indicates interface point.

Table 22. Grain yield response of sorghum and pearl millet intercrop rows in Treatment 4M (SSMSS) relative to their respective sole crop yield under soil moisture non-stress and stress conditions

Soil moisture levels	Inter-row planting arrangement	Sole crop row-plot yield (kg ha^{-1})	Intercrop row-plot yield (kg ha^{-1})	Relative yield difference (kg ha^{-1})	Relative yield difference (%)
NON-STRESS					
	Sorghum	4160	4490	+330	+ 8
	Sorghum	4160	4727	+567	+14
	Millet	2201	1854	-347	- 6
	Sorghum	4160	4727	+567	+14
	Sorghum	4160	4490	+330	+ 8
	LER=1.06				
STRESS					
	Sorghum	2191	2165	- 26	- 1
	Sorghum	2191	2408	+217	+10
	Millet	533	167	-366	-69
	Sorghum	2191	2408	+217	+10
	Sorghum	2191	2165	- 26	- 1
	LER=0.90				

4.4 The relative performances of the intercrop treatments

Sorghum and pearl millet genotypes when grown in different inter-row planting arrangements under different levels of soil moisture performed differently. The relative grain yield performances of different proportion of intercrop treatments rows were measured by partial land equivalent ratio (LER) values of the two components (Table 23). Based on the overall responses of the intercrop treatments, relative grain yield advantages of 4:3 ratio of millet and sorghum in treatment 2S (MMSSSMM) was found advantageous in both non-stressed and stressed growing conditions. Most of the other intercrop combinations performed better only under soil moisture non-stress condition (Fig.8). The cropping pattern in treatment 2M (SSMMMSS), on the other hand, produced a grain yield which was less than the sole crop equivalent yield in both growing conditions. The planting pattern similar to strip crop (Treatment 3S & 3M), performed about the same as any of the sole crop in either soil moisture treatment.

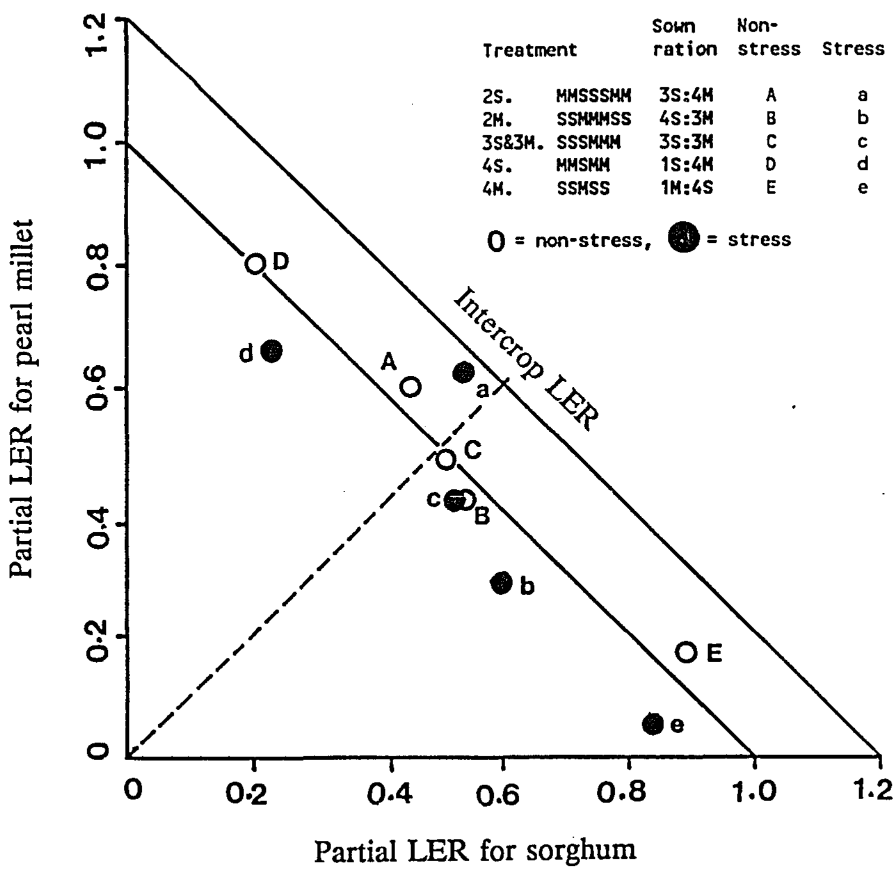

Fig. 8 Partial and total land equivalent ratios (LER) of sorghum (S) and pearl millet (M) in intercrop treatments under soil moisture non-stress and stress

Table 23. Partial land equivalent ratios (LER) of sorghum and pearl millet, and combined LER of intercrop treatments under soil moisture non-stress and stress.

Intercrop planting arrangements	Land equivalent ratio					
	Partial for component crops				Total for intercrops	
	non-stress		stress		non-stress	stress
	sorghum	millet	sorghum	millet		
1a. S-S-S-S-S-S-S	-	-	-	-	1.00	1.00
2a. M-M-S-S-S-M-M	0.46	0.60	0.53	0.62	1.06	1.15
3a. S-S-S-M-M-M	0.51	0.48	0.54	0.43	0.99	0.97
4a. M-M-S-M-M	0.20	0.80	0.23	0.66	1.00	0.89
1b. M-M-M-M-M-M-M	-	-	-	-	1.00	1.00
2b. S-S-M-M-M-S-S	0.54	0.42	0.60	0.29	0.96	0.89
3b. S-S-S-M-M-M	0.51	0.48	0.54	0.43	0.99	0.97
4b. S-S-M-S-S	0.89	0.17	0.84	0.06	1.06.	0.90

CHAPTER 5

SUMMARY AND CONCLUSION

Sorghum and pearl millet genotypes were grown in interplanted plots in a slightly heavy soil at Marana, Arizona during the summer of 1987. Inter-plot (inter-row) competition of the component crops were evaluated from intra-row performances of sorghum and pearl millet under soil moisture non-stress and stress conditions. Individual crop responses for 50% bloom, plant height, head length, head exsertions, number of effective tillers, 1000 seed weight, and grain yield were determined for both cereals. Based on the above observations, following conclusions were made:

1. Inter-plot competition between sorghum and pearl millet produced no inflence on 50% bloom of either plant species in either of the soil moisture treatments. The condition of soil moisture stress as compared to non-stress, however, significantly delayed pearl millet flowering by about 4 days within plot rows.

2. Soil moisture stress significantly reduced sorghum plant height by 24cm (21%) and pearl millet height by 20cm (16%). Inter-plot competition between sorghum and pearl millet produced no effect on intra-plot plant height of pearl millet. The variations of sorghum plant height due to

the reaction to inter-plot competition from pearl millet were significant in both levels of soil moisture.

3. Soil moisture stress significantly reduced sorghum head length 5cm (19.8%) while pearl millet head length was unaffected. Inter-plot competition between sorghum and pearl millet produced no difference in the head lengths of the two cereals in either of the soil moisture treatments.

4. The head exsertion of both sorghum and pearl millet was affected by soil moisture stress. A 7cm head exsertion of sorghum observed under soil moisture non-stress was significantly reduced to no measurable length (0cm) under moisture stress. The pearl millet head exsertion under soil moisture stress was significantly reduced by about 68% from 6cm exsertion observed under soil moisture non-stress. Inter-plot competition between sorghum and pearl millet significantly affected only pearl millet. Pearl millet head exsertion was reduced by about 1.7cm (30%) and 1.4cm (78%) under soil moisture non-stress and stress, respectively in interplot competition with sorghum.

5. The number of effective tillers per plant under the influence of soil moisture stress was significantly reduced only in pearl millet. Inter-plot competition between sorghum and pearl millet produced no measurable differences in the number of effective tillers of either crop in either soil moisture level.

6. Soil moisture stress, as compared to non-stress, significantly reduced the 1000 seed weight of sorghum by 5.4g (25%) and of pearl millet by 2.0g (16%). Inter-plot competition between sorghum and pearl millet did not produce any difference in 1000 seed weight of either cereal in either soil moisture level.

7(a). Soil moisture stress significantly lowered sorghum grain yield to 2191 kg ha^{-1} which is 47% less than the 4160 kg ha^{-1} obtained under soil moisture non-stress. The grain yield of pearl millet (533 kg ha^{-1}) obtained under soil moisture stress was significantly lower than the yield (2201 kg ha^{-1}) observed under soil moisture non-stress. Inter-plot competition between sorghum and pearl millet did not influence sorghum yield in either of the soil moisture treatment. The competition, however, affected the pearl millet grain yield in both levels of soil moisture. The influence of sorghum in a 4:1 ratio of sorghum-millet intercrop with millet in the center row reduced maximum millet grain yield. The reduction was 69% (367 kg ha^{-1}) under soil moisture stress and 16% (347 kg ha^{-1}) under soil moisture non-stress, respectively.

7(b). Grain yield performance of sorghum and pearl millet neighbor rows within a multi-row plot in this research suggests that sorghum is a better competitor than pearl millet. An intercrop study at this research site, reported by Menezes (1988), indicated that sorghum is a better competitor than beans as compared to the performance of millet with beans.

7(c). Relative grain yield totals obtained from inter-row plots suggests that, sorghum and pearl millet growing in neighbor rows could complement each other by adding extra grain yield provided that soil moisture is not limiting. Land equivalent ratios of most of the intercrop combinations studied were greater than unity (LER more than 1.0) under soil moisture non-stress and less than unity under soil moisture stress, respectively.

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