PLANT-WATER STATUS AND GRAIN YIELD OF SORGHUM (*Sorghum bicolor* (L.) MOENCH) IN RELATION TO SOIL WATER STATUS AT MOROGORO, TANZANIA.

BY

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DECLARATION

I, Liberatus John Hamis Matemu, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my original work and has not been submitted for a degree in any other University.

Date. 3rd JUNE 1987 Signature.

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ABSTRACT

A field experiment was conducted at the Sokoine University of Agriculture experimental Farm to study plant-water status and grain yield of sorghum (Sorghum bicolor (L.) Moench) in relation to soil-water status. The treatments consisted of two soils, one having high water holding capacity (soil 1), the other with a low water holding capacity (soil 2); and two sorghum cultivars namely, Serena (improved) and Mbangala (local) under two moisture regimes of limited irrigation and rainfed conditions.

Leaf water potential (ψl) and weighted soil-matric potential (ψw) were measured to assess the water status for the plant and soils, respectively. Other observations made were plant height, stem diameter, number of leaves, leaf area index (LAI), root length density, dry-matter (DM) and grain yields as well as total water use efficiency (TWUE) and irrigation water use efficiency (IWUE).

Plants growing in soil 1 showed higher ψl than those in soil 2 throughout the measurement period. Mbangala maintained a higher ψl than Serena with values of -5.42 and -7.51 bars respectively. The irrigated plants had higher ψl than those under rainfed conditions.

The weighted matric potential, ψ_m was lower in soil 2 than in soil 1. The averages for the entire season were -0.29 and -0.38 bars for soils 1 and 2, respectively. The plots planted with Mbangala showed a lower ψ_m than those with Serena their values being -0.34 and -0.33 bars, respectively.

The weighted soil matric potential was lower under irrigated than under rainfed conditions. The differences under rainfed and irrigated conditions were larger in soil 1 than in soil 2.

Soils did not show any significant difference in stem diameter at 56 days after planting (dap) despite the consistent trend observed whereby soil 1 produced plants with greater diameter than soil 2. Mbangala showed significantly ($P < 0.05$) greater stem diameter than Serena. While stem diameter of Serena averaged 1.88cm, that of Mbangala was 2.10cm. Moisture regime had no effect on stem diameter.

Soil 1 produced significantly ($P < 0.05$) taller plants than soil 2. Plant height in soil 1 exceeded that in soil 2 by 24.5cm. Cultivar and moisture regimes as well as their interactions were non-significant. However, the interaction between soil X cultivar was highly significant ($P < 0.01$). Both cultivars were taller (although not significantly so) in soil 1 than in soil 2. On the other hand, both cultivars showed consistently greater plant height under irrigated than rainfed conditions although the differences were non-significant.

Plants growing in soil 1 were observed to have a significantly ($P<0.01$) higher number of leaves at 56 d.a.p. than those growing in soil 2. Serena produced a significantly ($P<0.01$) higher number of leaves than Mbangala at 56 d.a.p. Moisture regime had no effect on leaf number. The interaction of cultivar X moisture regime significantly ($P<0.05$) affected the number of leaves.

Significantly ($P<0.05$) higher values of LAI were produced by plants growing in soil 1 compared to those growing in soil 2. At 56 d.a.p. LAI in soil 1 were higher by a factor of 0.9 than those in soil 2. The other factor viz; cultivar, moisture and their interactions were non-significant. At 76 d.a.p. soils showed no significant effect on LAI. Mbangala produced significantly ($P<0.01$) higher LAI than Serena, the former exceeding the latter by 2.2. Moisture regimes were highly significant ($P<0.01$). All other interactions except soil X cultivar were significant ($P<0.05$).

Significantly ($P < 0.05$) higher DM was produced by plants growing in soil 1 than those in soil 2 at 56 d.a.p. Soil 1 plants exceeded those in soil 2 by 2700kg DM per hectare. Dry matter yield was significantly ($P < 0.01$) higher for Serena than for Mbagala at 56 d.a.p. Moisture regimes and the interactions between the factors were non-significant. At 76 d.a.p. Plants in soil 1 produced significantly ($P < 0.05$) higher DM than in those for soil 2, the former exceeding the latter by about 1700kg DM per hectare. Mbangala produced significantly ($P < 0.01$) higher DM exceeding Serena by about 5200kg of DM per hectare. The irrigated plots produced 14% more DM than the rainfed plots.

Soil 1 showed higher root length density than soil 2. Mbangala showed better root development than Serena showing the following trend: Irrigated Mbangala $>$ Rainfed Mbangala $>$ Irrigated Serena $>$ Rainfed Serena.

Soils did not show any significant effect on grain yield. Serena produced significantly ($P < 0.05$) higher grain yield than Mbangala. Serena exceeded Mbangala by 286.6kg of grain per hectare. Moisture regimes showed a highly significant ($P < 0.01$) effect on grain yield. Plants growing under irrigation outyielded those under rainfed conditions by 170kg per hectare. The interaction between Soil X Moisture regime was not significant while that of cultivar X Moisture regime on grain yield was significant ($P < 0.05$).

Soil 1 showed higher TWUE than soil 2 in DM yield at 56 d.a.p. Soil 2 gave a TWUE value of 233.5kg DM per hectare-cm of water while that of soil 1 was 108.6. Serena showed higher TWUE than Mbagala in terms of DM at 56 d.a.p. having values of 85.15 and 56.90kg DM per hectare-cm of water, respectively. Total water use efficiency was observed to be higher under irrigated than rainfed conditions. By irrigation, the TWUE was increased by 24.3% over the rainfed conditions.

In the case of grain yield, soil 1 showed higher TWUE than soil 2, the latter giving 17% less TWUE compared to the former. Total water use efficiency of Serena was higher than that of Mbangala by 20.1kg grain per hectare-cm of water. With irrigation, TWUE was increased by 5.2% over the rainfed conditions.

Irrigation water-use efficiency (IWUE) for soil 1 appeared to be lower than that of soil 2. Soil 2 responded well to irrigation than soil 1. Serena had higher IWUE in soil 2 than in soil 1.

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1. INTRODUCTION

Sorghum is a staple crop in many parts of the world and ranks fifth as a cereal crop in terms of production and utilisation (Rooney and Murty, 1982). Sorghum and millets are the most important food crops of the semi-arid tropics, an ecological zone which stretches from China through India extending over most of Africa to America (Hulse, 1980).

Sorghum is of African origin. It was first domesticated in Ethiopia by people of Cancasoid origin living in Ethiopia at the time. It came to East Africa in about the 12th century A.D. as a result of migration of the Cancasoid people from Ethiopia who came to settle in the high altitude areas of East Africa. The sorghum cultivated in East Africa and Ethiopia are of the same type (Dogget, 1970).

Sorghum has varied usage in human life. Basically, sorghum is considered among the most nutritious cereals (Axtell _et al_., 1982). As reported by Rooney and Murty (1982) it is consumed in the world in a number of ways. It can be consumed as unleavened bread, leavened bread, thick porridge, steam cooked products, boiled sorghum snack foods (popped sorghum) and alcoholic and non-alcoholic beverages. Starch and gum production from sorghum for several uses form part of the non-food uses. The plant bases are used for fuel in some countries where wood is scarce (Rooney and Murty, 1982). Dried stems are used for thatching, for reed walls in houses and fences and for making baskets and fish traps (Rooney and Murty, 1982). A dye for dyeing leather is also obtained from sorghum (Purseglove, 1972). The stubble adds nutrients as well as organic matter to the soil (Shanmugasundaram _et al_, 1975) and offers wind erosion protection (Lyles and Allison, 1976). It's quick emergence and production of a relatively rapid ground cover make it useful in surface mulching and soil erosion control (Wiley _et al_, 1982). Other uses include the grain, silage and green forage for animal feed (Taylor, 1977) and straw as a source of energy (McCann and Saddler, 1976), source of biofertilizer and fibre (Schaffert and Gourley, 1982).

Agriculturally, sorghum has a number of qualities and displays wide adaptability which makes the crop worthwhile to be recommended to a world urgently in need of more food. The presence of tannins gives it an advantage in terms of birdproofness (Novellie, 1977). According to Woodhead _et al_ (1980) the polyphenols protect the seed against attacks by insects. They also protect it against post-harvest germination (Harris and Burns, 1970) and against fungal, bacterial and viral diseases (Friend, 1981).

Sorghum is drought resistant and is adapted to a wide range of ecological conditions which are unfavourable to other cereals. The crop can withstand drought and under favourable conditions grows fast and therefore, sorghum is known as "Crop Camel" (Chopra, 1982). Sorghum grows successfully even in the areas where average rainfall is as low as 300 to 400mm (Acland, 1979). It grows well between 900 - 1500m above sea level, though in some cases different varieties are adapted to different altitudes (Acland, 1979). Usually sorghum does well in areas where wheat, rice and maize cannot thrive. This is due to its ability to tolerate the high temperatures, and both the arid as well as water logged soil conditions (Dogget, 1970). Sorghum thrives well under arid conditions because of its physiology. It has an efficient root system; the working depth and the spread of the sorghum roots is approximately the same as that of maize, but the number of secondary roots in sorghum is twice that of maize (Miller, 1916). This coupled with the unusual ability of sorghums to remain practically dormant during drought makes the crop suitable for low rainfall areas (Dogget, 1970). For germination, the seeds need a temperature of 4.5°C to 10°C. The crop thrives well in the temperature range of 16°C to 40°C.

However its performance is good with a mean temperature of 27°C. Severe moisture and temperature stress may result in "blasting" i.e. death of plant parts (Chopra, 1982). Sorghum can be cultivated successfully on nearly all soils, but fertile loamy soils are considered to be the best. It has the ability to give satisfactory yields on soils that have been exhausted by previous cropping (Acland, 1979). It grows well under a wide range of soil types ranging from light sandy soils to heavy rich soils (Acland, 1979). A well developed root system and relatively impervious corky epidermis helps it in its adaptability over a wide range of soils and agro-climatic conditions (Chopra, 1982). The tolerable pH limits are 5.6 to 8.5. Sorghum generally does better than maize when growing conditions are dry, or wet (water logged) and when temperatures are high (Chopra, 1982).

Frequent reccurrence of drought in Africa in general and Tanzania in particular has resulted in ever increasing food imports during the past ten years. During the period of 1975/76 to 1982/83 Tanzania imported 816,600 tons of maize, 313,330 tons of rice and 293,860 tons of wheat on aggregates. The production of sorghum like other crops has also declined over the years and as a result marketed produce has also declined. In Morogoro region, sorghum production and its marketed produce, respectively declined from 91,702 and 115 tons in 1979/80 to 16,523 and 27 tons in 1981/82. During the same period yield declined from 2 tons per hectare to 0.65 tons per hectare (R.D.D. 1984/85).

The decline in agricultural production in Tanzania has largely been attributed to adverse weather (drought) conditions. The problem of drought which has resulted in low crop yields and therefore food importation for many years, in Tanzania seem to be long term. The problem of shortage of foreign currency to import this food does not seem to end either. Therefore, increasing the production and utilisation of drought resistant crops seems to be the only solution to feed the growing population. In view of this, the Government of Tanzania, as reported by Lukoo et al (1981) and Runte and Faure (1977), has been trying to encourage farmers to grow sorghum in the drought hit areas which are potentially suitable for sorghum growing; processing at village and industrial levels has also been promoted since 1977.

In Tanzania, sorghum is largely grown in marginal (low rainfall) areas like Dodoma, Tabora, Morogoro and Arusha regions together with the dry parts of Southern Tanzania (Fig. 1). In all, Tanzania cultivates about 400,000 hectares of sorghum annually (Acland, 1979). There are about nine cultivated species of sorghum grown in Tanzania (Dogget, 1970) which gives a wider choice for selection of species suited to different regions of the country.

As reported by Lukoo et al (1981) sorghum has a tremendous potential in Tanzania. Rainfall in the country varies between 300 to 2000 mm per annum and in most cases giving long dry periods. Because of its low water requirements and the ability to withstand drought sorghum can be a potential crop to be grown during short rains in Morogoro region where the average rainfall during short rains is about 600mm. However, the capacities of soils to support this crop during short rains and matching them with suitable sorghum cultivars have yet to be investigated. This will aid us to know more about soil moisture storage and depletion relations rather than depending just on rainfall information; which in turn would help a proper cultivar selection for a set of given soil and climatic conditions.

The present investigation was therefore, carried out with the following objectives:

1) To identify a proper matching of "soil type - sorghum cultivar" which maintains high productivity during short rains.

2) To identify a sorghum cultivar which responds favourably to limited irrigation.

3) To identify a cultivar which withstands drought better.

Fig. 1. A map of Tanzania showing sorghum growing areas. (S = Sorghum).

2. REVIEW OF LITERATURE

2.1 Consumptive water use by Sorghum

2.1.1 General

Seasonal water use patterns have been described for a number of sorghum production areas representing different soil conditions, water availability patterns and environmental demand (Brown and Schrander, 1959). In general, daily water use is largely a function of evaporation from the soil surface until sufficient leaf area is established for transpiration to become a measurable component of the total water use patterns. Well-watered sorghum usually has a leaf temperature several degrees below the air temperature indicating a significant sensible heat flux contribution to transpiration (Ackerson and Krieg, 1979).

2.1.2 Factors affecting Consumptive water use.

Plant growth is the resultant of an effective integration of many factors. Restriction of any one factor, for example, water deficits in plants generally lead to reduced leaf water potentials and stomatal closure, as manifested from an increased leaf resistance to transpiration (Sivakumar, et al. 1979).

The effects of depletion and replenishment of soil water on transpiration are of specific importance to water use and its efficiency in crop production (Sivakumar, *et al*., 1979). The relative rates of absorption and transpiration determine a plant's internal water balance, which directly affects the physiological and biochemical processes of the plant growth (Teare and Kanemasu, 1972).

In a field study, Ehrler and van Bavel(1967) showed that limited soil water availability lead to increased day time values of leaf diffusion resistance and decreased evapo-transpiration in contrast to the values for plants having water freely available. Teare and Kanemasu (1972) asserted that even though atmospheric demand for water use was similar for soybeans (*Glycine max* (L.) Moench), Sorghum was able to close its stomata more frequently than soybeans reducing its transpiration and conserving soil water.

A certain amount of water is required to establish the plant and allow adequate vegetative development to support potential yield without actually realizing any grain yield. This minimal level is dependent on environmental demand. In the Great plains of U.S.A. this minimal level ranged from 15 - 18cm of available water for sorghum crop (Hanks, 1974). When available water during the growing season exceeds this threshold level, grain yield will occur.

The high rate of plant water use continues well into grain filling with a measurable decline being observed in late grain filling (beginning of the hard dough stage). Much of the reduction in consumptive water use during the late stages of plant development can be related to reduced leaf area due to increasing leaf senescence (Fereres *et al.*, 1978). It is also possible that the size of the root system is reduced because of root decay during this period to the extent that absorption cannot maintain the high rates of transpiration. Additionally the resistance to water transport within the leaf may increase due to aging. These factors contribute to the decreasing leaf water potential in old leaves even under non-limiting soil water conditions (Fereres *et al.*, 1978).

2.1.3 Water use and plant populations:

In general, when water is not a limiting factor throughout the growing season maximum yields are attained with high populations of about 250,000 plants per hectare (Ritchie and Burnett, 1971). The effect of plant population on evapo-transpiration has been recognized as being similar to the effect of degree of ground cover on Evapo-transpiration, Et (Blum, 1970). Early in the growing season as leaf area is developing, Et would be greater on a daily basis from a high population, close row spacing, than from a low population or wide row spacing. Several studies in semi-arid and arid regions have emphasized the importance of developing ground cover as quickly as possible to minimize evaporation from the soil surface and to reduce sensible heat flux increasing transpiration beyond that attributed to net radiation (Ritchie and Burnett, 1971). The results emphasize the need to modify planting pattern so as to maximize degree of canopy cover as early as possible within the desired population limits based upon available water supplies (Ritchie and Burnett, 1971; Chaudhuri and Kanemasu, 1982; Owonubi and Kanemasu, 1982).

2.1.4 Availability of water to the crop:

Soil water supply capacity becomes a limiting factor in the total evapo-transpiration to evaporation (Et:Eo) relationship when the hydraulic conductivity is less than 10^{-6} to 10^{-7}cm day^{-1} (Reicosky and Ritchie, 1976). In sandy soils this is equivalent to a matric potential of about -1 bar; whereas in clay soils it is equivalent to a soil water potential of approximately -8 bars. This translates into utilization of about 60-70% of the "available" soil water in the effective root zone before the Et:Eo ratio will be altered (Ritchie *et al.*, 1972). The extent of depletion of the available water in the root zone is a function of root length density. Nakayama and van Bavel (1963) indicated that in sorghum crop 90% of the soil-water depletion occurred within the top 100cm of a 1500cm soil profile.

It has also been observed that root length density in sorghum crop is fairly high in the surface zone (4-5cm cm^{-3} in the 0-15cm depth), declining almost linearly to densities of less than 1cm cm^{-3} at 75 - 80cm depth. Water flux is apparently rather constant throughout the root zone at a rate of approximately 0.003 cm^3 cm^{-1} root length day^{-1} under non-limiting soil water condition (Burch *et al.*, 1978).

2.2 Development of Water deficits:

Plant water stress or water deficit refers to situations where cells and tissues are less than fully turgid (Kramer, 1969). It occurs wherever the loss of water in transpiration exceeds the rate of absorption. It is characterized by decrease in water content, osmotic potential, and total water potential accompanied by loss of turgor, closure of stomata, and in turn decrease in growth (Kramer, 1969). Severe water stress results in drastic reduction in photosynthesis and disturbance of many other physiological processes cessation of growth and finally in death by desiccation (Kozlowski,1968).

2.2.1 Causes of plant water stress:

Plant water stress is caused either by excessive loss of water or inadequate absorption or combination of the two (Kozlowski, 1968; Kramer, 1969). Transpiration is largely controlled by the aerial environment (solar radiation, temperature, humidity, wind, etc.) as well as by leaf structure and stomatal opening. Absorption is controlled by the rate of transpiration but it is also regulated by the size and distribution of the root system and several soil factors (temperature, soil moisture tension, concentration of the soil solution, aeration etc.) (Kozlowski, 1968; Cochrane and Jones, 1981).

Loomis (1934) and Thut and Loomis (1944) found out in Iowa extension (U.S.A.) that growth of corn and plants of other species is reduced more often by excessive transpiration than by deficient soil moisture. In general there is decreased growth with decreasing soil water (Richards and Wadleigh, 1952; Stanhill, 1957; Sumayao *et al.*, 1977). This was also observed by Denmead and Shaw (1962) who related growth of corn to the number of days the soil water content was below the estimated wilting point.

It has been argued (Kramer, 1969) that as the soil water content decreases, water becomes progressively less available, and there is no definite point at which it becomes unavailable to plants. This further indicated that the permanent wilting percentage is controlled by the osmotic potential of the leaves rather than soil characteristics (Slatyer, 1967). Variations of water content exists in various parts of a plant as well as among plants of different species and stages of development (Kramer, 1969).

2.2.2 Effect of Water stress conditions on crop growth, dry matter and grain yield of Sorghum.

Change in gorwth rate is one of the most sensitive plant responses to water stress (Hsiao, 1973). Leaf growth of sunflower plants in growth chambers only occurs when leaf pressure potential (ψ_{lp}) is greater than 6.5 bars (Boyer, 1968) and is greater at night when ψ_{lp} is highest. Leaf growth of corn, sunflower and soybean is more sensitive to water stress than to photosynthesis or respiration (Boyer, 1970). Acevedo *et al* (1971) reported from their studies on maize plants grown in pots that, leaf elongation ceased when the soil water potential (ψ_m) dropped to -2.5 bars and the leaf water potential (ψ_l) dropped to -7.0 bars.

In contrast to the greater leaf growth at night in sunflower plants (Boyer, 1968) leaf growth of sorghum has been observed to increase linearly throughout a 36h period even though ψ_l cycled between a minimum value of -9.0 bars during the day and a maximum value of -1.0 bar at night (McCree and Davis, 1974). However, Jordan and Arkin (1975) reported diurnal variation in sorghum leaf growth. They (Jordan and Arkin, 1975) observed that leaf growth of sorghum is minimum during the period 1100 - 1600h when ψ_{lp} is near zero. Maximum leaf growth occurred between 1800 and 2100h, a period when ψ_{lp} had not been reached.

Stout et al (1978) reported from their studies of water stress on sorghum that leaf length could have been decreased by water stress bacause of a lower growth rate or a shorter growth period or both. They also reported that chlorophyll content was lower in non-irrigated sorghum plants than irrigated. Stem length of irrigated sorghum plants was 1.16 times longer than that for non-irrigated plants. Tillers were affected more by water stress than the main stem. This was attributed to the fact that tillers retained a smaller percentage of living leaves than the main stem.

2.2.3 Effect of water stress on reproductive growth of sorghum.

Stout et al (1978) observed slower inflorescence development in non-irrigated than irrigated sorghum plants. Also there was lower inflorescence fresh weight and shorter inflorescence length of non-irrigated plants compared to irrigated plants. The results of Elston et al (1976) suggest that the effect of water stress on duration of growth of an organ can depend upon physiological age. Evidence that plants response to water stress has been suggested by the observation that corn stomatal recovery from water stress depended upon the degree of water stress imposed (Glover, 1959). It has also been reported (Stout *et al.*, 1978) that some sorghum cultivars shorten their life cycle under conditions of limited water supply before it becomes limiting. Some cultivars of sorghum may be at an advantage when growing under conditions of erratic rainfall, since ability to delay completion of the life cycle may allow them to complete their growth under more favourable soil-water conditions (Stout *et al*, 1978).

Hanks *et al* (1969) reported that the addition of as little as 10cm of water to field grown sorghum had a dramatic effect on dry weight. Normal metabolic processes and/or sustained lp are required for growth (Acevedo *et al*, 1971). The growth of sorghum is clearly very sensitive to water stress. Because of this sensitivity and because sorghum plants possess drought avoidance mechanisms (Stout and Simpson, 1978), plant growth and yield can be severely affected before large detectable changes in the plant water status can be detected.

2.2.4 Effect of moisture stress on grain yield of Sorghum:

The stage of development at which Sorghum is exposed to water stress influences final grain yield. When exposed to soil water potential (ψ_m) of -12 to -13 bars during the late vegetative to bloom stage, yield of field grown Sorghum plants was reduced by 17% (Lewis *et al*, 1974). The same water stress during boot through bloom stage reduced yield by 34% and during the milk through dough stage reduced grain yield by 10% (Lewis *et al*, 1974). These values demonstrate that a moderately severe water deficit had the greatest detrimental effect on yield when it occurred during the boot through bloom stage. In contrast, the same water deficit had the least detrimental effect on yield during the milk through soft dough stage.

Others (Musick and Grimes, 1961; Scholander *et al*., 1965; Salter and Goode, 1967) have reported reduced yields resulting from soil-water deficit during specific growth stages in grain sorghum. According to Salter and Goode (1967), grain Sorghum responds well to a plentiful water supply during the boot to head stages of growth and that yields are reduced by drought during this time. Grain sorghum is well adapted to additional moisture (Blum, 1973). Grain yield per unit area is a product of two components i.e. the number of panicles per unit area and grain weight per panicle (Blum, 1973). Panicle weight components vary appreciably with environment (Blum, 1967) and genotype (Blum, 1970 a), and changes in these individual components and their interactions determine the final yield.

Drought stress reduces grain yield through its effect on individual components, different components being affected according to the timing and magnitude of stress (Aspinall _et al_, 1964; Dubetz, 1966; Day and Suhbawatr, 1970).

Some plants have the ability to compensate for higher yield when subjected to moisture stress. Depending on the stage and degree of loss, however, compensation can occur such that yield need not be reduced. For example, Blum (1973) and Bagga _et al_ (1973) both showed that when the number of panicles of sorghum was reduced by drought stress the weight of grain per panicle could be increased by either an increase in the number of grains per panicle

(Blum, 1973) or by larger grains (Bagga et al, 1973).

2.3 Adaptation of Sorghum to water stress:

2.3.1 General:

Drought resistance of plants may depend upon drought avoidance or drought tolerance or both (Levitt, 1972). Drought avoidance depends upon maintaining an adequate cell water content and/or water potential despite a low external environmental water potential (soil and/or atmosphere (Stout and Simpson, 1978).

In drought tolerant plants, rapid growth may be prevented during a water stress because the driving force for growth, turgor pressure, is low or absent or because the required metabolic reactions are inhibited (Hsiao et al, 1976). Sorghum closes its stomata during water stress later than corn (Sanchet-Diaz and Kramer, 1971; Beadle et al., 1973) there is the implication that Sorghum continues to grow under higher water stress than corn. It would appear therefore, that sorghum has more drought resistance and/or avoidance than corn (Stout and Simpson, 1978).

Stout and Simpson (1978) further reported that leaf diffusive resistance, transpiration and photosynthesis in green house-grown corn and sorghum do not begin to decrease until the wilting point is reached. It has also been reported that there is a diurnal variation in leaf water potential, (ψ_L) of greenhouse-grown sorghum (McCree, 1974) as well as field-grown sorghum (Teare and Kanemasu, 1972).

Arking (1975) reported that Osmotic potential (ψ_s) and ψ_ℓ of Sorghum reached minimum values between 1300 and 1600h. On the other hand, Teare and Kanemasu (1972) observed that ψ_ℓ reached a minimum value by 1000h.

2.3.2 Some potential mechanisms of achieving drought resistance in Sorghum:

2.3.2.1 Osmoregulation:

Osmoregulation, a process that allows for cell regulation of Osmotic potential (ψ_s) and pressure potential (ψ_p) is commonly found in lower plants (Hellebust, 1976) and roots of higher plants (Greacen and Oh, 1972). On their studies on Sorghum Stout and Simpson, (1978) concluded that the effect of water stress and plant age on leaf was not a result of cell shrinkage because positive values of ψp were observed.

McCree and Davis (1974) observed that less than 50% of the inhibition of leaf area following water stress in sorghum plants can be explained by a decrease in cell size. Leaf length was inhibited by about 20% in the non-irrigated compared to the irrigated sorghum plants (Stout _et_ _al_., 1977). This suggested that a value of 10% or less could be expected for the increase in osmoles of solute per unit leaf area due to the formation of a greater number of cells per unit area i.e. smaller cells.

They (Stout _et_ _al_., 1977) further found out that the osmoles/cm^2 of leaf were respectively, 22 and 40% higher in the non-irrigated than irrigated sorghum plants. From this observation it was then concluded that Osmoregulation by increased formation of solutes per cell does occur in sorghum leaves (Stout and Simpson, 1978).

Osmoregulation in sorghum leaves has been suggested by others based on the observation of a low leaf osmotic potential and the presence of a positive pressure potential (ψp) for non-irrigated compared to irrigated plants

(Hsiao et al, 1976). In addition, Stout and Simpson (1976) reported that Osmoregulation in part can be genetically controlled in sorghum.

2.3.2.2 Stomatal diffusion resistance:

From their studies on drought resistance in sorghum, Stout and Simpson (1978) realised that the leaf water potential, (ψL) did not become very low during their experimental period even in the non-irrigated plants. Nevertheless, the plants were water stressed, since significant differences in leaf osmotic potential (ψL) and growth parameters occurred between irrigated and non-irrigated plants. Avoidance of water stress (avoidance of low leaf water potential) is possible if stomata are shut to decrease transpiration losses (Stout and Simpson, 1978).

The age effect on diffusive resistance, (R_L) may be related to plant age directly or to a preceding environmental condition altering stomatal responses to an existing environmental conditions (Blum and Sulivan, 1974). The diffusive resistance of the abaxial leaf surface was lower than of the adaxial leaf surface. This agreed with an observation by Sanchez-Diaz and Kramer (1971) made on greenhouse grown sorghum plants and also by Teare and Kanemasu (1972) for field grown sorghum plants. The lower diffusive resistance, R_L for abaxial leaf surface and the relatively low values for adaxial surfaces indicated that stomata remained open (Blum and Sulivan, 1974). This means that processes such as photosynthesis were not limited by a shortage of carbon dioxide. However, photosynthesis under water stress can be decreased due to decreased chloroplast activity as well as by decreased CO_2 availability (Keck and Boyer, 1974). It was observed (Stout _et_ _al_, 1977) that the non-irrigated sorghum plants had a lower chlorophyll content than irrigated plants.

Both Teare and Kanemasu (1972) and Turner (1974) reported that stomata of upper leaves of sorghum require a greater water stress than lower leaves before they close.

2.3.2.3 Leaf Senescence:

Plants can transpire less water per plant by decreasing the evaporative leaf surface either by forming less leaf area or by senescing leaves (Stout and Simpson, 1978). Boyer and McPherson (1975) reported that leaf senescence in response to water stress occurs in corn. In their experiment on irrigated and non-irrigated sorghum Stout *et al* (1977) reported that the functional leaf area of the last leaves that developed was reduced by about 20% in the non-irrigated treatments due, primarily, to reduced growth rate. In their experiment, the total number of leaves per plant was the same in the irrigated and non-irrigated treatments. This lead to the conclusion by Stout and Simpson (1978) that leaf senescence is an important mechanism used by sorghum plants to avoid reaching a low leaf water potential $\psi\ell$ through decreasing the absolute amount of water required per plant.

From an agronomic view point, the disadvantage of such a survival mechanism is the resultant decrease in amount of photosynthetic tissue and thus the yield (Boyer and McPherson, 1975). This view may not be valid in terms of grain yield since only a few upper leaves contribute photosynthate to the grain (Evans and Wardlaw, 1976). The underlying mechanisms by which the sorghum plants detect the water stress and respond through increasing cell solute concentration and leaf senescence is not known clearly (Stout and Simpson, 1978). A possibility is that a threshold, ψ_p triggers the avoidance response (Zimmerman _et al_, 1976).

2.3.2.4 ROOTING CHARACTERISTICS OF SORGHUM

Sorghum thrives well under arid conditions because of its physiology. As pointed out in the introduction section, sorghum has an efficient root system; the working depth and the spread of the sorghum roots is approximately the same as for maize, but the number of Secondary roots in Sorghum is twice that of maize. Thus sorghum has roots with twice the uptake capacity, judged by the number of secondary roots supplying a leaf area which is much smaller than that of maize (Miller, 1916).

According to Dogget (1970) top growth of Sorghum plant is slow in the beginning because the extensive root system is being developed. This fact together with the unusual ability of sorghums to remain practically dormant during drought, makes the crop suitable for low rainfall areas (Dogget, 1970). A well developed root system and relatively impervious corky epidermis help it (sorghum) in its adaptability over a wide range of soils and agro-climatic conditions (Chopra, 1982).

It has been reported by Ritchie (1972) from his work on cotton and grain sorghum that it is difficult to use a single soil water content or soil water potential to describe the entire root environment of field crops. This has been attributed to the fact that the rhizosphere resistance is determined by (i) the density of water absorbing roots, (ii) the unsaturated hydraulic conductivity of the soil near the absorbing root and (iii) the evaporative demand. According to Kramer (1949) the number and length of roots in the soil make it doubtful whether the hydraulic conductivity of the soil as such, is ever a limiting factor influencing the rates of water uptake. The pattern of water extraction by sorghum roots in a cyclinder of soil was tested by Gardner, (1964). The water extraction was determined by using tensiometers, and resistance blocks. The initial pattern of water extraction when the soil was wet was taken to reflect the distribution of roots in the cyclinder.

On his studies on effective rooting depths of sorghum growing in an Oxisol, Wahab et al (1976) found out that soil moisture was depleted significantly in the soil profile during a drought period. Sorghum plants extracted moisture from a depth of 90cm. As moisture tension at this depth increased to -13 bars plants began to use the available moisture between the 90 - and 120cm depth of soil layer since at no time were plants severely wilted.

Jordan, et al (1983) concluded from his work on strategies for crop improvement for drought-prone regions in Texas that the water use efficiency of deep rooted sorghum, expressed as grain yield/total crop water use, was significantly greater than the normal rooted crop. This was attributed to the additional water which was available later in the season when a high fraction of the total evapo-transpiration occurs as transpiration. Yields of the deeper rooted crops exceeded those of the normal rooted crop by at least 20%.

Deep rooting has been a difficult character to incorporate into breeding programmes(Jordan et al, 1983). No easy screening procedures are available that can accurately predict deep rooting under field conditions. Genetic variability in root and shoot characteristics of sorghum measured on plants grown in solution culture (Jordan et al, 1979) are often not expressed to the same degree in the field during drought (Jordan and Miller, 1980). Jordan et al (1983) suggested that deep rooting sorghum cultivars can be identified only in those years when the crop must grow for long periods (i.e. 30 days) on stored soil water. In sorghum, active root growth occurs deep in the soil profile during grain filling (Jordan and Miller, 1980). Due to this a subsequent water uptake from unexplored regions of the soil profile does occur.

3. MATERIALS AND METHODS

3.1 Description of the experimental site:

The experiment was conducted at the Sokoine University of Agriculture experimental farm. The site lies between the map co-ordinates E37°39' and S6°50' West of Morogoro town (Morogoro Series Y742 sheet 183/3) and North West of the Uluguru mountains. The altitude varies slightly from about 500m at Morogoro town to about 530m at the area of study.

The rainfall pattern of this area is bimodal with the highest precipitation falling during the months of March, April and May (long rains) and November, December and January (short rains). The months of June, July, August and September represent the driest period. The study was conducted during the short rains. The annual rainfall ranges from 600mm to 1400mm (Meteorological Station, Sokoine University of Agriculture, situated about ½ km from the study area).

The temperatures are generally high through out the year ranging from about 16°C in the month of July (lowest minimum) to about 32°C (highest maximum) in February. Twelve years-averages for the major climatic factors is shown in Table 1 and Figure 2.

The geology of the area (soils classified as Ferralsols, FAO/UNESCO, 1973) is mainly made of metasediments of the Usagaran system with pyroxene-horn blende associated with biotite granulites dominating (Geological Survey of Tanganyika - Quarter degree sheet Number 183-Morogoro). The geomorphic features of the area is typically alluvial fans and flood plain. The land form is almost flat with the gradient of less than 2%.

3.2 Treatments:

The treatments consisted of:-

i) Two soils, one having high water holding capacity (Soil 1), the other with a low water holding capacity (Soil 2).

ii) Two Sorghum cultivars namely Serena (improved) and Mbangala (local).

iii) Two moisture regimes of limited irrigation and rainfed conditions.

3.3 Plan, Layout and Agronomic Practices:

The eight treatments were laid out in a split-split experiment with three replications. The plot size was 5 x 4 m. The soil type formed the main plots, cultivars formed the sub-plots and the moisture regimes the sub-sub plots.

Small furrows, about 10cm wide were opened in each plot and the cultivars were planted by hand on the 22/11/85 at a spacing of 60 by 25cm between rows and plants respectively. About 2-3 seeds per hole were used. Thinning was done at two weeks after planting leaving only one plant per hill. At planting time, Triple Super Phosphate (TSP) was applied at the rate of 26 kg P/ha and later on after two weeks Nitrogen as Ammonium Sulphate (21% N) was applied at a dose of 23 kg N/ha. First weeding was done using a hand hoe twenty one days after planting and from there on wards the exercise was repeated as and when necessary.

The main pests of the crop were birds (<u>Quelea quelea</u> sp.). These were controlled through bird-scaring methods (mechanical)

3.4 Instrumentation:

A standard non-recording raingange (Regenmesser) was installed on a wooden plank about 76cm from the earth's surface (to minimize errors due to splashes) in an open space between the two soils and rainfall was recorded daily at 9.00 a.m.

Soil matric potential (ψ m) was monitored in each treatment by tensiometers (Hydratal 1000) installed at the depths of 30, 60 and 90cm.

3.5 Observations recorded:

3.5.1 Climatic factors:

Pan evaporation (mm), temperature (°C) (mean minimum and mean maximum), relative humidity (%), Radiation (MJ/m^2), and sunshine (hours) were recorded from the Meteorological Station located at the University farm at approximately ½ km from the study area.

3.5.2 Observations on Plants:

3.5.2.1 Leaf Area:

The leaf area was estimated using a leaf-area meter (Paton electronic planimeter). This exercise was done twice during the study period at 56 and 76 days after planting. Total leaf area using five plants uprooted randomly from each plot was estimated. Leaf area index per plant was later computed taking into consideration the spacing and the total leaf area for the five plants.

3.5.2.2 Leaf Water potential, (ψl:

Leaf water potential was estimated by the pressure bomb technique (Boyer, 1967). The equipment (ARIMAD 2) used was of digital type giving the potential in bars. The third leaf from the top was used for this purpose.

Eight measurements were taken on 8/1/86, 11/1/86, 12/1/86, 14/2/86, 18/2/86, 21/2/86, 22/2/86, and 28/2/86. For this study, the chamber of the bomb was filled with carbon-dioxide gas. For comparison. Some measurements were taken early in the morning (at 8.00 a.m.), others at noon (1.00 p.m.) and some were made late in the evening (5.00 p.m.).

3.5.2.3 Stem diameter:

The mean stem diameter (cm) of five randomly selected plants from each treatment was determined at 56 days after planting. A pair of Vernier Callippers was used for this purpose.

3.5.2.4 Plant height:

Plant height (cm) of five randomly selected plants from each treatment was measured at 56 days after planting using a normal tape measure. The mean plant height was computed (accuracy up to 1mm).

3.5.2.5 Number of leaves:

The number of leaves of five randomly selected plants from each treatment at 56 days after planting was determined by a counter and the mean number was computed.

3.5.2.6 Dry-matter:

Shoot dry-matter yield (kg/ha) was determined twice at 56 and 76 days after planting.

3.5.2.7 Root length density (cm/cm^3):

Root length density measurements at 90 days after planting were done by collecting soil root cores (duplicate); one was collected between the plants while the other was obtained between the rows. Later on the mean root length density was computed.

The depths of collection were at an interval of 15cm, the depth running from the soil surface to 90cm. The total root length was estimated using Newman's (1966) technique basing on the formula:

$$R = \frac{\pi N A}{2\,H}$$

where R = length of roots (cm)

N = number of intersections

A = Area of the rectangle (cm^2)

H = Total length of the straight lines (cm).

This was further simplified to 0.785N since $\frac{IIA}{2 H} = 0.785$. Hence the total root length $= 0.785N$. Cores used in this study measured 5.5 x 4cm in diameter and height, respectively.

3.5.2.8 Grain Yield:

Grain yield for each treatment was determined. Weighing was done on a Mettler P6 balance with an accuracy of ± 0.5g. This was later computed in kg/ha.

3.5.3 Measurement made on soils:

3.5.3.1 Sample preparation:

Samples collected from the two soils to a depth of 90cm at an interval of 15cm from the surface were air-dried, ground and sieved through a 2mm-sieve to get the fine earth. The fine earth was used for some soil physico-chemical properties (Appendix 1).

3.5.3.2 Chemical analyses:

Chemical analyses included, soil pH, total N, Available P and exchangeable K. Soil pH was determined potentiometrically in two soil suspensions, 1:2.5 soil-water suspension and

1:2.5 soil- suspension and in each case pH was read after 30 minutes of equillbration. Total N-content of the soil was determined by the macro-Kjeldahl method as described by Bremner (1965). Available P was determined according to the Bray and Kurtz No. 1 method (Bray and Kurtz, 1945). Exchangeable K was estimated by Atomic absorption Spectrophotometry (Dewis and Freitas, 1970).

3.5.3.3 Physical analyses:

Physical properties measured were: water retention at 0.1, 0.3 and 15 bars; bulk density (g/cm^3), mechanical analysis (particle-size distribution). Undisturbed core samples from 0-35, 35-80, 80-97, 97-118, 118-145 (soil 1), and 0-20, 20-51, 51-72, 72-98 and 98-145cm (soil 2) depth were collected from profiles dug in the two soils. These were used for moisture retention at lower sunctions (0.1 and 0.3 bars). Before being placed in pressure plate, the samples were saturated overnight. For higher tension (15 bars), the samples collected from the same layers as above were air-dried, ground and passed through 2mm sieve. About 25g soil of each layer was completely saturated with water in a beaker over night. These were later transferred into rubber rings which were placed on a pressure membrane plate. The plate was then placed into the pressure plate equipment and the required pressure (15 bars or pF 4.2) set in. Extracted water was collected in burettes. The samples were removed when water release ceased as observed by a constant water level in the burettes for 2h. The samples were then transferred to moisture-boxes, weighed and placed in the oven at 105°C until a constant weight was obtained. The % mass water content (θm) was calculated as:

$$\frac{\text{Weight of } \begin{array}{l}\text{moisture wet}\\ \text{box + sample}\end{array} - \begin{array}{l}\text{moisture box}\\ \text{+ Dry Soil}\end{array}}{\text{Weight of } \begin{array}{l}\text{moisture}\\ \text{box + dry soil}\end{array} - \text{moisture box}} \times 100$$

The mass water content % (θm) were later converted to volumetric moisutre content % (θv) by multiplying by their corresponding bulk density (eb). The equivalent water depth, (De) was obtained by multiplying $\theta v \times d$ where d is the respective layer depth (cm).

Bulk density (eb) measurements were done using bulk density core sampler as described by Blake (1965). Soon after taking the cores, they were brought into the laboratory and their weights were taken. The cores were then placed in an oven at 105°C and dried until constant weight was reached. The oven-dry weight of the samples divided by the volume of the core (5.5 x 4cm in diameter and height respectively) was taken to be the bulk density (g/cm^3) of the soils.

The textural analysis was done by the Bouyoucos hydrometer method. This involved a total fine-earth fraction as elaborated by Day (1965), using 50g of soil in which the organic matter was not destroyed (negligible) and 40 ml of 5% Sodium hexa-metaphosphate (Calgon) as a dispersing agent and shaking overnight by an end-over-end shaker. Determinations were made on a 1-litre soil suspension, using a hydrometer specially calibrated to give readings in grams of soil in the suspension. The first reading taken after 5 minutes of settling corresponds to the amount of silt and clay while the second reading taken after 5h, corresponds to the amount of clay alone. Sand content was obtained by subtraction.

Weighted soil matric potential (ψm) was obtained from the tensiometer readings basing on the formula:

Weighted matric potential, ψm

$$= \frac{30R_1 + 60R_2 + 90R_3}{90}$$

where R_1, R_2, and R_3 are the readings from the tensiometers installed at 30, 60 and 90cm, respectively. Since the readings were in centibers, each value was later divided by 100 to get units in bars.

Irrigated treatments were supplied with water after the tensiometer installed at 30cm depth showed a reading of 50 centibers. Irrigation water was applied five times during the study period:

Application	1	(10mm)	6	days	after	planting.
"	2	(15mm)	35	days	"	"
"	3	(5mm)	70	days	"	"
"	4	(10mm)	80	"	"	"
"	5	(5mm)	120	"	"	"

Applications 1 to 4 were applicable to both cultivars (i.e. Irrigated Serena + Irrigated Mbangala). The 5th application was only for the irrigated Mbangala since by this time (120 days after planting) Serena had already been harvested.

Total water use efficiency (TWUE) was computed basing on the formula:

$$\text{TWUE} = \frac{\text{Total Yield}}{\text{total water-applied (Irrigation + Precipitation)}}$$

Irrigation water use efficiency (IWUE) was computed using the formula:

$$\text{IWUE} = \frac{\text{Irrigated Yield of Treatment} - \text{Rainfed Yield of treatment}}{\text{Irrigation water applied}}$$

Both TWUE and IWUE were given the same units i.e. Kg/ha - cm. water

3.6 Statistical analysis:

All the data collected were analysed statistically according to Little and Hills (1978). Treatment means were compared by LSD test as discussed by Little and Hills (1978).

Table 1: 12 yr. Averages of the major climatic elements at the experimental site (1975 - 1986). After: Meteorology Office, Records SUA (1975-1986).

Month	Mean Maximum temp. (°C)	Mean min. temp. (°C)	Average temperature (°C)	Mean monthly rainfall (mm)	Relative Humidity 3pm. (%)	Radiation (MJ/m^2)	Sunshine (hours)	Evaporation (mm)
January	31.7	21.0	26.3	93.6	54.3	546.3	225.2	164.4
February	32.2	21.1	26.6	87.5	48.1	526.9	212.5	184.3
March	31.7	20.5	26.1	140.0	58.6	521.6	197.7	174.5
April	29.7	20.4	25.0	175.6	66.1	431.2	166.8	118.6
May	28.5	18.7	23.6	92.9	60.7	395.1	170.0	98.3
June	27,7	15.7	21.7	21.5	51.7	401.0	198.1	91.0
July	27.6	15.0	21.3	16.1	46.9	360.0	191.9	102.9
August	28.2	15.6	21.9	7.2	43.2	402.4	185.3	121.5
September	29.9	16.6	23.2	10.2	42.6	510.9	207.9	166.7
October	31.6	18.2	24.9	31.6	39.6	513.7	236.0	191.9
November	32.0	19.8	25.9	67.1	41.9	533.7	245.2	196.0
December	31.5	21.2	26.3	130.0	51.4	487.4	223.9	196.4
Monthly Mean	30.2	18.6	24.4	72.8	50.4	469.2	205.0	150.5

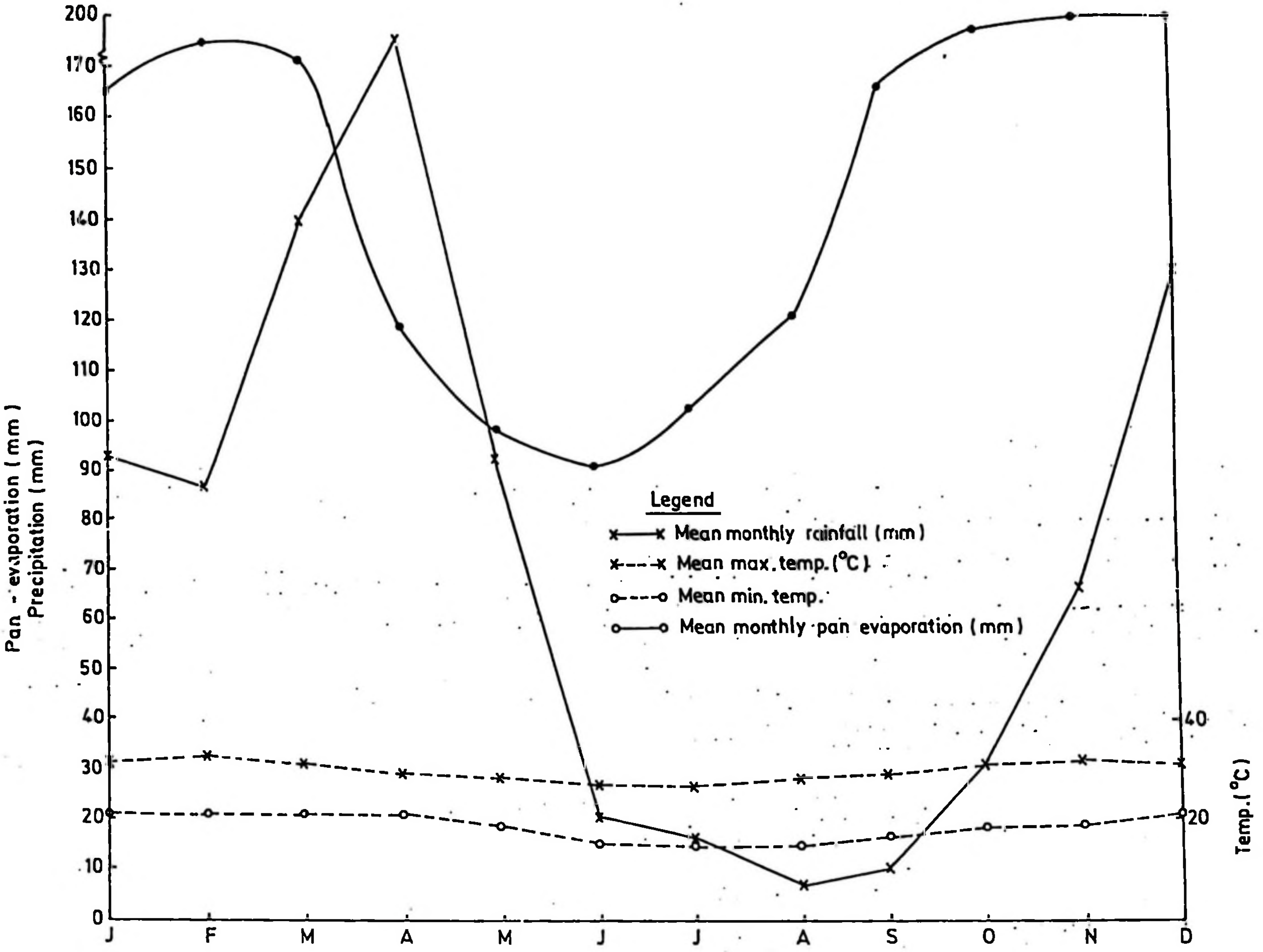

Fig.2. Twelve year averages precipitation, temperature and pan - evaporation for the experimental site (1975 — 1986)

4. RESULTS AND DISCUSSION

4.1 Effect of Soil, cultivar and Moisture regime on leaf water potential (ψ_l) of sorghum.

The results showing the effect of various factors on leaf water potential, (ψ_l) of sorghum plants are presented in Tables 2, a & b. . Plants in soil 1 (High WHC) throughout the measurement period showed higher leaf water potential than those in Soil 2 (low WHC). This indicated that plants growing in soil 1 were receiving a good supply of water compared to those in soil 2. The highest ψ_l,(-6.08 bars) in soil 1 was recorded at 51 days after planting (11th January, 1986), whereby the samples were collected at 8.00 a.m. (Table 2 (b).

The lowest ψ_l (-20.75 bars) was observed on the 21st Feb. 1986 (92 days after planting) when the samples were collected at 5.00 p.m. Table 2b from plants growing in Soil 1.

On the other hand, all the values obtained from plants growing in soil 2 showed lower ψ_l than those in Soil 1.

The difference in ψ_l for plants growing in the different soils could be due to the fact that soil 1 supplied more water indicating less stress to its plants compared to the lower water supply from soil 2 resulting in lower ψ_l for the plants in soil 2 than those in soil 1. The difference in water supply capacity of soils were also reported by Hillel (1971) and Jamison and Kroth (1959). Low ψ_l for both soils were recorded for the measurements taken at noon or late in the afternoon. This could probably be due to the increased radiant energy which increased the rate of water loss (evapo-transpiration).

From the results obtained, the local cultivar (Mbangala) maintained a higher ψ_l than the improved cultivar (Serena). The highest ψ_l for Mbangala was -5.42 bars while that for Serena was -7.51 bars. This means that probably Mbangala has some special features assisting it in increasing the drought tolerance compared to Serena.

Sorghum plant has the ability to close its stomata during water stress later than corn (Sanchez-Diaz and Kramer, 1971); Beadle _et al_, 1973) and wilts at a lower water potential than corn (Beadle _et al_, 1973). Because transpiration, leaf resistance and photosynthesis begin to be inhibited at the wilting point (Beadle _et al_ 1973) there is the implication that sorghum continues to grow under higher water stress than corn. It would appear therefore that Sorghum has more drought resistance and/or avoidance than corn (Stout and Simpson, 1978).

The irrigated Sorghum plants had higher ψ_L than those under rainfed conditions. Thus, the addition of water to Sorghum reduces the moisture stress. The highest ψ_L recorded under the irrigated condition was -6.02 bars (51 days after planting) while for the rainfed was -6.91 bars when the samples were collected at 8.00a.m.

Despite the fact that Sorghum is a drought tolerant crop, its growth is favoured by addition of water. Probably, the extent of stress is a function of soil, plant characteristics as well as the climatic factors. Sivakumar, *et al* (1979) found that irrigated Sorghum crop exhibited higher stomatal conductance and higher leaf water potential as compared to the non-irrigated Sorghum plants.

The present study indicated that probably tolerance in Sorghum is genetically controlled. Thus, selection against accelerated stress to moisture at low water potential may be desirable among the Sorghum cultivars.

Table: 2 (a) Mean leaf water potential (bars) of Sorghum plants

Sampling Date	Time of Day	Rainfed Mbangala		Irrigated Mbangala		Rainfed Serena		Irrigated Serena	
		Soil 1 (High WHC)	Soil 2 (Low WHC)	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1	Soil 2
8-1-86	5.00 pm	9.50	17.41	8.40	8.82	16.03	19.60	10.20	12.40
11-1-86	8.00 am	5.88	6.20	5.54	4.04	6.32	9.24	6.58	7.91
12-1-86	9.00 am	18.00	21.60	19.00	22.80	20.50	22.80	21.00	23.40
14-2-86	1.00 pm	15.50	16.03	14.03	14.08	19.50	21.20	6.28	12.70
18-2-86	4.00 pm	13.50	14.40	12.50	13.70	22.30	24.00	17.40	18.60
21-2-86	5.00 pm	20.00	21.00	18.70	19.40	23.70	22.80	20.60	20.90
22-2-86	1.00 pm	19.60	20.00	17.20	18.00	21.10	20.00	16.60	18.20
28-2-86	8.00 am	19.80	21.00	18.00	17.00	22.50	24.00	15.70	16.40
		15.22	17.20	14.17	14.73	18.99	20.46	14.29	16.31
	MEAN	±5.26	±5.16	±5.05	±6.02	±5.63	±4.83	±5.88	±5.06

Table 2 (b) Effect of Soil Cultivar and Moisture regime on leaf water potential, ψ_L (bars) of Sorghum plants

Date of Sampling	Time of day	SOIL		CULTIVAR		MOISTURE	
		Soil 1	Soil 2	Serena	Mbangala	Irrigated	Rainfed
8-1-86	5.00 pm	11.03	14.56	14.56	11.03	9.96	15.64
11-1-86	8.00 am	6.08	6.85	7.51	5.42	6.02	6.91
12-1-86	9.00 am	19.63	22.65	21.93	20.35	21.55	20.73
14-2-86	1.00 pm	13.83	16.00	14.92	14.91	11.77	18.06
18-2-86	4.00 pm	16.43	17.70	20.57	13.53	15.55	18.55
21-2-86	5.00 pm	20.75	21.03	22.00	19.78	19.90	21.88
22-2-86	1.00 pm	18.63	19.05	18.98	18.70	17.50	20.18
28-2-86	8.00 am	19.00	19.60	19.65	18.95	16.78	21.83

4.2 Effect of soil, cultivar and moisture regime on soil water potential, ψm.

The weighted soil matric potential, ψm for 15 - 105cm layer for the two soils (soils 1 and 2) are presented in Table 3a & b.

In general the weighted matric potential was lower under irrigated conditions than under rainfed in both soils. This is somewhat unexpected because the plants were supplied with irrigation water. However, the irrigation water supplied might have helped in a better development of root system thus allowing the plants to extract more water than under rainfed where the root system might have been smaller.

The differences under rainfed and irrigated conditions were larger in soil 1 (high WHC) than in soil 2 (low WHC). This might be due to the fact that from soil 2 considerable amount of water was lost beyond the root zone due to its low water holding capacity. Thus giving rise smaller differences in weighted ψm between irrigated and rainfed in soil 2. In general both cultivars were affected similarly under the two soils. Under irrigated conditions, the local cultivar (Mbangala) showed lower ψm than the improved cultivar (Serena) in soil 1.

This indicated more extraction of water by Serena than Mbangala. This could probably be attributed to the differences between total root length per unit volume of soil of the two cultivars (Table 9). However, total water use efficiency (TWUE) for grain yield was higher for Serena than that of Mbangala. Probably, most of the water extracted by Mbangala was used for dry-matter production rather than grain yield. The opposite could also be true for Serena.

In case of moisture regime when soil ψm were averaged over soils and cultivars, the rainfed Sorghum plots showed slightly higher ψm than irrigated Sorghum plots. This is somewhat unexpected observation according to theoretical principles. This could probably be explained by the fact that, under rainfed conditions, less roots per unit volume of soil were produced by plants growing in it. As a result, less water was extracted and consequently the observed higher ψm under rainfed. Another possibility is low evapotranspiration due to poor plant growth under rainfed condition which might have contributed to the results obtained.

Table 3 (a) Weighed Soil matric potential (ψ_m) for 15-105 cm depth.

		Days after planting								
		30-37	38-45	46-53	54-61	62-69	70-77	78-85	86-103	Mean
						ψ m(bars)				
	Serena(Irrigated)	0.20	0.26	0.45	0.48	0.48	0.43	0.59	0.43	0.42
Soil 1	Mbangala(Irrigated)	0.13	0.18	0.30	0.44	0.24	0.40	0.41	0.42	0.32
(High WHC)	Serena (Rainfed)	0.16	0.05	0.09	0.16	0.24	0.06	0.05	0.22	0.13
	Mbangala (Rainfed)	0.15	0.04	0.26	0.39	0.30	0.33	0.49	0.38	0.29
	Serena (Irrigated)	0.23	0.21	0.28	0.39	0.43	0.35	0.44	0.65	0.37
Soil 2	Mbangala (Irrigated)	0.33	0.20	0.41	0.46	0.35	0.59	0.46	0.63	0.43
(Low WHC)	Serena (Rainfed)	0.25	0.26	0.42	0.48	0.39	0.63	0.39	0.42	0.40
	Mbangala (Rainfed)	0.31	0.16	0.43	0.29	0.20	0.37	0.40	0.38	0.32
	Rainfall (mm)	0.0	114.2	0.0	41.3	28.8	4.5	53.8	41.7	
	Irrigation (mm)	10	NA	15	5	NA	10	NA	5^*	

Table 3 (b) Effect of soil, cultivar and moisture regime on weighed soil matric potential* (Bars) during the study period.

SOIL					
SOIL 1 (HIGH WHC)	SOIL 2 (LOW WHC)	IMPROVED (SERENA)	LOCAL (MBANGALA)	IRRIGATED	RAINFED
0.29	0.38	0.33	0.34	0.38	0.29

* Values given refer to averages for the entire season.

4.3 Effect of soil, cultivar and moisture regime on plant height.

The data on Sorghum plant height (cm) at 56 days after planting as influenced by various factors are presented in Table 4 and Appendix 3. Soil 1 (High WHC) produced significantly ($P < 0.05$) taller plants than soil 2 (low WHC). Plant height in Soil 1 exceeded the plant height in Soil 2 by 24.5cm.

Cultivar and moisture regime as well as their interactions were non-significant. However, the interactions between soil and cultivar (S x V) was highly significant ($P < 0.01$). Both cultivars were taller in Soil 1 than in soil 2 (Appendix 3). Plants of local cultivar (Mbangala) were shortest (46.8cm) in soil 2 but in soil 1 the shortest plants (70.6cm) were of the improved cultivar (Serena).

All other interactions had non-significant effect on plant height of sorghum. The significant effect of soil might have been due to the difference in WHC of soils as soil 1 might have stored and consequently released more water for the crop than soil 2 having low water holding capacity (Hillel, 1971 and Jamison and Kroth, 1958).

This probably favoured rapid growth of the plants and hence an increased plant height in soil 1 than in Soil 2.

In the present investigation both cultivars showed consistently greater plant height under irrigated than non-irrigated (rainfed) conditions although the differences were non-significant.

Since cultivars had no effect on plant height, significant interaction between soil and cultivar shows that the two cultivars responded differently to the soil as was evident from the observations that two cultivars produced smaller plants in two different soils rather than the same soil (Table 4).

4.4 Effect of soil, cultivar and moisture regime on stem diameter.

The data on the effect of various factors on stem diameter of Sorghum crop at 56 days after planting are presented in Table 5 and Appendix 4. Local cultivar (Mbangala) showed significantly ($P < 0.05$) greater stem diameter than the improved cultivar (Serena). While stem diameter of Serena averaged 1.79cm that of Mbangala was 2.13cm. The difference between the

Table 4. Effect of soil, cultivar and moisture on Sorghum plant height at 56 days after planting.

		MOISTURE REGIME (M)		
SOIL (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS[a/]
		Plant height (cm)		
		S X V X M		
Soil 1 (High Water holding capacity)	Serena	73.5	67.7	74.2
	Mbangala	82.1	73.6	74.2
Soil 2 (low water holding capacity)	Serena	53.0	52.3	
	Mbangala	48.3	45.2	49.7
		Soil (S) x Cultivar (V)[b/]		
		Serena	Mbangala	
Soil 1		70.6	77.9	
Soil 2		52.7	46.8	

[a/] LSD, 5% between soil means : 17.8

[b/] LSD, 5% between soil means for same or different cultivar: 12.8

cultivars might have been due to the genetic differences between them. Generally, Serena is considered as a short variety while Mbangala is one of the tall varieties.

Although the soils did not show significant difference in plant diameter, a consistent trend was observed where soil 1 (High WHC) produced plants with greater diameter than the soil 2 (Low WHC).

The moisture regime was observed to have no effect on plant diameter. Also all interactions between soil, moisture regime and cultivars were non-significant.

Lack of significance due to levels of moisture and soils shows that both the cultivars were affecte similarly under the different moisture regimes and soils.

4.5 Effect of soil, cultivar and moisture regime on the number of leaves of Sorghum plant.

The data on the effect of various factors on the number of leaves of Sorghum plants at 56 days after planting are presented in Table 6 and the Analysis of variance of the same is presented in Appendix 5.

Table 5: Effect of Soil, Cultivar and moisture regimes on stem diameter at 56 days after planting.

		MOISTURE REGIME (M)		
SOILS (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS
		Stem diameter (cm) S X V X M		
Soil 1 (High Water holding Capacity)	Serena	1.90	1.63	
	Mbangala	2.32	2.31	2.04
Soil 2 (Low Water holding Capacity)	Serena	1.89	1.76	
	Mbangala	1.89	2.0	1.88

Cultivar means: a

Serena = 1.8

Mbangala = 2.1

a/ LSD, 5% between cultivar means: 0.31

The plants growing in soil 1 (High WHC) were observed to have a significantly ($P < 0.01$) higher number of leaves than those growing in soil 2 (Low WHC). Plants growing in soil 1, exceeded those growing in soil 2 by 1.5 leaves.

Higher number of leaves for plants growing in soil 1 compared to those in soil 2 might have been due to the difference between the two soils whereby the former soil has high water holding capacity than the latter (low WHC) which as a result stored and consequently supplied more water to the growing plants. This favoured more leaf growth and development and consequently the observed increase in the number of leaves. Probably, due to increased moisture supply from soil 1 the leaf senescence of lower leaves was not observed. While plants growing in soil 2 suffered from moisture stress and some leaf senescence was observed.

The improved Sorghum (Serena) produced a significantly ($P < 0.01$) higher number of leaves than the local cultivar (Mbangala) at the same moisture regime. The difference between the cultivars in terms of leaf number could be attributed to the genetic variation between them.

Both cultivars had more leaves when irrigated compared to the non-irrigated or rainfed condition although there was no significant effect of moisture regime. There was a significant ($P < 0.01$) interaction between cultivar and moisture regime (V X M).

All other interactions (Soil x Moisture; Soil x Cultivar; Soil x Cultivar x Moisture were non-significant.

4.6 Effect of soil, cultivar and moisture regime on leaf area index (LAI) of Sorghum.

(i) At 56 days after planting

The data on the effect of various factors on leaf area indices of Sorghum plants at 56 days after planting are presented in Table 7 and Appendix (6). Significantly ($P < 0.05$) higher values of leaf area indices were produced by plants growing in soil 1 (High WHC) compared to plants growing in soil 2 (low WHC). The LAI of plants growing in soil 1 was higher by a factor of 0.9 than those in soil 2. Probably the ability of soil 1 to store greater amount of rain and/or irrigation water and in turn making more water available to the crop resulted in a better plant growth and thus higher LAI than of the plants grown in soil 2.

Table 6. Effect of Soil, Cultivar and Moisture regime on the number of leaves at 56 days after planting.

		MOISTURE REGIME (M)		
SOIL (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS [a/]
		(No. of leaves)		
		S X V X M		
Soil 1 (High water holding capacity)	Serena	9.0	8.3	
	Mbangala	7.0	8.7	8.2
Soil 2 (Low water holding capacity)	Serena	8.0	7.0	
	Mbangala	6.0	6.0	
		Cultivar x Moisture regime [b/]		
	Serena	8.5	7.7	
	Mbangala	6.5	7.3	

Cultivar means[c/] : Serena = 8.1; Mbangala = 6.9

[a/] LSD, 5% between soil means: 0.62

[b/] LSD, 5% between cultivar means for same or different moisture regime: 0.72

[c/] LSD, 5% between cultivar means: 0.61

The other factors viz; cultivar and moisture regime had no significant effect on LAI. In addition, all interactions between the factors were non-significant. This means that both cultivars responded similarly under the two moisture regimes.

At 76 days after planting:

The data on the LAI of Sorghum plants as affected by various factors at 76 days after planting are presented in Table 7 and Appendix (6). Soils which showed a significant effect at 56 days after planting had no significant effect on LAI at this stage (Appendix 6). Local cultivar (Mbangala) produced significantly ($P < 0.01$) higher LAI than the improved cultivar (Serena). This means that the differences between cultivars were highly significant. The LAI of Mbangala was higher than that of Serena by 2.2.

Also, the difference between moisture regimes was highly significant ($P < 0.01$). There was significant interaction between all other factors (Soil x Moisture; Cultivar x Moisture; and Soil x cultivar x Moisture) except soil x cultivar interaction which was non-significant. This means therefore that Soil did not have any influence on LAI at this stage in contrast to that at 56 days after planting. The LAI of Mbangala increased at 76 days from planting while that of Serena decreased compared to that of 56 days after planting. This could be attributed to the time to maturation of these cultivars. Serena is a short duration cultivar and at 76 days has already started leaf senescence and hence the observed decrease in LAI.

By this time, Mbangala was still at its vegetative phase and consequently showed higher LAI than Serena, (Appendix 6). The situation at 56 days after planting when serena showed a higher LAI than Mbangala was opposite to that observed at 76 days after planting.

Irrigation produced plants with higher LAI than rainfed for both cultivars and in both soils (Table 8 and Appendix 7). Usually increased moisture content leads to cell-enlargement

and this could account for the increased LAI for the Sorghum plants supplied with irrigation water.

According to McCree and Davis (1974) leaf area development is affected by several factors.

These include the time to panicle initiation (through its effect on leaf number); the rates of leaf appearance; leaf expansion; leaf senescence and canopy structure. These factors could explain the higher LAI obtained under irrigated conditions.

4.7 Effect of Soil, Cultivar and Moisture regime on root length.

Data on effect of various factors on root length per unit soil volume are presented in Table 9 and Figures 3a and b.

Soil 1 (High WHC) showed higher root length per unit volume of soil than soil 2 (low WHC). For both soils higher root lengths occurred in 0-45cm depth. The differences in water holding capacity between the soils probably affected root growth and as a result plants growing in soil 1 received adequate moisture which later favoured root development compared to soil 2.

Root lengths (cm), by 15cm increments to 90cm are given in Table 9 and figures 3a and b for the two soils. In case of cultivars ranked: Irrigated Mbangala > Rainfed Mbangala > Irrigated Serena > Rainfed Serena. The trend was the same in both

Table 7. Effect of soil, cultivar and moisture regime on leaf area index (LAI) at 56 days after planting.

		MOISTURE REGIME (M)		
SOIL (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS [a/]
		(LAI) S X V X M		
Soil 1 (High Water holding capacity)	Serena	1.8	1.9	
	Mbangala	1.7	1.4	1.7
Soil 2 (Low water holding capacity)	Serena	0.9	1.0	
	Mbangala	0.5	0.8	0.8

[a/] LSD, 5% between soil means: 0.67

Table 8. Effect of soil, cultivar and moisture regimes on leaf area index (LAI) at 76 days after planting.

		MOISTURE REGIME (M)		
SOIL (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS
		(LAI) S X V X M [a/]		
Soil 1 (High water holding capacity)	Serena	1.6.	1.5	
	Mbangala	5.2	3.0	2.8
Soil 2 (Low water holding capacity)	Serena	1.2	1.0	
	Mbangala	3.1	2.8	2.0

Cultivar means: [b/]
Serena = = 1.3
Mbangala = 3.5

Cultivar x Moisture regimes [d/]
Soil x Moisture regimes[e/]

Moisture means: [c/]
Irrigated = 2.8
Rainfed = 2.1

[a/] LSD, 5% between soil means for same or different cultivar and moisture: 0.14

[b/] LSD, 5% between cultivar means: 0.75

[c/] LSD, 5% between moisture regimes: 0.4

[d/] LSD, 5% between cultivar means for same or different moisture regime: 0.6

[e/] LSD, 5% between soil means for same or different moisture regime: 0.29

soils. Root length for both cultivars decreased with depth. Root length of the irrigated Mbangala were greater in the 0-15cm depth than in any other depth in soil 1 and 2. The opposite was true for the rainfed Serena. This showed that Mbangala has a deeper rooting system compared to Serena. This probably contributed to more water extraction by Mbangala resulting into higher leaf water potential (Table 2a and b).

The moisture regime showed an effect on root length in the two soils. Under irrigated condition, higher root lengths were observed than in rainfed. Both cultivars increased their root lengths under irrigated compared to rainfed. This implies that through irrigation root development is enhanced.

The differences in cultivar behaviour under similar conditions was attributed to the differences in rooting depth of the cultivar. Deep rooted cultivar such as Mbangala could exploit more stored moisture and could withstand an extended dry spell compared to Serena.

Table 9. Root length density (cm/cm^3) from the different treatments.

	SOIL 1 (HIGH WHC)				SOIL 2 (LOW WHC)			
Depth (cm)	Irrigated Serena	Rainfed Serena	Irrigated Mbangala	Rainfed Mbangala	Irrigated Serena	Rainfed Serena	Irrigated Mbangala	Rainfed Mbangala
				cm/cm^3				
0-15	0.45	0.35	1.07	0.89	0.38	0.34	0.49	0.39
15-30	0.28	0.19	0.35	0.27	0.15	0.09	0.37	0.30
30-45	0.07	0.05	0.19	0.09	0.11	0.07	0.29	0.26
45-60	0.04	0.02	0.15	0.12	0.04	0.03	0.20	0.13
60-75	0.06	0.03	0.08	0.07	0.10	0.05	0.14	0.07
75-90	0.09	0.07	0.13	0.09	0.16	0.13	0.19	0.09

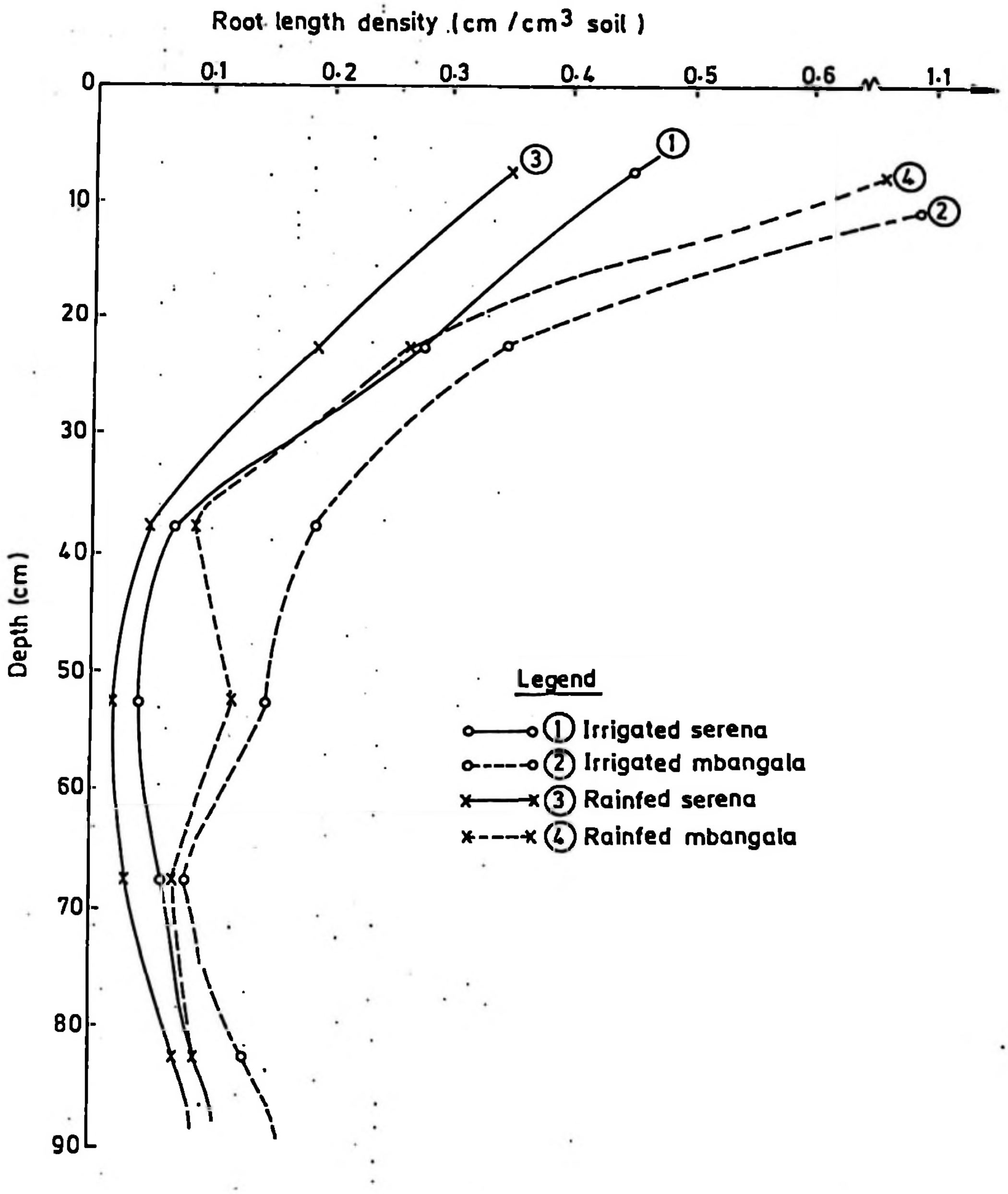

Fig. 3a. Effect of cultivar, moisture regime on root length density with depth in soil 1 (high WHC).

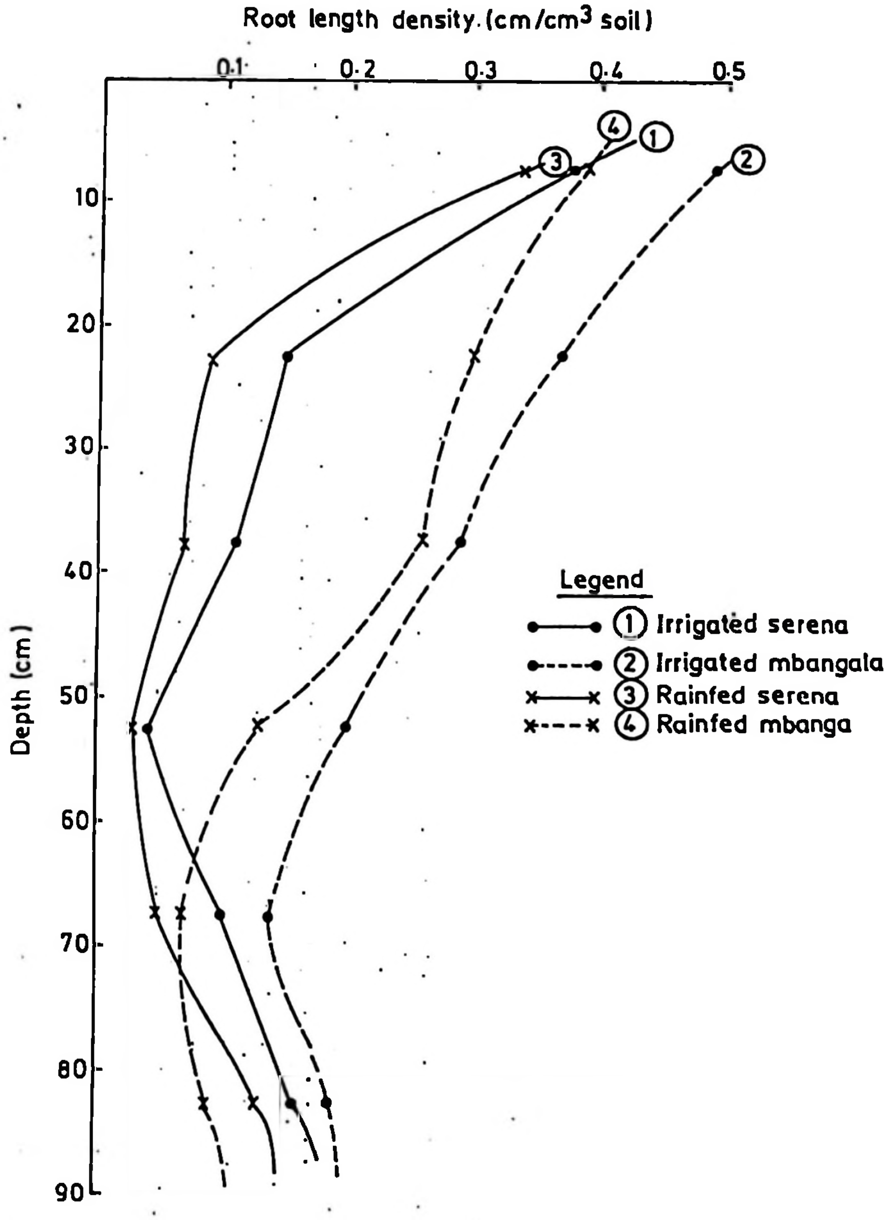

Fig. 3b. Effect of cultivar, moisture regime on root length density with depth in soil 2 (low WHC).

4.8 Effect of soil, cultivar and moisture regime on dry matter (DM) yield of Sorghum.

(i) At 56 days after planting

The data on the effect of various factors on dry-matter (DM) yield of Sorghum at 56 days after planting (d.a.p.) are presented in Table 10 and the analysis of variance of the same is presented in Appendix 8.

Significantly ($P < 0.05$) higher DM was produced by plants growing in soil 1 (High WHC) than those in soil 2 (Low WHC). The DM yield of plants growing in soil 1 was higher by about 2700kg per ha than those growing in soil 2. The increased DM yield obtained from plants growing in soil 1 might be due to the high amount of water retained and released by the soil 1 compared to soil 2. This being the case more water was available to the plants growing in soil 1 giving rise to rapid growth and hence more dry-matter accumulation.

Significantly ($P < 0.01$) higher dry matter yield was produced by the improved cultivar (Serena) than the local cultivar (Mbangala). The reason for this could be due to the fact that Serena has reached quite an advanced stage of vegetative growth producing more DM compared to

Mbangala which is a long-duration cultivar and might still be in its early vegetative growth stage. This resulted in higher DM production of Serena than Mbangala.

Moisture regime had no-significant effect on the DM yield. All the interactions between the factors were also non-significant. Thus, the DM yield depended on the soil type as well as the cultivar growing in it.

(ii) DM yield at 76 days after planting

The data presented in Table 11 and the Analysis of variance in Appendix (9) shows the effect of various factors on dry-matter yield of Sorghum plants at 76 d.a.p.

Plants growing in soil 1 produced significantly ($P < 0.05$) higher DM than those growing in soil 2. In general plants growing in soil 1 produced about 1700kg DM more than those in soil 2. Thus the trend was similar to that observed at 56 d.a.p.

The local cultivar (Mbangala) produced significantly ($P < 0.01$) higher DM than the improved cultivar (Serena). Mbangala exceeded Serena by about 5200kg DM.

The dry matter yield of Mbangala increased at 76 days from planting while that of Serena decreased compared to that at 56 d.a.p. This could be attributed to the time to maturation of the two cultivars. At 76 days, Serena has already started leaf senescence resulting in low DM yields. On the other hand, Mbangala was still showing more green leaves. Thus Mbangala could be more useful for dry matter production (Animal fodder) while the short duration cultivar (Serena) for grain production.

The irrigated plots produced 14% more DM than the rainfed plots. From their studies, on Sorghum Wahab et al. (1976) reported that the dry matter yield of the irrigated plots were 26% higher than yields of the non-irrigated plots. Thus, the addition of irrigation water to Sorghum plants increased the dry matter yield but not significantly. This might be due to the limited irrigation water applied.

Another study by Sivakumar et al. (1979) showed that both leaf area index and DM accumulation were higher in the irrigated sorghum plants than the non-irrigated plants. This was attributed to the higher stomatal conductance and less negative leaf water potential which were associated with higher DM production rates of the irrigated plots.

Present findings thus, conform with the results obtained by Wahab et al (1976) and Sivakumar et al (1979).

4.9 Effect of soil, cultivar and moisture regime on grain yield of Sorghum.

The data on the effect of various factors on grain yield of Sorghum are presented in Table 12 and the analysis of variance of the same is presented in Appendix 10.

Soil did not show any significant effect on grain yield. This result is somewhat unexpected considering the trend observed for other plant growth parameters in relation to soils as most of the plant growth parameters studied (viz. leaf area, plant height, shoot dry weight and leaf number) were significantly higher in Soil 1 (High WHC) than in Soil 2 (low WHC). However, the amount of rainfall received by the crop during its life cycle provides a clue to the observed results.

Of the total rainfall of 283.9mm received by Serena from planting up to the stage of physio-

Table 10. Effect of soil, cultivar and moisture regimes on dry matter yield at 56 days after planting.

		MOISTURE REGIME (M)		
SOIL (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS[a/]
		Dry matter (kg/ha) S X V X M		
Soil 1 (High water holding capacity)	Serena	4564.7	4222.3	
	Mbangala	4562.3	2289.0	3909.6
Soil 2 (Low water holding capacity)	Serena	2081.7	1348.0	
	Mbangala	855.7	542.3	1206.9

Cultivar means: b/

Serena = 3054.2

Mbangala = 2062.3

[a/] LSD, 5% between soil means: 2133.2

[b/] LSD, 5% between cultivar means: 365.1

Table 11. Effect of soil, cultivar and moisture regime on dry matter yield at 56 days after planting.

		MOISTURE REGIME (M)		
SOIL (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS[a/]
		Dry-matter (kg/ha) S X V X M		
Soil 1 (High water holding capacity)	Serena	7812.7	6603.0	
	Mbangala	15333	12451.3	10549.9
Soil 2 (Low water holding capacity)	Serena	6912.7	7054.0	
	Mbangala	11620	9790	8844.2

Cultivar means: b/

Serena = 7095.6

Mbangala = 12298.6

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a/ LSD, 5% between soil means: 1385.2

b/ LSD, 5% between cultivar means: 2205.15

logical maturity (93 days after planting) 212.3mm was received within 60 days from planting. There after from 60 to 82 days from planting the rainfall received amounted to only 2.2mm and remaining 69.4mm was received between 82 to 86 days after planting. It is thus obvious that considerable amount of rainfall received up to 60 days from planting resulted in a different amounts of water stored and released from the two different soils for the vegetative growth of the crop consequently bringing about significant differences in the plant growth parameters.

However, during the reproductive stage of the crop 2.2mm of rainfall was ineffective to bring about any changes in the water storage and thus water supply under two different soils. The remaining rainfall of 69.4mm received during 82 to 86 days after planting could not have contributed to the grain yield as the crop was already nearing physiological maturity. It thus becomes clear that the lack of any significant amount of rain during reproductive stages of the improved cultivar (Serena) was the main factor that soils had no effect on grain yield.

On the other hand, local cultivar (Mbangala) received rainfall amounting to 485.4mm from planting up to the stage of physiological maturity (145 days after planting). Compared to Serena, Mbangala received about 352.1mm rainfall from day 60 to the stage of physiological maturity. Thus, enough water was supplied by the rain to Mbangala during its growth period especially that during reproductive phase resulting in no significant difference in the yield due to soils. And consequently when the yield was averaged over moisture regime and cultivar no differences were recorded due to soils.

Serena produced significantly ($P < 0.05$) higher grain yield than Mbangala. Serena exceeded Mbangala by 286.6kg of grain per hectare. The significant effect due to cultivar might be due to the difference in the genetic component which controls the yielding ability. This is also supported by the fact that although Mbangala stayed longer in the field and thus got a longer photosynthesis period than Serena yet it yielded less than Serena.

Moisture regime showed a highly significant ($P < 0.01$) effect on grain yield. The plants growing under irrigation outyielded those under rainfed by 170kg per hectare. The interaction between Soil x Moisture regime was not significant.

Interaction of cultivar and moisture regime on the grain yield was significant ($P < 0.05$). This was due to the fact that while Serena gave a significantly ($P < 0.05$) higher yield under irrigated than under rainfed conditions there were no differences in the grain yield of Mbangala under the two conditions. The different response of two cultivars to the moisture regime seems logical when the amount of rainfall received during the crop growth is taken into account. Considering the crop had attained physiological maturity two weeks prior to harvesting, Serena received only 283.9mm of rainfall up to the physiological maturity (93 days from planting) compared to 485.4mm by the Mbangala (145 days from planting).

Thus, while Mbangala was still in its reproductive stage, when the long rains have began and supplied it with sufficient amount of water making the effect of irrigation on grain yield negligible.

The Sorghum yield is quite sensitive to moisture stress during the boot through bloom stages and if supplied with enough water during these stages, the yields are considerably higher (Lewis *et al*, 1974). Musick and Dusek (1971) reported that a single 10-cm irrigation applied at heading or milk stage gave maximum yields in Sorghum.

However assessing sensitivity of a particular stage of Sorghum to moisture stress becomes difficult in most of the irrigation studies if there is a considerable seasonal variability of rainfall (Stone *et al*, 1978).

4.9.1 Effect of Soil, Cultivar and moisture regime on Total Water use efficiency (TWUE) for dry-matter and grain yield.

The data on total water use efficiency (TWUE) for dry-matter (DM) production at 56 days after planting (d.a.p.) and grain yield are presented in Table 13.

The high water holding capacity soil (Soil 1) showed higher TWUE than the low water holding capacity soil (Soil 2) in DM yield. Soil 1 gave a TWUE value of 108.6kg DM per hectare-cm of water while soil 2 showed a value of 33.5kg DM per hectare-cm of water.

The difference in TWUE in terms of DM production under the two soils could be attributed to the difference in water holding capacity of

Table 12. Effect of soil, cultivar and moisture regimes on grain yield.

		MOISTURE REGIME (M)		
SOIL (S)	CULTIVAR (V)	IRRIGATED	RAINFED	SOIL MEANS
		(Grain yield kgha^{-1})		
		S X	V X M	
Soil 1 (High water holding capacity)	Serena	1444.0	1214.7	
	Mbangala	1108.3	1038.3	1201.3
Soil 2 (Low water holding capacity)	Serena	1266.3	1008.3	
	Mbangala	899.3	740.7	978.6
	Cultivar (V) x Moisture (M) means [a]			
	Serena	1355.2	1111.5	
	Mbangala	1003.8	889.5	1090.0

Means for Cultivar: b

Serena = 1233.3
Mbangala = 946.7

Means for moisture regimes: c

Irrigated = 1179.5
Rainfed = 1000.5

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a/ LSD, 5% between cultivar means for the same or different moisture regime: 168.1

b/ LSD, 5% between cultivar means: 219.9

c/ LSD, 5% between moisture means: 58.99

Table 13. Dry matter and grain yields and water use efficiency for the different treatments.

		Dry matter and total water use at 56 days after planting			Grain and Total use efficiency		
	Treat	Yield (kg/ha)	Total water use (cm)	Total water use efficiency (kg/ha-cm)x	Yield (kg/ha)	Total water use (cm)	Total water use efficiency (kg/ha-cm)
Soil 1 (High water holding capacity)	Rainfed Serena	4222.3	34.3	123.1	1214.7	28.39	42.8
	Irrigated Serena	4564.7	37.3	122.4	1444.0	32.39	44.6
	Rainfed Mbangala	2289.0	34.3	66.7	1038.3	44.04	23.6
	Irrigated Mbangala	4562.3	37.3	122.3	1108.3	48.54	22.8
Mean		3909.6		108.6	1201.3		33.4
Soil 2 (Low water holding capacity).	Rainfed Serena	1348.0	34.3	39.3	1008.3	28.39	35.5
	Irrigated Serena	2081.7	37.3	55.8	1266.3	32.39	39.1
	Rainfed Mbangala	542.3	34.3	15.8	740.7	44.04	16.8
	Irrigated Mbangala	855.7	37.3	23.0	899.3	48.54	18.5
Mean		1206.9		33.5	978.6		27.5

x Total water use efficiency (TWUE)

$$= \frac{\text{Total Yield}}{\text{Total water use (Irrigation + Precipitation)}}.$$

the two soils. Probably more water was retained within the root zone and made available to the plants growing in soil 1 than in soil 2 resulting in increased TWUE for both cultivars within soils.

In case of cultivars, TWUE of the improved cultivar (Serena) was higher than that of local (Mbangala). The TWUE for Serena was 85.15 and for Mbangala it was 56.90 kg DM per hectare-cm of water. The TWUE of Serena was higher by 33.2% over that of Mbangala. This could probably be explained by the time to maturity. Serena is a short duration cultivar. Thus at this time (56 d.a.p.) it has already attained its maximum vegetative growth while Mbangala being a longer duration cultivar was still at its active vegetative phase. This means therefore, that at this stage (56 d.a.p.) more tissues were available as DM for Serena than Mbangala. Shipley (1971) reported that dry-matter production was most rapid during early to late boot stage and as by this time Serena was approaching the boot stage it might have produced dry-matter at a faster rate resulting in higher TWUE.

Total water use efficiency was observed to be higher under irrigated compared to that under rainfed conditons. Through irrigation TWUE was increased by 24.3% over the rainfed.

Total water use efficiency for grain yield is presented in Table 13. Soil 1 showed higher TWUE than soil 2. Soil 2 showed 17% less TWUE compared to soil 1. This could probably be due to the differences in the amounts of water made available to the plants growing in two soils. Soil 1 has higher water retaining capacity than soil 2 (Appendix 1). This means therefore, that plants in soil 1 were exposed to more moisture and consequently higher growth occurred in terms of yield components viz: leaves, stem height and DM. As a result the final grain yield turned out to be higher in soil 1 than in soil 2. The TWUE values for soil 1 and soil 2 were 33.4 and 27.4 kg grain per hectare-cm of water respectively.

The total water use efficiency of Serena was higher than that of Mbangala by 20.1kg/ hectare-cm of water. Serena gave a TWUE of 40.5 while Mbangala gave 20.4 kg grain/ha-cm of water. Thus, Serena appeared to be almost twice as efficient as Mbangala in grain yield production. It could thus be inferred that Serena is suitable for grain production while Mbangala for animal fodder production. This is also supported when their growth periods are taken into consideration. Mbangala being a long duration cultivar stayed longer in the field and yet produced lower grain yield than Serena.

Total water use efficiency for grain yield was observed to increased with irrigation although the differences were small. Under rainfed, TWUE was about 5.2% less than that under irrigated conditions.

The results of the irrigation water use efficiency (IWUE) of grain yield are presented in Table 14. The IWUE for soil 1 appeared to be lower than that of soil 2.

Serena had higher IWUE in soil 2 than in soil 1. In this case IWUE in soil 2 was higher by 11.2% than that of soil 1. Mbangala also showed higher IWUE in soil 2 than in soil 1. The IWUE for Mbangala in soil 2 was higher by about 5% than that of soil 1. It is therefore clear from the results that soil 2 responded well to irrigation than soil 1.

These differences in soils could be attributed to the fact that by supplying water to soil 1, IWUE tends to be lower as might be due to the fact that since soil 1 has high water holding capacity it might

Table 14. Irrigation water use efficiency (IWUE) of the different treatments with respect to the grain yield.

Treatments		Yield (kg/ha)	Irrigation water applied (cm)	Irrigation water use efficiency (IWUE)* (kg/ha-cm)
Soil 1 (High water holding capacity)	Irrigated Serena	1444.0	4.0	57.3
	Irrigated Mbangala	1108.3	4.5	15.5
Soil 2 (Low water holding capacity)	Irrigated Serena	1266.3	4.0	64.5
	Irrigated Mbangala	899.3	4.5	35.2

* Irrigation water use efficiency (IWUE)

$$= \frac{\text{Irrigated Yield of Treatment} - \text{Rainfed Yield of treatment}}{\text{Irrigation water applied}}$$

have retained and released more rainfall water making the effect of irrigation water less effective than that in soil 2 which due to its low water holding capacity responded favourably to irrigation. Thus, soil 2 gave higher IWUE contributed by the addition of water over the rainfall (i.e. by irrigation).

5. SUMMARY AND CONCLUSIONS

Plant-water status and grain yield of Sorghum (Sorghum bicolor (L.) Moench) in relation to soil-water status was investigated during short rains of 1985 at the Sokoine University of Agriculture experimental farm. The treatment combinations consisted of two soils one with a high water holding capacity (soil 1) the other with a low water holding capacity (soil 2) and two Sorghum cultivars, namely improved (Serena) and local (Mbangala) under two different moisture regimes of limited irrigation and rainfed conditions.

The parameters studied included: weighted soil matric potential (ψm), leaf-water potential (ψ_l), stem diameter, plant height, number of leaves, leaf area index (LAI), dry-matter (DM) yield, Root length density, grain yield, total water use efficiency (TWUE) and irrigation water use efficiency (IWUE).

Weighted soil matric potential, $\psi'm$ (15-105cm layer) was lower in soil 2 than in soil 1. The plots planted with Mbangala showed lower $\psi'm$ than those planted with Serena. Furthermore, the rainfed plots indicated higher $\psi'm$ than the irrigated plots.

Plants growing in soil 1 showed higher ψl than those in soil 2. In case of cultivars, Mbangala had higher ψl than Serena. Both cultivars had higher ψl under irrigated than under rainfed conditions. There was a significant ($P < 0.05$) effect of cultivar on the stem diameter at 56 days after planting (d.a.p.). Mbangala showed greater stem diameter than Serena. However, soils and moisture regimes had no effect on stem diameter.

Plant height at 56 d.a.p. indicated a significant ($P < 0.05$) effect of the soil. Plants growing in soil 1 were taller than those in soil 2 by 24.5cm. The interaction effect of soil x cultivar was also significant ($P < 0.01$).

Number of leaves at 56 d.a.p. was significantly (P 0.01) higher for plants growing in soil 1 than those in soil 2. Also, Serena showed significantly ($P < 0.01$) higher number of leaves than Mbangala. The effect of the interaction of cultivar x moisture regime on the number of leaves was also significant ($P < 0.05$).

Leaf area index (LAI) determined at 56 d.a.p. was significantly ($P < 0.05$) affected by soil. Plants growing in soil 1 showed greater LAI than those in soil 2. Cultivar and moisture regime had no effect on LAI. At 76 d.a.p. cultivars showed a significant ($P < 0.01$) effect on LAI. At this stage Mbangala had higher LAI than Serena. Moisture regime also showed a highly significant ($P < 0.01$) effect on LAI at 76 d.a.p. Plants growing under irrigation had higher LAI than those under rainfed conditions. The interactions of soil x moisture regime, cultivar x moisture regime and soil x cultivar x moisture regime were also significant ($P < 0.05$).

Soils showed a significant ($P < 0.05$) effect on dry-matter (DM) yield at 56 d.a.p. Higher DM yields were produced by plants growing in soil 1 than those in soil 2. Cultivars had a highly significant ($P < 0.01$) effect on DM yield. Serena produced more DM at 56 da.p. than Mbangala. Moisture regime had no effect on DM yield. Dry-matter yield determined at 76 d.a.p. indicated that soils had a significant ($P < 0.05$) effect on DM. Soil 1 plants produced higher DM yields than those in soil 2. Also the cultivar had a highly significant ($P < 0.01$) effect on DM yields. Mbangala produced more DM than Serena.

Root length density measurements made at 90 d.a.p. indicated that plants growing in soil 1 had their roots more profilic (higher root length density) than those in soil 2. Mbangala showed higher root length density than Serena. Root distribution was also influenced by the moisture regime such that more development occurred in plants under irrigated compared to those under rainfed conditions.

There was a significant ($P < 0.05$) effect of cultivar on grain yield. Serena outyielded Mbangala by 286.6 kg grain per hectare. Soils had no significant effect on grain yield. Moisture regimes significantly ($P < 0.01$) affected the grain yield. Irrigated plants yielded more grains per hectare than the rainfed ones. The interaction of Cultivar x Moisture regime on grain yield was significant ($P < 0.05$).

Total water use efficiency (TWUE) for DM at 56 d.a.p. and grain yield was also determined. It indicated that plants growing in soil 1 had higher TWUE than those in soil 2 for both DM and grain yields. Serena showed higher TWUE than Mbangala in terms of both DM as well as grain production. Total water use efficiency was higher under irrigated than under rainfed conditions.

Irrigation water use efficiency (IWUE) for grain yield was higher for Serena compared to Mbangala. This was true for both soils.

In view of the above results, the following conclusions can be made:

1) During short rains Sorghum plants perform better in soils of high water holding capacity. This is evident from the better growth, higher DM production and greater yield obtained for plants growing in soil 1 than in soil 2.
2) In view of a higher grain yield Serena could be recommended for grain production while

Mbangala which produces more dry-matter and for a longer time could be recommended as animal fodder. This is true especially during the short rains since Mbangala stayed much longer in the field than Serena and yet produced much less grain but a higher DM yield than Serena.

3) Sorghum grain yield is significantly increased by irrigation especially when the crop is grown in soils having low water holding capacity. However, Serena responded more to irrigation in terms of grain yield. Thus, if limited irrigation is available Serena should be preferred over Mbangala.

4) Of the two cultivars, Mbangala showed more drought tolerance than Serena. Probably this could be attributed to the deep-rooting system increasing water extraction from the soil. Hence, Mbangala could be suitable for drier areas than Serena.

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Appendix 1. Some physical and chemical characteristics of the two soils

Location	Depth	Particle Size Sand	 Silt	 Clay	Textural Name	Bulk Density	pH	N	P	K meq./ 100g soil	Water Retention at Saturation	 0.1 bars	 0.3 bars	 15 bars	Water equivalent depth
	(cm)	(%)	(%)	(%)		(g/cc)	(water)	(%)	(ppm)						(cm)
												θm			θm.ρb.d
Soil 1 (High water Holding capacity)	0-35	84	6.0	10.0	Loamy sand	1.59	6.2	0.07	40.7	0.77	35.50	21.12	16.58	5.51	6.16
	35-80	67	8.6	24.4	Sandy Clay loam	1.32	6.2	0.035	27.4	1.03	34.40	26.82	25.05	10.64	8.56
	80-97	78	9.8	12.2	Sandy loam	1.64	6.5	0.14	7.0	0.26	22.95	18.12	16.47	9.44	1.96
	97-118	89	4.9	6.1	Sand	1.44	6.5	0.21	13.3	0.26	29.63	22.61	19.97	11.65	2.52
	118-145	83.5	10.4	6.1	Loamy Sand	1.50	6.5	0.07	12.6	0.26	24.99	19.92	17.00	9.86	2.89
															22.09cm/ 1.45m = 15.23cm/m
Soil 2 (Low water holding capacity)	0-20	89	6	5	Sandy	1.44	6.4	0.17	8.4	0.77	26.62	15.69	12.71	5.28	2.14
	20-51	84	6	10	Loamy Sand	1.30	6.6	0.07	3.5	0.77	22.75	11.95	10.58	3.33	2.92
	51-72	74	11	15	Loamy Sand	1.37	6.6	0.14	14.0	0.51	32.40	18.06	13.56	7.18	1.84
	72-98	79	6	15	Loamy Sand	1.31	6.6	0.14	10.5	0.26	29.59	15.62	11.76	5.80	2.03
	98-145	84	6	10	Loamy Sand	1.26	6.5	0.14	16.8	0.26	36.75	27.31	24.24	14.44	5.80
															14.73cm/ 1.45m = 10.16Cm/m

Appendix 2. Summary of climatic data during the experimental period

	Nov.	Dec.	Jan.	Feb.	March	April	May
Average maximum temp. (°C)	31.55	35.5	31.3	33.7	31.5	30.1	28.3
Average minimum temp. (°C)	19.6	21.3	20.8	20.7	20.7	20.2	19.6
Average mean temp. (°C)	25.6	28.4	26.0	27.2	26.1	25.2	23.9
Average Relative humidity (%)	47	49	59	46	65	68	70
Total Pan-evaporation (mm)	182.8	215.3	151.6	190.6	134.2	91.7	89.6
Mean bright Sunshine (hrs.)	7.9	8.6	6.2	9.2	5.3	6.2	4.1
Mean wind run (m/S)	82.8	89.2	61.3	60.5	40.6	30.3	26.8
Total rainfall (mm)	58.3	43.3	134.6	70.1	155.5	142.7	157.7
Mean Radiation (MJ/m^2)	17.29	19.01	16.06	20.42	16.04	15.0	11.81

Appendix 3. Effect of soil, cultivar and moisture regime on plant height at 56 days after planting.

Source of Variation	Degrees of freedom	Sum of Squares	Mean squares	Observed F	Required F 5%	Required F 1%
Sub-Sub plots	23	4609.425	196.0619565			
Sub-plots	11	4117.325	374.3022727			
Main plots	5	3814.83	762.966			
Blocks, B	2	7.3125	3.65625			
Soils, S	1	3601.5	3601.5	34.96^x	18.51	98.50
Main plot error, BS	2	206.0175	103.00875			
Cultivar treat, V	1	2.801666	2.801666	0.27	7.71	21.20
S X V	1	258.726667	258.726667	25.26	7.71	21.20
Sub-plot error, BV + B(S X V)	4	40.966667	10.2416675			
Moisture, M	1	123.306666	123.306666	4.55	5.32	11.26
S X M	1	42.135	42.135	1.55	5.32	11.26
V X M	1	9.626668	9.626668	0.35	5.32	11.26
S X V X M	1	0.014999	0.014999	0.0006	5.32	11.26
Sub-Sub plot error, BM + B(S X M) + B(V X M) + B(S X V X M)	8	217.016667	27.12708338			

Appendix 4. Effect of soil, cultivar and moisture regime on stem diameter at 56 days after planting.

Source of variation	Degrees of Freedom	Sum of Squares	Mean Squares	Observed F	Required F 5%	Required F 1%
Sub-Sub plots	23	1.98249583	0.08619547			
Sub plots	11	1.43174583	0.130158711			
Main plots	5	0.17057083	0.034114166			
Blocks, B	2	0.00775833	0.003879165			
Soils, S	1	0.139537496	0.139537496	11.99	18.51	98.50
Main plot error, BS	2	0.023275004	0.011637502			
Cultivar treat, V	1	0.670004163	0.670004163	8.72^{x}	7.71	21.20
S X V	1	0.283837504	0.283837504	3.69	7.71	21.20
Sub-plot error, BV + B(S X V)	4	0.307333333	0.076833333			
Moisture, M	1	0.034504163	0.034504163	0.070	5.32	11.26
S X M	1	0.023437504	0.023437504	0.48	5.32	11.26
V X M	1	0.10010417	0.10010417	2.04	5.32	11.26
S X V X M	1	0.000204163	0.000204163	0.004	5.32	11.26
Sub-Sub plot error, BM + B(S X M) + B(V X M) + B(S X V X M)	8	0.3925	0.0490625			

Appendix 5. Effect of soil, cultivar and moisture regime on number of leaves at 56 days after planting.

Source of Variation	Degrees of freedom	Sum of squares	Mean squares	Observed F	Required F 5%	Required F 1%
Sub-Sub plots	23	34.0	1.47826087			
Sub plots	11	24.0	2.181818182			
Main plots	5	14.0	2.8			
Blocks B	2	0.25	0.125			
Soils, S	1	13.5	13.5	108.0^{xx}	18.51	98.50
Main plot error, BS	2	0.25	0.125			
Cultivar treat, V	1	8.1666666	8.1666666	27.99^{xx}	7.71	21.20
S X V	1	0.6666667	0.6666667	2.29	7.71	21.20
Sub-plot error BV + B(S X V)	4	1.1666667	0.291666675			
Moisture, M	1	0.00	0.00	0.0	5.32	11.26
S X M	1	1.50	1.50	3.27	5.32	11.26
V X M	1	4.1666667	4.1666667	9.09^{x}	5.32	11.26
S X V X M	1	0.6666666	0.6666666	1.45	5.32	11.26
Sub-sub plot error BM + B(S X M) + B(V X M) + B(S X V X M)	8	3.6666667	0.458333337			

Appendix 6. Effect of soil, cultivar and moisture regime on leaf area index at 56 days after planting.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F	Required F 5%	Required F 1%
Sub-Sub plots	23	6.77958333	0.294764492			
Sub plots	11	5.96458333	0.542234848			
Main plots	5	5.24208333	1.048416666			
Blocks, B	2	0.18083333	0.090416665			
Soils, S	1	4.770416663	4.770416663	32.81*	18.51	98.50
Main plot error, BS	2	0.290833337	0.145416668			
Cultivar treat, V	1	0.510416663	0.510416663	2.83	7.71	21.20
S X V	1	0.00041667	0.00041667	0.002	7.71	21.20
Sub- plot error BV + B(S X V)	4	0.72208333	0.180520832			
Moisture regime, M	1	0.003749996	0.003749996	0.06	5.32	11.26
S X M	1	0.183750004	0.183750004	3.04	5.32	11.26
V X M	1	0.050416671	0.050416671	0.83	5.32	11.26
S X V X M	1	0.093700026	0.093700026	1.55	5.32	11.26
Sub-Sub plot error, BM + B(S X M) + B(V X M) + B(S X V X M)	8	0.483383303	0.060422912			

Appendix 7. Effect of soil, cultivar and moisture regime on leaf area index at 76 days after planting.

Source of Variation	Degrees of freedom	Sum of squares	Mean squares	Observed F	Required F 5%	Required F 1%
Sub-Sub plots	23	46.925	2.040217391			
Sub plots	11	38.035	3.457727273			
Main plots	5	5.665	1.133			
Blocks, B	2	0.8575	0.42875			
Soils, S	1	3.68166666	3.68166666	6.54	18.51	98.50
Main plot error, BS	2	1.12583334	0.56291667			
Cultivar treat, V	1	29.92666666	29.92666666	67.38**	7.71	21.20
S X V	1	0.66666668	0.66666668	1.50	7.71	21.20
Sub-plot error, BV + B(S X V)	4	1.77666666	0.444166665			
Moisture regime, M	1	2.94	2.94	16.49**	5.32	11.26
S X M	1	1.30666667	1.30666667	7.33*	5.32	11.26
V X M	1	1.815	1.815	10.18*	5.32	11.26
S X V X M	1	1.40166666	1.40166666	7.86*	5.32	11.26
Sub-Sub plot error, BM + B(S X M) + B(V X M) + B(S X V X M)	8	1.42666667	0.178333333			

Appendix 8: Effect of soil, cultivar and moisture regime on dry matter at 56 days after planting.

Source of Variation	Degrees of freedom	Sum of squares	Mean squares	Observed F	Required F 5%	1%
Sub-Sub plots	23	75283174.5	3273181.5			
Sub-plots	11	54300737.5	4936430.682			
Main plots	5	47979785.5	959595.625			
Blocks, B	2	1203989.25	601994.625			
Soils, S	1	43826442.66	43826442.66	29.72^{x}	18.51	98.50
Main plot error, BS	2	2949353.59	1474676.795			
Cultivar treat, V	1	5902400.16	5902400.16	56.88^{xx}	7.71	21.20
S X V	1	3456.01	3456.01	0.03	7.71	21.20
Sub-plot error BV + B(S X V)	4	415095.83	103773.9575			
Moisture regime, M	1	5030672.66	5030672.66	3.33	5.32	11.26
S X M	1	922768.18	922768.18	0.61	5.32	11.26
V X M	1	855792.68	855792.68	0.57	5.32	11.26
S X V X M	1	2073288.15	2073288.15	1.37	5.32	11.26
Sub-Sub plot error, BM + B(S X M) + B(V X M) + B(S X V X M)	8	1209915.33	1512489.416			

Appendix 9. Effect of soil, cultivar and moisture regime on dry-matter at 76 days after planting.

Source of Variation	Degrees of freedom	Sum of Squares	Mean Squares	Observed F	Required F 5%	Required F 1%
Sub-Sub plots	23	264236736	11488553.74			
Sub-plots	11	210964350	19178577.27			
Main plots	5	27798844	5559768.8			
Blocks, B	2	9096033.2	4548016.6			
Soils, S	1	17459204.3	17459204.3	28.08*	18.51	98.50
Main plot error, BS	2	1243606.5	621803.25			
Cultivar treat, V	1	1624272554.1	162427254.1	85.80**	7.71	21.20
S X V	1	13166090.6	13166090.6	6.95	7.71	21.20
Sub-plot error BV + B(S X V)	4	7572161.3	1893040.325			
Moisture regime, M	1	12528150.1	12528150.1	2.99	5.32	11.26
S X M	1	2164802.6	2164802.6	0.52	5.32	11.26
V X M	1	4977704.1	4977704.1	1.19	5.32	11.26
S X V X M	1	33600.2	33600.2	0.008	5.32	11.26
Sub-Sub plot error, BM + B(S X M) + B(V X M) + B(S X V X M)	8	22568129	4196016.125			

Appendix 10. Effect of soil cultivar and moisture regime on grain yield.

Source of Variation	Degrees of freedom	Sum of Squares	Mean Squares	Observed F Value	Required (%)	F (%)
Sub-sub plots	23	1407169.96	61181.30261			
Sub-plots	11	1151900.46	104718.2236			
Main plots	5	504604.71	100920.942			
Blocks, B	2	92752.335	46376.1675			
Soils, S	1	297260.043	297260.043	5.19	18.51	98.50
Main plot error, BS	2	114592.332	57296.166			
Cultivar treatment, V	1	490886.626	490886.626	13.04*	7.71	21.20
S X V	1	5865.291	5865.291	0.16	7.71	21.20
Sub-plot error BV + B(SXV)	4	150543.833	37635.95825			
Moisture regime, M	1	190065.96	190065.96	48.39**	5.32	11.26
S X M	1	5385.29	5385.29	1.37	5.32	11.26
V X M	1	27270.707	27270.707	6.94*	5.32	11.26
S X V X M	1	1127.376	1127.376	0.29*	5.32	11.26
Sub-sub plot error, BM + B(SXM) + B(VXM) + B(SXV XM)	8	31420.167	3927.520875			

Appendix 11. Monthly rainfall, irrigation water applied (mm) for the different treatments during the study period.

Treatments		NOV. 1985		DEC. 1985		JAN. 1986		FEB. 1986		MARCH[1/] 1986		APRIL[2/] 1986		Total wat use
		P	I	P	I	P	I	P	I	P	I	P	I	
	Rainfed Serena	35.9	0	43.3	0	134.6	0	70.1	0	NA	0			283.9
Soil	Irrigated Serena	35.9	10	43.3	15	134.6	5	70.1	10	NA	0			323.9
1 high	Rainfed Mbangala	35.9	0	43.3	0	134.6	0	70.1	00	156.5	0	NA	0	440.4
WHC	Irrigated Mbangala	35.9	10	43.3	15	134.6	5	70.1	10	156.5	5	NA	0	485.4
Soil 2	Rainfed Serena	35.9	0	43.3	0	134.6	0	70.1	0	NA	0			283.9
Low WHC	Irrigated Serena	35.9	10	43,3	15	134.6	5	70.1	10	NA	0			323.9
	Rainfed Serena	35.9	0	43.3	0	134.6	0	70.1	0	156.5	0	NA	0	440.4
	Irrigated Mbangala	35.9	10	43.3	15	134.6	5	70.1	10	156.5	5	NA	0	485.4

P = precipitation (mm)

I = Irrigation water applied (mm)

1/ = Serena harvested on 9th March 1986

2/ = Mbangala harvested on 30th April 1986

NA = Not applicable - The crop had already reached physiological maturity.