SOME ASPECTS OF DROUGHT RESISTANCE IN GRAIN SORGHUM

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CHAPTER I

INTRODUCTION

Grain sorghum [Sorghum bicolor (L.) Moench] is a staple food for vast numbers of peoples in Asia, India, China, and Africa. In the United States of America grain sorghum is used primarily as a feed crop. In terms of acreage planted, sorghum ranks fifth among world grain crops being exceeded by wheat (Triticum spp.), rice (Oryza spp.), maize (Zea mays), and barley (Hordeum spp.). The leading producing countries are the U.S., China, India, Nigeria, and the Sudan.

The crop is adapted to tropical, sub-tropical, and temperate areas; but its maximum production is frequently reduced because of drought. However, both grain and forage types of sorghum, do have the ability to withstand drought from considerable lengths of time and still produce a crop. The term "crop camel" has been applied to kafir sorghum because the plants can tolerate a considerable dry period without an apparent suffering from moisture deficiency (33).

In most sorghum producing areas, the crop is subjected to damage by severe weather, particularly high temperatures, and drought conditions. Recent drought years in the Southwest U.S. and in the tropical regions of Africa have emphasized the need for developing new strains of sorghum more tolerant to deficiencies of water.

The term "drought resistance" usually refers to the morphological, physical, and physiological characteristics which enable sorghum plants to survive and produce grain under unfavorable moisture conditions. Maximov (34) reported that xerophytic plants exhibited decreases in the size of all cells (including stomata), thickened cell walls, strong development of palisade mesophyll, and a dense network of veins. Martin (33) examined the leaves of sorghum and corn under identical conditions and found the stomata in sorghum leaves were 2/3 the size of those in corn. However, stomata per unit area was 50% greater in sorghum.

The lack of a simple practical screening method for drought resistance in sorghum has limited research in this area for many years. Field testing is considered by some workers (32, 68) to be the most reliable method a breeder can use, yet such methods are unrepeatable under field conditions, and of little practical value. Furthermore, the influence of biotic factors may affect the field results. For these reasons suitable quantitative laboratory tests may be the practical answer for the measurement of drought resistance.

In view of the importance of this problem in breeding for drought resistance in sorghum in both Oklahoma and Sudan, and due to the significance of utilizing such a factor in solving some drought problems, it was decided to pursue the investigation of the problem of drought resistance in sorghum in the following ways:

a) To study the ability of sorghum seedlings to withstand repeated drought cycles under controlled environmental conditions,

b) To study root characteristics in relation to drought resistance,

c) To study shoot characteristics in relation to drought resistance, and

d) To study the ability of sorghum seeds to germinate and develop under different osmotic conditions.

CHAPTER II

REVIEW OF LITERATURE

Crop production is a function of many factors such as climate, physical and chemical properties of the soil, moisture supply, plant nutrition, and management practices in addition to the genetic potential of the plant which controls its ability to respond to the environment. Drought is one of the major environmental factors that greatly affect crop production. It is a serious problem for most crops, but more severe on sorghum and cotton (*Gossypium hirsutum*) which are better adapted and more frequently grown on drier areas than less drought tolerant crops such as corn and soybeans (*Glycine max*).

Several definitions have been suggested for drought and drought resistance. "Drought" is defined as any period during which water deficiency affects plant growth. The term drought tolerance has been used to refer to the ability of a plant to escape dry conditions.

One of the most practical definitions for drought resistance is that suggested by Maximov (35), i.e., drought resistance is the ability of plants to withstand drought and recover readily after permanent wilting with minimum damage to the plant and to the yield produced.

Kramer (27) thinks of drought as a severe deficiency of soil moisture which brings about internal water deficits in plants that ultimately result in reduced plant growth. He added that atmospheric factors such as high temperature, low humidity, and wind may intensify the injurious effects of water stress through an increased rate of transpiration.

Wright (70) suggested a definition for drought tolerant range grasses as those plants which are able to establish, develop, and maintain themselves through drought periods by efficient use of soil moisture. Drought is considered by Levitt, Sullivan, and Krull (32) as the potential of the environment to influence water loss from the plant (Appendix A).

In short, drought resistance is a complex subject; and the lack of standard terminology, readily apparent in the literature dealing with drought resistance, has been discussed by many workers (27, 35, 25, 57). However, no standardization has yet been achieved.

Classification

A practical classification of drought-resistant plants was suggested by Shantz (54), whereby he divided the plants succeeding in an area subjected to drought stress into (a) those plants which escape drought by a short rapid growth period; (b) those which evade drought by conserving the scanty moisture by small plant size, restricted growth, wide spacing, or low water requirement, (c) those which endure drought by passing into a dormant condition; and (d) those which resist drought by storing up a supply of water in their plant parts to be used when insufficient quantities can be secured from the soil and by the ability to push their roots into dry soil.

The tendency to divide drought resistance into components was further emphasized by Levitt et al. (32) who think of drought resistance as consisting of avoidance, (the ability to prevent reduction in water content) and of tolerance, (the ability to survive reduction in water content). The authors were aware of the difficulty in separating the two components due to the lack of adequate testing methods, especially for avoidance.

Aamodt (1) classified drought into edaphic and atmospheric. Edaphic (or soil) drought occurs when the soil ceases to provide the plant with sufficient moisture to replace that lost by transpiration. Atmospheric drought is caused by excessive temperatures and winds which may kill plant tissue even when the soil moisture is adequate.

Newton and Martin (41) did a comprehensive study on the nature of drought resistance in crop plants, placing strong emphasis on the colloidal properties of the cell sap and correlating the ability to tolerate drought with structural modifications. Drought resistance, they explained, depends on (a) absorption which is controlled by soil factors, root development, and physiological adaptation; (b) transpiration which depends on atmospheric factors, structural factors, and physiological adaptation; and (c) wilt endurance (Appendix B).

Moisture Stress

Varietal differences in survival following artificial soil drought have been reported by many workers (51, 43, 2, 70, 69). In most cases, survival values are well correlated with field reactions. One of the earliest works on seedling resistance in wheat to drought was conducted by Tumanov (63). He grew eight varieties with wide differences in drought resistance and studied their respective abilities to endure wilting. His procedure was to grow the plants under adequate moisture until they reached the shooting stage, at which time water was withheld for two weeks. Then, the plants were rewatered, and the number of surviving plants was recorded. He found that the percentage survival varied from 94 for a drought resistant variety to 23 for a susceptible one and that the survival values corresponded with field results.

Although much research has been done on the relationship between soil moisture content and plant growth, some important problems remain unsolved, especially the effect of small soil water deficits on plant processes. Kramer (28) studied the relationship between plant growth and water stress and reported that stress depends on the relative rates of water absorption versus loss rather than on soil moisture supply alone. So, it is not necessary to assume that a given degree of soil moisture stress is always accompanied by an equivalent degree of plant water stress.

Sanchez-Diaz, and Kramer (50) studied the behavior of corn and sorghum under water stress, and found that the average resistance of the lower epidermis of well watered plants was lower for corn than for sorghum. When water stress developed, the stomata began to close at a higher water potential in corn than in sorghum. However, the stomata of both species began to reopen normally soon after the plants were rewatered. They added that the average leaf water potential of well watered corn was - 4.5 bars, and that of sorghum was - 6.5 bars. However, the lowest leaf water potential in stressed corn was - 12.8 bars at a water saturation deficit of 45%, and that of sorghum was - 15.7 bars at a water saturation deficit of only 29%. At these values the leaves of both species were tightly rolled or folded and symptoms of some injury was apparent. The authors added that the small reduction in water content of sorghum for a given reduction in leaf water potential is characteristic of drought resistant species.

Todd and Webster (62) studied the effect of repeated drought periods on photosynthesis and survival of cereal seedlings. They reported no significant differences in photosynthetic rates among wheat varieties differing in drought hardiness, although slightly higher rates were found at lower turgor for all the cereal varieties after they had been subjected to single drought periods. They further noted a continuous loss of plants with each successive cycle of drought.

Metabolism and Water Stress

Various biochemical reactions within the plant are greatly influenced by water deficits. In most cases water stress causes a decrease in total carbohydrates and stimulates amylase activity through the entire leaf (26).

The effect of water stress on growth tends to be more pronounced in rapidly growing tissues. This is readily shown by the developmental phases of germination, emergence, and initial growth. Increased moisture stress delayed germination and reduced germination of several range grasses (36). Growth retardation or stunting as a result of water deficiency is well recognized. Robins and Domingo (46) noted a shortening of internodes in corn particularly in the upper portion of the plant. Kramer (24) reported that among the direct effects of severe and long continued internal water deficits is reduction in cell division and cell elongation.

Newton and Martin (41) studied the drought resistance of several crop plants including grasses. They found that bound water content could be used as a basis for classifying plants as to their drought resistance. However, Whitman (68), working with four grass species was unable to find any correlation between bound water content and the ability to withstand drought conditions.

Iljin (19) reported that mesophytes are more susceptible to wilting than xerophytes and that plants growing in dry habitat usually contain more sugar. Xerophytes, being more tolerant to water stress, consume a smaller quantity of organic substances in respiration than do mesophytes. A group of xerophytes lost an amount of sugar equal to 4.0 - 9.0% of their dry weight by respiration in a period of 24 hours while mesophytes lost in the same period an amount of sugar equal to 7.7 - 15.4% of their dry weight.

To obtain a better understanding of the physiological adaptation of creosotebush (Larrea divaricata), Saunier, Hull, and Ehrenreich (52) studied the metabolism of carbohydrates and nitrogen after a 7-day desiccation period under controlled conditions. They found no significant differences in the amount of fructose in the leaves of desiccated plants compared to those maintained under normal moisture conditions. However, glucose and sucrose were significantly reduced. Total amino acids more than doubled under moisture stress, the increase being predominantly due to proline, phenylalanine, and glutamic acid. A similar study by Maximov (35) showed that endurance is obtained by the accumulation of sugar and other soluble carbohydrates. Hexoses are increased during drought conditions, while the effects of stress on sucrose were quite variable.

Julander (20) pointed out that the breakdown of carbohydrates in leaves may be accompanied by its deposition in roots. This accumulation of food reserves is essential for heat resistance, which he believes is a valid measure of drought resistance.

Vassiliev and Vassiliev (64) studied the hardening of five varieties of wheat by severe wilting and subsequently brought to recovery by irrigation. They made a series of chemical analyses of cell contents at the beginning of wilting, at permanent wilting, 24 hours after irrigation, and 8 days after recovery. They showed that the amount of monosaccharides and sucrose were greatly increased on the day following the beginning of wilting. During permanent wilting, sucrose decreased, monosaccharides increased, and hemicellulose increased. After irrigation there was an increase in water content and a decrease in soluble sugar content. However, 8 days after recovery the water content was still lower than the control, while sucrose and hemicellulose had greatly increased. They suggested that the hardening process leads to a permanent change and also emphasized the importance of hemicellulose to drought resistance.

One of the more striking examples of drought resistance in non-agricultural crops was observed by Bjorkman and Berry (5). They noted that the herbaceous perennial Tidestromia oblongifolia grew well on the floor of the Death Valley in California from May to August, the hottest and driest months of the year. On examining the plants for photosynthetic activity, it was found that they photosynthesized at higher rates throughout the hours of daylight. In addition, the leaves were covered with a waxy substance that reduced surface transpiration. They further studied carbon dioxide assimilation in detail using labeled carbon and found that the carbon atoms were mainly concentrated in the four-carbon compounds, e.g., malic acid.

They concluded that the four-carbon compound species, of which Tidestromia oblongifolia is one, are superior photosynthesizers under the combined circumstances of intensive solar radiation and high temperature which are characteristics of an arid habitat.

Water Content

Measurements of leaf water potential are essential to the understanding of sorghum response under different drought stress conditions. Although many leaf water potential measurements have been made under experimental conditions in the growth chamber, greenhouses, and research field plots (40) little is known of the level of leaf water potential found in sorghum plants under actual farming conditions.

In studying the physiological response of plants to drought, it is necessary to know the moisture tension which exists within the tissue while the response is being tested. Soil moisture determinations, may give some indication of moisture tension within the plant. However, under certain conditions water loss from transpiration exceeds the water up-take by the roots, in which case soil moisture determinations are not a good indicator (61). Several workers (4,51) have suggested that a correlation exists between drought hardiness and water retention in both winter and spring wheat varieties.

Blum (8) studied the relationship between leaf water saturation deficit (WSD) and leaf water potential in 10 sorghum genotypes under stress conditions. He reported that the leaf water potential at which an exponential increase in WSD appeared, varied among the genotypes and ranged from -10 to -12 bars in the resistant varieties and from -10 to -16 bars in the susceptible ones. Relating the mean increase in WSD per unit decrease in leaf water potential, it was found that the greatest dehydration avoidance was observed in the susceptible genotypes, and the least in the resistant ones. In an earlier study, Levitt (31) pointed out that a relatively small increase in WSD per unit reduction in leaf water potential is a measure of dehydration avoidance. However, total drought avoidance is mainly related to avoidance of low leaf water potential under increased moisture stress.

Blum (6) evaluated the variability within cultivated sorghums exposed to a limited supply of soil moisture in the field, and found that the most drought susceptible variety (e.g. Shallu) had a relatively low leaf water potential, high leaf diffusion resistance, and the poorest total soil moisture extraction. On the other hand, drought avoiding varieties (e.g. feterita) had, under stress, comparatively high leaf water potential, low leaf diffusion resistance, and the greatest amount of soil moisture extraction. Inter-genotypic differences were also observed in the amount of soil moisture extracted prior to heading.

Relating water content as a percent of dry or fresh weight alone proved to be a measurement of limited utility, because of the occurrence of changes in dry weight (66). However, relating water content to that at full turgidity,should be given some consideration in determining the relative water content (RWC) of a plant. Although this measurement has some significance, it is still undetermined whether it is more, less, or equally as important as water activity in evaluating plant response to drought (65). Some consider RWC more significant in plant growth and development and water activity more important in enzymatic reactions and direction of water movements.

Salim and Todd (49) studied the transpiration rate of wheat, barley, and oats under growth chamber and greenhouse conditions. They reported that barley had the lowest transpiration rate while oats had the highest. A linear relationship between transpiration rate and soil moisture was recorded between the permanent wilting point and 70 to 80% of available soil moisture. Water use efficiency was the same for all species in the growth chamber. However, under greenhouse conditions, barley had the highest efficiency followed by wheat and oats. They concluded that the observed differences contribute to differences in drought hardiness observed in the field.

Water Absorption

Some believe that the greater and more extensive root system a plant has and the deeper the roots, the better chance that plant has to absorb and hold water in its tissue and, thus, endure drought. Bayles, Taylor, and Bartel (4) reported that the ability of wheat plants to produce grain under drought conditions might be directly due to two phenomena: (a) the ability of the root system to take in moisture as fast as, or faster than, it is transpired and (b) the ability of the plant to limit transpiration and to continue the process of photosynthesis under conditions conducive to high evaporation.

Painter and Leamer (42) observed that sorghum roots remove moisture to a depth of at least 57 inches on high moisture tension plots with the greatest removal above 45 inches. On lower tension plots, moisture was removed to an approximate depth of 45 inches with the greatest removal above 21 inches.

Kmoch, et al. (23) working with winter wheat, found a dense network of roots developed in soil when soil moisture tension was about 15 atmospheres and the roots were even observed at a depth of 13 feet. However, Salim et al. (48) reported little penetration of soils at or below the permanent wilting point for wheat, oats, and barley.

Sandhu et al. (51) studied the drought and heat hardiness in five winter wheats, and found that resistance to heat and drought was associated with high root/shoot ratio, slow water loss from plants, and better yield under drought conditions.

When stomata are closed, the loss of water is controlled mainly by cuticle characteristics. Much argument exists as to the time when transpiration begins to decrease in plants grown on dry soils. However, several investigators (17, 45, 56, 15) have presented some evidence that rate of transpiration is the highest at field capacity and decreases markedly with decreasing soil moisture.

Methods of Testing Drought Resistance

Several methods of testing drought resistance in cereal crops have been reported (14, 16, 21, 44), but relatively few investigations have actually been made on sorghum. One of the earliest studies of drought resistance in sorghum was the work of Newton and Martin (41), in which they compared the drought resistance of sorghum versus corn. They reported that grain sorghums were significantly superior to corn for drought resistance. They attributed this to the fact that sorghum leaves and stalks have waxy and cutinized epidermis which is largely responsible for slow drying of sorghum.

Field screening methods for drought resistance are inefficient due to the fact that so many factors are involved including time, the impossibility of repeating the same atmospheric conditions in different years and at different locations, and the difficulty in obtaining the precisely right type of conditions when needed. For these reasons, most workers have resorted to the use of greenhouse and laboratory methods, employing artificial conditions and using various physiological manifestations as guides for drought resistance.

One of the oldest methods for testing heat and drought resistance was reported by Levitt (30), in which potted plants were exposed to high temperatures in a heat chamber, and survival was noted sometime after the return to normal conditions. A similar method, involving the placing of potted plants in a heated chamber for a specific time and observing the injury was used by Julander (20). He immersed grass seedlings in water heated to 118°F for 0, 0.5, 1, 2, 4, 8, and 16 hours and demonstrated that 2 to 4 hours were enough to kill the susceptible entries, while 16 hours did not kill the hardened buffalograss and bermudagrass.

Misra (37) studied the effect of edaphic drought on four varieties of wheat and four strains of hybrid corn. His procedure was to grow the plants in 15 cm clay pots and subject them to a dry period of 15 days duration at four different stages, i.e., 2, 3, 4, and 6 weeks of age. After the drought period the plants were watered and percentage survival was recorded. At 2 weeks of age the varieties ranged from 79.2 to 54.2% survival, at three weeks 75.7 to 22.2%, at four weeks 64.1 to 21.7%, and at six weeks 42.5 to 7.9% survival. By using a hardening process consisting of allowing the plants to grow with scanty water supply, greater variation was shown between hardened and non-hardened plants. The percentage recovery was far greater for hardened plants and the variation increased as the plants become older.

Measurement of the water consumption of plants by measuring transpiration rates has been used by many investigators. Maximov (34) presented an extensive survey of the methods used in transpiration studies. He emphasized the importance of the effect of artificial conditions on transpiration. The methods used included (a) the collection and determination of the water vapor transpired by the plant; (b) the determination of changes in the plant weight due to loss of water; and (c) the determination of the amount of water absorbed by the plant to replace that lost by transpiration.

A study for evaluating drought resistance based on the assumption that chlorophyll breakdown could give a measure for relative drought tolerance was suggested by Kaloyereas (21). He determined the C.S.I. of pine by heating 5 grams in 50 ml of water at $56^{\circ}C \pm 1^{\circ}C$ in a bath for 30 minutes and extracted chlorophyll with 100 ml of 80% acetone. He found a good correlation between C.S.I. and drought resistance. However, Fanous (14) using pearl millet obtained results that disagreed with the conclusion that C.S.I. is well correlated with drought resistance. Murty and Majumder (38) and Sahaderan (47) modified the technique for use with rice seedlings by reducing the leaf sample to 2 grams and extending the period to 1.5 hours. They reported that the optimum temperature and duration for screening varieties were $65^{\circ}C$ and 1 hour, respectively.

Several methods have been used in selecting for superior root type. Root volume (amount of water displaced by roots) has been used to select for superior genotypes by several investigators (39, 60). Root evaluation of 40 genotypes of corn were studied by Nass and Zuber (40) in sand culture at 28 and 35 days after germination. They found that the total root weight, root volume, and weight of nodal roots were significantly and positively correlated with root-clump weight, and root-pulling resistance of mature plants under field conditions.

De Roo (13) investigated the use of pressure chambers for estimating leaf water potential in the sorghum hybrid 'RS610'. In principle, the pressure chamber method is based on sealing a leaf inside the pressure chamber with its petiole protruding externally. The pressure inside the chamber is increased until the xylem sap appears at the surface of the xylem vessels; the pressure is then an estimate of the water potential of that leaf. He concluded that the applied pressure was a direct estimation of sorghum leaf water potential. However, Blum, Sullivan, and Eastin (9) reevaluated the pressure chamber technique and disagreed with this finding. They reported that pressure chamber readings (xylem pressure) cannot be used directly as an estimate of leaf water potential, and that it should be corrected according to a calibration of a thermocouple psychrometer determination of leaf water potential. They further added that different rates of pressure increase in the chamber affected the regression between xylem pressure and leaf water potential. Accordingly, no differences were detected between genotypes in their regression.

Drought resistance in terms of yield and yield components was studied by Blum (7) whereby he evaluated 21 different grain sorghum hybrids under normal and stress conditions. He found that resistant hybrids performed better than the susceptible ones under stress by producing a relatively high number of panicles per unit area, and more grain per panicle branch. However, under non-stress (irrigated) conditions susceptible hybrids performed better than the resistant ones due to a relatively high number of panicles per unit area, and larger 1000-grain weight.

Osmotic solutions have frequently been used in drought resistance studies. Thimann (59) believed that d-mannitol, a hexanhydric alcohol which is nontoxic to seeds, was among the best chemicals to limit water uptake by plants without affecting metabolic action. Some workers (14, 16, 44) have successfully used d-mannitol solutions for drought resistance studies. The chemical is water soluble, and osmotic pressures up to 15 atmospheres may easily be prepared with it.

Other sophisticated tests for drought resistance are those which involve the study of bound water, elasticity of the cell wall and permeability of the cell membrane, and the electrical resistance of the cell sap to a given electrical potential. These and other similar methods required more expensive and sophisticated equipment.

Heat Chamber Study

During the growing season, hot dry winds blow frequently; and as a result, many plants die even though soil moisture has not been reduced to the wilting point. Such desiccation of plants is termed atmospheric drought and has not received as much attention as soil (or edaphic) drought (11). Due to the difficulty in using field methods, some researchers have used heat chambers to attack the problem. Aamodt and Johnston (2) tested the effect of atmospheric drought on several varieties of spring wheat and found that the plants could be hardened to atmospheric drought by short exposures to either kind of drought.

Carroll(10) studied the effect of both soil and air temperatures on turf grasses, and found that the lethal low temperature for the majority of the species appeared to be between - 10 and - 15°C. On the other hand exposure to soil and air temperatures of 40, 50, and 60°C showed that soil temperature is more distructive than similar air temperature.

Hunter, Laude, and Brunson (18) were able to distinguish drought-tolerant strains by testing the seedlings of corn plants under controlled conditions. They concluded that the seedling evaluation may give a good indication to the field behavior of normal plants under natural conditions.

According to Maximov (34), the best measure of the drought resistance of a plant is its capacity to withstand permanent wilting, but it is practically impossible to use this criterion for study of drought resistance for plants having leathery, sclerophyllous, or needle-like leaves, where the determination of different stages is liable to great human error. Therefore, it is desirable to develop a method which is as free as possible from errors of judgment and which will subject the plants in question to conditions similar to those in natural habitats. Accordingly, a simple machine was devised for subjecting plants to atmospheric drought. This device was well described by Shirley (55) and used by Schultz and Hayes (53) who obtained results agreeing closely with field observations.

The use of artificial heat treatments to determine differences in unknown genotypes of oats was employed by Coffman (12). He subjected oat varieties to different temperatures for various lengths of time and found that a temperature of 48.5 to 52^{o}C for a period of 45 minutes would give results indicating differences in heat resistance of oat varieties. Heyne and Laude (17) studied the effect of heat on different strains of corn and stated that the reaction of corn seedlings to artificial heat was well correlated with the behavior of the same strains under field conditions.

Kenway, Peto, and Neatby (22) presented data which showed that wheat plants were most susceptible to artificial drought during the period from 6:00 a.m. to 12:00 noon. Similar results were obtained by Laude (29) using wheat, barley, corn, and sorghum in that the minumum resistance of plants to heat occurred early in the morning.

CHAPTER III

MATERIAL AND METHODS

Ten varieties of sorghum were evaluated for drought resistance. These varieties were as follows:

1. M-35-1 (IS 1054, a heat resistant yellow endosperm feterita) was developed at Texas Agricultural Research Station, Lubbock, Texas;
2. Feki Mustahi (A-121) was developed by the Agricultural Research Corporation, Medani, Sudan;
3. C-42C (privileged information) hybrid from Dekalb AgResearch Inc., Lubbock, Texas.
4. C-42Y (privileged information) hybrid from Dekalb AgResearch Inc., Lubbock, Texas;
5. PI 288881 from India;
6. Early Kaoliang (CI791) was maintained by Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma;
7. Sol Kafir (Kafir selected for resistance to heat and drought) was selected at Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma;
8. Cross 1 (36/14, selection from T.U.B. 7 X Gassabi) was developed by Agricultural Research Corp., Medani, Sudan;
9. B. Dwarf Redlan (waxy dwarf Kafir X Redlan) was selected at Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma.
10. Karkatib (4/1/1, feterita selected for early maturity) from

Agricultural Research Corp., Medani, Sudan.

The varieties M-35-1, C-42C, and C-42Y have been used in a number of drought studies and have exhibited more tolerance to drought than many other sorghums. The remaining seven emerged from a series of extensive screening tests (Table X) using the method outlined by Todd and Webster (62). The seed of all the varieties were treated with the fungicide captan with 50% active ingredients.

Four different experiments were used: a controlled growth chamber study using soil and various drought cycles to test for seedling survival; a controlled growth chamber pot experiment to study the characteristics of sorghum roots; a controlled growth chamber pot experiment to study the characteristics of sorghum shoots; and osmotic solutions of d-mannitol for laboratory germination tests. The first three experiments were conducted in the Controlled Environment Research Laboratory on the campus of Oklahoma State University, Stillwater, Oklahoma, in 1974. The last experiment was conducted in the Sorghum Laboratory on the same campus. The growth chamber was a walk-in type with automatic temperature and light controls. The light source was a combination of fluorescent and incandescent blubs which delivered light at about 3500 foot-candles. A small fan kept the air in constant motion and tended to insure uniform temperature throughout the chamber. No attempt was made to measure or control relative humidity.

Drought Study

The 10 sorghum varieties listed above were used in this study. Eight metal trays (50 cm long X 35 cm wide X 10 cm deep) were filled to a depth of 8 cm with a mixture of soil and peat moss in a ratio of 3:1. A thin layer of sand was placed on top of the soil-peat moss mixture to reduce surface evaporation. Twelve rows were arranged in the tray so that there were 4 cm between rows and each row was 33 cm long. Each variety was planted at random in each of the eight trays, resulting in a randomized complete-block design with eight replications.

Fifteen to twenty treated seeds of each variety were planted for each row, and the seedlings were thinned to 10 plants per row five days after emergence. Trays were watered on alternate days with approximately 1.5 liters of tap water. When the seedlings were nine days old, sufficient water was added to bring the soil in each tray to approximately field capacity; and then, the seedlings were left without watering for seven to eight days until the plants showed severe curling and twisting of leaves, and took on a slate gray color, at which time the plants were rewatered. Two days later, the percentage survival for the first cycle was recorded. The same procedure was repeated with the same plants for a second, third, and the fourth cycle of simulated drought.

Root Study

The 10 varieties were also used in this study. Plastic pots 20 cm in diameter and 32 cm deep were filled with washed sand. The sand culture was used to facilitate the removal of roots. Ten treated seeds were planted per pot, and the seedlings were thinned to five per pot five days after emergence. A soluble nutrient solution prepared by dissolving two teaspoons of RA.PID.GRO (23:19:17) per gallon of tap water was used. Approximately one half a liter of this solution was added to each pot on alternate days, and adequate water was provided. A randomized complete-block design with four replications was used in this study.

When the plants were three weeks old, the plants were carefully washed free-of sand, wrapped in wet paper towelling, brought to the laboratory, blotted dry, and then the following observations were recorded:

Root wet weight, weight in grams of a five-plant sample composite;

Root length, mean length in centimeters of five plant roots;

The root volume, volume in cc of a five-plant sample measured by water displacement; and

Root/shoot ratio, weight of the root divided by weight of the shoot on a dry matter basis for 5-plant sample.

Shoot Study

Two experiments were conducted to determine the relationship between relative water content and the rate of water loss from sorghum leaves to drought resistance.

Relative Water Content Experiment

The 10 varieties and the growth chamber described above were used in this study. Plants were grown in 23-cm plastic pots, in which approximately 20 Kg of 3:1 mixture of soil to peat moss were placed. A thin layer of sand was added to each pot to reduce surface evaporation. Ten treated seeds were planted per pot, and later the seedlings were thinned to five plants per pot. A randomized complete block design with four replications was used in this study.

When the plants were four weeks old, sections of leaves 4 to 5 cm. long were cut, immediately weighed, and floated on distilled water in covered petri dishes for 24 hours, and the turgid weight obtained. The samples were dried for several days at 60°C and the dry weight was determined. The percent water content was then calculated by the following formula:

$$\text{Relative water content} = \left[(Fw - Dw)/(Tw - Dw) \right] \times 100$$

where

Fw = fresh weight or immediate sample weight.

Tw = turgid weight, or weight of sample after floated in water.

Dw = dry weight.

Water Loss Experiment

Four sorghum varieties M-35-1, C-42Y, B. Dwarf Redlan, and Karkatib, were used in this study. The first two represent tolerant varieties while the others represent susceptibles. Seedlings were established in plastic pots 20 cm in diameter and 25 cm deep. Ten treated seeds were planted in each pot, and the seedlings were thinned to five plants per pot five days after emergence. A randomized complete-block design with four replications was used herein.

When the plants were four weeks old, random samples of 4 to 5 cm. leaf sections were cut (three per pot), usually from the central portion of the third or fourth leaf. The samples were immediately weighed and then placed in a forced draft oven at a temperature of 60°C for 15, 30, 45, and 60 minutes. The percentage water loss was calculated for each interval by the following formula:

$$\text{Percent water loss} = \left[(Fw_o - Fw_t)/(Fw_o - Dw)\right] \text{X } 100$$

where:

Fw_o = initial weight (fresh weight at zero time),

Fw_t = fresh weight after "t" minutes, and

Dw = oven-dry weight.

Germination Study

Solutions of 2, 4, 6, 8, and 10 atm of osmotic pressure were prepared from d-mannitol and ionized distilled water and the Ψ was calculated by using the Van't Hoff formula:

$$-\Psi = miRT$$

where:

Ψ = osmotic potential,

m = molality of the solution,

i = a constant which accounts for ionization of the solute and/or other deviations from perfect solutions (i = 1.0),

R = the gas constant (0.082 liter atmospheres/mole degree)

T = absolute temperature.

All 10 sorghum varieties were used in this study. Three-inch square plastic boxes with lids were used as germination containers. Absorbent tissue was placed on the bottom of each container and an equal amount of distilled water was added to each box. The lids were sealed with masking tape to prevent evaporation. Distilled water was used as a check. Each box containing 25 fungicide treated seeds was considered as experimental unit. The experimental design employed for this study was a split-plot with main plots being osmotic concentrations and the subplots being varieties. The main plots were replicated four times. The boxes were then placed in a germinator at 30° and $20^{\circ}C$ day and night, respectively, for 8 days. At the end of the germination period, the percent germination of seeds and the total length of seedling development (from tip of shoot to tip of root) was determined in cm.

Unless otherwise indicated the order of the varieties in Tables and Figures will be the same as the order at the beginning of this section.

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CHAPTER IV

RESULTS AND DISCUSSION

Drought Study

Ten sorghum varieties were grown in rows in trays in which the seedlings were subjected to free competition in a restricted root community. The mean percentages of plant survival in four successive drought periods are shown in Figure 1. From that data, one sees that with each successive drought period, a continuous reduction occurs in percent survival. Analyses of variance (Table I) and Duncan's Multiple Range Tests comparing mean percent survival (Table II) were calculated from the data of the last two cycles (i.e., III and IV). There were significant differences among the sorghum varieties in both cycles at the 0.01 level of probability. All varieties, except Karkatib, recovered 100% after the first drought period. However, on the second and succeeding drought cycles there was a continuous loss of plants. The reduction in plants was not the same in all the varieties (Figure 1). In general, the previously designated tolerant group lost relatively fewer plants than the other varieties, except for PI 288881. Karkatib, from the susceptible group, had the lowest survival in all the four drought cycles.

In the Multiple Range Test (Table II) on percentage survival, the varieties thought most tolerant were grouped together at the top of the list, and the more susceptible varieties were grouped at the bottom.

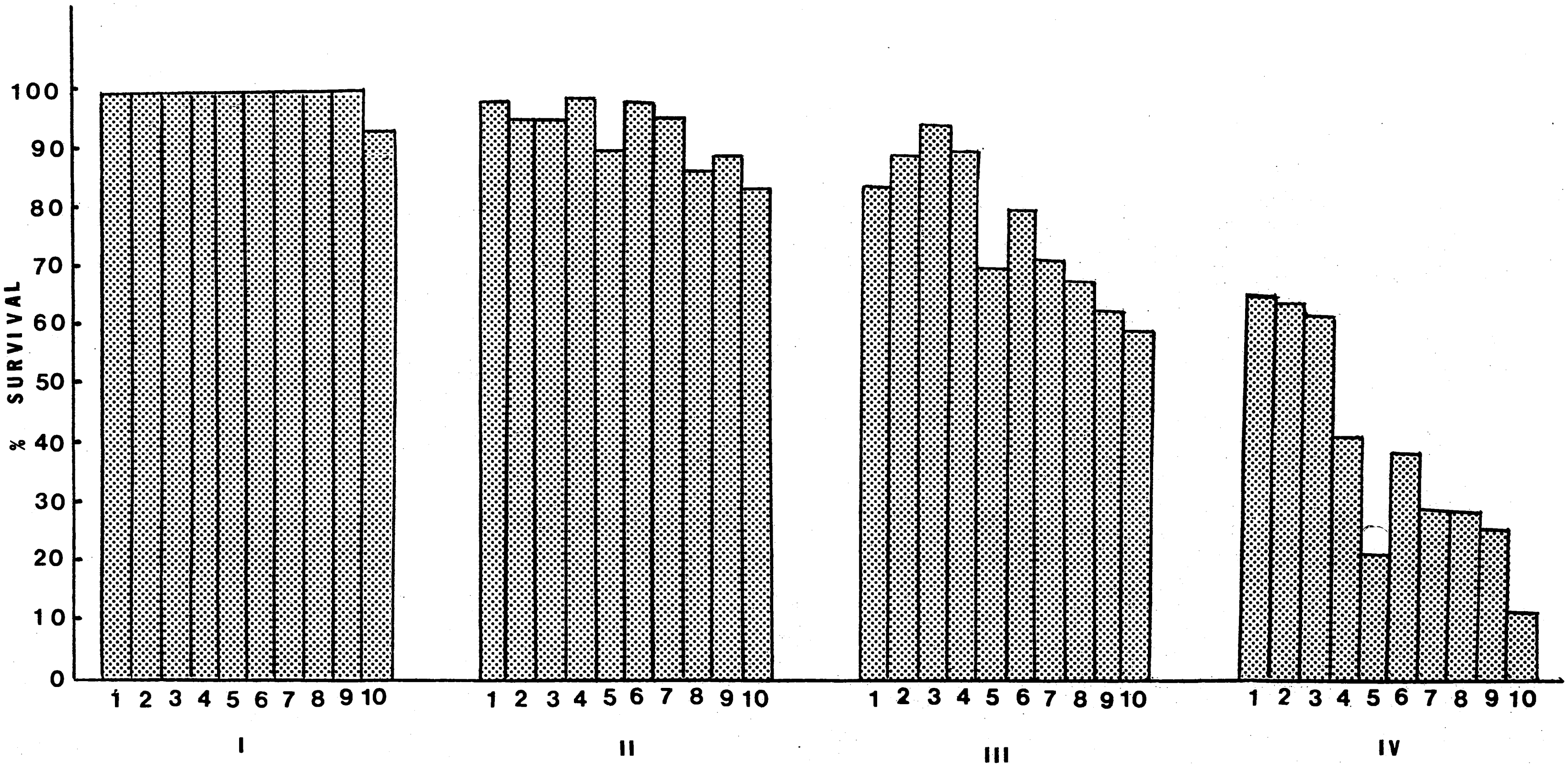

Figure 1. Mean Survival Percentage of 10 Sorghum Varieties After Exposure to 4 Successive Drought Periods (I Through IV).

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TABLE I

ANALYSES OF VARIANCE AMONG 10 SORGHUM VARIETIES FOR DROUGHT CYCLES III AND IV

		Drought Cycle III		Drought Cycle IV	
Source	df	SS	MS	SS	MS
Reps	7	8825.60	1260.80**	19997.20	2856.77**
Variety	9	14721.38	1635.71**	26985.91	2987.32**
Error	63	6625.01	105.16	19170.20	304.29
CV			16%		46%

**Significant at the 0.01 level of probability.

TABLE II

MEAN PERCENTAGE SURVIVAL OF 10 SORGHUM VARIETIES FOR DROUGHT CYCLES III AND IV

Drought Cycle III		Drought Cycle IV	
Variety	Mean Percentage Survival	Variety	Mean Percentage Survival
C-42C	94.50 a*	M-35-1	65.25 a
C-42Y	90.00 a b	Feki Mustahi	63.50 a
Feki Mustahi	88.75 a b	C-42C	61.25 a
M-35-1	82.50 a b c	C-42Y	41.25 b
Early Kaoliang	80.00 b c	Early Kaoliang	27.50 b c
Sol Kafir	71.25 c	Sol Kafir	27.50 b c
PI 288881	70.00 d	Cross 1	27.00 b c
Cross 1	67.50 d	B. Dw Redlan	25.00 b c d
B. Dwarf Redlan	62.50 d	PI 288881	21.25 c d
Karkatib	60.00 d	Karkatib	10.00 d

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*Varieties followed by the same letter were not significantly different at the 0.05 probability level using Duncan Multiple Range test.

However, the two groups were not distinctly separated from one another as indicated by the overlapping of the ranges. Early Kaoliang, Sol Kafir, PI 288881, B. Dwarf Redlan, and Cross 1 were intermediate in reaction. M-35-1 had the highest percent survival among all the varieties after cycle IV while Karkatib had the lowest.

The survival technique, in which the seedlings were exposed to successive drought cycles, proved to be a simple and effective method of screening for drought resistance among unknown genotypes. Assuming that the seedling survival technique of applying selection pressure will isolate superior genotypes which are drought tolerant in later stages of plant development as well, such a technique could be used effectively for sorghum and, perhaps, other crops. Probably the most significant feature of seedling evaluation would be the ability to select from much larger populations than would be possible with mature plants. Another important aspect is that the controlled environment for specific conditions can be repeated as desired. A third advantage of the technique is that it is rapid, i.e., each experiment will last from 4 to 8 weeks depending on the number of cycles. In addition, the survival values determined by such a method are well correlated with the field results (51, 43, 70, 63), and that the surviving plants could be planted and produce seeds for further work. This would be of significance in breeding programs for developing drought resistance.

Root Study

This experiment was designed to determine if there were differences in root development among the sorghum varieties tested. The seeds were germinated in sand-filled plastic pots and grown for a period of three weeks before root weights, lengths, and volume measurements were taken.

Figure 2 displays graphically the wet root weight (g), root length (cm), root volume (cc), and root/shoot ratio (as decimal) of the 10 varieties. It is apparent from Figure 2 that the first five varieties (tolerant group) had relatively greater root weight, larger root volume, and higher root/shoot ratios than the rest of the varieties. However, the data on the root length did not show striking differences between the two groups. Analyses of variance (Table III), and Duncan's Multiple Range Tests among the variety means (Table IV) were calculated for root wet weight, root length, root volume, and root/shoot ratio. Significant differences among varieties were detected for all four trials. B. Dwarf Redlan had the lowest value for all characters except root/shoot ratio; and even there, it was significantly lower than six other varieties. On the other hand, M-35-1 and C42Y had the highest root weight and root volume. High root volume is indicative of the ability to penetrate a larger volume of soil and, thus, have more water available per plant for growth and survival.

The Multiple Range Test on root weight and root volume showed two groups of varieties which are not distinctly separated from one another. Similar grouping was obtained in the drought study. There was relatively little variation in root length which could be caused by using pots which were not deep enough. The roots of all varieties had penetrated to the bottom of the pots by the time the experiment was terminated.

Root/shoot ratios of the 10 varieties at the seedling stage are also shown in Table IV. C-42Y had a significantly greater ratio than

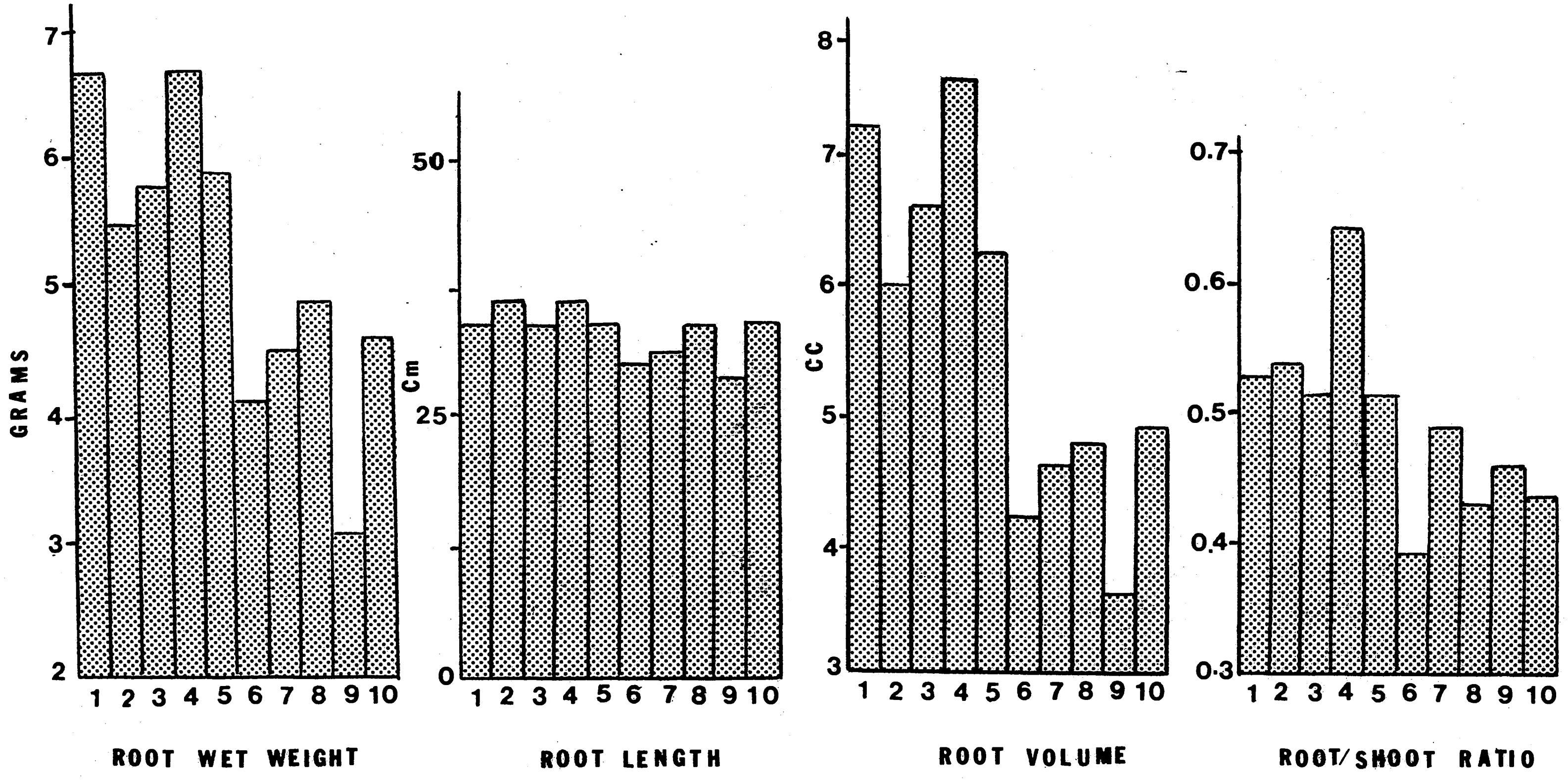

Figure 2. Mean Root Wet Weight, Root Length, Root Volume, and Root/Shoot Ratios for 10 Sorghum Varieties.

TABLE III

ANALYSES OF VARIANCE AMONG 10 SORGHUM VARIETIES FOR ROOT WET WEIGHT, ROOT LENGTH, ROOT VOLUME AND ROOT/SHOOT RATIO

		Root Wet Weight		Root Length		Root Volume		Root/Shoot Ratio	
Source	df	SS	MS	SS	MS	SS	MS	SS	MS
Reps	3	5.97	1.99	5.05	1.64	6.33	2.11	0.005	0.0002
Variety	9	47.16	5.24**	39.96	4.44*	66.32	7.36**	0.219	0.024**
Error	27	21.02	0.78	32.60	1.21	25.51	0.94	0.003	
CV			17%		8%		17%		

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

TABLE IV

ROOT WET WEIGHT, ROOT LENGTH, ROOT VOLUME AND ROOT/SHOOT RATIO FOR 10 SORGHUM VARIETIES GROWN IN SAND

Root Wet Weight		Root Length		Root Volume		Root/Shoot Ratio	
Variety	Mean, g	Variety	Mean, cm	Variety	Mean, cc	Variety	Ratio
C-42Y	6.73a*	C-42Y	36.65a	C-42Y	7.62a	C-42Y	0.65a
M-35-1	6.68a	Feki Mustahi	36.25a	M-35-1	7.35a	Feki Mustahi	0.54 b
PI 288881	5.90ab	M-35-1	34.38a	C-42C	6.62a	M-35-1	0.53 b
C-42C	5.83ab	C-42C	34.38a	PI 288881	6.25ab	C-42C	0.52 b
Feki Mustahi	5.48abc	Karkatib	34.00ab	Feki Mustahi	6.00abc	PI 288881	0.51 b
Cross 1	4.90 bc	Cross 1	33.70ab	Karkatib	4.87 bcd	Sol Kafir	0.49 b
Karkatib	4.55 bcd	PI 288881	32.80abc	Cross 1	4.75 bcd	B. Dwarf Redlan	0.46 c
Sol Kafir	4.50 bcd	Sol Kafir	31.50abc	Sol Kafir	4.62 cd	Cross 1	0.44 cd
Early Kaoliang	4.13 cd	Early Kaoliang	30.13 bc	Early Kaoliang	4.17 d	Karkatib	0.42 cd
B. Dwarf Redlan	3.15 d	B. Dwarf Redlan	28.13 c	B. Dwarf Redlan	3.62	Early Kaoliang	0.39 d

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*Varieties followed by the same letter were not significantly different at the 0.05 probability level using Duncan's Multiple Range test.

any other variety. No significant differences were detected among Feki Mustahi, M-35-1, C-42C, PI 288881, and Sol Kafir, nor among Cross 1, B. Dwarf Redlan, and Karkatib. In general, drought tolerant varieties had higher root/shoot ratios than did the susceptibles.

The root evaluation technique using sand culture may be considered among the better methods to screen for drought resistance, except that it requires much time and labor. Another difficulty with the technique is that sand culture is not a good representation of soil under field conditions. Field evaluation of roots is the ideal procedure, but due to the difficulty in removing soil from roots and due to the time involved, the procedure is not often used.

Shoot Study

Relative Water Content Experiment

The relative water content technique consists of comparisons between the initial and fully turgid weight of selected plant tissue on a percentage basis. In principle, this is quite simple; but in practice, two possible errors may occur. First, the dry weight may change during the floating period, and second, the final weight may not represent the fully turgid water content. Possible causes for the latter inequality include the continued increase in water content after the attainment of full turgidity due to the growth of cut leaves (3).

The mean relative water content at approximately field capacity, at slight wilting, and at severe wilting of sorghum leaves are given in Table V. There were no great differences among the sorghum varieties at a given stage, as indicated by the lack of significance of the varieties mean squares at 0.05 level for any of these trials.

TABLE V

MEAN RELATIVE WATER CONTENT OF 10 SORGHUM VARIETIES AT THREE LEVELS OF MOISTURE STRESS

	Relative Water Content		
Variety	Approximately Field Capacity	Slight Wilting	Severe Wilting
M-35-1	96.50	74.75	58.75
Feki Mustahi	95.25	74.25	61.75
C-42C	96.25	70.50	61.50
C-42Y	96.50	79.50	60.00
PI 288881	93.75	69.50	53.75
Early Kaoliang	94.25	70.50	53.00
Sol Kafir	97.00	69.50	57.50
Cross 1	94.50	64.00	44.50
B Dwarf Redlan	96.75	74.75	56.75
Karkatib	96.50	61.50	52.75
$LSD_{0.05}$	NS	NS	NS

However, the relative water content for the varieties decreased gradually as the soil moisture approached the permanent wilting point. These results are in agreement with those reported by Todd et al. (61). However, the latter worker measured relative water content over a much wider range of soil moisture tension and found that when the value of (RWC) dropped below 25%, the plants usually did not recover after rewatering.

The relative turgidity method, at least as it was used in this experiment, is not a good technique for screening for drought resistance among unknown genotypes.

Water Loss Experiment

The ability of plants to reduce water loss is one of the major characteristics of drought-tolerant species. Reduction in water loss is brought about primarily by closing of stomata, together with other morphological modifications. In the present experiment the rate of water loss per unit of dry weight was determined for four sorghum varieties. The percentage water loss over a period of one hour is shown in Figure 3. There was very rapid water loss during the first 15 minutes of the experiment, after which the rate of loss decreased gradually with time. In fact, all the varieties, except for M-35-1, lost more than 85% of their water content during the first 15 minutes. It appears probable that the greatest differences in percentage water loss between the tolerant (m-35-1 and C-42Y) and susceptible varieties (B. Dwarf Redlan and Karkatib) were attained after the first 15 minutes, and then decreased with additional time. After 45 minutes, the differences were very small; one may fairly safely suggest reducing

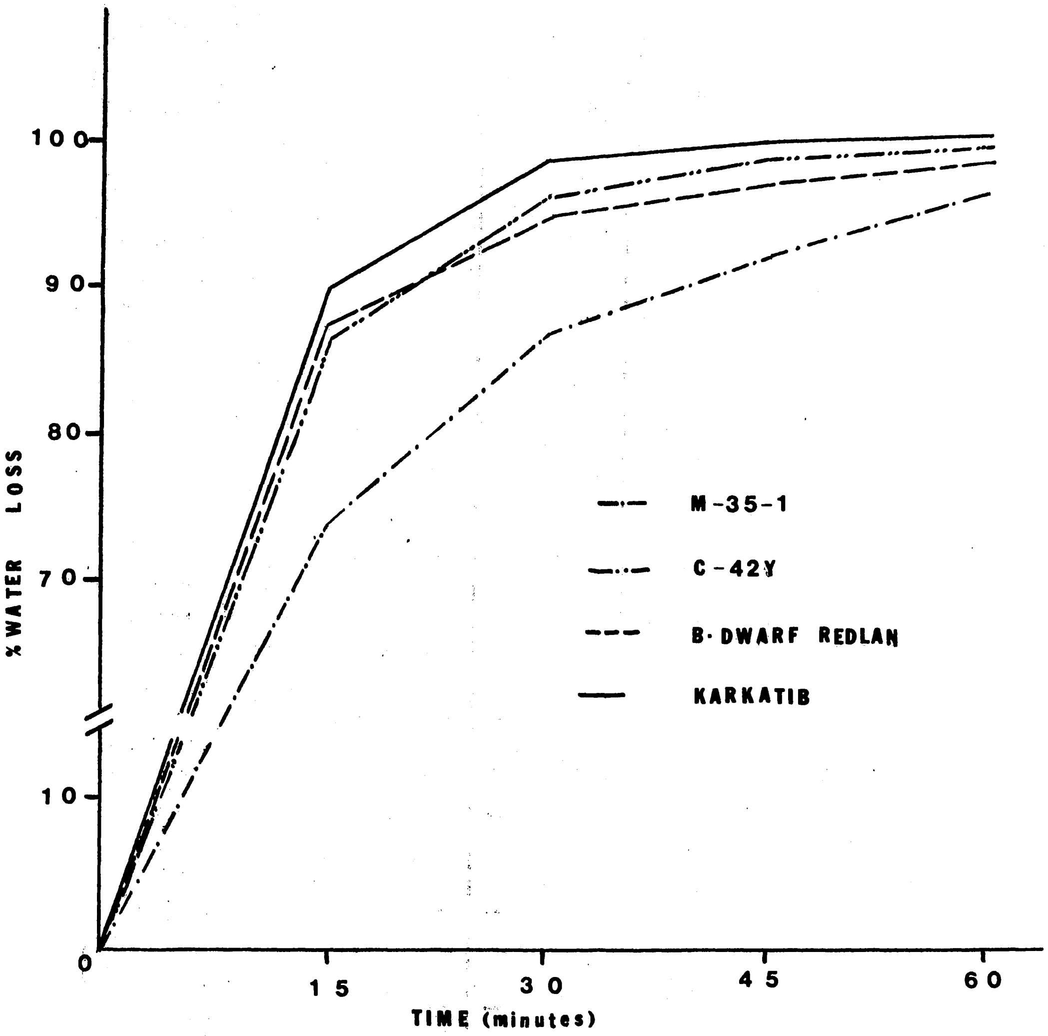

Figure 3. Percentage Water Loss of Cut Leaves of 4 Sorghum Varieties.

the time to 30 minutes for each experiment instead of an hour. Another suggestion would be to reduce the first 15 minute interval into five minute intervals since most of the water loss occurred during that time span.

M-35-1 had a significantly lower rate of water loss over the entire period while Karkatib had the highest rate among the varieties tested. The other two varieties have very nearly the same pattern.

The analysis of variance (Table VI) for this test indicated that time and varietal effects were highly significant. This indicates that the varieties differed greatly in their ability to lose water. Variety X time interaction was significant at the 0.01 probability level which implied that the relative water loss among varieties was not a constant over time. Since the interaction was significant investigations for drought resistance should be concerned with variety behavior under different time intervals.

The water loss technique proved to be a fairly good procedure to screen for superior genotypes for drought resistance. It was able to separate one tolerant variety (M-35-1) and one susceptible variety (Karkatib) from the others, but it was unable to distinguish between other tolerant (C-42Y) and a susceptible (B. Dwarf Redlan). However, it may well be that the tolerance of C-42Y to drought is attained by a different mechanism than rate of water loss. This method can easily be used for field experiments, provided that certain cautions, such as careful handling of samples are taken.

TABLE VI

ANALYSIS OF VARIANCE AMONG 4 SORGHUM VARIETIES FOR PERCENT WATER LOSS

Source	df	SS	MS
Reps	3	66.56	22.19
Variety	3	966.31	322.10**
Error (a)	9	156.06	17.34
Time	3	2040.06	680.02**
Var X Time	9	208.06	23.12**
Error (b)	36	76.87	2.14

[**] Significant at the 0.01 level of probability.

Germination Study

This experiment was designed to determine the effect of osmotic concentration on seed germination and seedling development. The percentage seed germination of 10 sorghum varieties after eight days is shown in Figure 4. All the varieties tended to follow the same pattern under increasing osmotic concentrations. At the lower concentrations (2 and 4 atm), the variation among varieties was relatively small; however, under the higher concentrations (8 and 10 atm) the differences among varieties were at a maximum. From this pattern of response, one can suggest that the greater opportunity to differentiate among genotypes exists under the higher atm pressures. Feki Mustahi and PI 288881 had the highest percentage germination under 6 and 8 atm of pressure, while B. Dwarf Redlan had the lowest. Highly significant differences (Table VII) were detected among varieties.

From the analysis of variance (Table VII), the effects of concentrations were highly significant for percentage germination. The increasing order of overall mean treatment responses for germinated seeds was 42, 61, 74, 81, 85 and 89% for 10, 8, 6, 4, 2 and 0 atm of osmotic concentrations, respectively. The variety by concentration interaction was highly significant which implied that the varieties did not respond the same relative to one another under different osmotic concentrations and that selections made at different concentrations can be expected to differ to some extent.

The effect of d-mannitol on percentage germination of 10 sorghum varieties is shown in Table VIII. B. Dwarf Redlan and Sol Kafir (susceptible group) had the highest reduction in percentage germination under both 8 and 10 atm pressures, while Cross 1 and Karkatib, (also

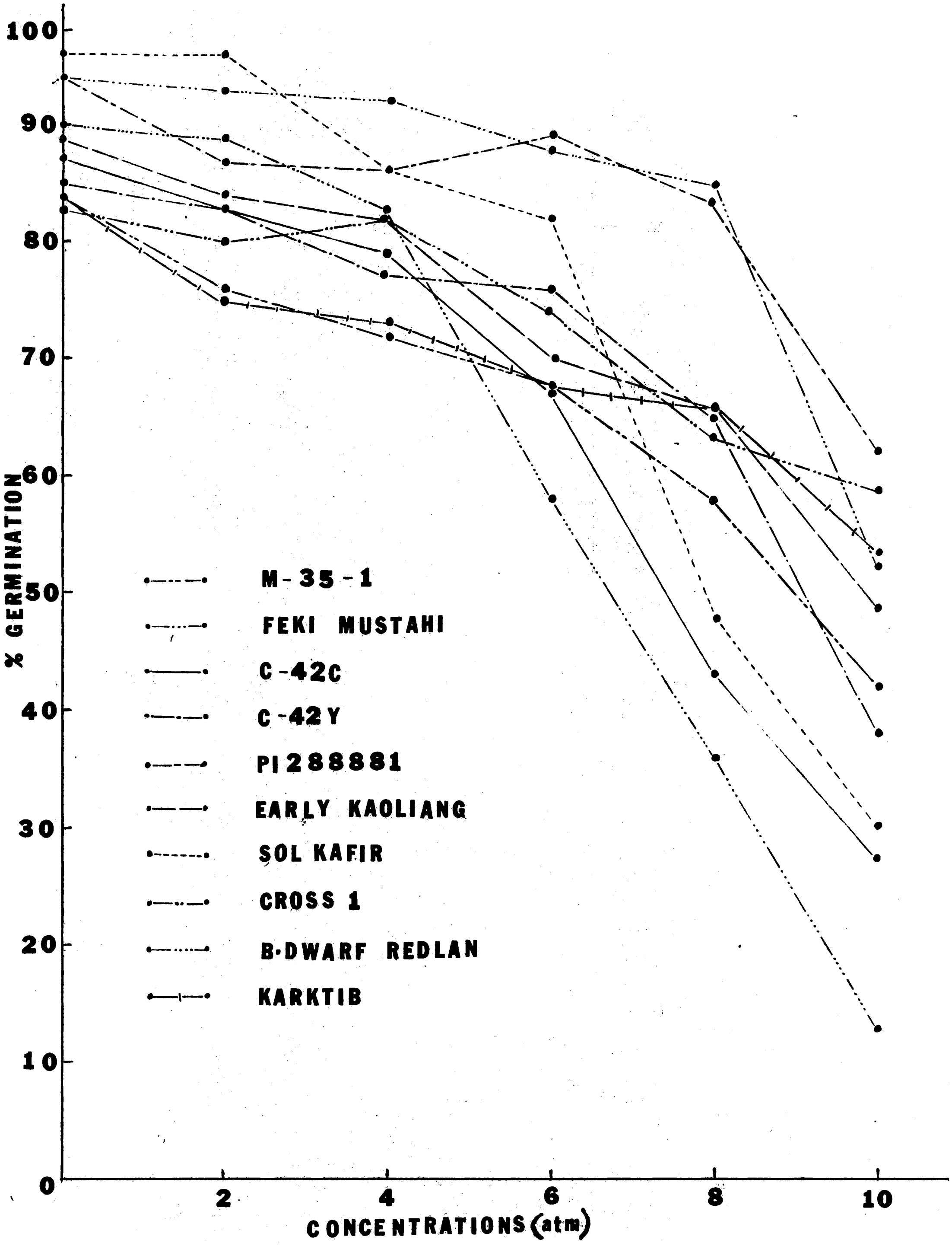

Figure 4. Percentage Seed Germination of 10 Sorghum Varieties After 8 Days.

TABLE VII

ANALYSIS OF VARIANCE AMONG 10 SORGHUM VARIETIES FOR PERCENT GERMINATION IN 6 CONCENTRATIONS OF D-MANNITOL

Source	df	SS	MS
Reps	3	3299.55	1281.83**
Variety	9	11536.50	1281.83**
Error (a)	27	2233.58	82.72
Concentration	5	60867.62	12173.52**
Var X Con.	45	13652.92	303.40**
Error (b)	150	9689.63	64.60

**Significant at the 0.01 level of probability.

TABLE VIII

REDUCTION IN PERCENTAGE GERMINATION OF 10 SORGHUM VARIETIES IN 5 CONCENTRATIONS OF D-MANNITOL*

Variety	10 atm.	8 atm.	6 atm.	4 atm.	2 atm.
B. Dwarf Redlan	78 a**	55 a	33 a	8 a	2 a
Sol Kafir	66 a	48 a	14 b c	10 a	0 a
C-42C	60 a b	44 a	20 b	8 a	4 a
C-42Y	47 b c	20 b	9 b c	8 a	2 a
Feki Mustahi	43 c	9 c	6 c	2 a	1 a
M-35-1	42 c	26 b	16 b	12 a	8 a
Early Koaliang	40 c	23 b	19 b	6 a	4 a
PI 288881	32 c d	10 c	5 c	8 a	7 a
Karkatib	32 c d	18 b c	16 b	11 a	9 a
Cross 1	24 d	20 b c	9 b c	1 a	3 a

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*See Figure 4 for germination percentages

**Varieties followed by the same letter were not significantly different at the 0.05 probability level using Duncan's Multiple Range test.

from the susceptible group), had the lowest reduction under 10 atm pressure and near the lowest at 8 atm. These results are not in very close agreement with those from the drought and root studies. This may be because the different varieties have different mechanisms for drought tolerance.

The data obtained for seedling length among the sorghum varieties at different osmotic concentrations in the d-mannitol study were analyzed by two methods (a) an analysis based on weighted means, i.e., the mean of seedling length in each experimental unit was found by dividing the total length of seedlings by the number of germinated seeds (Figure 5) and (b) an analysis based on unweighted means, i.e., the ungerminated seeds were considered to have a seedling length of zero (Figure 6). In both Figures 5 and 6, the differences among varieties were greater under the lower concentrations (2 and 4 atm). This implies that concentrations higher than 8 atm result in great reduction in seedling development for all varieties, regardless of reaction to drought.

The analyses of variance (Table IX) indicate that osmotic concentrations and varietal effects were highly significant in both weighted and unweighted methods of analysis. The variety by concentration interaction was significant at the 0.01 probability level for both methods of analysis, and indicated that the varieties did not all respond the same to the different concentrations.

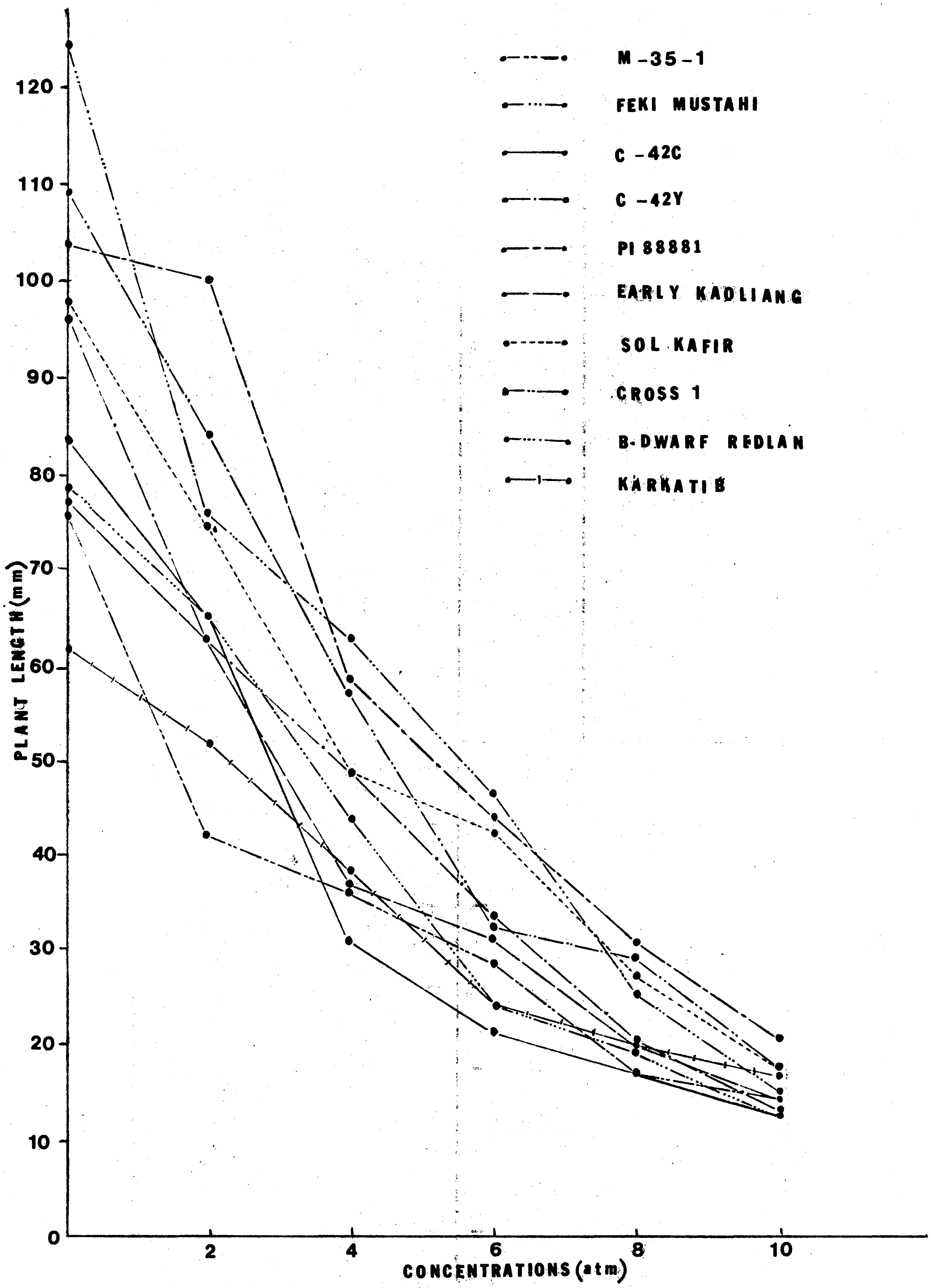

Figure 5. Weighted Mean Length of Seedlings in Millimeters for 10 Sorghum Varieties in 6 Concentrations of D-Mannitol.

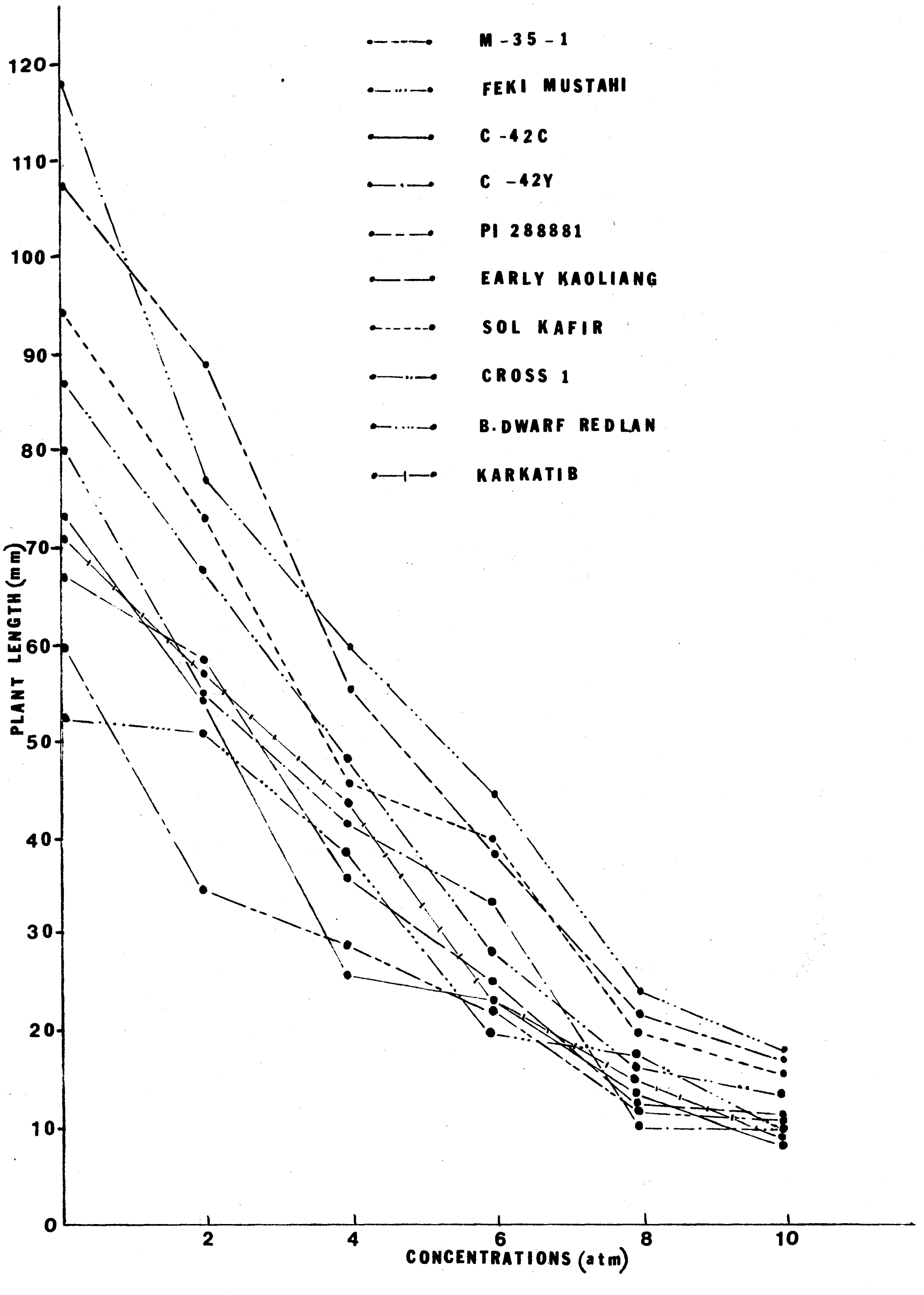

Figure 6. Unweighted Mean Length of Seedlings in Millimeters for 10 Sorghum Varieties in 6 Concentrations of D-Mannitol.

TABLE IX

ANALYSES OF VARIANCE OF SEEDLING LENGTH AMONG 10 SORGHUM VARIETIES IN 6 CONCENTRATIONS OF D-MANNITOL BASED ON WEIGHTED AND UNWEIGHTED MEANS

		Weighted Means		Unweighted Means	
Source	df	SS	MS	SS	MS
Reps	3	40.79	13.60	81.73	
Variety	9	206.55	22.95**	193.51	21.50**
Error (a)	27	42.20	1.56	39.26	1.45
Concentration	5	1460.62	292.12**	1665.81	333.16**
Var. X Con.	45	105.67	2.35**	125.64	2.79**
Error (b)	150	198.31	1.32	211.15	1.41

**Significant at the 0.01 level of probability.

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CHAPTER V

SUMMARY AND CONCLUSIONS

The vital importance of drought resistance in many parts of the world justifies any efforts possible to devise means by which drought hazards can be reduced.

The purpose of these experiments were to (a) study the ability of sorghum seedlings to withstand repeated drought cycles under controlled environmental conditions; (b) determine the characteristics of root development in relation to drought resistance; (c) investigate shoot characteristics relative to drought resistance; and (d) characterize the ability of sorghum seeds to germinate and develop under different osmotic pressures. The experimental material included 10 sorghum varieties representing a range in drought adaptation varying from varieties known to be tolerant to others known to be susceptible.

In the survival study, seedlings were established in trays and subjected to four weekly cycles of drought followed by rewatering. The results showed that in successive drought periods, there was a continuous loss of plants. The results also indicated that the more tolerant varieties lost significantly fewer plants than did the susceptible ones. This technique appeared to be simple and effective in selecting for drought-resistant seedlings from among unknown genotypes.

The analysis of variance on root evaluations showed significant varietal differences in all characters. In general, the most tolerant varieties had heavier root weights, greater root volumes, longer roots, and higher root/shoot ratios. This technique shows promise but involves considerable time and labor.

Relative water content values of 10 sorghum varieties were determined for three different moisture conditions (approximately field capacity, slight wilting, and severe wilting) using the method outlined by Weatherly (66) and used by Todd et al. (61). No significant differences were detected among varieties in each moisture condition. However, relative turgidity values over all varieties decreased markedly with decreased soil moisture. On the other hand, rate of water loss showed highly significant differences among varieties tested. This reemphasizes the hypothesis that the ability of a plant to hold water is one of the major characteristics of drought-resistant species. The data also showed that the most susceptible varieties lost water at a much faster rate than the resistant ones. This technique was judged to also be of value.

In the d-mannitol study, the seeds of 10 sorghum varieties were germinated in different osmotic pressures for eight days. At the end of that period, the percentage germination and length of seedlings were determined. The results indicated that as the soil moisture tension increased, the growth responses for all sorghum varieties decreased in the same general pattern. Differences in magnitude of responses were also observed among the varieties. This method is more effective at the less extreme osmotic pressures.

From these results the following conclusions would seem justified:

1. The use of the repeated drought cycle survival technique on sorghum

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seedlings allowed differences among varieties to be determined. This method appears to be one of the simplest and most effective for use in screening seedlings for drought resistance among unknown genotypes.

2. Root wet weight, root length, root volume, and root/shoot ratios showed clear differences between varieties tested.

3. The relative water content technique did not detect any significant differences among varieties tested for a given soil moisture content. On the other hand, measurements of water loss by cut leaves showed significant differences among the varieties tested.

4. The d-mannitol treatments generally resulted in a decrease in the percentage germination and a decrease in the length of seedlings in all the varieties tested. All varieties appeared to react in the same general direction; but at the less extreme osmotic pressures, differences in varieties could not be distinguished.

5. These 10 sorghum varieties differ enough in drought resistance that their differences can be detected by most of the methods used in this study.

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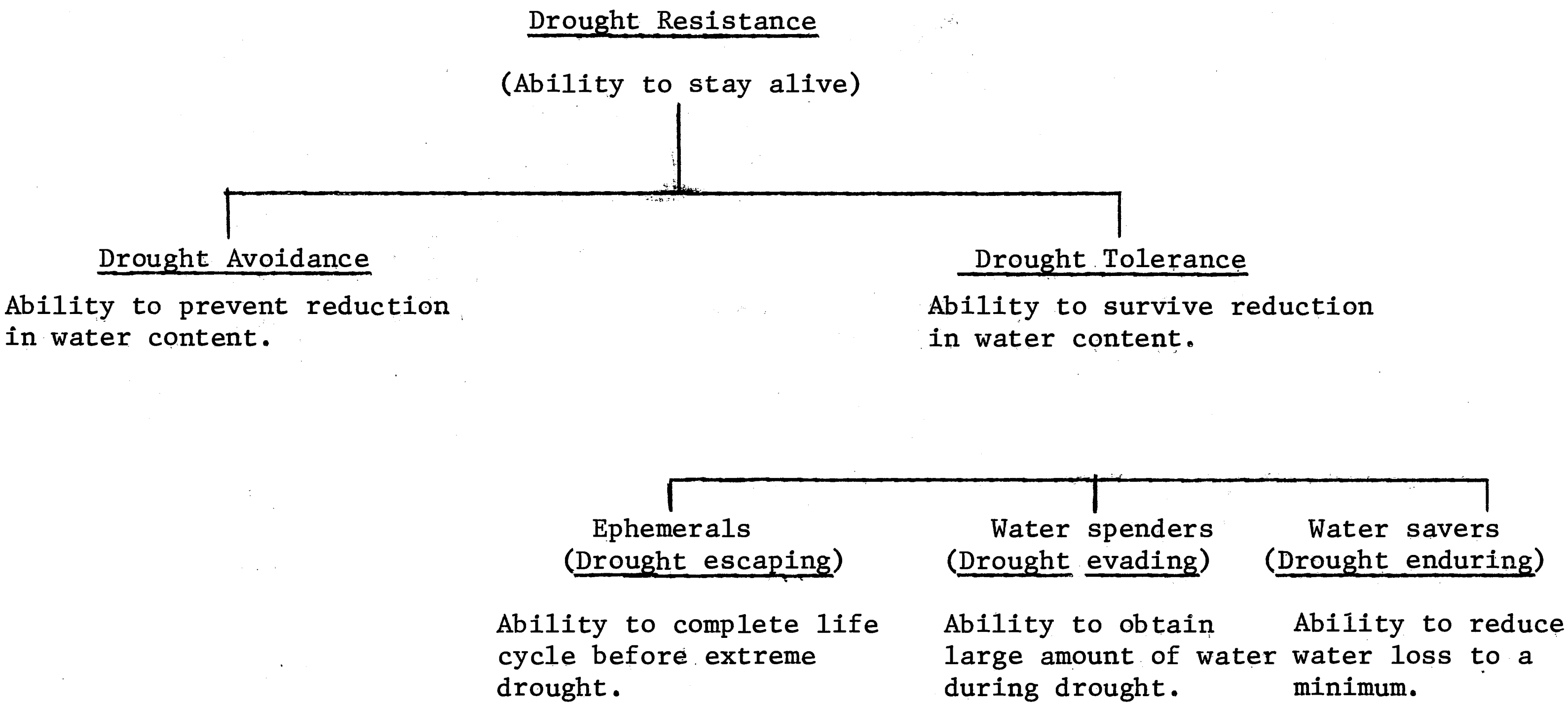
APPENDIXES

APPENDIX A

CLASSIFICATION OF DROUGHT RESISTANCE IN PLANTS

(According to Levitt et al. ref. 32)



Drought Resistance

(Ability to stay alive)

Drought Avoidance

Ability to prevent reduction in water content.

Drought Tolerance

Ability to survive reduction in water content.

Ephemerals (Drought escaping)

Ability to complete life cycle before extreme drought.

Water spenders (Drought evading)

Ability to obtain large amount of water during drought.

Water savers (Drought enduring)

Ability to reduce water loss to a minimum.

APPENDIX B

PRINCIPAL FACTORS AFFECTING DROUGHT RESISTANCE IN PLANTS

(According to Newton and Martin, ref. 41)

- A. Absorption
  - 1. Soil factors
    - (a) Available moisture
    - (b) Concentration of soil solution
    - (c) Toxic substances in solution
    - (d) Temperature
    - (e) Aeration
  - 2. Root development
    - (a) Spread & depth of penetration
    - (b) Intensiveness of branching
    - (c) Number & persistance of hairs
  - 3. Physiological adaptations
    - (a) Osmotic pressure of cell sap of root hairs
    - (b) Imbibition pressure of hydrophilic colloids in cells
    - (c) Mucilaginous secretions in regions of root hairs
- B. Transpiration
  - 1. Atmospheric factors
    - (a) Temperature
    - (b) Humidity
    - (c) Air movement
    - (d) Light intensity
    - (e) Atmospheric pressure
  - 2. Structural features
    - (a) Ratio of root to leaf
    - (b) Conducting tissue
    - (c) Reduction of leaf surface
    - (d) Rolling, Folding, or thickening of leaves
    - (e) Deciduous leaves
    - (f) Epidermal coverings
    - (g) Diminution of intercellular space
    - (h) Sunken stomata
    - (i) Size and number of stomata
    - (j) Stomatal regulation
    - (k) Surface hairs
  - 3. Physiological adaptations
    - (a) Osmotic pressure of cell sap
    - (b) Imbibition pressure of hydrophilic colloids in cells
- C. Wilt endurance

TABLE X

A LIST OF THE SORGHUM VARIETIES USED IN THE SCREENING TESTS FOR DROUGHT RESISTANCE *

No.	Variety	% Survival**	Remarks
1	Cross 3: 17/17 (Bonita x Hegari) x Gassabi	30	From Sudan
2	L. R. White: 20/27/1	27	" "
3	Ziraizira II: B/23/1/1	47	" "
4	Ziraizira I: 3/5/1	22	" "
5	Cross 1: 36/14 (T.U.B7 x Gassabi I)	32	" "
6	Gadam Elhamam: 33/2/1	50	" "
7	Bargawi: A/56	47	" "
8	Gassabi II: A/3/1/2	29	" "
9	Gorib: 10/3/1/1	58	" "
10	Cross 12: 9/6/1 (Kafir ms x Ziraizira)	30	" "
11	Mayo A-239: 7/1/11	14	" "
12	T. W. Akar: 51/3	40	" "
13	Karkatib: 4/1/1	11	" "
14	T. W. Yabis	17	" "
15	Zanab Elshah: 1/3/1	42	" "
16	Cross 4: 42/32 (AD) (Queensland Kalo x T. W. Akar)	46	" "
17	T. U. B. 7	26	" "
18	T. U. B. 22	54	" "
19	T. F. M. 7	45	" "
20	Zinnari	46	" "
21	Abu Chabash A-5: 1/3/1	36	" "
22	Dabar: 1/1/1/1	10	" "
23	L. R. Red: B/23/27/1	41	" "
24	Feki Mustahi	73	" "
25	Cross 11: 46/11/8 (Kafir ms X Mugod Abiad)	47	" "
26	Nyan Doil A-263	15	" "
27	Lwel 2 A-216	33	" "
28	Query 1 A-269	14	" "
29	Wad Fahal	52	" "
30	PI 288643	37	From India
31	PI 288867	39	" "
32	PI 288868-1	60	" "
33	PI 288868-2	41	" "
34	PI 288869	42	" "
35	PI 288870	47	" "
36	PI 288871	53	" "
37	PI 288872	35	" "
38	PI 288874	50	" "
39	PI 288876	43	" "
40	PI 288881	57	" "

TABLE X "CONTINUED"

No.	Variety	% Survival	Remarks
41	PI 288882	62	From India
42	Sol Kafir	31	From Oklahoma
43	Texas 63 X Sol Kafir 1-3-1-2	25	" "
44	Bonar day x # 1-7-1-2-2-PK	12	" "
45	57 X 2E-1-1-1-2-PK	30	" "
46	Bonar-Day x #1-7-1-2-WD	5	" "
47	57 x 2E-3-1-1-2-WO	43	" "
48	58 x 16-3-2-1-1-2	19	" "
49	58 x 38 E-7-1-1-2	12	" "
50	Red-Kan. x Dr. Res. 2-1-1-2	4	" "
51	Standard White Milo CI 352	49	" "
52	Ryer Milo	48	" "
53	Standard Yellow Milo CI 234	50	" "
54	Shantung Kaoliang CI 293	45	" "
55	Early Kaoliang CI 791	37	" "
56	Hegari CI 750	37	" "
57	Bok 11	63	" "
58	Dr. Res. Cross -4-5-2	48	" "
59	B. Dwarf Redlan	33	" "
60	Def. Endo. x Ryer 1-5-1-1-1-2	72	" "
61	Sonner Milo GC 241	70	" "

*In each tests 10 plants of each variety were planted in a row and replicated three times.

**Mean percentage survival of 3 drought cycles.

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