BOURQUE, PETER JAMES

FIELD EVALUATION OF DROUGHT TOLERANCE IN SORGHUM GENOTYPES PRE-SELECTED BY IRRIGATION GRADIENT.

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FIELD EVALUATION OF DROUGHT TOLERANCE IN SORGHUM GENOTYPES PRE-SELECTED BY IRRIGATION GRADIENT

by

Peter James Bourque

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

R. L. VOIGT
Professor of Plant Sciences

22 July 1982
Date

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ABSTRACT

Based on the results of an irrigation gradient study in Yuma, Arizona in 1979, eighteen grain sorghum (*Sorghum bicolor* (L.) Moench) varieties were selected as either tolerant of or susceptible to moisture stress. These varieties, along with six checks, were planted in a total of 480 plots in Marana, Arizona in 1980. Each entry was subjected to optimal and sub-optimal moisture conditions, resulting in "wet" and "dry" irrigation treatments receiving a total amount of water of 41.91 and 33.02 cm/ha, respectively.

Various agronomic and physiological characteristics were measured in the Marana test. A significant difference between the water levels was found with grain yield, plant height, head exsertion, panicle length, heads/ha, head weight, apparent photosynthesis, transpiration rate and leaf diffusive resistance. Tests on grain yield, plant height, 300-seed weight, grain test weight, plants/ha and head weight showed significant differences between the pre-selected tolerant and susceptible varieties. Significant positive correlations (r) between grain yield and head weight and significant negative correlations between grain yield and plants/ha and between heads/ha and head weight were found.

The same eighteen varieties were tested in the Yuma irrigation gradient in 1980 and 1981. Results were inconclusive and did not support the tolerant-susceptible selections made from the 1979 Yuma data.

CHAPTER 1

INTRODUCTION

Water, like petroleum and certain minerals needed for modern agriculture, is becoming a limited natural resource. In the United States, underground water supplies which took millions of years to form are quickly being depleted. In the more arid regions of this country and the world it is imperative that agriculture become more efficient in its use of this precious commodity.

Grain sorghum (*Sorghum bicolor* (L.) Moench) is a plant which, among the world's more important cereal crops, has a relatively low water requirement and is grown in most of the arid regions of the world. In the United States grain sorghum is grown almost exclusively for livestock feed (i.e. converted to meat, eggs and dairy products), however it is consumed directly by many people who inhabit the less-developed world's arid regions.

Given the world's decreasing water resources and vagaries of precipitation, the development of grain sorghum varieties which produce well under minimal moisture conditions would be of help to many who depend directly on this crop for their livelihood. The author sees the most important result of efficient water-using grain sorghum varieties in the potential increased availability of directly consumed food to Third World people who live in low-rainfall areas. While most of the problems of "feeding the world" are economic, political and social in origin, increased production and availability of food are important technological contributions toward alleviating hunger.

The objectives of this study were:

(1) to determine the differences in growth, development and grain yield under optimal and sub-optimal moisture conditions of grain sorghum genotypes previously selected as tolerant of or susceptible to moisture stress by irrigation gradient evaluation;

(2) to determine the effectiveness of an irrigation gradient in predicting relative drought tolerance potential of various sorghum genotypes under low-moisture stress field conditions;

(3) to evaluate the effect of low-moisture stress on the growth and development of selected grain sorghum genotypes.

CHAPTER 2

LITERATURE REVIEW

Water Stress and Its Effects

That a plant's sustained life is dependent on water is an obvious fact. The functions that water serves in the plant include being: 1) a solvent in which sugars, salts and other solutes are transported throughout the plant; 2) a crucial reagent for photosynthesis; 3) a major constituent for physiologically active tissue; 4) the essential ingredient for maintaining turgidity, without which there would be no cell and plant growth (Kramer, 1963).

When sufficient water is not present in the plant it is said to be "water stressed." The above functions will be affected, usually to the detriment of the plant's overall growth. This growth and, consequently, the crop yield is a result of how well the physiology and the cell elongation and division of the plant progress. The following, then, is a discussion of the effects of water stress on the physiology of the plant and on its general cell growth.

Physiology and Water Stress

Finding a direct, causative relationship among photosynthesis, photorespiration, stomatal conductance, transpiration and assimilate partitioning is very complex and often theoretical (Milthorpe and Moorby, 1974). The various physiological functions of the plant are interrelated. Here, however, they will be treated separately.

<u>Stomatal Behavior</u>. The role of the stomates as related to water stress and the plant's physiological functions is of major importance. Not only do the stomates provide an exit for the release, or loss, of plant water (in transpiration), they also are the point at which CO_2 enters the plant (for photosynthesis).

The leaf water status will usually be the main factor in regulating stomatal aperture (Turner, 1974a). As the leaf water status decreases, the stomatal aperture also decreases because the guard cells lose their turgor pressure. As the stomates close, the resistance to water vapor flow from the leaves increases. In addition, the stomatal closure effects a reduction in CO_2 entry, thereby limiting photosynthesis.

Henzell et al. (1976) found that stomates within plant species can differ greatly in their response to water stress. The stage of plant development can also be an important factor in influencing stomatal reactions. Morgan (1977) found that stomates in wheat (<u>Triticum aestivum</u> L.) were always open more before flowering than after for any given leaf water potential. Grain sorghum stomates, in one study, became much less sensitive to leaf water status in the post-anthesis stage compared to the pre-anthesis stage (Ackerson and Krieg, 1977)

<u>Photosynthesis</u>. Experiments to establish a direct relationship between photosynthesis and water stress are complex and sometimes inconclusive. Severe water stress is known to cause closure of the stomates, thereby decreasing CO_2 absorption, which reduces the photosynthetic rate (Turner, 1974a, b). Boyer (1976b) found that photosynthesis may be decreased by water stress because of its effects

on CO_2 diffusion into the leaf or by the direct effect on the photochemical apparatus, or by both factors working together. More generally speaking, Boyer (1976b) points out that water stress may limit the net photosynthesis of the plant by decreasing the photosynthetic activity per leaf area or by limiting the production of new leaf area.

Transpiration. Rawson, Begg and Woodward (1977) found a linear increase in transpiration from sorghum leaves as the difference between air and leaf vapor pressure increased. At a point, however, stomates will tend to close and transpiration will "shut down" when water loss is excessive. Johnson, Frey and Moss (1974) found that in wheat and barley (*Hordeum vulgare* L.) plants at leaf water potentials of -28 bars transpiration had completely stopped.

As the stomates close and the transpiration rate decreases or stops, the leaf temperature will increase. Zelitch (1963) said that the rise in leaf temperature may increase internal resistance to CO_2 carboxylation--one indicator of the intricate link between water stress, transpiration and photosynthesis.

Translocation and Partitioning of Assimilates. A significant influence that water stress has on plant growth is in the partitioning of assimilates. Wardlaw (1967) found that water stress served to accentuate hierarchical relationships among various sinks within the plant. With wheat, for example, he found that, under stress, the flag leaf and the second leaf directed more assimilates to the forming grains and less to the roots or tillers than in an unstressed plant. Wardlaw (1969) later concluded, working with *Lolium temulentum* L., that the photosynthate's increased movement in one direction was not due to any effect on the actual translocation appartus, but, rather, was due to the effect of water stress on photosynthate production and on phloem loading. McWilliam's (1968) research supports the stability of the conducting system in plants. Working with Phalaris tuberosa(var. stenoptera Hitch.), he found that assimilate movement was hardly altered when plants were stressed so much that they lost their leaves.

Turgor and Cell Structure

Plant growth is dependent on adequate turgor pressure in the cell wall which yields irreversibly to this pressure, resulting in cellular and plant growth (Noggle and Fritz, 1976). A plant that is water stressed will have sub-optimal turgor pressure which will decrease cell growth and division (Noggle and Fritz, 1976; Kirkham, Gardner and Gerloff, 1972). Hsiao (1973) found that cell enlargement is more sensitive to water stress than is cell division.

As previously stated, the turgor of the leaf's stomatal cells determines how much they are open. This turgor is dependent on the leaf water potential. A water stressed plant, then, will have reduced turgor pressure which reduces the intake of CO_2, affecting photosynthesis and the general cell growth. Hsiao et al. (1976) pointed out, however, that water stress, at any given time, may be severe enough to affect cell expansion and plant growth and yet not so severe as to reduce stomatal openings and resultant photosynthesis.

It follows, then, that the general growth and development of the plant is adversely affected by water stress. Reduced transpiration and photosynthesis along with reduced cell growth due to turgor loss all contribute to a reduction in plant growth. The degree of stunting depends on the severity and timing of water stress as well as on the species (Inuyama, Musick and Dusek, 1976). This will be pursued more as it relates to sorghum.

Water Stress in Sorghum

Comparative Resistance

Sorghum is considered one of the most resistant of crop plants to drought (Colby and Steele, 1976). In Ivory Coast, for example, as one moves north from the rain forest up to the arid Sahel and Sahara Desert regions of Upper Volta and Mali, one begins to see sorghum being grown in areas which have too little rainfall to grow corn (Zea maize L.), yams (Dioscorea spp.) and upland rice (Oryza sativa L.). Only millet (Pennisetum americanum L.) demands less rainfall than sorghum and it is grown in the most arid of West Africa regions.

Martin (1930) attributed sorghum's drought resistance to the efficiency of its root system: it has a relatively high number of secondary roots--twice as many per unit of primary root as does corn. Hsiao et al. (1976), however, maintain that there is no real evidence that roots are the primary reason for drought resistance in sorghum. They contend that the reason that sorghum yields higher than corn under stressed conditions is attributable partly to a greater ability to adjust grain numbers according to the environmental conditions and to the differences in assimilate partitioning. Also, they point out, sorghum's ability to produce many tillers when water is adequate allows for dry matter and/or grain production which compensates for slow or no growth during stressed periods. This "basal bud dormancy" appears to be a major reason for sorghum's ability to yield dry matter under water stressed conditions.

The behavior of sorghum stomates also appears to be superior to that of corn where water stress is concerned. Sanchez-Diaz and Kramer (1973) reported that corn stomates would close sooner and at a higher leaf water potential than would sorghum stomates and that "corn loses much more of its water before the stomates are fully closed than does sorghum." As mentioned in the section on photosynthesis, open stomata are necessary for CO_2 intake and, as a result, for photosynthesis. Corn also wilts--a sign of turgor loss--at a higher leaf water potential than does sorghum (Beadle et al., 1973).

Mechanisms of Drought Resistance

Drought resistance in plants, according to Levitt (1972), may come about from avoidance or from tolerance or from both. Avoidance occurs when a plant is able to maintain an adequate cell water potential in spite of adverse environmental conditions. Plants are considered drought tolerant, on the other hand, when they are able to survive despite low cell water potentials by "shutting down" under stressful conditions. The work of Sanchez-Diaz and Kramer (1973) and Beadle et al. (1973) indicate that sorghum is a drought avoider, i.e. able to continue photosynthesis and growth despite water stress.

Sorghum can be said to avoid drought by three mechanisms: escape, evasion and endurance (Levitt, 1972, Hill, 1976). Through escape, a plant completes its life cycle before being subjected to water stress.

Because of this, much sorghum breeding has gone toward selecting genotypes that mature early. Blum (1970) found that an early maturing sorghum hybrid yielded better than medium and late maturing hybrids when all three were grown under limited soil water conditions (determined by plant density); the late maturing hybrid yielded the highest under the high soil-moisture conditions.

Hill (1976) pointed out that the higher yield of an earlier genotype may be because of its pattern of moisture extraction so that less water is used during early vegetative stages when atmospheric conditions are mild. The plants then extract the conserved soil water during the crucial anthesis and grain-filling stages. The late maturing genotype, on the other hand, may go through the harsher (hotter, more arid) periods while still in the vegetative stage, thereby using the crucial soil water at this time, leaving an inadequate amount for anthesis and grain-filling.

Through evasion a plant can extract adequate soil moisture despite drought conditions because of a well-developed root system (Levitt, 1972, Hill, 1976). Sorghum has much more root area per plant weight than do most other crop plants (Martin, 1930, Cobley and Steele, 1976). Mayaki, Stone and Teare (1976) reported that, under both irrigated and non-irrigated conditions, sorghum produced about twice as much root dry matter as did corn. Sorghum and soybean (Glycine max Merril) root systems were compared by Teare and Kanemasu (1972). Sorghum had twice as many roots per unit weight as soybeans and had a higher percentage of the roots in the upper soil region (0-32 cm.). These upper roots account for a high percentage of water absorption in most plants.

Through drought endurance a plant minimizes water loss by such means as cutinized leaf layers and reduced transpiration rates (Levitt, 1972). Sorghum has a cuticular white layer on its leaves and stalks called "bloom." This contributes toward restricting water loss through transpiration (Webster, 1980).

Through reduced transpiration rates sorghum is able to minimize water loss through the stomates. Downes (1969) reported that wheat plants transpired 2.25 times as much as did sorghum, expressed on a per unit leaf area basis. Sorghum has also been shown to have a lower transpiration rate than soybeans per unit leaf area (Rawson, Turner and Begg, 1978).

The larger a plant's leaf area, the more surface area there is exposed and the more transpirational loss of water will occur. This is best exhibited by desert flora which minimize leaf area in order to conserve water. Comparing sorghum to corn, sorghum has a smaller leaf area, per unit weight, than does corn (Cobley and Steele, 1976).

Timing of Drought and Effects on Yield

Knowing the growth stage that a particular crop is at when plants are subjected to water stress is helpful in predicting how much influence the stress will have on the crop's yield and yield components (Slatyer, 1973, Inuyama, Musick and Dusek, 1976, Bennett, 1979). Inuyama et al. (1976) did a drought experiment with sorghum where six different "water deficit treatments" were set up such that different plants were stressed during various growth periods. They found that the greatest effect on yield occurred when the sorghum was stressed from the late boot stage to the blooming stage. They concluded that this boot-blooming stage is the most critical because of: 1) decreased differentiation of subbranches in the developing head; 2) decreased leaf area; and 3) a premature and increased senescence. The direct cause of the decreased yield, concluded Inuyama et al., was a limitation of head size which reduced the number of seeds per head.

Bennett (1979) stressed four different grain sorghum hybrids at various growth stages. He found 39% and 33% yield reductions when stress occurred during panicle development and during bloom, respectively. He concluded that both periods are the most sensitive to water deficits.

Fischer (1973), working with wheat, reported that water stress which occurred about ten days before ear emergence had the greatest effect on yield. Water deficits which occurred during the very early or very late stages of plant development had little effect on yield. Sandhu and Horton (1977), working with oats (*Avena sativa* L.) reported that stress at the booting and at the anthesis-through-grain-filling stage depressed kernal yields 20% and 58% respectively. Gardner et al. (1981) found yield reductions were greatest when water stress occurred during pollination or grain-filling periods of corn.

Hsiao et al. (1976) maintain that when yield is in the reproductive organs (e.g. grain crops) that there is no easy explanation for why anthesis and early grain filling are such critical times to have optimal water. Total photosynthate can be constant but fruit or grain yield may decrease. "The key consideration," according to Hsiao et al., "is the partition of assimilates." They suggest that stress during anthesis may indirectly affect yield by decreasing the source intensity, reducing sink size or by interfering with proper pollination.

Genotypic Differences in Response to Water Stress

Crop performance and, ultimately, yield are determined not only by continuous interactions with the environment (heat, moisture, etc.) but equally by the genetic makeup of the crop in general and the cultivar of that crop in particular (Hsiao et al., 1976). In breeding and selecting for genotypes within a species that will perform well under drought stress there are two major avenues of approach, according to Blum (1974). One is working under the assumption that a high-yielding genotype that performs well under optimal conditions will also do well under drought; the other approach is in assuming that yield and drought resistance are controlled by separate and individual genetic entities. Drought resistant attributes must be identified and then transferred to "high-yielding and agronomically acceptable cultivars."

Hanson (1980), working with sorghum, found that under mild stress Blum's first approach held true, i.e. the yield of a genotype under optimal water conditions is a good predictor of its performance under mild drought. Under severe stress, however, Hanson found that Blum's second approach was valid, i.e. the high-yielding genotypes under optimal water conditions were not necessarily the same ones that did well under severe stress.

Over a period of two years, Blum (1974) tested a number of sorghum genotypes for drought resistant characteristics. Periodic determinations were made of leaf water potential, leaf diffusive resistance and the amount of soil moisture present. 'Shallu' was the genotype he found to be the most drought susceptible, based on the three measurements. Cultivar 'Combine Kafir-60' and hybrid 'RS 610' exhibited the most drought avoidance. 'Feterita' and 'Durra' were in the middle, showing some drought avoidance tendencies and some drought susceptible tendencies. In addition, Blum found, there were "appreciable intergenotypic differences. . .in the amount of soil moisture extracted prior to heading as determined by percent of the total at maturity."

Henzell et al. (1976) found that stomatal sensitivity to water stress varies greatly within sorghum genotypes, concluding that stomates may be the key to understanding genotypic differences in response to water stress in sorghum. Miyata (1978) concluded that in order to alleviate the effect of water stress at the grain-filling period of sorghum one should select cultivars that have a large assimilate reserve pool with great mobility and less senescent leaves.

Water Stress and Yield

It is well-documented that sub-optimal water conditions will reduce final grain yields in sorghum (Blum, 1973, Inuyama et al, 1976, Miyata, 1978). In particular, Blum (1973) studied different sorghum hybrids under drought both in their yields and in their component analysis. His study will receive particular attention in this literature review because of its close relevance to this author's experiment.

Twenty-one hybrids were planted under stress and non-stress conditions. After harvest, the hybrids were then classified as either 'resistant'(R) or 'susceptible' (S) based on each one's yield performance in the 'wet' versus 'dry' plots. Thus classified, the R selections were found to be "significantly superior in grain yield to S hybrids under stress, whereas under non-stress conditions, S hybrids were significantly superior to R hybrids."

The entries labelled 'R' yielded higher than 'S' under stress due to a greater number of panicles per area and a higher number and weight of grains per panicle and per branch. On the other hand, S yielded higher than R under non-stress conditions because of more tillering--causing more panicles per area--and a higher 1000-grain weight.

Blum's conclusions for this experiment were: 1) hybrids showing drought resistance were characterized by reduced tillering and smaller grains when tested under non-drought conditions; 2) variations in hybrid yields between 'wet' and 'dry' were associated with variations in tillering; 3) resistance of sorghum to stress is based on the number of grains per branch rather than on other components of panicle weight and that there exist significant genotypic differences in this type of resistance; and 4) resistant hybrids had reduced tillering, relative stability of tillering with changing moisture levels, small grains and a high number of grains per branch.

The work of Inuyama et al. (1976) supports Blum's conclusions. They maintain that the greatest effect that stress had on yield is during the boot-anthesis stage because of the effect on limiting head size (numbers of seeds per head) and that "grain sorghum has a very limited ability to compensate for reduced head size by increasing grain weight."

Irrigation Gradients for Testing Water Stress

The practice of employing irrigation gradients to study water stress in field crop production is fairly recent. Working with corn, Bauder, Hanks and James (1975) used a trickle drip system. This provided for accurate control and measurement of the water applied but was somewhat impractical based on expense and manpower (Hanks et al., 1976).

The Line Source Sprinkler

Hanks et al. (1976) developed a system in 1973 which uses a single line of sprinklers down the center of the plot. This line source sprinkler irrigation system "produces a water application pattern which is uniform along the length of the plot and continuously, but uniformly, variable across the plot (Hanks et al., 1976)." Production-wise they found that there was a "strong linear relationship between dry matter yield [of corn] and estimated evapotranspiration," i.e. as water was decreasingly available (increasing distance from the sprinkler), evapotranspiration was reduced, leading to reduced dry matter yield. A similar, but less dramatic, relationship was shown between evapotranspiration and grain yield. Sorenson, Hanks and Carter (1978) found similar results with corn using this system.

Miller and Hang (1980), working with sugar beets (*Beta vulgaris* L.), used the line source technique of Hanks et al. with differing soil types. With loam soils, sugar yields were not reduced when irrigation rates were reduced to 35% and 50% of estimated evapotranspiration rates. Irrigation rates on a sandy soil, however, cannot be significantly reduced below the estimated evapotranspiration rate without reducing the sugar yields, according to Miller and Hang's (1980) research.

CHAPTER 3

MATERIALS AND METHODS

Twenty-four grain sorghum genotypes were treated and evaluated in this study. Based on the results obtained from the 1979 Sorghum Gradient Irrigation described by O'Neill, Dobrenz and Ross (1980), nine varieties were chosen that appeared to be drought tolerant and nine were chosen that appeared to be drought susceptible. An additional six genotypes (four hybrids and two varieties) were selected as checks (Table 1). This study involves two separate tests: grain yield and other agronomic and physiological characteristics were studied in a field production trial and relative performances were studied under an irrigation gradient.

Grain Yield Study

This experiment was conducted on the University of Arizona Marana Branch Experimental Farm in 1980. The soil at the experimental site (Field B-1) is a Pima clay loam (Typic torrifluvent). The field had been planted to long staple cotton the previous year. No fertilizer was applied during the 1980 season. Chemical analysis of a composite soil sample in the field taken July 23 gave the following results: ph 7.7; exchangeable sodium percentage 3.47; electrical conductivity 1.01 mmho/cm; nitrogen (as N) 3.75 ppm; and phosphorous (as P) 1.75 ppm. Field preparation and planting followed normal cultural practices.

Table 1. Sorghum varieties planted in grain yield study at Marana, Arizona in 1980 grouped according to appearance of being tolerant of or susceptible to moisture stress based on an irrigation gradient study in Yuma, Arizona in 1979.

Tolerant	Susceptible	Checks
Martin	Custer	RS 626
RB 60	IS 7444	RS 610
Feterita	IS 2177	CK 60
Combine Hegari	IS 12587	DK C42Y
Double Dwarf Sooner	IS 12656	DK C46
TX 414	RRR Quadroon	TX 415
MP 10	TX 09	
TX 04	IS 6895	
Double Dwarf 38	IS 7864	

The experiment was planted in dry soil on May 20 and irrigated on May 21. Plant rows were 1.02 m apart with each plot consisting of two adjacent rows, 7.32 m long with .61 m wide alleys perpendicular to the rows. Plants were thinned such that there was a maximum of 120 seedlings /row for a plant population of 161,328 plants/ha.

The soil was treated for broadleaf weeds over a period of three days beginning July 24 with Banvel herbicide (Dimethylamine salt of dicamba [3,6-dichloro-O-anisic acid]) at 563 ml/ha. Plots, when in early stages of seed development most susceptible to bird damage, were sprayed with Mesurol (3,5-dimethyl-4-[methylthio] phenol methyl carbamate) to minimize bird damage.

All entries were tested under optimal soil moisture conditions (hereafter called the wet treatment) and sub-optimal soil moisture conditions (hereafter called the dry treatment). The entries were planted in a randomized complete-block design with five replications. Both the wet and dry treatments were duplicated such that there was a total of four sections with a four-row border between each section.

The two soil moisture treatments received different amounts of irrigation water as shown in Table 2. The total irrigation water received by the wet treatment equaled 41.91 cm/ha while the dry treatment received 33.02 cm/ha (Table 3). The total amount of water for the wet treatment was 56.36 cm/ha while the dry treatment received 47.47 cm/ha.

Determination of Morphological Characteristics

Plant height, heads per plot, plants per plot and grain yield were measured in all plots. 300-seed weight, grain test weight, head

Table 2. Dates and amounts of water applied in yield study at Marana, Arizona in 1980.

Dry Treatment		Wet Treatment	
Date	Amount (cm/ha)	Date	Amount (cm/ha)
May 21	20.32	May 21	20.32
July 1	7.62	July 1	7.62
August 9	5.08	July 28	8.89
		August 9	5.08
Total	33.02	Total	41.91

Table 3. Dates and amounts of precipitation during yield study at Marana, Arizona in 1980.

Date	Amount (cm/ha)	Date	Amount (cm/ha)
June 30	1.27	August 13	.10
July 12	4.67	August 14	.13
July 19	1.65	August 15	.40
July 21	.51	August 23	.25
July 23	.25	August 24	.30
July 25	.76	Sept. 7	.23
August 12	.13	Sept. 26	3.18
		Total	14.45

exsertion and panicle length were measured in the three middle replications of all four sections (60% of total plots). Days to 50% bloom was measured in 60% of the plots with no specific pattern.

Plant height was measured by taking the mean height of the plot from the ground level to the top of the head. Head exsertion was measured by taking the mean length in each plot of the distance between the collar of the flag leaf and the bottom of the head. Days to 50% bloom was measured by calculating the number of days from May 21 (the first irrigation) to the day that 50% of the florets in a given row were in anthesis.

All plots were combine harvested for grain yield from October 22 to October 27. These yields were weighed on the combine at the time of harvest. 300-seed weights and grain test weights were measured in the laboratory from harvest samples after the seed had been uniformly air dried.

Physiological Measurements

Measurements indicating transpirational and photosynthetic rates were taken on two dates: July 23 and August 6. Ten entries were measured of which five had been chosen as drought tolerant (Martin, Combine Hegari, MP 10, TX 04 and Double Dwarf 38), three had been chosen as drought susceptible (Custer, IS 7444 and IS 12587) and two had been selected as checks (RS 610 and DK C42Y). They were measured in three replications from one of the two wet treatments and three replications from one of the two dry treatments. (Based on irrigation differences [Table 2] no dry treatment had yet been established by July 23).

In measuring transpiration, two samples were taken from each plot while one sample from each plot was taken for photosynthetic measurements.

Transpiration rate and leaf diffusive resistance were measured using the LI-1600 Steady State Porometer. Apparent photosynthesis was measured with a closed chamber syringe system as described by Clegg and Sullivan (1975) and Clegg, Sullivan and Eastin (1978). A portion of the uppermost fully-expanded leaf of the sorghum plant was enclosed in a plexiglass chamber for 15 seconds. The CO_2 uptake by the leaf during this time was measured by taking, with a syringe, a 5 ml sample of gas at zero time and, with another syringe, a 5 ml sample of gas 15 seconds later. The CO_2 concentrations in the syringes were measured in the laboratory by injecting the gas into N_2 gas flowing through a model 865 Beckman Infra-Red Analyzer. The CO_2 differential between the two syringes was then calculated. By knowing this differential and the leaf's area (leaf length and width were measured in the field) the photosynthetic rate was calculated from the following equation:

$$\text{Net PS in mg } CO_2 \text{ dm}^{-2} \text{ per hour} = \frac{\dfrac{44{,}000 \text{ mg } CO_2\text{/mole}}{22.4 \text{ l/mole}} \times 10^{-6} \times \underset{\text{(liters)}}{\text{chamber volume}} \times \underset{\text{(per sec)}}{\text{d ppm}} \times \dfrac{273}{T} \times \dfrac{760}{\text{atm}} \times 3600}{\text{dm}^2 \text{ (leaf area)}}$$

where chamber volume = 2.35 l,

PS = photosynthesis,

d ppm = (ppm CO_2 initial sample - ppm CO_2 second sample) divided by 15 seconds.

T = ambient (air) temperature in degrees Kelvin,

atm = atmospheric pressure (mm Hg),

3600 = conversion from seconds to hours.

Irrigation Gradient Study

This experiment was conducted at the Yuma-Mesa Agricultural Experiment Station, Yuma, Arizona in 1980 and 1981. The soil in this study was 91% sand and had a volumetric available moisture of 3.6%. A sprinkler system,designed by Hanks et al. (1976), delivered a water application gradient perpendicular from the line source to the edges of rows on either side of the sprinkler. Row length was 15.3 m extending from each side of the line water source.

Total rainfall for 1980 and 1981 was 1.8 cm and 3.4 cm, respectively(Figures 1 and 2). The amount of water applied through the sprinkler system is illustrated in Figure 3 for 1980 and Figure 4 for 1981.

The same twenty-four varieties that were planted in the Marana yield study (Table 1) were planted both years in the irrigation gradient at Yuma. The planting dates for 1980 and 1981 were March 17 and May 2, respectively. Plants were thinned to allow for one plant every 15.24 cm in 1980 and 1981 on April 17 and May 27, respectively. Due to poor stands, some replanting was done in 1980 at the time of thinning.

Growth and development data collected included: days to anthesis, which was the number of days after planting to 50% bloom in the region of high water application of each entry; a ranking of panicle development (1980) and total plant development (1981) on a 0-5 scale

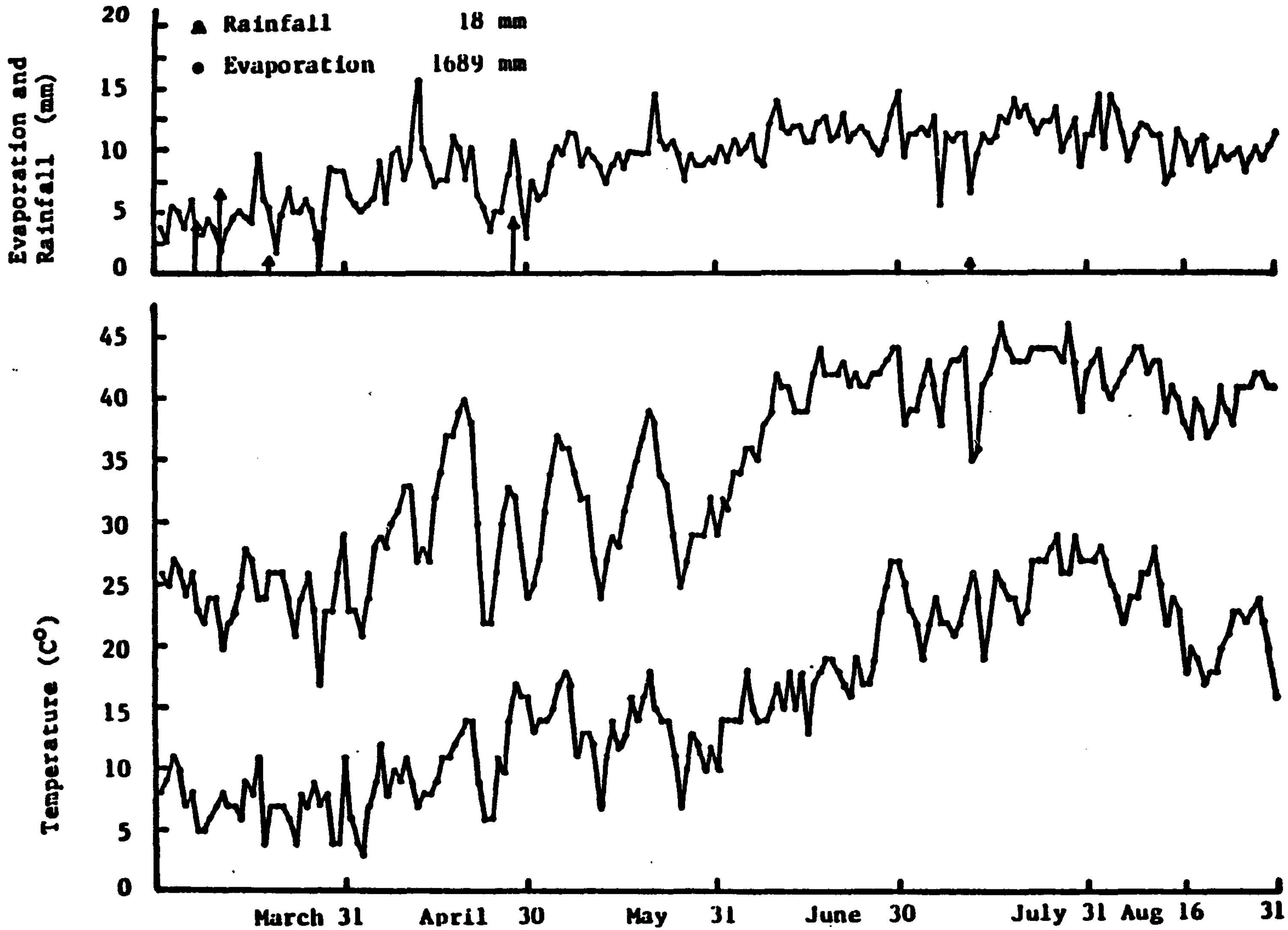

Figure 1. Meteorological data for Yuma-Mesa Agricultural Experiment Station, Yuma, Arizona from March through August, 1980.

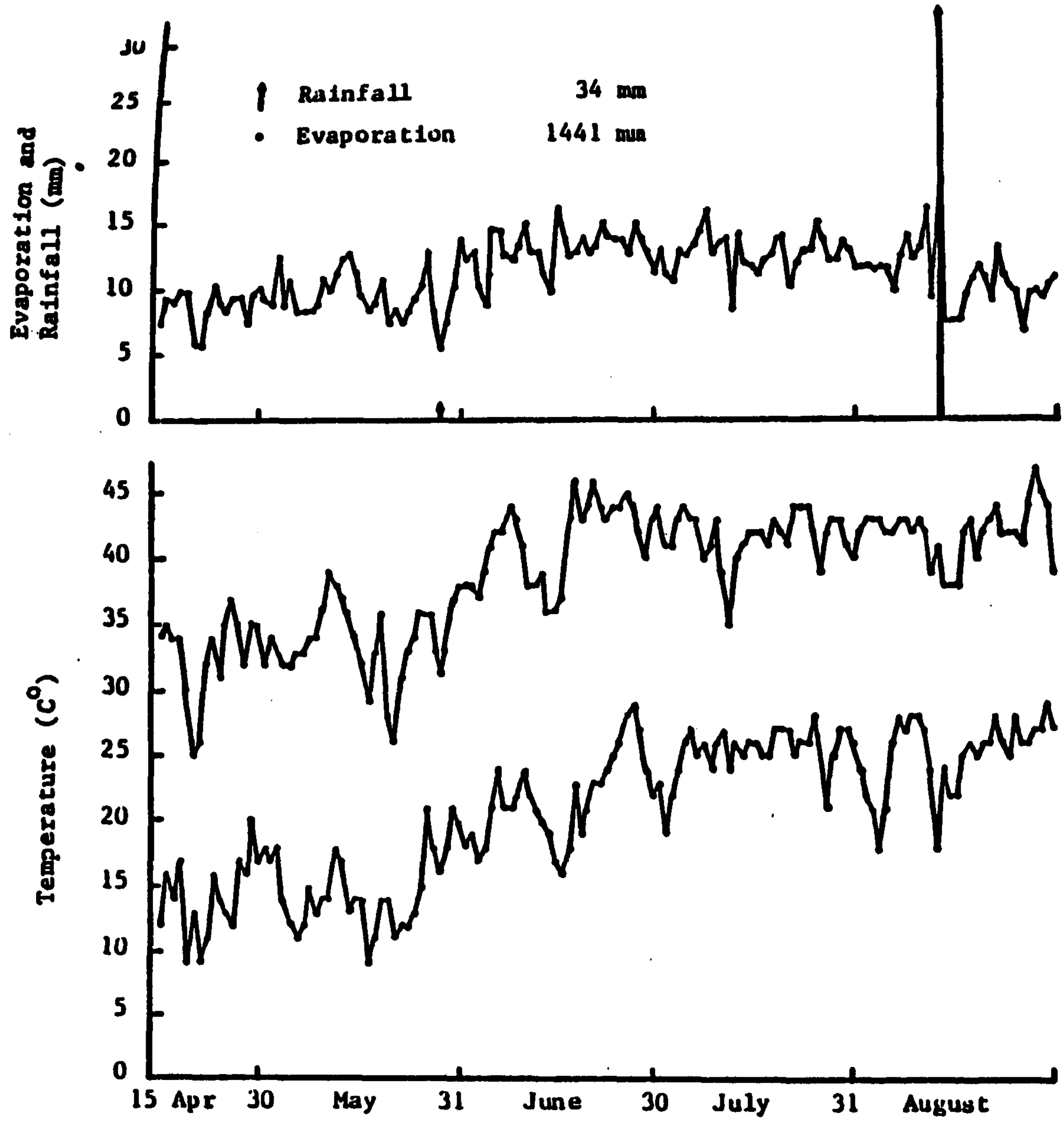

Figure 2. Meteorological data for Yuma-Mesa Agricultural Experiment Station, Yuma, Arizona from April 15 through August, 1981.

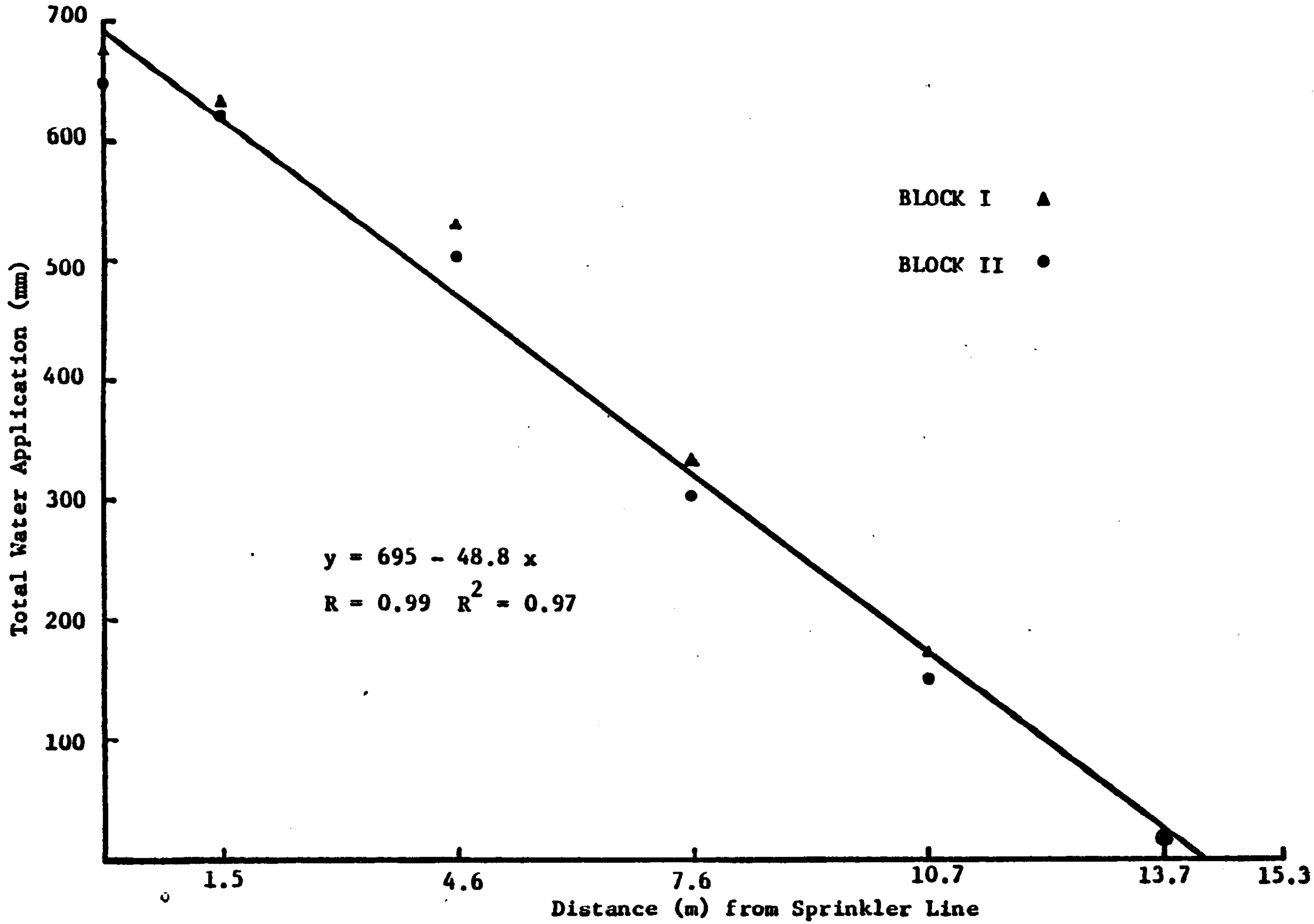

Figure 3. Regression line of total water application of mean of all sites of two blocks combined at distances of 1.5, 4.6, 7.6, 10.7 and 13.7 m from the line source at Yuma-Mesa Agricultural Experiment Station in 1980.

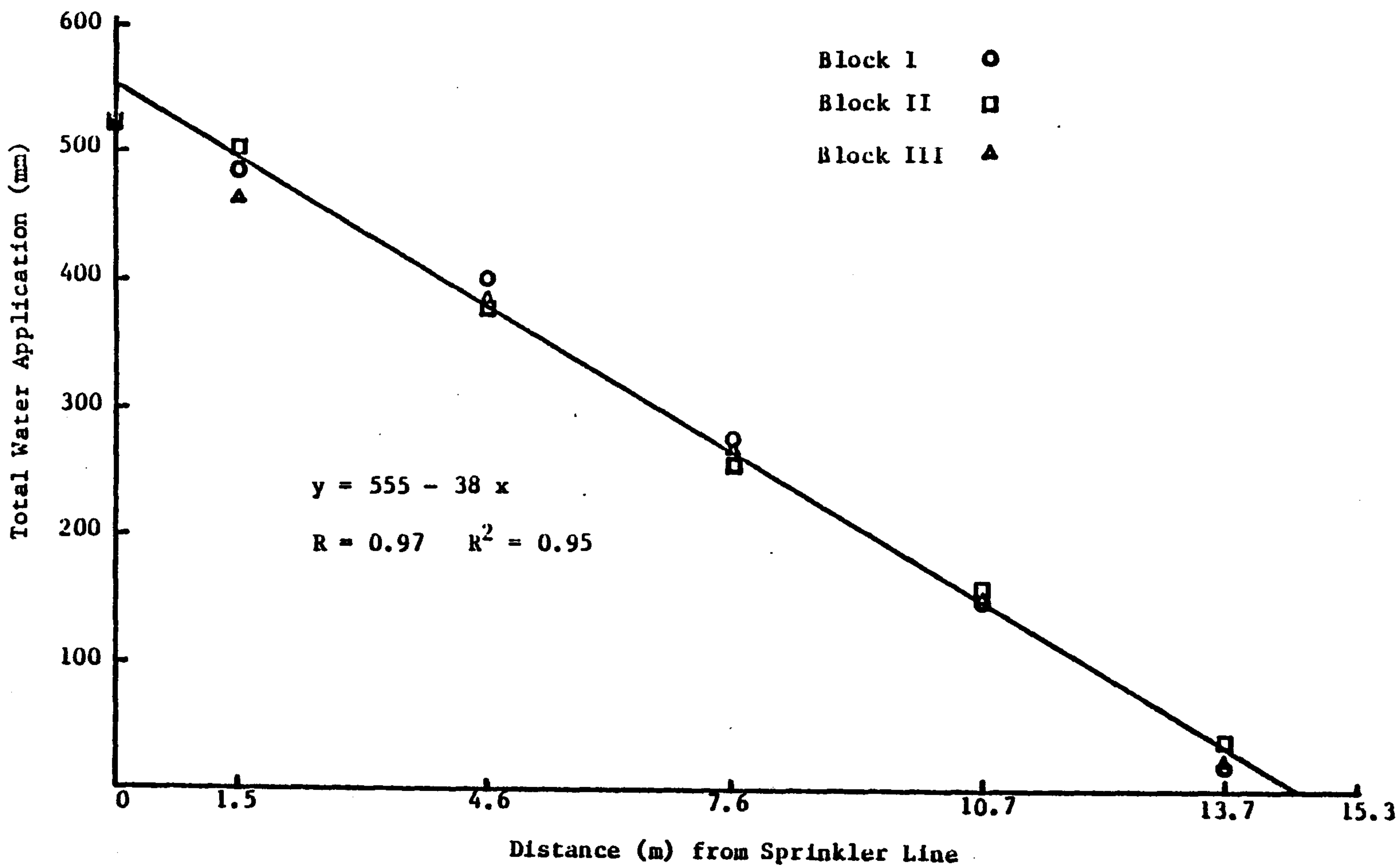

Figure 4. Regression line of total water application of mean of all sites of three blocks combined at distances of 1.5, 4.6, 7.6, 10.7 and 13.7 m from the line source at Yuma-Mesa Agricultural Experiment Station in 1981.

with the former and a 1-5 scale with the latter, with 5 representing excellent development in both-- this ranking was done 145 days and 72 days after planting in 1980 and 1981, respectively; plant height, measured in the areas of high and low water application (1981 only); lastly, the distance from the sprinkler line to the last viable formed head of each entry.

CHAPTER 4

RESULTS AND DISCUSSION

All agronomic and physiological values were analyzed using the F test of significance. These values are found in the appendix.

Grain Yield Study

In analyzing all of the following agronomic characteristics with F tests, statistically significant differences (at the 1% level) among the twenty-four entry means were found for each characteristic.

Morphological Characteristics

Grain Yield. Plants in wet treatment plots produced higher grain yields than those in dry treatment plots (Table 4). Water stress in the dry treatment plots reduced grain yields an average of 30% with a range of 12% (DK C42Y) to 49% (Feterita). Drought tolerant varieties were reduced in yield by an average of 33.1% while susceptible varieties decreased 30.8% from the wet to the dry treatment. The checks were reduced in yield by an average of 23.7%

There was a significant entry x water level interaction for grain yield and a strong trend (90% probability) toward significance between the two water levels.

There were highly significant differences among all of the combinations of various groups involving the tolerant and susceptible varieties and the two water levels (Table 5). The yield means of the

Table 4. Mean yields of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

Variety	Yield (kg/ha) Wet Treatment	Dry Treatment	Mean	Dry/Wet %
Martin	4333.3	3057.2	3695.2	71
RB 60	3850.3	2866.7	3358.5	74
Feterita	4139.8	2128.9	3134.4	51
Combine Hegari	3680.3	2776.0	3228.2	75
Double Dwarf Sooner	4923.2	3039.1	3981.2	62
TX 414	4273.0	3163.1	3718.0	74
MP 10	4702.4	2851.8	3777.1	61
TX 04	4911.0	3444.4	4177.7	70
Double Dwarf 38	5615.6	3607.8	4611.7	64
Tolerant Mean	4482.4	2992.8	3733.4	67
Custer	4466.4	2522.5	3494.4	56
IS 7444	4448.2	2700.6	3574.4	61
IS 2177	3096.6	2092.6	2594.6	68
IS 12587	2237.8	1657.0	1947.4	74
IS 12656	2639.8	1702.6	2171.2	64
RRR Quadroon	4460.3	3108.6	3784.4	70
TX 09	3970.7	3060.3	3515.5	77
IS 6895	2670.3	2093.5	2381.9	78
IS 7864	4496.7	3368.8	3932.8	75
Susceptible Mean	3608.7	2478.5	3046.7	69
RS 626	5821.1	4493.7	5157.4	77
RS 610	5933.1	4152.0	5042.6	70
CK 60	3770.8	2803.2	3287.0	74
DK C42Y	5037.9	4427.1	4732.5	88
DK C46	5361.6	4097.5	4729.6	77
TX 415	4212.3	3045.3	3628.8	72
Check Mean	5022.8	3836.5	4429.6	76
All Varieties	4290.2	3010.9	3652.4	70

Table 5. Observed t values of yield in comparing various groups based on water treatment levels and/or susceptibility and tolerance of entries (determined from 1979 Yuma irrigation gradient study) at Marana, Arizona in 1980.

Groups Tested	Mean Yield (kg/ha)	Degrees of Freedom	t Value
1 2	4482.4 2992.8	177	12.41**
1 4	4482.4 3608.7	178	6.44**
2 5	2992.8 2478.5	178	4.30**
4 5	3608.7 2478.5	179	8.36**
3 6	3733.4 3046.7	358	6.02**
7 8	4040.7 2735.6	358	13.34**

Group 1 = tolerant entries, wet treatment

Group 2 = tolerant entries, dry treatment

Group 3 = tolerant entries, wet and dry treatments

Group 4 = susceptible entries, wet treatment

Group 5 = susceptible entries, dry treatment

Group 6 = susceptible entries, wet and dry treatments

Group 7 = tolerant and susceptible entries, wet treatment

Group 8 = tolerant and susceptible entries, dry treatment

**Values are significant at the 1% level tolerant varieties were significantly higher than the yield means of the susceptible varieties in both water levels. In addition, plants grown in the wet treatment yielded significantly higher than plants in the dry treatment.

These data suggest that grain sorghum yields are significantly reduced when the application of irrigation water is reduced only as much as 29%. These results also suggest that the 1979 Yuma Irrigation Gradient was, in fact, fairly accurate in terms of predicting what could be called drought tolerant and drought susceptible varieties.

Table 6 ranks the yields in four different ways: by wet, dry and mean rank and by the dry/wet percentage. Only dry/wet percentage does not support the grouping of tolerant and susceptible that were made from the 1979 Yuma Irrigation Gradient study. Blum (1973) maintains that a minimal reduction in yield under water stress as compared to non-stress conditions is the best way for measuring drought resistance "in agronomically-adapted high performance hybrids." The data from Tables 4, 5 and 6 indicate that this is not true for grain sorghum varieties but is true for the six checks, four of which are hybrids. These data indicate, therefore, that there is no connection between the dry/wet percentage and the other grain yield results. A correlation (Spearman's Coefficient of Rank Correlation) of the rankings of the six checks, however, shows an r value of +.47 for the dry/wet precentage vs. the dry yield rank.

Plant Height. Plants in the wet treatment plots were taller than the same genotypes in the dry treatment plots (Table 7). Water stress in the dry plot reduced plant height an average of 15% with a

Table 6 Rankings of yield for twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Rank*			
Variety	Dry	Wet	Dry/Wet %	Mean
Martin	7	9	8	8
RB 60	9	13	5	12
Feterita	14	11	18	14
Combine Hegari	11	14	3	13
Double Dwarf Sooner	8	2	14	3
TX 414	4	10	5	7
MP 10	10	4	16	6
TX 04	2	3	9	2
Double Dwarf 38	1	1	12	1
Tolerant Mean	7.3	6.3	10.0	7.3
Custer	13	6	17	11
IS 7444	12	8	14	9
IS 2177	16	15	11	15
IS 12587	18	18	5	18
IS 12656	17	17	12	17
RRR Quadroon	5	7	9	5
TX 09	6	12	2	10
IS 6895	15	16	1	16
IS 7864	3	5	3	4
Susceptible Mean	11.7	11.6	8.2	11.7

* 1 = highest rank

18 = lowest rank

Table 7. Mean plant heights of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Plant Height (cm)		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	115.0	96.5	105.7
RB 60	119.4	103.1	111.2
Feterita	237.7	183.6	210.6
Combine Hegari	124.4	108.9	116.6
Double Dwarf Sooner	113.8	93.3	103.6
TX 414	80.3	72.3	76.3
MP 10	125.1	103.8	114.4
TX 04	113.2	98.1	105.6
Double Dwarf 38	125.5	98.3	111.9
Tolerant Mean	128.3	106.4	117.3
Custer	132.0	101.5	116.8
IS 7444	105.7	90.8	98.2
IS 2177	108.3	103.7	106.0
IS 12587	129.2	109.3	119.2
IS 12656	115.1	105.2	110.2
RRR Quadroon	189.4	154.8	172.1
TX 09	103.0	94.0	98.5
IS 6895	70.6	61.9	66.2
IS 7864	108.9	100.7	104.8
Susceptible Mean	130.1	102.4	116.4
RS 626	122.5	103.8	113.2
RS 610	127.6	106.0	116.8
CK 60	118.8	99.4	109.1
DK C42Y	127.1	103.3	115.2
DK C46	114.2	102.5	108.4
TX 415	81.3	68.9	75.1
Check Mean	115.2	97.3	106.3
All Varieties	121.2	102.6	111.9

range of 4% (IS 2177) to 23% (Feterita and Custer). Tolerant varieties were reduced in height by an average of 16% while susceptible varieties decreased an average of 12% from the wet to the dry treatment. The six checks were reduced in height by an average of 15%.

There were highly significant differences in height in the entry x water level interaction. There was also a strong trend (91% probability) toward significance between the two water levels as reflected in plant height. Table 8 shows that there were significant differences between wet and dry, between tolerant wet and tolerant dry, between susceptible wet and susceptible dry and between tolerant and susceptible groups.

Days to 50% Bloom. There was virtually no difference in the average days to 50% bloom between the wet and dry treatment plots--68.2 and 68.1 for wet and dry respectivley (Table 9). There were no significant differences in days to 50% bloom with respect to tolerant-susceptible groups or water levels (Table 8).

300-Seed Weight. The mean 300-seed weight over all of the twenty-four varieties was greater in the dry treatment plots than in the wet plots (Table 10). The dry/wet percentages were 101%, 94%, 101% and 97% for all varieties, checks, susceptible varieties and tolerant varieties, respectively.

According to the F test, there was significant entry x water level interaction. The t tests showed significant differences between tolerant and susceptible and between tolerant wet and susceptible wet varieties (Table 8).

Table 8. Observed t values from comparing various grain sorghum groups based on water treatment levels and/or susceptiblilty and tolerance of entries to moisture stress at Marana, Arizona in 1980.

Morphological Characteristic	Groups Tested					
	1,2	1,4	2,5	4,5	3,6	7,8
Grain Yield	12.41**	6.44**	4.30**	8.36**	6.02**	13.34**
Plant Height	4.02**	1.87	.97	3.72*	2.00*	5.43**
Days to 50% Bloom	.15	.41	1.22	1.03	1.23	.30
300-Seed Weight	.85	2.60*	1.76	.15	3.10**	.41
Grain Test Weight	1.05	2.40	2.34*	.56	3.35**	1.00
Head Exsertion	5.19**	.17	1.61	2.56*	1.23	5.15**
Panicle Length	2.61**	.86	.07	1.75	.55	3.10**
Plants/Hectare	.19	2.37*	2.84**	.79	3.69**	.62
Heads/Hectare	4.88**	1.04	.06	5.35**	.68	7.09**
Weight/Head	5.20**	4.76**	3.98**	4.53**	5.81**	6.55**

Group 1 = tolerant entries, wet treatment
Group 2 = tolerant entries, dry treatment
Group 3 = tolerant entries, wet and dry treatments
Group 4 = susceptible entries, wet treatment
Group 5 = susceptible entries, dry treatment
Group 6 = susceptible entries, wet and dry treatments
Group 7 = tolerant and susceptible entries, wet treatment
Group 8 = tolerant and susceptible entries, dry treatment

* significant at 5% level
**significant at 1% level

Table 9. Mean days to 50 percent bloom of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Days to 50 Percent Bloom		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	68.5	69.0	68.8
RB 60	66.2	64.7	65.4
Feterita	78.2	82.3	80.0
Combine Hegari	86.4	92.0	89.0
Double Dwarf Sooner	62.6	61.8	62.2
TX 414	66.2	65.5	65.9
MP 10	68.0	67.1	67.2
TX 04	67.3	66.9	67.0
Double Dwarf 38	62.1	61.3	61.7
Tolerant Mean	68.7	69.0	68.8
Custer	80.0	75.7	77.8
IS 7444	71.0	71.5	71.3
IS 2177	67.2	67.2	66.0
IS 12587	76.0	65.4	74.0
IS 12656	66.0	73.0	65.8
RRR Quadroon	68.8	65.7	67.9
TX 09	69.0	67.4	69.8
IS 6895	64.1	70.0	62.6
IS 7864	74.5	60.9	74.5
Susceptible Mean	68.1	67.0	67.5
RS 626	65.9	74.5	66.6
RS 610	65.9	66.4	65.8
CK 60	73.0	65.7	70.8
DK C42Y	68.0	70.0	68.0
DK C46	67.8	68.0	67.3
TX 415	76.0	67.0	73.6
Check Mean	69.4	68.6	69.0
All Varieties	68.2	68.1	68.2

Table 10. Mean 300-seed weights of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	300-Seed Weight (g)		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	7.14	6.64	6.89
RB 60	7.24	6.87	7.05
Feterita	11.47	9.88	10.67
Combine Hegari	6.95	6.33	6.64
Double Dwarf Sooner	8.27	8.52	8.39
TX 414	8.01	8.14	8.08
MP 10	5.67	5.90	5.78
TX 04	7.51	7.42	7.47
Double Dwarf 38	8.99	9.35	9.17
Tolerant Mean	7.92	7.67	7.79
Custer	7.12	7.95	7.54
IS 7444	9.23	9.05	9.14
IS 2177	6.45	5.95	6.20
Is 12587	3.79	3.96	3.88
IS 12656	7.85	8.02	7.94
RRR Quadroon	8.36	7.87	8.12
TX 09	8.21	8.35	8.28
IS 6895	4.37	4.22	4.29
IS 7864	8.21	8.67	8.44
Susceptible Mean	7.07	7.12	7.09
RS 626	7.31	6.94	7.11
RS 610	7.75	7.11	7.43
CK 60	6.18	5.69	5.93
DK C42Y	8.14	7.67	7.90
DK C46	6.83	6.20	6.52
TX 415	8.23	8.23	8.23
Check Mean	7.41	6.97	7.19
All Varieties	7.47	7.58	7.52

<u>Grain Test Weight</u>. Test weights were affected only slightly by the different treatments (Table 11). In the dry treatment/wet treatment percentage, five entries were greater than 100%, eleven were 100% and eight were less than 100% with the range being 97% to 101%. Tolerant vs. susceptible and tolerant dry vs. susceptible dry treatments showed significant differences with the t test (Table 8).

<u>Head exsertion</u>. Plants in the wet treatment plots had longer head exsertion than those in dry treatment plots, with the exception of one check (RS 610) which had an 8% increase in the dry treatment (Table 12). Moisture stress in the dry plots reduced head exsertion by an average of 30% with a range of 5% (IS 2177) to 100% (IS 7864). Tolerant varieties decreased by an average of 61% while susceptible varieties decreased by an average of 58% from the wet to the dry treatment. The six checks were reduced by an average of 28%.

There was a significant entry x water level interaction and a trend (84.5% probability) toward significance between the two water levels. Table 8 shows that there were highly significant differences between wet and dry, between tolerant wet and tolerant dry and between susceptible wet and susceptible dry entries.

<u>Panicle Length</u>. This measurement was longer in the wet treatment plots than in the dry treatment plots in seventeen cases, shorter in six cases and the same in one case (Table 13). Moisture stress in the dry plots decreased panicle length by an average of 7%. Change from wet plots to dry plots ranged from +6% (DK C42Y) to -23% (TX 414). Tolerant and susceptible varieties decreased by an average of 10.3% and

Table 11. Mean grain test weights of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Grain Test Weight (kg/hl)		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	76.2	77.1	76.6
RB 60	73.2	71.8	72.5
Feterita	75.9	73.8	74.8
Combine Hegari	76.0	74.6	75.3
Double Dwarf Sooner	71.8	72.2	72.0
TX 414	73.1	73.6	73.4
MP 10	77.6	76.8	77.2
TX 04	74.8	74.8	74.8
Double Dwarf 38	73.7	74.4	74.0
Tolerant Mean	74.7	74.3	74.5
Custer	75.5	75.1	75.3
IS 7444	74.4	73.6	74.0
IS 2177	77.9	76.6	77.2
IS 12587	72.0	72.0	72.0
IS 12656	72.3	72.3	72.3
RRR Quadroon	73.7	73.6	73.7
TX 09	71.9	71.9	71.9
IS 6895	67.4	67.5	67.4
IS 7864	76.5	75.9	76.2
Susceptible Mean	73.5	73.2	73.4
RS 626	74.4	74.2	74.3
RS 610	74.3	74.3	74.3
CK 60	75.3	75.0	75.2
DK C42Y	75.7	75.7	75.7
DK C46	78.0	78.0	78.0
TX 415	74.7	75.7	75.2
Check Mean	75.4	75.5	75.5
All Varieties	74.4	74.2	74.3

Table 12. Mean lengths of head exsertion of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

Variety	Head Exsertion (cm) Wet Treatment	Dry Treatment	Mean
Martin	12.67	9.17	10.92
RB 60	11.83	11.17	11.50
Feterita	9.50	7.67	8.58
Combine Hegari	1.83	.67	1.25
Double Dwarf Sooner	14.50	12.83	13.67
TX 414	10.67	4.17	7.42
MP 10	13.67	3.50	8.58
TX 04	11.67	7.33	9.50
Double Dwarf 38	14.50	4.50	9.50
Tolerant Mean	11.20	6.78	8.99
Custer	11.00	2.67	6.83
IS 7444	10.00	7.67	8.83
IS 2177	14.50	13.83	14.17
IS 12587	14.83	13.33	14.08
IS 12656	16.67	15.33	16.00
RRR Quadroon	12.83	9.67	11.25
TX 09	6.17	1.00	3.58
IS 6895	15.50	12.67	14.08
IS 7864	.83	.00	.42
Susceptible Mean	11.37	8.46	9.92
RS 626	13.75	10.33	11.70
RS 610	12.67	13.67	13.17
CK 60	10.83	6.33	8.58
DK C42Y	13.17	11.17	12.17
DK C46	11.17	10.33	10.75
TX 415	5.00	.83	2.92
Check Mean	11.10	8.77	9.94
All Varieties	11.32	7.60	9.55

Table 13. Mean panicle lengths of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Panicle Length (cm)		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	24.5	21.5	23.0
RB 60	26.7	25.3	26.0
Feterita	20.7	17.0	18.8
Combine Hegari	21.2	19.0	20.1
Double Dwarf Sooner	16.8	16.0	16.4
TX 414	21.5	16.5	19.0
MP 10	26.5	26.5	26.5
TX 04	24.7	23.2	23.9
Double Dwarf 38	17.8	15.3	16.6
Tolerant Mean	22.3	20.0	21.2
Custer	21.7	22.3	22.0
IS 7444	25.5	25.0	25.3
IS 2177	23.5	18.3	20.9
IS 12587	19.0	19.8	19.4
IS 12656	24.2	20.8	22.5
RRR Quadroon	17.0	15.2	16.1
TX 09	23.5	21.8	22.7
IS 6895	16.5	13.5	15.0
IS 7864	23.0	24.0	23.5
Susceptible Mean	21.5	20.1	20.8
RS 626	24.2	21.5	22.6
RS 610	23.2	21.3	22.2
CK 60	18.2	18.5	18.3
DK C42Y	23.8	25.2	24.5
DK C46	22.2	23.3	22.8
TX 415	20.2	18.0	19.1
Check Mean	22.0	21.3	21.6
All Varieties	21.9	20.4	21.1

7.0%, respectively. The six checks were reduced only by an average of 3.0% from wet to dry plots.

There was a significant entry x water level interaction with panicle length. There was also a strong trend (90% probability) toward significance between the two water levels. As Table 8 shows, there were significant differences in panicle length between wet and dry and between tolerant wet and tolerant dry entries.

Plant Population. The dry treatment plots had slightly more plants/ha than did the wet treatment plots (Table 14). The dry/wet percentages were 100%, 98%, 102% and 101% for all varieties, checks, susceptible varieties and tolerant varieties, respectively.

The tolerants and the susceptibles produced very different plant populations (Table 8): there was significant difference between their means under the wet, the dry and under both water treatments combined.

Head number. There were 15% more sorghum heads per hectare in the wet treatment than there were in the dry treatment (Table 15). The dry/wet percentages showed 85% for all twenty-four varieties, 80% for checks, 87% for susceptible varieties and 85% for tolerant varieties.

Head number is the only agronomic measurement taken that showed a significant difference (at the 5% level) between the two water levels. The F test also revealed a highly significant interaction between entry and water level.

Wet vs. dry, tolerant wet vs. tolerant dry and susceptible wet vs. susceptible dry were highly significant when the t test was used.

Table 14. Mean plant populations of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Plants Per Hectare		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	150,640	150,774	150,707
RB 60	135,179	135,045	135,112
Feterita	76,765	84,025	80,395
Combine Hegari	113,803	121,063	117,433
Double Dwarf Sooner	103,115	103,250	103,183
TX 414	151,178	149,968	150,573
MP 10	154,539	152,253	153,396
TX 04	98,141	117,702	107,922
Double Dwarf 38	101,569	79,051	90,310
Tolerant Mean	120,548	121,459	121,003
Custer	158,101	158,438	158,269
IS 7444	153,060	156,690	154,875
IS 2177	130,003	134,373	132,188
IS 12587	119,786	122,811	121,298
IS 12656	133,701	135,852	134,776
RRR Quadroon	155,077	157,093	156,085
TX 09	101,166	102,443	101,805
IS 6895	123,550	129,802	126,676
IS 7864	100,359	103,115	101,737
Susceptible Mean	130,534	133,402	131,968
RS 626	133,028	126,344	129,936
RS 610	151,850	151,043	151,447
CK 60	159,110	160,118	159,614
DK C42Y	161,261	161,328	161,294
DK C46	159,580	159,647	159,614
TX 415	156,824	152,253	154,539
Check Mean	153,609	151,872	152,741
All Varieties	132,557	133,541	133,049

Table 15. Mean head numbers of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Heads Per Hectare		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	144,657	124,693	134,675
RB 60	129,667	113,602	121,635
Feterita	227,876	173,629	200,753
Combine Hegari	146,540	115,618	131,079
Double Dwarf Sooner	149,833	119,315	134,574
TX 414	141,633	135,381	138,507
MP 10	169,798	144,187	156,992
TX 04	106,409	103,989	105,199
Double Dwarf 38	135,448	103,989	119,720
Tolerant Mean	150,207	126,045	138,126
Custer	142,103	101,435	121,769
IS 7444	143,716	129,936	136,826
IS 2177	160,387	136,994	148,691
IS 12587	130,003	134,911	132,457
IS 12656	131,684	112,190	121,937
RRR Quadroon	148,489	128,316	138,933
TX 09	123,080	104,930	114,005
IS 6895	188,149	165,765	176,957
IS 7864	141,095	122,273	131,684
Susceptible Mean	145,412	126,238	135,901
RS 626	132,491	117,837	125,164
RS 610	146,472	124,626	135,549
CK 60	152,186	128,525	140,355
DK C42Y	166,638	133,096	149,867
DK C46	144,859	125,231	135,045
TX 415	136,927	119,920	128,424
Check Mean	146,596	124,872	135,734
All Varieties	147,541	124,872	136,695

Head Weight. Weight/head in the wet treatment plots was higher than in the dry treatment plots for all entries except one--DK C42Y (Table 16). The average decrease, for all varieties, from wet to dry treatments was 18%. Reduction in weight/head was 22% for tolerant varieties, 21% for susceptible varieties and 10% for checks.

There was a highly significant entry x water level interaction and a trend (probability of 86%) toward a significant difference in the water levels. All of the tolerant, susceptible and water level groupings were significantly different at the 1% level of probability (Table 8).

Correlations. Correlations (r) were tested with various combinations of morphological characteristics (Table 17). The most obvious observation is that grain yield and head weight are highly correlated. Figures 5, 6 and 7 show selected correlations between grain yield and head weight, with r values of +.88, +.89 and +.86 for wet, dry and all treatments, respectively.

These data also indicate that the grain yield of the drought tolerant varieties is negatively (and significantly) correlated with days to 50% bloom and with plants/ha. Grain yield of the susceptible varieties, however, shows a positive correlation to these two characteristics. These relationships are illustrated in Figures 8 through 14. Given the extremely small differences in days to 50% bloom between the tolerant and susceptible entries and the wet and dry treatments (Tables 8 and 9) and given the above correlations, the results are inconclusive regarding the connection between days to 50% bloom and grain yield.

Table 16. Mean weights of heads of twenty-four grain sorghum varieties under wet and dry treatments at Marana, Arizona in 1980.

	Weight Per Head (g)		
Variety	Wet Treatment	Dry Treatment	Mean
Martin	30.1	25.7	27.9
RB 60	30.0	25.2	27.6
Feterita	18.4	12.6	15.5
Combine Hegari	25.1	24.2	24.7
Double Dwarf Sooner	32.9	25.3	29.1
TX 414	30.4	23.5	26.9
MP 10	27.7	19.7	23.7
TX 04	46.2	33.3	39.8
Double Dwarf 38	42.8	34.2	38.5
Tolerant Mean	31.5	24.9	28.2
Custer	31.5	25.1	28.3
IS 7444	31.1	20.7	25.9
IS 2177	19.5	15.2	17.3
IS 12587	17.5	12.8	15.1
IS 12656	20.2	15.0	17.6
RRR Quadroon	30.5	23.9	27.4
TX 09	32.3	29.5	30.9
IS 6895	14.3	12.6	13.4
IS 7864	32.3	27.6	29.9
Susceptible Mean	25.5	20.2	22.8
RS 626	43.9	38.1	41.0
RS 610	40.7	34.0	37.3
CK 60	24.9	21.8	23.4
DK C42Y	30.3	34.3	32.3
DK C46	37.1	32.8	35.0
TX 415	31.3	25.7	28.4
Check Mean	34.7	31.1	32.9
All Varieties	30.1	24.7	27.4

Table 17. Coefficient of correlation (r) of morphological characteristics of 18 grain sorghum varieties classified as tolerant or susceptible and under two water levels in Marana, Arizona in 1980.

Correlation	Classification								
	Wet	Dry	Tol.	Susc.	Tol. Wet	Tol. Dry	Susc. Wet	Susc. Dry	All
Yield vs. Days to 50% Bloom	-.17	-.06	-.32**	.50**	-.58**	-.31	.56**	.47*	-.09
Yield vs. Panicle Length	-.19	-.02	-.20	.05	.48**	-.28	-.15	-.04	-.01
Yield vs. Plants/Hectare	-.44**	-.20	-.32**	.42*	-.57**	-.27	.48	.36	-.27**
Yield vs. Heads/Hectare	-.25	-.20	.38**	.15	.02	.17	.01	-.06	.02
Yield vs. Weight/Head	.88**	.89**	.78**	.79**	.76**	.82**	.79**	.84**	.86**
Plants/Hectare vs. Heads/Hectare	.15	.51**	.38**	.05	.24	.64**	-.31	.29	.31**
Heads/Hectare vs. Weight/Head	-.63**	-.60**	-.26*	-.47**	-.62**	-.45**	-.60*	-.57*	-.45**
Panicle Length vs. Heads/Hectare	-.38	-.26	.05	-.49**	-.22	.18	-.58*	-.79**	-.22*
Panicle Length vs. Weight/Head	-.02	.03	-.24	.32	-.25	-.35*	.22	.35	.04

*significant at 5% level **significant at 1% level

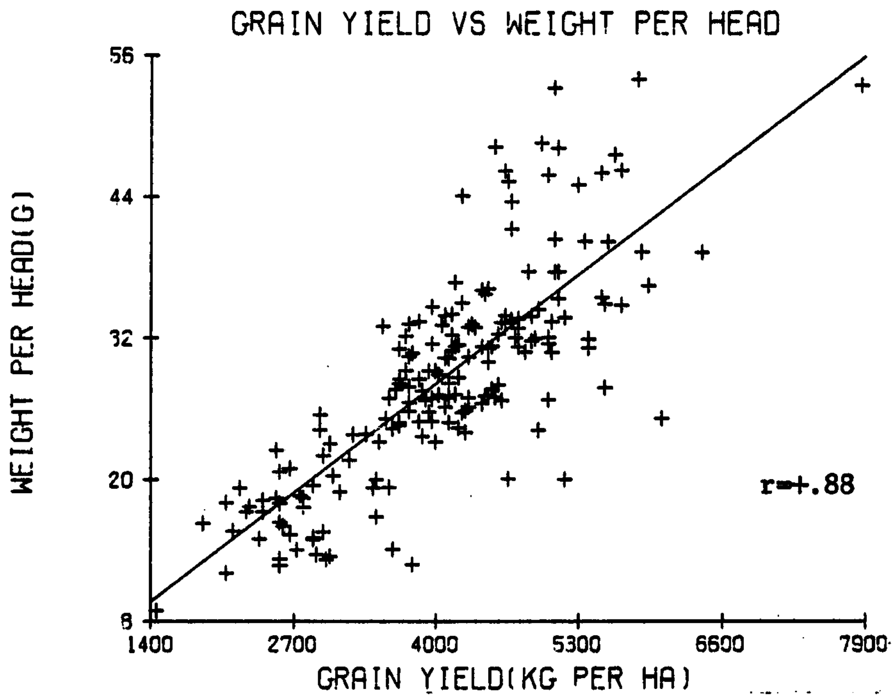

Figure 5. Correlation of grain yield vs. weight per head with all varieties, wet treatment.

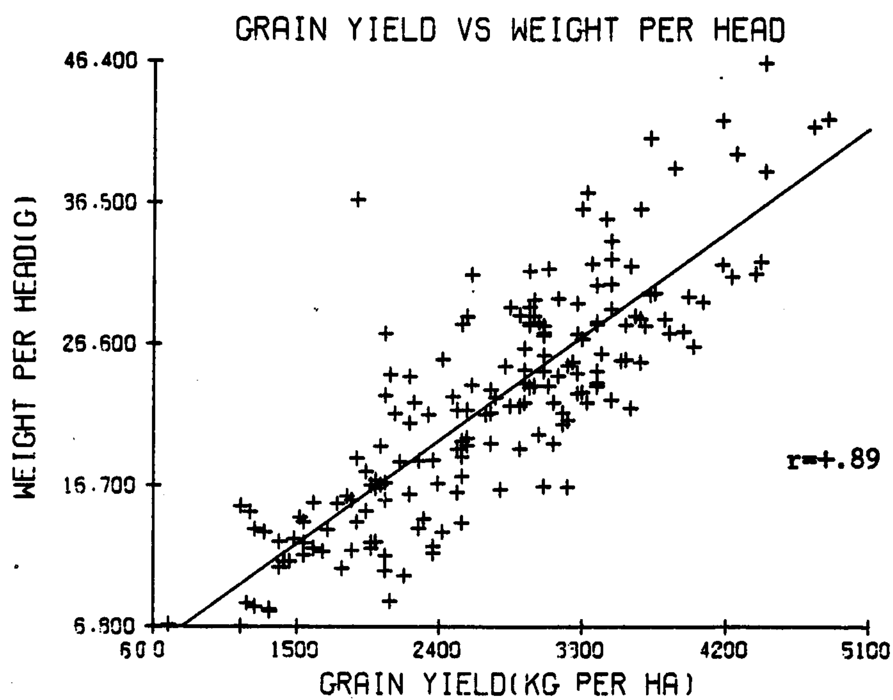

Figure 6. Correlation of grain yield vs. weight per head with all varieties, dry treatment.

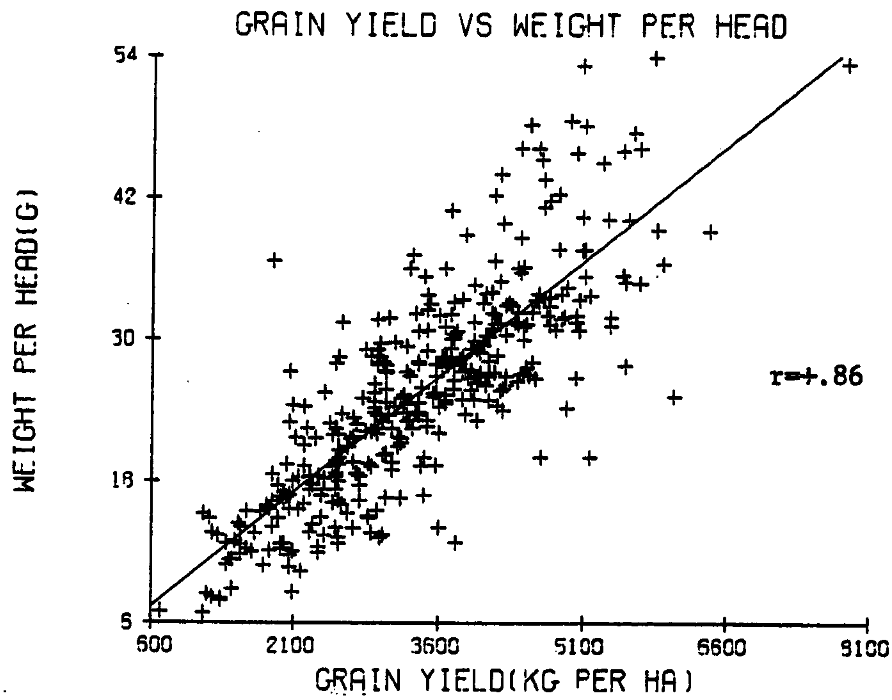

Figure 7. Correlation of grain yield vs. weight per head with all varieties, both water levels.

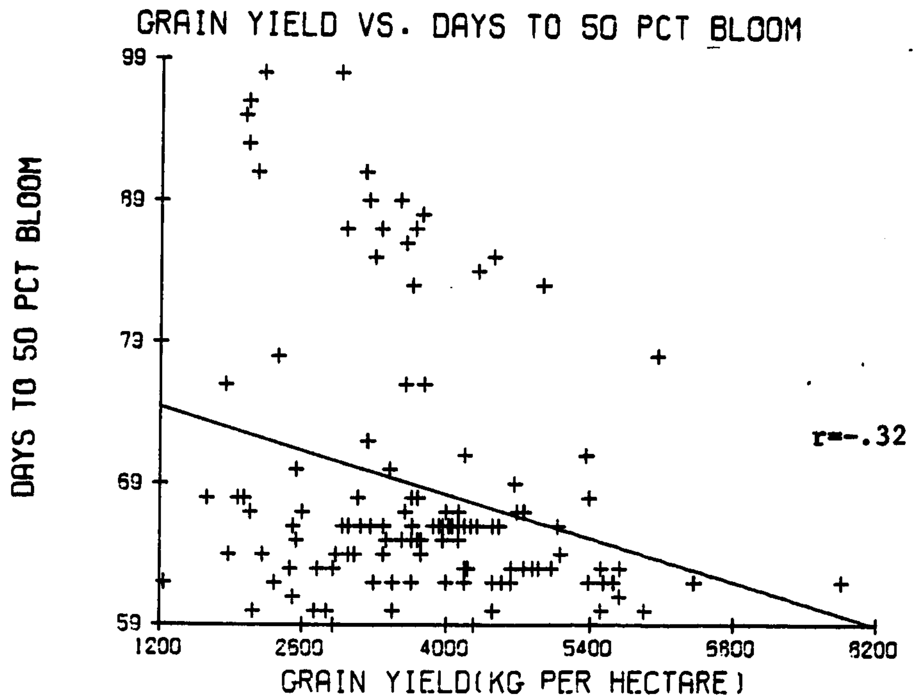

Figure 8. Correlation of grain yield vs. days to 50% bloom with tolerant varieties, both water levels.

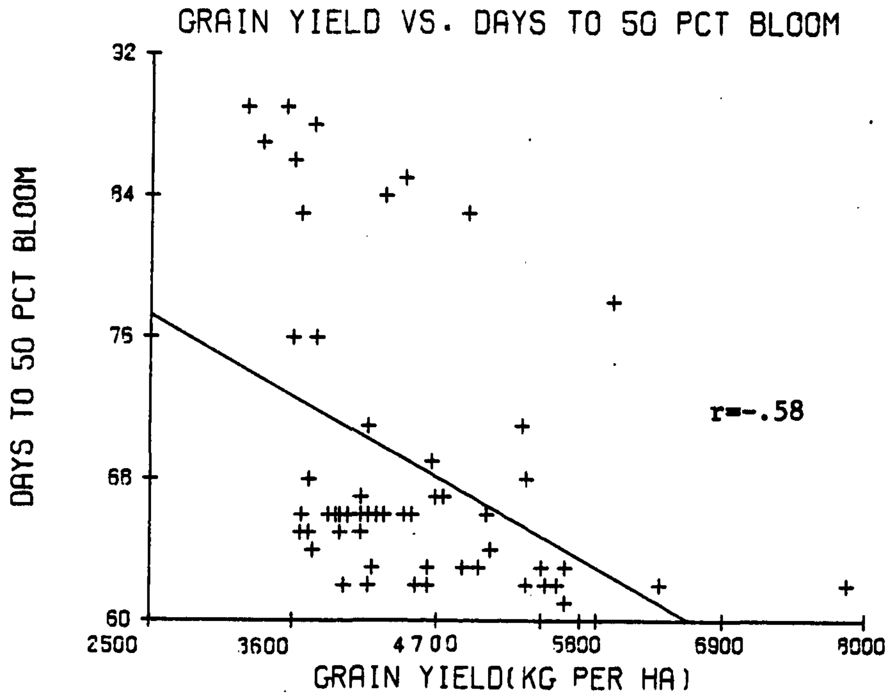

Figure 9. Correlation of grain yield vs. days to 50% bloom with tolerant varieties, wet treatment.

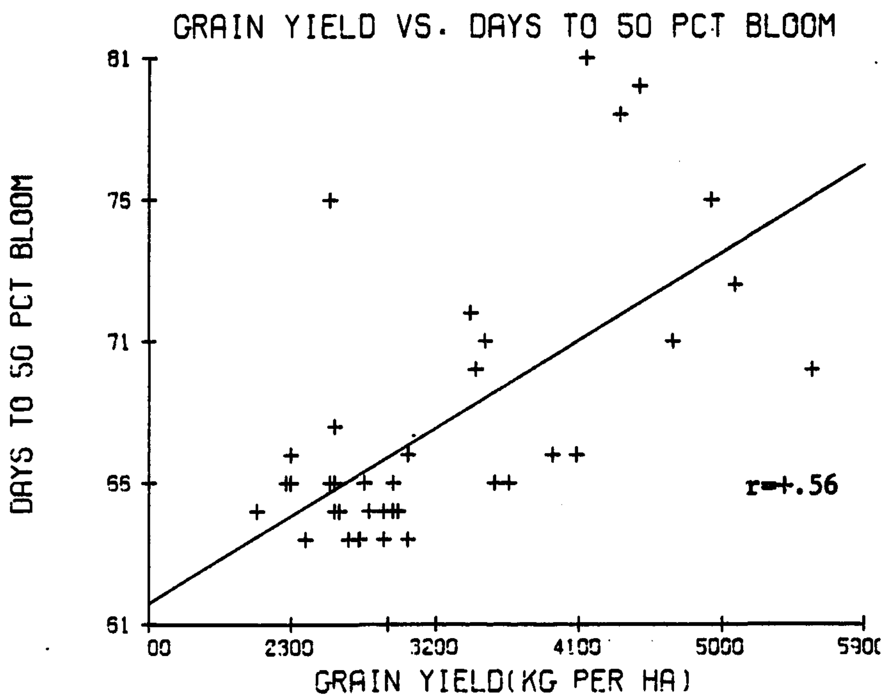

Figure 10. Correlation of grain yield vs. days to 50% bloom with susceptible varieties, wet treatment.

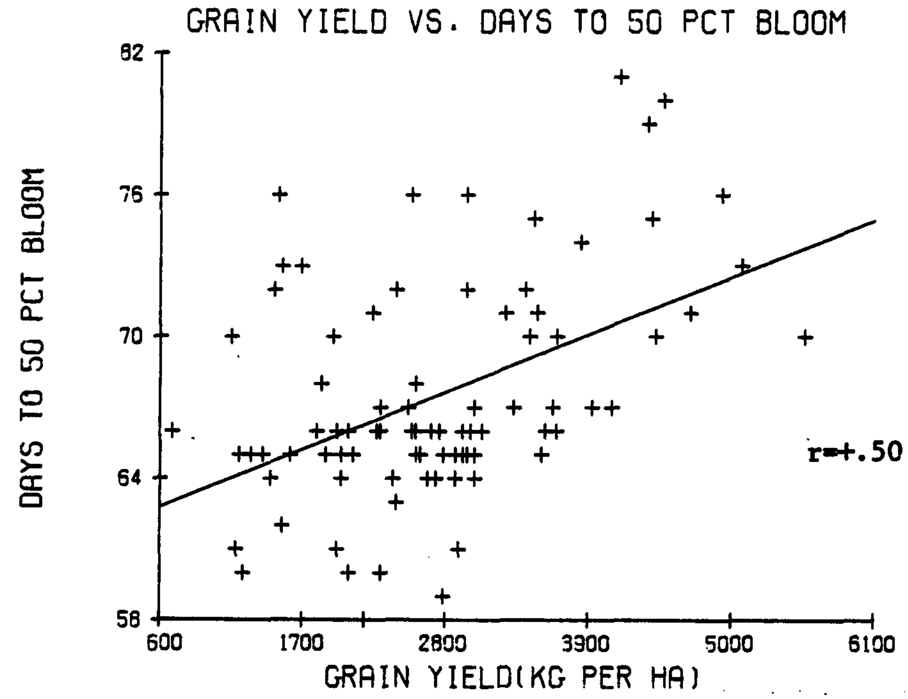

Figure 11. **Correlation of grain yield vs. days to 50% bloom with susceptible varieties, both water levels.**

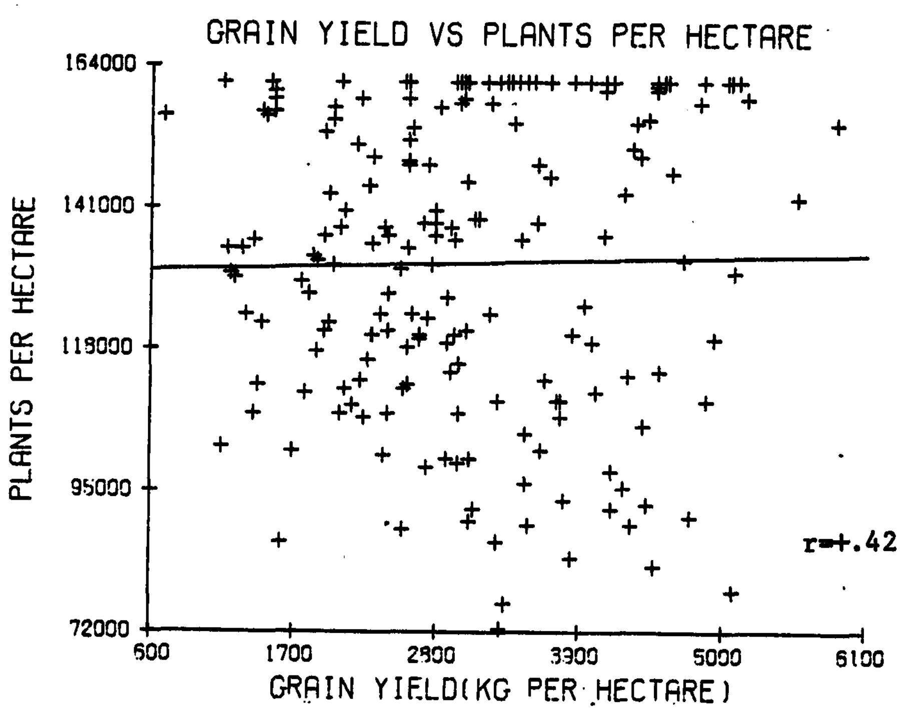

Figure 12. **Correlation of grain yield vs. plants per hectare with susceptible varieties, both water levels.**

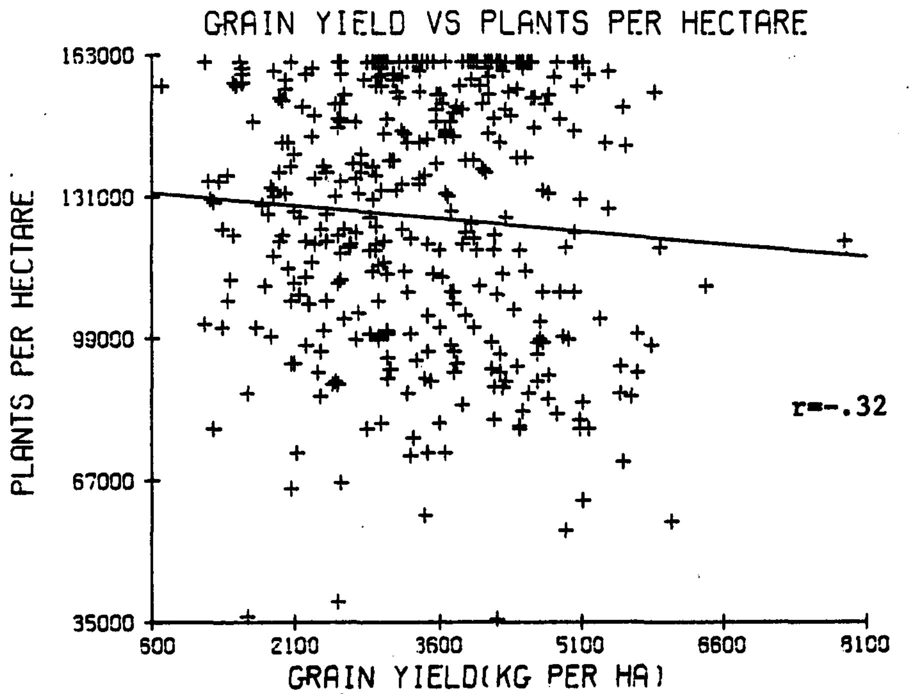

Figure 13. Correlation of grain yield vs. plants per hectare with tolerant varieties, both water levels.

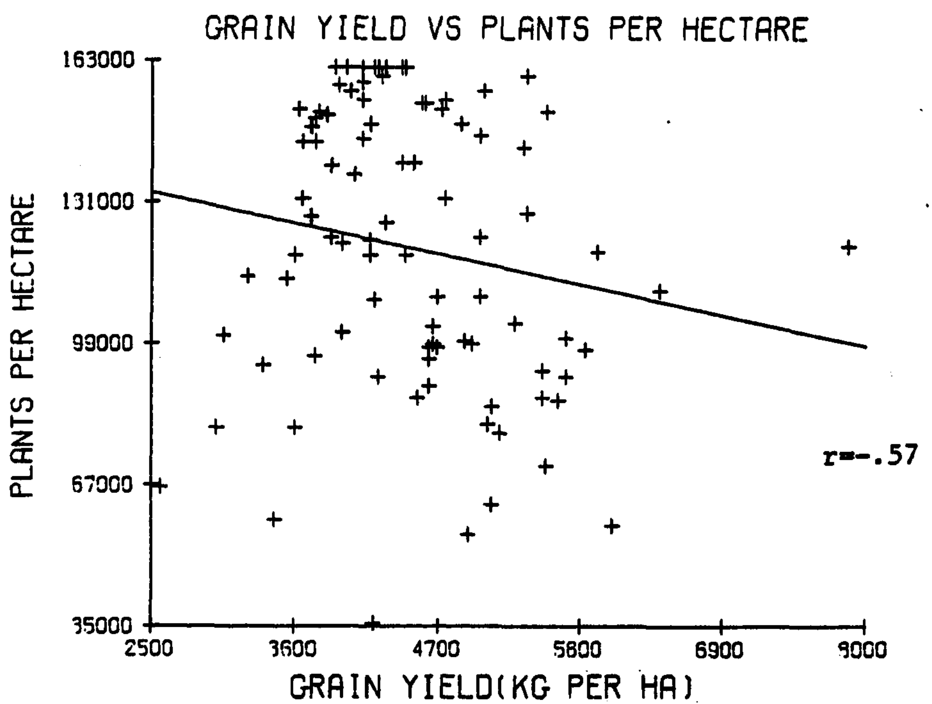

Figure 14. Correlation of grain yield vs. plants per hectare with tolerant varieties, wet treatment.

The correlations do indicate, however, that part of the reason for the increased yield in the tolerant vs. susceptible entries was because the tolerants had smaller plant populations with more heads/plant (i.e. more tillering) which allows for limited water to go more toward seed production and less toward the production of other dry matter in additional plants. While plants at a low density are able to tiller more than those at a high density (Blum, 1973), this study shows that more plants will produce a larger total number of heads than fewer plants will (Table 17, Figures 15 and 16).

Heads/ha vs. weight/head shows a high negative correlation (Table 17, Figures 17 and 18). The more heads produced by a given number of plants, the less each head will weigh because of limited water and photosynthates. The case of the check DK C42Y illustrates this well: it was the only entry to have a mean lower weight/head in the wet treatment than in the dry treatment; it compensated for this in the wet by producing 22% more heads than in the dry treatment.

Heads/ha is negatively correlated with panicle length (Table 17), suggesting that, as with heads/ha vs. weight/head, the more energy and water that is put into head production, the fewer heads there will be. These data show that this is especially true with the susceptible entries (Figures 19 and 20).

Blum (1973) found that moisture stress on sorghum plants resulted in decreased yield and heads/ha (less tillering) and increased grains/head and grains/branch. The findings in this study support Blum's first two conclusions; the last two measurements were not taken in Marana. In addition, this study shows that decreased weight/panicle

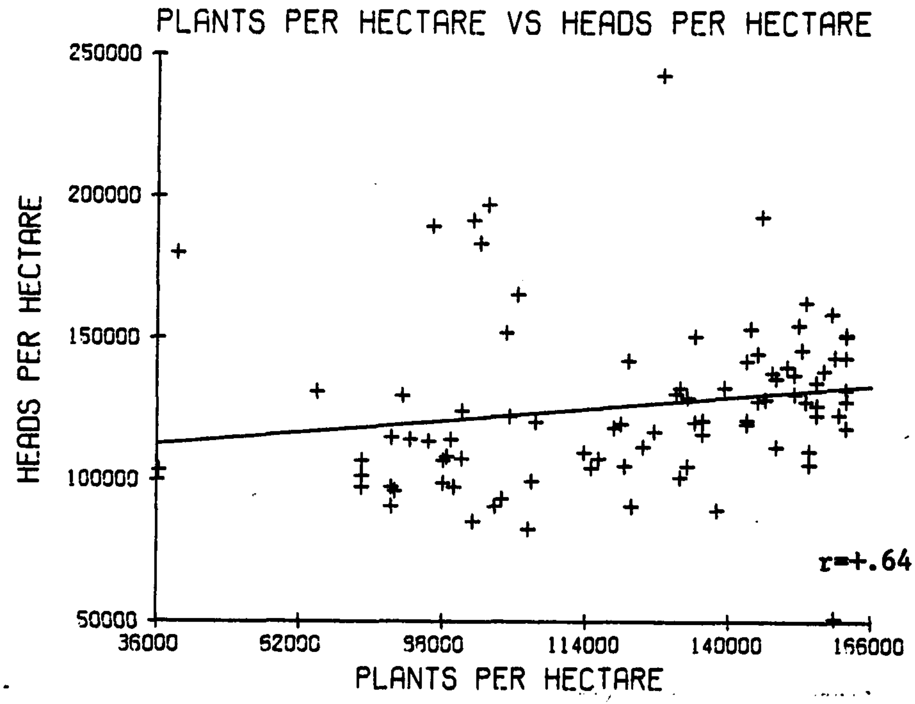

Figure 15. Correlation of plants per hectare vs. heads per hectare with tolerant varieties, dry treatment.

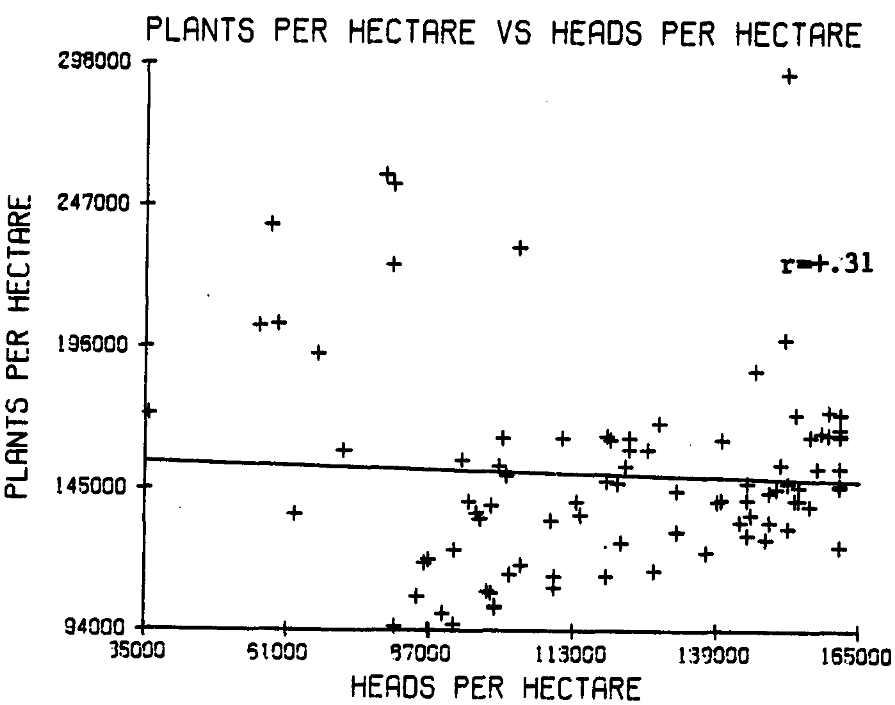

Figure 16. Correlation of plants per hectare vs. heads per hectare with all varieties, both water levels.

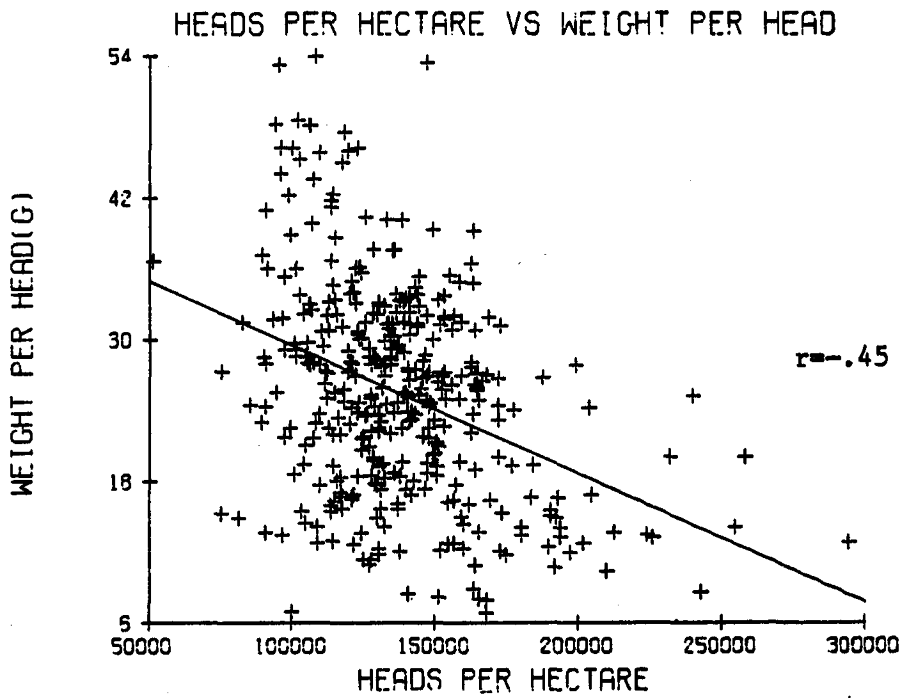

Figure 17. **Correlation of heads per hectare vs. weight per head with all varieties, both water levels.**

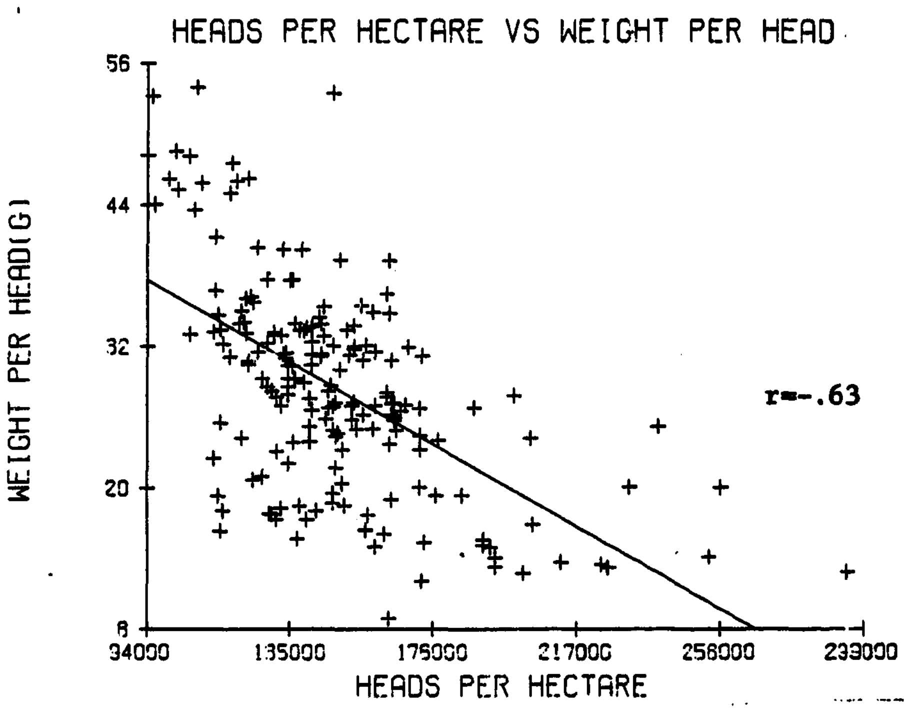

Figure 18. **Correlation of heads per hectare vs. weight per head with all varieties, wet treatment.**

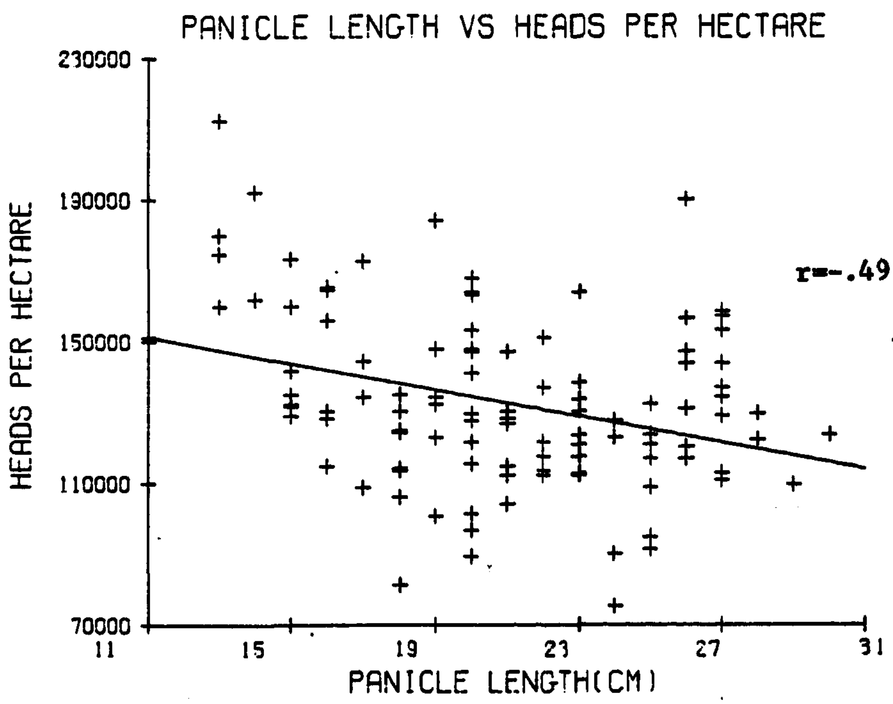

Figure 19. Correlation of panicle length vs. heads per hectare with susceptible varieties, both water levels.

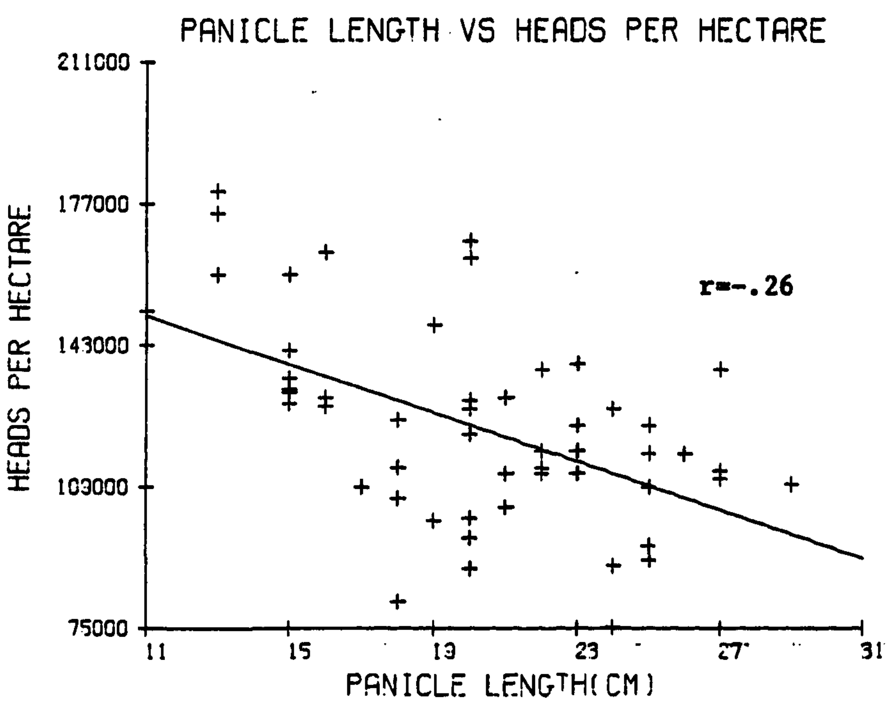

Figure 20. Correlation of panicle length vs. heads per hectare with all varieties, wet treatment.

results from moisture stress and is a major factor in yield reduction, overshadowing a slightly increased plant population in the water-stressed plots.

Blum concluded that tolerant grain sorghum varieties, i.e. those that had a minimal reduction in yield from non-stress to stress moisture conditions, tillered more than stress-susceptible ones. Data from this study do not support this as there was no difference in heads/ha from tolerant to susceptible plots.

Physiological Measurements

It bears repeating that there was no real distinction between wet and dry plots until July 28 when, for the first time, the designated "dry" treatment received less irrigation water than the designated "wet" treatment. The first of two physiological measurements was taken on July 23. The following discussion will refer to a wet treatment on July 23 (Date 1) to report data which show, for the most part though not entirely, that there was no moisture difference between wet and dry treatments until July 28.

Photosynthesis. Apparent photosynthesis was greater in the wet plots than in the dry plots on August 6 (Table 18). The overall dry/wet percentage on July 23 was 104% whereas the August 6 percentage was 71%.

On Date 1 there were no significant differences in the water level or in the water x entry interaction. On Date 2, however, there was significance between entries (1% level) and between the water levels (5% level). Date 1 showed that there were no significant tolerant-wet or wet-dry groups (Table 19). There was significance, however,

Table 18. Mean photosynthetic rates of ten grain sorghum varieties under wet and dry treatments on two dates at Marana, Arizona in 1980.

	Apparent Photosynthesis (mg CO_2/dm^2 $hour^{-1}$)						
	July 23			August 6			
Variety	Wet Treatment	Dry Treatment*	Mean	Wet Treatment	Dry Treatment	Mean	Overall Mean
TX 04	42.9	46.5	44.7	42.4	38.7	40.6	42.6
Combine Hegari	41.3	42.7	42.0	34.0	16.2	20.1	31.0
Martin	42.1	37.1	39.6	43.5	20.4	32.0	35.8
MP 10	58.6	48.9	53.7	40.9	31.6	36.2	44.9
Double Dwarf 38	35.7	61.0	48.4	56.2	41.6	48.9	48.6
Tolerant Mean	44.1	47.1	45.6	43.2	29.7	36.4	41.0
IS 7444	49.3	49.5	49.4	48.8	37.7	43.2	46.3
IS 12587	57.5	39.9	48.7	42.1	30.6	36.4	42.6
Custer	46.2	51.0	48.6	48.0	24.9	36.4	42.5
Susceptible Mean	51.0	46.8	48.9	46.3	31.1	38.7	43.8
DK C42Y	43.8	41.0	42.4	43.1	33.3	38.2	40.3
RS 610	60.8	44.5	52.6	50.7	41.5	46.1	49.4
Check Mean	52.3	42.8	47.5	46.9	37.4	42.2	44.8
All Varieties	47.8	46.1	46.9	44.8	31.8	38.3	42.6

*Based on irrigation differences (Table 2) no dry treatment had yet been established by this date.

Table 19. Observed t values of physiological measurements from comparing various grain sorghum groups based on water treatment levels and/or susceptibility and tolerance of entries to moisture stress at Marana, Arizona in 1980.

	Physiological Measurement					
Groups Tested	Apparent Photosynthesis		Transpiration Rate		Leaf Diffusive Resistance	
	Date 1	Date 2	Date 1	Date 2	Date 1	Date 2
1 and 2	.63	2.69*	1.85	3.39**	.01	2.90**
1 and 4	1.22	.58	.72	.06	.43	.33
2 and 5	.07	.23	.74	1.47	.48	2.36*
4 and 5	.74	3.24**	1.27	3.49**	.09	2.94**
3 and 6	.89	.25	1.01	1.02	.63	2.01*
7 and 8	.08	3.97**	2.22*	4.85**	.06	3.79**

Group 1 =tolerant entries, wet treatment

Group 2 =tolerant entries, dry treatment

Group 3 =tolerant entries, wet and dry treatments

Group 4 =susceptible entries, wet treatment

Group 5 =susceptible entires, dry treatment

Group 6 =susceptible entries, wet and dry treatments

Group 7 =tolerant and susceptible entries, wet treatment

Group 8 =tolerant and susceptible entries, dry treatment

* significant at 5% level
**significant at 1% level

between the water levels overall, in the tolerants and in the susceptible varieties on Date 2.

Transpiration Rate. Rate of water loss through the stomates was greater in the wet plots than in the dry plots on August 6. As with the photosynthetic rate, the water stress on the dry plots is evident by this second date. The dry/wet percentage was 105% on July 23 and 74% on August 6 (Table 20).

On July 23 there were significant differences between the water levels and among the varieties, with no explanation for the former. August 6 data show significance among varieties and in the water x variety interaction. The difference in transpiration rate between wet and dry treatments is also shown in the t test (Table 19). For Date 2 there were highly significant differences between the water levels overall and in both the tolerant and susceptible treatment plots while there were no differences for Date 1. No significant differences were detected between the tolerant and susceptible varieties on either date.

Leaf Diffusive Resistance. This measurement was virtually the same in the wet and dry treatment plots on July 23. On August 6, however, the mean diffusive resistance of the dry plots was 192% that of the wet plots (Table 21).

For Date 2 the F test shows water, variety and water x variety all to be highly significantly different while the t test indicates that all but one of the groupings (tolerant wet vs. susceptible wet) resulted in significance. Although on Date 1 the t test showed no differences in the groupings, the F test did reveal a significant water level difference between the wet and dry means.

Table 20. Mean transpiration rates of ten grain sorghum varieties under wet and dry treatments on two dates at Marana, Arizona in 1980.

	Transpiration Rate (g x 10^{-6} cm^{-2} sec^{-1})						
	July 23			August 6			
Variety	Wet Treatment	Dry Treatment*	Mean	Wet Treatment	Dry Treatment	Mean	Overall Mean
TX 04	33.26	30.65	31.95	34.00	26.05	30.02	30.98
Combine Hegari	27.22	27.28	27.25	32.48	14.86	23.67	25.46
Martin	29.52	28.54	29.03	31.36	22.54	26.95	27.99
MP 10	31.90	29.98	30.94	33.85	27.39	30.62	30.78
Double Dwarf 38	33.11	30.19	31.65	26.02	32.23	29.12	30.38
Tolerant Mean	31.00	29.33	30.16	31.54	24.61	28.08	26.34
IS 7444	33.22	31.53	32.38	32.25	22.94	27.60	29.99
IS 12587	30.15	28.18	29.16	35.04	16.23	25.64	27.40
Custer	32.45	30.50	31.48	27.74	21.84	24.79	28.14
Susceptible Mean	31.94	30.07	31.01	31.51	20.34	26.01	28.51
DK C42Y	31.63	32.18	31.90	33.11	26.46	29.78	30.84
RS 610	33.87	31.19	32.53	33.46	26.56	30.01	31.27
Check Mean	32.75	31.68	32.22	33.28	26.51	29.90	31.06
All Varieties	31.63	30.02	30.82	31.93	23.71	27.82	29.32

*Based on irrigation differences (Table 2) no dry treatment had yet been established by this date.

Table 21. Mean rates of diffusive resistance of ten grain sorghum varieties under wet and dry treatments on two dates at Marana, Arizona in 1980.

	Diffusive Resistance (sec/cm)						
	July 23			August 6			
Variety	Wet Treatment	Dry Treatment*	Mean	Wet Treatment	Dry Treatment	Mean	Overall Mean
TX 04	.6550	.7067	.6808	.8617	.9750	.9184	.7996
Combine Hegari	.9100	.8233	.8666	.7900	2.2650	1.5275	1.1970
Martin	.7983	.7800	.7892	.7283	1.4050	1.0666	.9279
MP 10	.7217	.7317	.7267	.6233	.9800	.8016	.7642
Double Dwarf 38	.6883	.7300	.7092	1.0417	.7517	.8967	.8029
Tolerant Mean	.7547	.7543	.7545	.8090	1.2753	1.0422	.9993
IS 7444	.6500	.7100	.6800	.7517	3.1233	1.9375	1.3088
IS 12587	.8350	.7850	.8100	.6667	2.3250	1.4958	1.1529
Custer	.7183	.7233	.7208	.8983	1.4867	1.1925	.9566
Susceptible Mean	.7344	.7394	.7369	.7722	2.3117	1.5419	1.1394
DK C42Y	.7150	.7133	.7141	.7083	.9783	.8433	.7787
RS 610	.6833	.7000	.6916	.8500	1.0400	.9450	.8183
Check Mean	.6992	.7066	.7028	.7792	1.0092	.8942	.7985
All Varieties	.7375	.7403	.7389	.7920	1.5330	1.1625	.9507

*Based on irrigation differences (Table 2) no dry treatment had yet been established by this date.

The above physiological results demonstrate that moisture stress markedly reduces sorghum's photosynthetic and transpirational rates and increases its leaf diffusive resistance to water loss. In this study, from wet to dry treatment photosynthesis decreased 29% overall, 31% in the tolerant, 33% in the susceptible and 21% in the hybrid checks. Transpiration decreased 22%, 36% and 21% in the tolerants, susceptibles and checks, respectively. Diffusive resistance increased with the tolerants, susceptibles and checks by 58%, 199% and 29%, respectively, from wet to dry treatment. These data are from the August 6 date only.

These numbers indicate that: 1) the two hybrid checks were influenced markedly less by water stress as shown in photosynthetic rate and diffusive resistance than were the other varieties; and 2) only with leaf diffusive resistance was there a significant difference between tolerant and susceptible varieties.

Irrigation Gradient Study

Tables 22 and 23 show the results from the 1980 and 1981 Yuma Irrigation Gradient. In 1980 the tolerant and susceptible varieties formed viable heads an average of 9.9 m and 8.4 m , respectively, from the sprinkler line, a 16% difference. In 1981 the tolerant and susceptible varieties formed viable heads an average of 9.7 m and 9.3 m, respectively, from the sprinkler line, a 4% difference.

In 1981 the dry/wet percentage on plant height was 71.8% and 74.4% for the tolerants and susceptibles, respectively, a difference of 3.5%. No plant height measurements were taken in 1980.

Table 22. Agronomic data from eighteen grain sorghum varieties grown under an irrigation gradient system at Yuma, Arizona in 1980.

Variety	145 Day Ranking[1] H	M	L	Days to Anthesis	Distance from Sprinkler Line(m)[2]
Martin	2	2	1	85.5	15.3
RB 60	2	2	2	85.0	12.7
Feterita	2	2	2	86.0	7.7
Combine Hegari	2	2	2	81.0	15.3
Double Dwarf Sooner	3	2	2	83.0	7.7
TX 414	2	2	2	85.0	15.3
MP 10	2	2	2	85.0	0
TX 04	2	2	2	85.5	7.7
Double Dwarf 38	3	2	1	85.0	7.7
Tolerant Mean	2.2	2.0	1.8	84.6	9.9
Custer	3	2	2	85.5	15.0
IS 7444	2	2	2	87.0	15.3
IS 2177	3	2	2	86.0	13.8
IS 12587	2	2	2	86.0	7.7
IS 12656	2	1	1	83.5	0
RRR Quadroon	3	3	3	85.0	15.3
TX 09	3	2	1	85.5	0
IS 6895*	-	-	-	-	-
IS 7864	2	1	0	85.5	0
Susceptible Mean	2.5	1.9	1.6	85.5	8.4
All Varieties	2.3	1.9	1.7	85.0	9.2

[1]total plant development; 0=poorest, 5=best
H=high water level
M=medium water level
L=low water level

[2]of last viable formed head

* ommitted from 1980 planting

Table 23. Agronomic data from eighteen grain sorghum varieties grown under an irrigation gradient system in Yuma, Arizona in 1981.

Variety	Days to Anthesis	72-Day Rank[1]	Plant Height (cm) High[2]	Low	Distance from Sprinkler Line(m)[3]
Martin	62.0	2	41	31	8.0
RB 60	58.0	3	52	38	7.5
Feterita	59.0	4	75	20	14.0
Combine Hegari	-	1	42	28	0
Double Dwarf Sooner	54.0	4	47	30	14.0
TX 414	57.0	2	34	36	9.0
MP 10	62.0	3	43	38	12.0
TX 04	65.0	2	36	27	9.0
Double Dwarf 38	56.5	4	45	32	14.0
Tolerant Mean	59.2	2.8	46.1	31.1	9.7
Custer	83.0	1	43	37	5.5
IS 7444	54.0	4	53	41	14.0
IS 2177	65.0	2	40	27	9.0
IS 12587	71.5	1	52	28	4.5
IS 12656	65.0	2	38	25	7.0
RRR Quadroon	59.0	2	57	31	10.0
TX 09	65.0	2	50	36	8.5
IS 6895	55.0	3	28	27	14.0
IS 7864	58.0	3	34	33	13.0
Susceptible Mean	65.1	2.2	43.9	31.7	9.5
All Varieties	62.3	2.5	45.0	31.4	9.6

[1]total plant development; 1=poorest, 5=best

[2]level of water application

[3]of last viable formed head

These data do not support the tolerant-susceptible selections that were made from the 1979 irrigation gradient which were supported by the Marana yield data presented here. There are possible explanations for this:

1. In 1980 the planting date was in March. It is speculated by those involved in the project that the soil temperature was not sufficiently high at this time to be conducive to rapid seed germination. Consequently, stands were poor. Some reseeding was done at the time of thinning but the result was non-uniform stands. Also in 1980, the line sprinkler did not begin to function until late May, which meant that there was no water stress on the plants furthest from the sprinkler line until this time.

2. In 1981, because of frequent winds at the time of irrigation, the water applied to the field was not distributed as well as desired. This resulted in, for example, plants at the end of the rows on one side of the sprinkler line getting more water than plants at the ends of rows on the other side of the sprinkler line.

Attempts to correlate the 1980 and 1981 irrigation gradient distances from the sprinkler line to the last viable formed head with the 1980 Marana yield study data were unsuccessful. The 1979 Yuma irrigation study was the best predictor of yield based on the Marana results.

CHAPTER 5

SUMMARY AND CONCLUSIONS

In Marana, Arizona in 1980, twenty-four grain sorghum genotypes were planted in a total of 480 plots. Eighteen of these genotypes had been selected from ones grown under an irrigation gradient in Yuma, Arizona in 1979. Based on the Yuma results, nine of the selections were classified as tolerant of and nine were classified as susceptible to moisture stress. Six checks (four hybrids and two varieties) were also planted in Marana.

All entries in the Marana test were subjected to optimal and sub-optimal moisture conditions. The wet and dry treatments received a total amount of water of 41.91 and 33.02 cm/ha, respectively.

Various agronomic measurements were made on the plants in this study. Water stress reduced plant growth overall. Grain yield and head weights were particularly affected. The results from these two categories supported what Blum (1973) had found in analyzing grain sorghum genotypes under moisture stress for their components of yield.

The results on grain yield and weight per head, in particular, supported the selection of tolerant and susceptible varieties from the 1979 irrigation gradient. Significant differences were found between the means of the tolerant and susceptible varieties in grain yield, head weight, plant population, 300-seed weight, grain test weight and plant height.

Correlations were determined between various morphological characteristics. Grain yield and head weight were highly positively correlated in all treatments and tolerant-susceptible groups. Among tolerant varieties grain yield was negatively correlated with plants/hectare whereas it was positively correlated with the susceptible varieties. Among the tolerants, grain yield was also positively and significantly correlated with heads/hectare. This would indicate that the tolerant varieties were able to yield more than the susceptible ones by putting more heads on fewer plants (tillering) with a high weight for each head.

Transpiration, photosynthesis and leaf diffusive resistance were measured on two dates in the Marana field. Since there was no distinct dry water level treatment by the first date, conclusive analyses of data were limited to results from the second date. Moisture stress caused photosynthesis and transpiration to decrease by 29% and 26%, respectively, while leaf diffusive resistance increased by 92%. On the whole, the hybrid checks showed much fewer dramatic effects on their physiological functions from water stress than did the varieties. Only transpiration showed any difference in response to water stress between tolerant and susceptible varieties.

The same twenty-four varieties that were planted in Yuma in 1979 were again planted under the irrigation gradient in 1980 and 1981. The gradient was again effective in applying less amounts of water as the distance from the sprinkler increased. Plants further from the sprinkler line, then, had less growth and development. The results from the 1980 and 1981 gradient studies did not support the tolerant and susceptible variety selections that were made in 1979; neither did they support the results found in the Marana grain yield study. These differences in the irrigation gradient performance may be attributed to lack of adequate moisture stress in 1980 and irregular irrigations due to wind in 1981.

Conclusions that can be reached from these studies are:

1. Water stress has a marked effect not only on the grain yield of sorghum but on many of its morphological and physiological characteristics.

2. Various sorghum genotypes show a wide range of responses to water stress in yield and other morphological and physiological characteristics.

3. Sorghum hybrids were less affected by water stress than were varieties. Since the hybrids selected for this test were not bred for drought tolerance *per se*, it could be speculated that the heterosis in hybrids is responsible not only for increased yields but also for some tolerance of moisture stress.

4. An irrigation gradient system as described by Hanks, et al. (1976) can be an effective way, qualitatively at least, of predicting grain yields in field tests. The gradient does appear to need refining, however, based on the three years' data collected for this study. One year's data (1979) were very effective in predicting what could be called moisture stress tolerant and moisture stress susceptible grain sorghum varieties.

APPENDIX A

MEAN VALUES AND OBSERVED F VALUES OF DATA

Mean values of morphological characteristics of eighteen grain sorghum varieties classified as tolerant or susceptible to moisture stress and under two water levels at Marana, Arizona in 1980.

	Classification								
Morphological Characteristic	Wet	Dry	Tol.	Susc.	Tol. Wet	Tol. Dry	Susc. Wet	Susc. Dry	All
Grain Yield (kg/ha)	4046	2736	3733	3046	4482	2993	3609	2478	3390
Plant Height(cm)	129	104	117	116	128	106	130	102	117
Days to 50% Bloom	68.5	68.1	68.8	67.5	68.7	69.0	68.1	67.1	68.1
300-Seed Weight(g)	7.5	7.4	7.8	7.1	7.9	7.7	7.1	7.1	7.4
Grain Test Weight (kg/hl)	74.1	73.7	74.5	73.4	74.7	74.3	73.5	73.2	73.9
Head Exsertion(cm)	11.3	7.6	9.0	9.9	11.2	6.8	11.4	8.5	9.4
Panicle Length(cm)	21.9	20.1	21.2	20.9	22.3	20.0	21.5	20.1	21.0
Plants/Hectare ($x 10^2$)	125.5	127.4	121.0	132.0	120.5	121.5	130.5	133.4	126.5
Heads/Hectare ($x 10^2$)	147.8	126.2	138.1	135.9	150.2	126.0	145.4	126.3	137.0
Weight/Head(g)	28.5	22.5	28.2	22.9	31.5	24.9	25.5	20.2	25.5

Mean values of physiological measurements of eight grain sorghum varieties classified as tolerant of or susceptible to moisture stress and under two water levels on August 6 at Marana, Arizona in 1980.

Physiological Measurement	Wet	Dry	Tol.	Susc.	Tol. Wet	Tol. Dry	Susc. Wet	Susc. Dry	All
Apparent Photosynthesis (mg CO_2/dm^2 $hour^{-1}$)	44.3	30.3	37.0	38.1	43.4	29.7	46.1	31.0	42.4
Transpiration Rate (g x $10^{-6}/cm^2/sec$)	31.6	23.0	28.1	26.0	31.5	24.6	31.7	20.3	25.9
Leaf Diffusive Resistance (sec/cm)	.79	1.66	1.04	1.54	.81	1.28	.77	2.31	1.02

Observed F values of yield and other agronomic data of twenty-four grain sorghum varieties at Marana, Arizona in 1980.

	Morphological Characteristic									
Source of Variation	Grain Yield	Plant Height	50% Bloom	300-Seed Weight	Test Weight	Head Exsertion	Panicle Length	Plants/ Ha	Heads/ Ha	Weight/ Head
Water Level	38.7	41.2	2.29	16.1	76.5	16.1	35.9	.96	159*	19.3
Sorghum Variety	52.4**	398**	163**	206**	106**	30.5**	19.0**	72.7**	30.6**	64.9**
Block	.21	.23	276*	2.2	126	1.4	10.3	.49	.49	11.4
Water x Variety	3.86**	13.7**	3.9*	5.6**	2.9**	3.7**	1.6*	1.45	2.79**	2.9**

* significant at 5% level

**significant at 1% level

Observed F values of physiological measurements of ten grain sorghum varieties at Marana, Arizona in 1980.

Source of Variation	Physiological Measurement: Apparent Photosynthesis Date 1	Apparent Photosynthesis Date 2	Transpiration Rate Date 1	Transpiration Rate Date 2	Leaf Diffusive Resistance Date 1	Leaf Diffusive Resistance Date 2
Water Level[1]	.872	2.58*	3.60**	1.93	3.41**	3.60**
Sorghum Variety	.195	22.67**	7.59**	53.6**	.018	35.2**
Water x Variety	1.48	.50	.393	3.72**	.455	4.41**

[1]Based on irrigation differences (Table 2), no dry treatment had yet been established by Date 1; therefore there was no water level distinction at this time.

* significant at 5% level
**significant at 1% level

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