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ONLY

PLANT-WATER STATUS AND GRAIN YIELD OF
MAIZE (Zea mays L) IN RELATION TO
SOIL WATER STATUS AT MOROGORO,
TANZANIA

BY

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of the requirements for the degree of

MASTER OF SCIENCE (AGRICULTURE)


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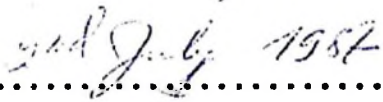
SOKOINE UNIVERSITY OF AGRICULTURE

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ABSTRACT

Analysis was made of reference crop evapotranspiration (ET_o) and rainfall (R) data on a 10-day basis over a 10-year period (1973/74 - 1982/83). On the average, ET_o exceeds R during the entire short rain season thus making production of crops other than those tolerant to water stress a risky undertaking.

The effects of soil water holding capacity (WHC), cultivars, and water regimes on soil - and plant - water status, growth, grain yield and yield components of maize (Zea mays L) were identified. The study was conducted during short rains on two soils (both Ferralsols) one with high and the other with low WHC. Katumani and Ilonga Composite maize cultivars with different maturation periods were grown under rainfed condition and under limited irrigation.

High values of weighted soil matric potential (ψ_m) were associated with high WHC of soil. In all treatments, ψ_m values declined near tasselling stage due to high demand for water and increased with the approach of physiological maturity. Averaged over the entire season, leaf water potential (ψ_l) was 2.22 bars higher in soil 1 (high WHC) than in soil 2 (low WHC). On the average, Katumani had ψ_l values 3 bars higher than Ilonga Composite. Plants had ψ_l 4.0 bars higher under limited irrigation than under rainfed conditions on the average.

Plant height, stem diameter, number of leaves/plant, leaf area/leaf and leaf area index were significantly affected by cultivars. Plants of Ilonga Composite were 16.4% taller, had

stems 25.4% thicker and had 2 more leaves which were 55.9% larger than those of Katumani on the average. Leaf area index was significantly increased by irrigation and was 79% higher for Ilonga Composite compared to Katumani.

In 0-90 cm depth, root length density (RLD) was 42% higher in soil 1 than in soil 2 with Ilonga Composite having RLD 10% higher than that for Katumani.

Ilonga Composite outyielded Katumani in dry matter (DM) production at 54 and 74 days from planting (DFP) by a factor of about 2, a difference attributed to bigger plants, more and larger leaves by the former than the latter cultivar. At 54 DFP, irrigation significantly increased DM yield by 92 and 46% for Ilonga Composite and Katumani, respectively as compared to DM yield under rainfed conditions.

Ilonga Composite had barren plants in all treatments. However, there were fewer barren plants (3 to 11%) under limited irrigation than under rainfed (26 to 35%) conditions. Katumani had barren plants (4%) only in soil 2 and under rainfed conditions. Under similar conditions, percentage of barren plants was highest (35%) for Ilonga Composite.

Cultivars, water regimes and their interaction had significant effect on the number of kernels set per cob. Over-all, Ilonga Composite (because of bigger cobs) set about 295 kernels/cob, 27% more than the number set by Katumani. Irrigation led to a non-significant 7 and a significant 98% increase in the number of kernels/cob for Katumani and Ilonga Composite, respectively.

Cultivars and water regimes had significant effect on a thousand kernel weight. A thousand kernels of Ilonga Composite weighted 313.7 g, 23% heavier than those of Katumani. Irrigation increased the weight of a thousand kernels by 43% from 234.2 g under rainfed to 335.5 g under irrigated conditions.

All factors studied had significant effect on grain yield. In soil 1, grain yield was 1322.1 kg/ha, 18% more than that in soil 2 on the average. Ilonga Composite gave 1410.9 kg/ha of grain, 37% more than the average yield for Katumani. This was accounted for by bigger cobs and heavier grains for Ilonga Composite as opposed to Katumani. Overall, irrigation increased grain yield by 67% from 915.5 kg/ha under rainfed to 1527.1 kg/ha under limited irrigation. However, the increase was a non-significant 7% and a significant 138% for Katumani and Ilonga Composite, respectively.

The amount of irrigation water varied with the WHC of soils. It was 40 and 50 mm in soil 1 while in soil 2 it was 50 and 80 mm for Katumani and Ilonga Composite, respectively. Ilonga Composite took longer to mature and thus it received more rain as well as irrigation water than Katumani.

Total water use efficiency (TWUE) values for both DM and grain yield were higher in soil 1 than in soil 2 on account of WHC. Ilonga Composite had TWUE (DM) values ranging from 1.3 to over 2.0 times greater than those for Katumani in the two water regimes. This was accounted for by bigger plants, more and larger leaves for Ilonga Composite than for Katumani. Irrigation increased TWUE (DM)

for both cultivars. However, with respect to grain yield, Katumani had higher TWUE values than Ilonga Composite under rainfed conditions and vice versa under limited irrigation.

High values of irrigation water use efficiency (IWUE) both for DM and grain yield were associated with a soil having high WHC and for Ilonga Composite.

Comparison of the two cultivars grown showed Katumani to produce more grain weight/ha than Ilonga Composite under rainfed conditions (short rains) and vice versa under irrigation. Thus, Katumani was drought tolerant while Ilonga composite was not.

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1. INTRODUCTION

1.1 General

Agricultural production is the principal source of well-being for eight out of ten persons in Africa (Mascarenhas, 1982). Frere (1982) estimates that 65% of the African population is actively engaged in agriculture rising to more than 75% in 28 Countries. Despite this large investment in the agricultural sector in terms of human-power, many African Countries are currently faced with the problem of feeding rapidly growing populations (Mascarenhas, 1982). Africa's population is considered to increase at a rate twice as fast as food production (Anonymous, 1986). In East Africa, the rate of population growth is among the highest in the world. It is about 4% in Kenya and 3.2% in Tanzania (Palutikof et al., 1982). The reduced food production is now frequently assigned to drought (Anonymous, 1986). Climate and weather among the basic resources to increase food production have not been cooperative (Mascarenhas, 1982). Rains ideal for planting crops in most countries have been erratic, unreliable and inadequate with the resultant disruption of peasants efforts and farming schedules (Palutikof et al., 1982). As a result, millions of peasants and children have died of hunger in Ethiopia and Sudan in a period of one year (Anonymous, 1986). In countries most affected by drought, survival has been possible through continuous massive international relief operations. Against such a background, drought is a hazard of increasing importance the future impact of which may be worse than that in the past.

1.2 Drought and Food Shortages in Tanzania

Since the early seventies, most regions of Central Tanzania -- Dodoma, Morogoro, Shinyanga, Singida and Tabora have repeatedly registered poor grain yield and total crop failure at times because of drought (Budget Speech, 1984). Localized and sometimes widespread food shortages due to adverse weather conditions in the country have been reviewed (Mascarenhas, 1968). The country has moved from a position of self sufficiency in most cereal production to being a net importer (Budget Speech, 1984). Importation of cereals such as maize, rice and wheat to cover food deficits during the period 1981 to 1984 was as follows:

	Year		
	1981/82	1982/83	1983/84
Maize	231,699 tons	122,685 tons	228,550 tons
Rice	66,650	29,373	58,756
Wheat	50,072	9,373	39,024

Source: Budget Speech (1984)

From the table, it is evident that maize is the cereal needed in large quantities. Given our limited foreign earnings, massive importation of cereals cannot be sustained without adverse effects on the national economy (Budget Speech, 1986).

The increased incidences of drought and food shortage are now considered to originate from changes both in the characteristics of the rural economy and in the characteristics of rainfall (Gomes and Houssian, 1982; Palutikof et al., 1982). A shift within the agricultural community towards high yielding food crops away from the traditional subsistence crop mix is the main human factor involved (Palutikof et al., 1982). On the other hand, the increase in the proportion of the land planted with maize in the central and central-northern regions of Tanzania has been considerable (Gomes and Houssian, 1982). Above normal rainfall in the sixties (Rise, 1971; North, 1973) is considered to have been one of the factors which encouraged this shift. In Morogoro region, the area under maize has increased from 86,032 ha in 1978/79 to 137,258 ha in 1980/81 (RDD, 1984). Farmers have moved from traditional crops such as bulrush millet and sorghum to maize (Berry et al., 1972) which has now become the preferred cereal in the country despite repeated crop failures resulting from unreliable rainfall. Composite maizes, suited to dry environments, are reported to have a longer growing season and a higher water requirement (crop coefficients) than sorghum during all stages of growth (Palutikof et al., 1982). From the above, it can be inferred that soil moisture deficits have increased rapidly and the potential for drought has become greater. The fact that maize is almost exclusively raised as a rainfed crop is also an added problem. A map of Tanzania showing agroclimatic growing seasons (Gomes and Houssian, 1982) shows the whole of central Tanzania falling into zones with unreliable rainfall. This coupled

maize as a food crop and the predominance of rainfed agriculture in the country calls for a study to evaluate the plant water status and yield performance of early and late maturing maize in relation to available water supplying capacity of different soils.

1.6 Objectives

The investigation was conducted under limited irrigation (hereafter irrigation only) and rainfed conditions with the following objectives:

- (a) To identify a proper matching of "soil type - maize cultivar" which maintains high productivity during short rains.
- (b) To identify a maize cultivar which responds favourably to limited irrigation.
- (c) To find out the amount of water, in addition to rainfall, required to produce an economic yield of maize.
- (d) To identify a cultivar which withstands drought better.

2. REVIEW OF LITERATURE

2.1 Water Stress and Plant Growth

2.1.1 General

In most plants, water constitutes more than 90% of the fresh weight and in few does it constitute less than 70% (Turner and Burch, 1983). Plant roots must thus absorb enough water to satisfy the plant needs for growth and development. Depending on the type of soil and irrespective of the actual amount of water it contains, the plant will have to use increasingly more energy to counter the increasing force with which the soil holds the water as it is depleted (Richards and Weaver, 1944). The preceding view is further collaborated by the hyperbolic nature of the soil moisture characteristic curve as was observed by Veihmeyer and Henrickson (1950). As the reservoir of water in the soil is depleted, plant dehydration increases such that physiological and morphological processes in the plant are adversely affected (Turner and Burch, 1983). Larson and Eastin (1971) consider drought to be a factor in yield reduction even when the damage is not apparent.

Drought is a serious threat to crop production in most areas of the world and can result from any combination of the physical factors of the environment to produce sufficient internal water stress in plants to limit their productivity. The development of water deficits in the plant together with their effect on plant growth, drymatter and grain yield will be reviewed.

with sandy soils of low available water holding capacities (Hathout, 1983), increase the probability that water stress will occur at some time during the growing season. The problem aggravates when what could have been considered as adequate rainfall is concentrated into a few heavy storms with long intervening dry spells. In this case, deep soils with high water holding capacities (WHC) coupled with surface conditions encouraging rapid infiltration will store and avail more water to growing plants long after rains have ceased than soils with low WHC (Sanchez, 1976).

1.3 Previous Work

In Tanzania, the first work on drought and crop production seems to be that of Samson (1954). Papers more specifically oriented towards agriculture, were published by Dagg (1965); Nieuwott (1973(a), 1973(b), 1976) and De Pauw (1980). Their common feature is that rainfall variability is compared with the physiological water requirements of the crops. Major contributions on the subject are those by Gomme and Houssian (1982). First, they give recommendations as to which cereal crop to grow and where in the country. Second, they have assessed the risk and extent of yield reductions in maize and sorghum due to moisture stress. Dagg (1965) and Gomme and Houssian (1982) view food shortage in Tanzania as a shortcoming in the cropping pattern with peasants growing maize at any cost in areas suitable only for sorghum. In Morogoro region and other areas with bimodal rainfall regimes Gomme and Houssian (1982) predict that maize will yield properly during 20% of the years during short rains.

However, no mention is made of the maize cultivar(s) and the soil type as their predications are based only on meteorological data with no backing of field experiments.

1.4 Future Prospects

Given the fact that peasants will grow maize at any cost, a strategy likely to reduce yield fluctuations caused by drought would be to grow cultivars of maize whose water requirements properly match soil and seasonal patterns of climatic variables. The variety of maize most commonly grown in Central Tanzania is Ilonga Composite (late maturing) but early maturing varieties are also available. Since most yield losses occur during short rains, shorter season cultivars, for example, Katumani should stand a better chance. The Ministry of Agriculture (1984) is reported to have embarked on both large and small irrigation schemes, six zones (Morogoro, Kilimanjaro, Irwanza, Tabora, Mbeya and Mtwara) were formed to coordinate the implementation of small scale irrigation projects. Such projects are well placed to effect life saving irrigation when rains stop suddenly.

1.5 Statement of the Problem

Outside tropical Africa, the effects of moisture deficiency on maize seems to be better understood, however relatively little work seems to have been done on tropical cultivars. For example, no published work on plant water status, plant growth and grain yield of maize has been conducted in Tanzania. The importance of

2.1.2 Causes of development of water deficit

Plant water stress is caused by either excessive loss of water (transpiration) or inadequate absorption, or a combination of the two (Kramer, 1972).

Midday water deficits occur because absorption tends to lag behind transpiration (Kramer, 1937). It results from resistance of water flow through plants plus the fact that the rates of water absorption and transpiration are controlled by different sets of factors. The transpiration rate is controlled by: (1) leaf area and structure (2) stomatal opening, and (3) those factors which affect the steepness of the vapour pressure gradient from plant to air. Absorption, on the other hand is controlled by: (1) rate of water loss (2) extent and efficiency of root systems, and (3) the water potential and hydraulic conductivity of the soil. Although excessive transpiration is responsible for temporary midday daily water deficits, Orchard (1967) attributes decreased absorption caused by decreasing availability of soil water to be responsible for the long severe periods of water stress which cause the largest reductions in plant growth.

Slatyer (1967) analyzed the changes which occur in a transpiring plant as it progressively reduces the water potential of the soil over a period of several days. His treatment is illustrated in Fig. 2.1. This diagram shows a daily cycle in plant and soil water potential which occurs because absorption lags behind transpiration.

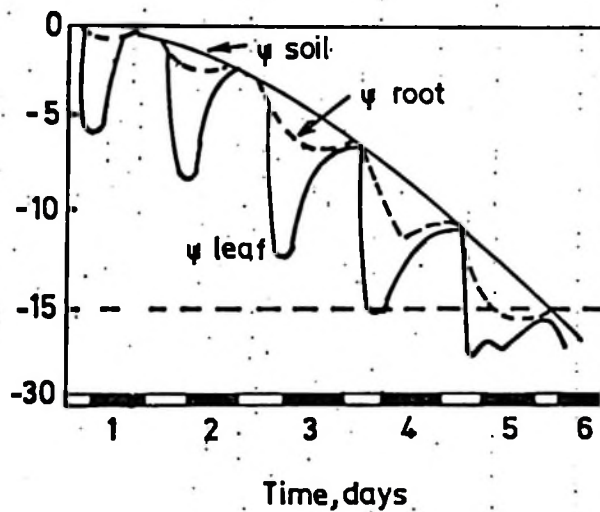


Fig.2-1 Probable changes in leaf water potential (ψ_{leaf}) and root water potential (ψ_{root}) of a transpiring plant rooted in a soil allowed to dry from a water potential (ψ_{soil}) near zero (wet soil) to a water potential at which wilting occurs. Dark bars indicate darkness (From Slatyer, 1967).

It also shows that in the absence of added soil water both plant and soil water potentials (ψ plant and ψ soil) decrease over a period of days until ψ plant = ψ soil and the plant ceases to absorb water because there no longer is a gradient in water potential from the soil to roots. At first, while the soil water potential is relatively high ψ plant returns to a value equal to ψ soil at night, but as ψ soil and water conductivity of the soil decrease, this becomes impossible, because the rate of water movement toward the roots is too slow to replace daytime losses. At this point permanent wilting occurs, as shown on days 4 and 5 in Fig. 2.1.

2.1.3 Critical water demand periods

Experimental findings from a number of sources indicate that the growth stages of crops in which water deficits occur have different effect on the relative yield response. Sensitivity of maize (Zea mays L) grain development to moisture stress is related to the physiological stage of development at which the stress occurs (Harder et al., 1982). Among those who have studied maize in this regard are Robins and Domingo (1953), Denmead and Shaw (1960), Barnes and Woolley (1969), Claassen and Shaw (1970(a), 1970(b); Dawney (1972), Shaw (1974), Stewart et al., (1975, Hall et al., (1981), Harder et al., (1982) Stegman (1982), Bennett and Hammond (1983).

From a field experiment, Robins and Domingo (1953) reported that wilting conditions for only 1 to 2 days during the pollination period reduced maize yield as much as 22 percent, and 6 to 8 days about 50 percent. Denmead and Shaw (1960) grew maize in 5 gallon

crocks buried in the field (three plants/crock) and imposed acute water deficits during three growth periods, and combinations of these periods. Due to their uniform root volume and method of measuring moisture stress, it is probable that each stress period represents nearly the same absolute ET deficit. Making this assumption, moisture stress in the pollination period which they judged to be approximately equal to that imposed by Robins and Domingo again produced a 50 per cent yield loss. The same stress during the late vegetative period reduced yield by 25 per cent, and during ear growth by 21 per cent. Thus, Denmead and Shaw (1960) concluded that moisture stress at silking was more harmful to grain yield than stress at any other single growth stage. Barnes and Woolley (1969) grew maize in plastic lined field trenches and imposed water stresses of equal severity at different stages of growth on a single-eared and a two-eared maize hybrid. Pollination period stress affected the single-eared hybrid significantly more than the two-eared hybrid which in effect has two chances to produce grain somewhat separated in time. Claassen and Shaw (1970a) grew maize in large buried containers under a movable rain shelter and stressed the plants nonrepetitively by cessation of irrigation at nine different times during the season. Each stress treatment consisted of 4 days on which the uppermost, fully-expanded leaves were wilted. Results demonstrated that each vegetative component of yield was significantly influenced by one or more of the stress periods. However, maximum reductions in total vegetative dry matter production of 15 to 17%

resulted from water deficits approximately 3 weeks before 75% silking. In yet other experiments using a similar set up as the previous one, Claassen and Shaw (1970) observed a significant grain yield reduction of 12 to 15 per cent after stress during the vegetative period. On the other hand, moisture deficits in the 3-week period after silking consistently reduced yields approximately 30% in two years running. Once again, maximum reduction in grain yield (53%) was associated with stress at 75% silking. Furthermore, significant reductions in kernel numbers were associated with yield reductions from stress before or during silking and pollination. Downey (1972) showed greatly reduced maize yields resulting from ET deficits in different growth stages and found that pollination period was most sensitive to water stress. He generalized for non-forage crops including maize and grain sorghum that "water stress at any time from flowering to maturity was undesirable and gave inefficient water use". Shaw (1974) has assigned weighting factors to various development periods, emphasizing that the greatest vulnerability exists during a period extending from 5 days before to 5 days after silking, followed by a 30-day period that is less vulnerable and relatively constant in sensitivity to stress. Experimental evidence generated by Stewart et al; (1975) led to the conclusion that maize is especially sensitive to water stress during pollination but becomes progressively more tolerant of water deficits as maturity approaches. Hall et al; (1981) grew maize to maturity in sand-nutrients solution cultures to one or two successive cycles of

drought at three developmental stages - immediately prior to tasseling, before pollen-shedding, and during silking. Similar to earlier findings elsewhere, drought reduced plant photosynthetic area and total dry matter and grain yields, and altered developmental patterns. Plants droughted at silking had the lowest number of kernels a component of yield which proved to be most affected by drought. A study by Harder et al; (1982) investigated the effect of single and multiple periods of moisture stress imposed on maize plants after silking. One, two, or three successive stress cycles were imposed on plants grown in containers under field conditions. Grain yield reductions of up to 33% depending primarily upon the severity and duration of soil-moisture stress were recorded. Moisture stress that occurred within 2 weeks after silking reduced the number of kernels/plant by about 15% with little influence on final mass/kernel. However, plants that were stressed shortly after silking and suffered reduction in kernels/plant had shorter, but uniformly filled ears suggesting that stress inhibited development of kernels at the top of the ear. This demonstrates the undesirability of moisture stress during the silking period. Two experiments conducted by Bennett and Hammond (1983) to evaluate the responses of several corn genotypes to imposed water deficits indicated that moisture stress at any stage of development of maize is undesirable. Three water management treatments - rainfed, vegetative stress, and full irrigation were applied. All genotypes responded similarly to the imposed water stresses. Water stresses imposed during vegetative

growth conserved 5.9 cm and 8.9 cm of irrigation water in the two experiments, but reduced leaf area indices by 19%, plant height by 17%, and grain yields by 10 to 15% on the average. Rainfed plants were severely affected by water deficits, producing grain yields of only 45% and 33% of the fully irrigated plants in the two experiments respectively. Studies by Stegman (1982) have shown an increased demand for water during silking than during vegetative development. In order to maintain grain levels in rainfed plots within 50% of yields of fully irrigated plants, Stegman noted that root zone available depletions must be limited to less than 60% to 70% during the early vegetative period, 30% during the 12th leaf to blister kernel stage, and 50 to 60% in the later grain filling periods.

2.2 Effects of Water Deficits on Plant Growth, Drymatter, Grain Yield and Yield Components

2.2.1 Plant growth

Everyone is aware of the general reduction in size of plants subjected to prolonged water stress. Kramer (1972) considers water stress to affect every aspect of plant growth, modifying the anatomy, morphology, physiology, and biochemistry. Studies on this aspect have been made by Denmead and Shaw (1960), Claassen and Shaw (1970a), Hall et al; (1981), and Bennett and Hammond (1983) to mention a few. Apart from a decrease in grain yield, Denmead and Shaw (1960) noted maize plants stressed during the vegetative stage of growth also to be shorter than those not subjected to moisture stress.

They generalized that when water stress is applied while the plant is actively growing, it retards enlargement of plant parts. Imposing a 4 day moisture stress period on different maize plants at 58 and 72 days after emergence, Claassen and Shaw (1970a) observed reduction in maximum height of 10.2 and 15.2 cm respectively in stressed as compared to non-stressed plants. The two moisture stress periods (at 58 and 72 days) coincided with tassel and silk emergence respectively, stages of maize development already identified as very sensitive to moisture stress. Claassen and Shaw also observed alteration of developmental patterns due to moisture stress. A 1 to 2 day delay in tasseling associated with stress treatments occurring at initiation of rapid tassel development was noted. On the other hand, moisture stress treatments imposed just before and during tasseling delayed 75% silking by 2 to 5 days. The percentage of plants silked remained constant until irrigation when water stress occurred just after first silking. Delays in the initiation of silking, the increase in the interval between the start of pollen shedding and the exertion of silks by apical and basal ears occurred in maize plants following one or two successive cycles of drought immediately prior to tasseling, before pollen-shedding, and during silking (Hall et al., 1981). However, the magnitude of these effects was noted to decrease as the exposure to drought was delayed and to increase in plants exposed to two successive periods of stress with respect to those subjected to a single drought at a given developmental stage. Recently, Bennett

and Hammond (1983) observed a reduction in maize stalk height by 17% due to water stress imposed during vegetative growth. This is in agreement with earlier findings by Denmead and Shaw (1960) and Claassen and Shaw (1970a).

2.2.2 Leaf expansion and senescence

Several studies indicate that leaf expansion is very sensitive to water deficits. For example, data from maize grown in controlled environments indicate that leaf enlargement declines rapidly at leaf water potentials below - 2 bars and cease at potentials of - 7 to - 9 bars (Boyer, 1970, Hsiao et al., 1970; Acevedo et al., 1971). Similar sensitivity has been observed in soybean and sunflower (Boyer, 1970). Boyer reported the inhibition of leaf enlargement by declining leaf water potential to be more severe than that of photosynthesis and respiration in the stressed plants. Under conditions of rapid enlargement, Boyer (1970) observed a small lowering of leaf water potential (at - 4 bars) to reduce leaf enlargement to 20% of the observed maximum in maize. In yet another study, Acevedo et al., (1971) observed leaves of a maize plant stressed for 1 or more days to attain almost the length of the control leaves after rewatering. This points to the direct role of water in growth; its uptake providing the physical force for cell enlargement.

In addition to affecting leaf expansion, water deficits can affect leaf area permanently by the senescence and death of leaves

during all phases of growth. Compared with full irrigation, Bennett and Hammond (1983) observed a 19% reduction in leaf area indices (LAI) in maize plants denied moisture during vegetative growth. The lower LAIs with stress resulted from smaller leaves and increased rates of leaf senescence, the total number of leaves produced not having been affected by any of the water stress treatments. Accelerated leaf senescence at low leaf water potentials is also associated with permanent loss of potential photosynthetic surface (Aparicis-Tejo and Boyer, 1983). In maize, McPherson and Boyer (1977) and Furgens et al. (1978) observed that neither viable nor non-viable leaf tissue is capable of photosynthesis at water potentials of - 18 to - 20 bars.

Evidence from this review permit the conclusion that decreased leaf expansion and increased leaf senescence reduce potential photosynthesis with consequential loss of both grain and DM yield in maize.

2.2.3 Dry matter, grain yield and yield components

In crop production, one is concerned with the dry matter (DM) yield of the whole or part of the plant. However, it is the proportion of the dry matter, that is harvested as economic yield that is important. The yield potential in maize is closely related to water availability (Waldren, 1983). Although other factors such as plant population and fertilizer use can affect the yield potential of maize, these are usually adjusted according to the

amount of water the crop will have during the growing season (Waldren, 1983). A linear relationship between water loss through seasonal evapotranspiration (ET) and dry matter production of a number of crop plants has been established (Arkley, 1963). A similar response of DM or grain yield to seasonal ET has been reported in sorghum (Stewart et al., 1975, Garrity et al., 1982) and in maize (Stewart et al., 1975). However, the relationship between grain yield and ET is more complex than that for DM because grain yield is more sensitive to ET reductions during certain growth stages (Garrity et al., 1982). Moreover, when other growth factors such as fertility and temperature are not optimum the linear relationship does not hold (Viets, 1962).

The dependence of reduction in grain yield of maize and its components upon the severity, duration and timing of soil moisture stress has been reported by several workers (Robins and Domingo, 1953; Denmead and Shaw, 1960; Claassen and Shaw, 1970a; Shaw, 1977; Stewart et al., 1975; McPherson and Boyer, 1977; Shaw et al., 1980; Hall et al., 1981, Harder et al., 1982; Bennett and Hammond, 1983).

Soil moisture depletion to the wilting percentage by field maize for periods of 1 to 2 days during the tasseling or pollination period resulted in as much as a 22% grain yield reduction and periods of 6 to 8 days to a yield reduction of about 50% (Robins and Domingo, 1953). Applying a moisture stress approximately equal to that imposed by Robins and Domingo, Denmead and Shaw (1960)

obtained a similar trend and magnitude in maize grain yield reduction. A 12 to 15% and a 53% reduction in grain yield associated with moisture stress during vegetative growth and at 75% silking respectively have been reported by Claassen and Shaw (1970b). This loss in yield was explained by significant reductions in kernel numbers associated with yield reductions from stress before or during silking and pollination. Kernel weights were also significantly reduced by stress during or after silking. In a review summarizing the range of results obtained by several researchers over the period 1953 - 72, Shaw (1977) established a relationship between age of crop (maize) and percentage yield decrement due to one day of moisture stress. About 50 days after planting the yield reduction average near 3% per day of stress. Around the tasseling-silking stage, there is a sharp increase in the yield reduction per day of stress (6-7%). A maize stand stressed by withholding water from the soil shortly after tasseling and maintaining a - 18 to 20 bars soil water potential to maturity gave grain yield 47 to 69% of the control yield (McPherson and Boyer, 1977). Evaluating the influence of management and water-use interactions on maize yield, Shaw et al. (1980) concluded that severe stress just before pollination leads to average percentage of barren stalks of 7.3, 27.5 and 42.7% for the low, medium and high management levels respectively. In an experiment involving maize in which different plots were exposed to one or two successive cycles of drought at three development stages: immediately prior to tasseling, before pollen-shedding, and during silking, Hall et al. (1981) noted decreased grain yield to be caused by a reduction in kernel number.

Failure of the basal ear and, in the apical ear, reduction in the number of spikelets, and reduction in kernel set were identified to be the causes of changes in kernel number. In turn, lack of pollen due to increased asynchrony in anthesis of male and female inflorescences and the drying of silks before pollination were recognized as potential sources of reduction in kernel number brought on by moisture stress. A similar explanation has been advanced by Waldren (1983). Waldren suggests that water stress at tasseling not only hinders the plants ability to flower and shed pollen, but also greatly affects the viability of maize pollen, especially when drought is accompanied by high temperatures as is usually the case. Waldren also considers water stress at silking to impair extrusion of the silks from the husk and to cause desiccation of the silks, reducing the number of seeds set on the ear.

There is a considerable range of the effects obtained. The degree of stress applied and fertility level maintained are two factors which would affect this variation. In experiments of this type, Harden et al., (1982) assert that it is extremely difficult to impose similar moisture stress treatments during different time periods. Soil moisture levels may be very similar, but atmospheric demand may be quite different. The plant response, therefore, can be different for treatments assumed alike. From soil-plant moisture studies conducted to date no evidence emerges that ET could be reduced under certain circumstances without incurring some yield reductions.

2.3 Strategies for Optimizing Crop Production Under Drought Conditions

2.3.1 Use of shorter maturity crops

In regions with unpredictable drought, matching crop maturity to seasonal patterns of water availability has been advocated (Dagg, 1965; Blum, 1970). In this regard, shorter season varieties appear to have a distinctly better chance, but there are many more criteria involved in the choice of a variety (Dagg, 1965). In an attempt to match climate and crops, Dagg outlines the following factors to be investigated:

- (a) Reliable monthly or ten-day rainfall
- (b) Monthly or ten-day estimate of E_o (Open water evaporation)
- (c) The pattern of crop water use in terms of

$$\frac{E_t}{E_o} = \frac{\text{Actual evapo-transpiration}}{\text{An estimate of evaporative power of the environment}}$$

- (d) The approximate root development with stage of growth
- (e) Depth and water holding capacity of soil.

With increasing incidences of rainfall failures even during the long rain period, it should appear logical to grow shorter season cultivars during both the long and short rains. However, the advantage of early maturity is reported to be realized only in years where yields are greatly reduced by lower water supply (Jordan et al., 1983).

In situations in which the probability of drought increases with the life of the crop, the shorter the crop duration the greater the yield will be in most years. Working over a period of 20 years with from 7 to 14 cultivars of wheat grown at 30 sites in the Great Plains of U.S.A., Reitz (1974) showed that each day of earliness imparted a yield advantage of 40 - 100 kg ha⁻¹ over that of a standard late cultivar of wheat. Similar results have been obtained for Barley and triticale by Fischer and Maurer (1978). A yield advantage of almost 30 kg ha⁻¹ was conferred by each day of earliness. However, when moisture conditions are optimum, Jordan and Sullivan (1981) report late-maturing sorghum hybrids to out yield those maturing early.

2.3.2 Use of drought resistant cultivars

Not all plants suffer equally as a result of water deficit. Annual crop plants possess a variety of anatomical, morphological and physiological features that enable them to survive and reproduce in water-limited environments (Jordan et al., 1983). Thus, some cultivars are able to withstand severe drought (are drought resistant) and maintain measurable physiological activity whereas others die. In an agronomic sense, Jordan et al., (1983) regard drought resistance to imply maintenance of productivity at levels that provide an economically acceptable yield for the producer.

Attempts to define and categorize drought resistance have been many (May and Multhorpe, 1962; Arnon, 1972; Kramer, 1980).

The one utilized here is that of May and Milthorpe (1962). They identified three types of drought resistance:

- (i) Drought escape: the ability of a crop species or cultivar to complete its life cycles before serious plant water deficits develop.
- (ii) Drought tolerance at high plant water status: the ability of a crop species or cultivar to tolerate prolonged dry periods while maintaining a high plant water status.
- (iii) Drought tolerance at low plant water status: the ability of a crop species or cultivar to tolerate prolonged dry periods and tolerate low tissue water contents.

Characteristics of plants that enable them to escape or tolerate drought have been summarized by Turner (1970):

1. Drought Escape
 - (i) Rapid phenological development
 - (ii) Developmental plasticity
2. Drought Tolerance at High Plant Water Status
 - (a) Reduction in water loss
 - (i) Increased stomatal and cuticular resistance
 - (ii) Reduced absorption of radiation
 - (iii) Reduced leaf area

- (b) Maintenance of water uptake
 - (i) Increased rooting depth and density
 - (ii) Increased hydraulic conductance
- 3. Drought Tolerance at Low Plant Water Status
 - (a) Maintenance of turgor
 - (i) Osmotic adjustment
 - (ii) Increased elasticity
 - (iii) Decreased cell size
 - (b) Tolerance of dehydration or desiccation
 - (i) Protoplasmic tolerance
 - (ii) Cell wall properties

2.3.3 Improving moisture storage of a soil profile

The soil layer on the landscape accepts, stores, and releases water in a continuous cycle and so is often likened to a reservoir. However, not all soils perform these three functions in a manner considered optimum for plant growth. Specific soil properties will determine each soil's ability to optimize water relations (Thien, 1983).

In all areas where maize is grown, whether dryland or irrigated, the potential of a soil to produce maize under conditions of adequate fertility and a high level of management is largely determined by the soil's capacity to store and supply water to the crop (Leeper et al., 1974). This is determined by the amount of available stored soil water per centimeter of soil and the depth

that the roots can easily penetrate the soil. After rains, fine textured soils retain and release relatively more water to plants than coarse textured soils (Jamison and Kroth, 1958; Hillel, 1971). On the other hand, damaging plant water stress develops in rainfed maize grown on coarse-textured, low water retaining soils when growing seasons are coupled with dry spells (Rhoads et al., 1978). This situation has been observed to occur even when what could have been considered as adequate rainfall but came over a short period (Sharma, 1985). In this case, deep soils with high water holding capacity (WHC) coupled with surface conditions encouraging rapid infiltration are reported to store and avail more water to growing plants long after rains have ceased than shallow soils with low WHC (Sanchez, 1976). In practically all cases, it is desirable to maximize infiltration because this significantly reduces the alternative hazards of runoff, erosion and ponding. Subsoiling compacted soils (soil tillage pans) and incorporation of organic residues in light soils enhance moisture storage capacity (Jamison and Kroth, 1958).

2.3.4 Inducing deep penetration and increased distribution of roots

The amount of water and mineral nutrients available to a plant is determined by the volume of soil with which its roots are in contact (Wahab et al., 1976). The volume of soil depends on the amount of branching and the distances to which roots extend

horizontally and vertically (ASAE, 1971). Water movement toward roots is relatively slow, and the only water immediately available is that occurring within a few millimeter or, at most, a few centimeters from roots (Kramer, 1972). Thus, the horizontal and vertical extent of root systems and the degree of branching are important to the success of plants.

Deficiencies of precipitation occur sometime during the growing season in most agricultural areas. In many of these regions subsoil moisture accumulates during the off season. For maximum production it is important that this soil water resource be utilized to the greatest possible extent. For this purpose maximum root penetration and development is required and factors which influence the development of root systems become of great agronomic importance.

Maize plants have an extensive fibrous root system typical of most grasses. However, the size and depth of the root system is determined genetically but modified by the environment. Waldren (1983) reports the usual spread of maize roots to be about 1.25 m and the depth of many of the roots to be 1.6 m with some approaching 2 m. Compared with a small type, a large type of maize may have a 50% greater spread, 10% deeper penetration, 65% more functional main roots per plant, 31% greater root weight, and 29% larger diameter of main roots (Martin *et al.*, 1976). When faced with less than optimum soil moisture, maize plants have been observed to expand their root systems (Mayaki *et al.*, 1976).

In irrigated maize, Mayaki et al. observed 64% of the root dry matter to be in the upper 30 cm and 92% in the upper 90 cm. In dry land maize, they report 39% of the total root dry matter to be in the upper 30 cm of the soil and 70% in the upper 90 cm. This indicates that nonirrigated maize will expand its root system deeper in the soil during periods when soil water is less than optimum in comparison with irrigated maize thereby tapping water reserves located deeper in the soil. Based on these findings, Mayaki et al. (1976) concluded that maize root system possesses a potential drought avoiding mechanism.

The relationship of various soil factors to root growth was discussed in detail in "Soil Physical Conditions and Plant Growth", edited by Shaw (1952). Zones of compaction and relatively impervious horizons coupled with poor aeration are identified to act as physical barriers to root penetration. Bertrand and Kohnke (1957) observed maize roots 5 weeks old to be unable to penetrate a subsoil compacted to a bulk density of 1.5 g cm^{-3} but to grow profusely in subsoil with a density of 1.2 g cm^{-3} . Resistance to penetration can affect lateral root growth as with interrow compaction from tractor tyres; or it can affect the depth of roots due to a compacted horizontal layer in the soil (ASAR, 1971). Sometimes cultivation can help alleviate problems with interrow compaction (Chaudhary and Prihar, 1974) and sometimes deep tillage can aid roots in penetrating deeper in the soil (Reicosky et al., 1976).

Fox et al., (1953) and Linscott et al., (1962) associated restricted root development not only with high bulk density but also with low nutrient availability in the substratum. Fox et al., (1953) studied a sandy soil into which roots of maize following vetch penetrated more than 2.4 m and almost completely extracted readily available moisture to a depth of over 1.8 m. In contrast, in the same area, nitrogen-deficient maize was wilting in the presence of readily available moisture in 15 cm to 30 cm depth of soil between rows. Similar results were also reported by Linscott et al., (1962). In a nitrogen fertilized sandy soil, Linscott et al. observed root development and moisture extraction to exceed that in unfertilized soil during early growth of maize. Thus, a combination of soil and crop management techniques considered to be adequate in enhancing proliferation of the root system should provide conditions advantageous for drought avoidance.

2.3.5 Supplimentary irrigation strategy

Stored soil water, growing season precipitation and added irrigation water are all equally effective in enhancing maize production and can substitute for each other (Power et al., 1973). Consequently, when rains stop at a critical stage of crop development, supplementary irrigation can alleviate the situation.

As stated in the preceeding sections of this chapter, peak water use by maize occurs about the time of silking or shortly thereafter. Much more research has shown that water deficits at the time of tasseling and silking also cause the greatest reduction

in yield. Although sufficient water is required for most crops even for those varieties having drought resistance to maintain high productivity, Inuyama (1978) and Garrity et al. (1982a) suggest that where water is a limiting resource, the objectives of irrigation management may shift rfrom obtaining maximum yield to obtaining maximum economic production per unit of applied water. In this regard, Waldren (1983) after reviewing previous work on this subject suggests a policy of irrigating for about 3 weeks, beginning just before tasseling and extending through silking. Although yields often are higher with full irrigation, Gwin (1978) reports water-use efficiency (WUE) to be highest when water is applied about the time tasseling occurs.

Kramer (1972) mentions of the beneficial effects of water stress, emphasizing that water stress is not always entirely injurious. He cites work indicating that moderate water stress under some circumstances can improve the quality of plant products, even though it reduces vegetative growth. Independent findings by Stewart et al., (1975) and Boyer and McPherson (1976) have revealed that evapotranspiration (ET) deficits in maize during the vegetative period reduce plant size but condition the crop to withstand a pollination period ET deficit with a much less negative effect on grain yield. Consequently, under limited irrigation drought stress may be allowed to develop early in the growth cycle to induce a conditioning response which may lessen the adverse effects of severe stress during the later stages.

3. MATERIALS AND METHODS

3.1 Description of the Experimental Sites

3.1.1 Location

The study was conducted in the Main Horticultural Unit of the University Farm, Sokoine University of Agriculture, Morogoro during short rains, in the 1985/1986 growing season. Geographical location is approximately $37^{\circ} 39' 30''$ E longitude and $6^{\circ} 51'$ S latitude. The site is relatively flat, at an altitude of about 550 m above sea level.

3.1.2 Climate

Rainfall distribution is bimodal-short and long rains with two peaks (end of November-early December and April). Rainfall (R) and Reference crop evapotranspiration (ET₀) data (Table 2.1a & b) on 10-day basis for 10 years (1973/74 - 1982/83) was analyzed to establish an average trend of these parameters during short rains. Climatic data - temperature, relative humidity (RH%), sunshine hours and pan evaporation during the growing season (November 1985 - March 1986) were collected from Morogoro Meteorological Station and are presented on 10-day basis (Table 2.2).

3.1.3 Selection of experimental sites

Previous work by Zimmer (1985) was used to locate soils having high and those having low available water holding capacities (AWHC) respectively. Extensive augering was also employed.

Table 2.1a. Ten-year (1973/74/1982/83) rainfall and reference crop evapotranspiration (Penman method)

data for each 10-day period during short rains for Morogoro (in mm/10 days)

Ten day period	Rainfall										\bar{x}
	73/74	74/75	75/76	67/77	77/78	78/79	79/80	80/81	81/82	82/83	
Nov. 7-16	0.4	0.0	0.0	12.6	2.6	40.3	7.3	0.0	43.6	0.0	10.68
17-26	1.0	29.7	1.0	10.1	148.5	0.0	68.3	1.5	26.6	10.2	29.69
27-Dec. 6	0.0	2.5	12.9	27.4	62.4	12.7	32.6	51.9	93.2	0.5	20.66
Dec. 7-16	9.4	71.9	0.7	52.2	141.4	14.1	80.0	122.3	0.0	5.2	40.72
17-26	1.0	0.3	43.6	99.9	37.7	76.3	30.7	50.0	105.1	64.2	50.88
27-31	9.6	1.5	12.2	0.0	12.1	5.7	0.0	3.7	113.9	77.3	23.60
Jan. 1-10	1.1	81.9	6.8	59.6	99.8	7.9	9.1	10.1	0.0	11.3	28.76
11-20	14.4	21.9	99.6	15.5	35.1	46.2	4.5	0.0	0.0	2.3	23.95
21-30	11.1	0.0	0.0	54.6	77.1	45.3	56.7	31.3	12.7	0.2	28.90
31-Feb. 9	0.0	0.5	11.6	132.5	0.0	72.9	32.7	4.3	27.5	0.0	28.20
Feb. 10-19	2.0	0.0	9.9	0.0	1.7	143.1	13.6	34.1	4.2	55.6	26.42
20-Mar. 1	33.0	37.5	0.7	33.9	54.3	43.3	42.8	3.3	0.0	2.1	25.09
Mar. 2-11	27.9	30.3	10.9	50.9	41.0	21.0	56.8	0.0	20.4	1.0	26.07
12-21	3.2	83.3	14.7	21.6	128.5	108.6	4.8	35.4	24.3	69.5	49.44
22-31	31.9	49.2	75.1	56.0	35.3	46.9	17.5	150.6	20.9	38.3	52.27

Table 2.1b. Ten-year (1973/74 - 1982/83) rainfall and reference crop evapotranspiration (Penman method) data for each 10-day period during short rains for Morogoro (in mm/10 days)

Ten day period	Evapotranspiration										\bar{x}
	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	82/83	
Nov. 7-16	73.5	79.3	82.4	52.1	65.0	67.1	50.8	79.1	43.1	79.4	67.2
17-26	91.9	82.0	93.9	61.7	34.2	71.4	45.7	81.0	46.4	81.7	68.9
27-Dec. 6	72.9	83.2	60.5	41.5	7.82	62.1	55.2	40.3	66.5	65.5	
Dec. 7-16	75.4	52.2	96.4	49.5	33.1	56.4	33.1	37.9	48.9	67.3	55.0
17-26	75.4	88.3	87.0	38.9	47.7	36.0	45.6	49.0	46.1	49.5	56.4
27-31	75.9	54.4	71.2	55.8	46.3	52.6	51.2	58.6	49.1	37.7	55.3
Jan. 1-10	76.8	55.6	60.5	60.5	60.6	51.2	67.7	53.9	75.0	43.1	60.5
11-20	55.0	46.7	51.8	5.18	41.6	32.7	46.3	76.7	73.7	42.0	51.8
21-30	53.0	68.9	56.0	56.0	49.3	46.7	47.5	53.5	70.4	58.7	56.0
31-Feb. 9	68.8	76.9	44.9	70.2	56.8	43.7	52.2	60.1	54.9	70.0	59.8
Feb. 10-19	74.4	83.8	49.5	66.9	55.6	41.1	47.5	59.9	75.7	45.8	60.0
20-Mar. 1	61.2	60.9	50.2	39.6	50.5	33.7	46.2	65.0	60.0	44.6	51.2
Mar. 2-11	51.3	52.8	60.4	45.9	55.8	46.4	42.0	92.2	65.6	63.2	57.7
12-21	59.2	40.6	40.1	43.3	37.7	33.0	45.1	43.4	50.4	38.2	43.6
22-31	25.4	38.7	35.7	29.1	29.8	32.2	39.2	28.5	53.3	34.2	34.6

Table 2.2. Climatological data for the experimental area during the crop growing season -

November 1965 through March 1966

10-Day Period	Mean Max. °C	Mean Min. °C	Mean 12.00 Noon RH%	Mean 3 PM RH%	Sun Shine hours	Pan Evapo-ration (mm/day)	Mean Rain-fall mm/day	Days Without Rain-fall
Nov. 7-16	32.19	19.55	53.3	47.8	6.92	6.71	2.23	5
17-26	31.8	19.56	56.2	48.3	8.59	5.96	2.93	8
27-Dec. 6	32.45	20.63	59.3	49.8	8.10	6.22	0.67	8
Dec. 7-16	31.86	20.53	60.5	53.6	7.29	5.63	4.33	3
17-26	33.2	21.82	57.7	48.6	9.36	7.4	0.0	10
27-31	33.2	22.2	58.8	43.6	9.50	9.10	0.0	5
Jan. 1-10	32.43	21.35	60.7	54.8	6.34	4.54	2.04	5
11-20	30.03	20.82	69.4	64.0	4.63	4.25	10.4	5
21-30	31.28	20.36	67.7	57.4	7.22	5.67	1.02	7
31-Feb. 9	33.67	21.26	56.4	44.2	9.0	6.52	0.07	9
Feb. 10-19	34.09	20.83	59.0	47.5	8.97	6.19	6.94	8
20-Mar. 1	32.85	20.20	57.9	48.1	9.62	7.3	0.0	10
Mar. 2-11	32.07	20.75	61.7	45.6	5.01	7.98	2.59	6
12-21	31.79	20.89	69.9	44.2	5.48	4.58	7.46	5
22-31	30.25	20.36	67.8	71.9	5.32	3.91	5.60	2

3.1.4 Soils of the experimental area

3.1.4.1 Parent material

The parent material is derived from the Uluguru Mountains by fluvial erosion and deposition. Two profiles, one at each experimental site were excavated. Presence of buried horizons is evidence of periodic/recurring deposition. Soils of the experimental area have been classified by FAO and UNESCO (1973) as Ferralsols.

3.1.4.2 Physico-chemical characteristics and their analyses

Soil samples taken from each horizon were analyzed for

- (i) Bulk densities: Bulk densities were determined from undisturbed soil cores (5.5 cm x 4.0 cm) using standard techniques.
- (ii) Texture: Soil texture was determined by hydrometer method as outlined by Day (1965).
- (iii) Water holding capacity (WEC) and available WHC: Soil moisture retention at various suctions was determined using pressure plate/membrane apparatus (Richards and Fireman, 1943; Richards, 1947).
- (iv) pH: pH was measured using a pH meter in a 1:2 soil-water suspension. pH was read after 30 minutes of equilibration (Peech, 1965).
- (v) Nitrogen: Total Nitrogen was determined using Micro Kjeldahl method for total Nitrogen (Dremmer, 1965).

- (vi) Potassium: Potassium was determined by atomic absorption spectrophotometry using ammonium acetate extract (Pratt, 1965).
- (vii) Phosphorus: Phosphorus was measured using Bray and Kurtz No 1 method for phosphorus (Bray and Kurtz, 1945); and was determined colorimetrically as a phosphomolybdate complex developed by stannous chloride (Jackson, 1958).

Relevant physico-chemical soil characters of the experimental sites are shown in Table 2.3a & b.

3.2 Treatments

The study was designed to investigate the performance of two maize cultivars at different moisture regimes in soils with different available water holding capacities (AWHC). Hence, treatments were soil types, maize cultivars, and moisture regimes as outlined below.

3.2.1 Soil types

Two soils on the basis of AWHC were used:

- (a) A soil with high AWHC - soil 1 (Site 1)
- (b) A soil with low AWHC - soil 2 (Site 2)

3.2.2 Maize cultivars

(i) Katumani is a short maturing cultivar bred primarily for areas where the duration of rainfall is limited. Plants of this cultivar are short and small in size.

Table 2.3a. Relevant physico-chemical soil characters of the experimental sites

Soil	Depth (cm)	Particle size analysis (%)			Textural Class	BD (g cm^{-3})	pH	N (%)	P (ppm)	K me/ 100 g
		Sand	Silt	Clay						
Soil I	0-35	84	6	10	LS	1.59	6.2	0.07	40.7	0.77
	35-80	67	8.6	24.4	SCL	1.32	6.2	0.04	27.4	1.03
	80-97	78	9.8	12.2	SL	1.64	6.5	0.14	7.0	0.26
	97-118	89	4.9	6.1	S	1.44	6.5	0.21	13.3	0.26
	118-145	83.5	10.4	6.1	LS	1.50	6.5	0.07	12.6	0.26
Soil II	0-20	89	6	6	S	1.44	6.4	0.18	8.4	0.77
	20-51	84	6	10	LS	1.30	6.6	0.07	3.5	0.77
	51-72	79	60	15	LS	1.37	6.6	0.14	14.0	0.51
	72-98	74	11	14	LS	1.31	6.6	0.14	10.5	0.26
	98-145	84	6	10	LS	1.26	6.5	0.14	16.8	0.26

Table 2.3b. Relevant physico-chemical soil characters of the experimental sites

Depth (cm)	Moisture retained at different suction					AWC	Equivalent depth (cm)
	Saturation	0.1 bar	0.3 bar	15 bar	% (v/v)		
Soil I							
0-35	56.45	33.58	26.36	8.76	17.60	6.16	
35-80	45.41	35.40	33.07	14.04	19.03	3.56	
80-97	37.64	29.72	27.01	15.48	11.53	1.96	
970118	42.67	32.56	28.76	16.78	11.98	2.52	
118-145	37.49	29.88	25.50	14.79	10.71	<u>2.89</u>	
Soil II							
0-20	38.33	22.59	18.30	7.60	10.70	2.14	
20-51	29.58	15.54	13.75	4.33	9.43	2.92	
51-72	44.39	24.74	18.58	9.84	8.74	1.84	
72-98	38.76	20.46	15.41	7.60	7.05	2.03	
98-145	46.31	34.41	30.54	18.19	7.51	5.80	
							14.73 cm (10.16 cm/m)

(ii) Ilonga composite is a late maturity cultivar relatively larger in size than Katumani. It is commonly planted during the long rains.

Both cultivars were sown at each site.

3.2.3 Moisture regimes

Two moisture regimes were employed:

- (i) Rainfed: Rainfed treatments depended on seasonal rainfall as the only source of water.
- (ii) Limited irrigation: Limited irrigation (hereafter, irrigation only) treatments received ten - 20 l buckets of water (equivalent to 10 mm of rain) each time the tensiometer installed at 30 cm depth registered 0.5 bars.

3.3 Experimental Design

Treatments were laid out in a split - split plot with 3 replications. Plot size were 4 m x 5 m with headland of 1 m within blocks and subplots. Soils were the mainplots, maize cultivars the subplots and moisture regimes the sub - subplots.

3.4 Cultural Practices

3.4.1 Land preparation

The experimental sites were ploughed followed by harrowing in the first week of November, 1985. The sites were in fallow the previous 2 years.

3.4.2 Planting

On both sites, planting was on November 22nd, 1985. Spacing was 80 cm x 30 cm achieving 5 rows in a plot and thus a crop population of 41667 plants per hectare. Seeds were hand planted two per hill and thinned to one after 2 weeks. Rainfall amounting to 29.2 mm occurred a day before planting and resulted in excellent germination and plant establishment.

3.4.3 Fertilizer application

Phosphorus at the rate of 40 kg P_2O_5 ha⁻¹ was band applied as TSP at planting time. Nitrogen at the rate of 50 kg N ha⁻¹ was top-dressed in two splits as sulphate of ammonia (S/A), at 14 and 53 days after planting respectively.

3.4.4 Weeding

The first three weeding were done at 8, 25 and 40 days from planting respectively. Later, the exercise was carried out as and when necessary. A hand hoe was employed.

3.5 Instrumentation of the Field

3.5.1 Raingauge

A standard raingauge was installed 20 m from the experimental area. It was monitored daily at 9.00 a.m.

3.5.2 Tensiometers

Gauge type tensiometers (HYDRATAL 1000) were installed in each plot a few days after germination at depths of 30 cm, 60 cm

and 90 cm. The manufactures instructions were followed in this exercise.

3.6 Observations and Measurements Made

3.6.1 On soil

3.6.1.1 Water content profiles

Soil samples were taken using a tube auger at various stages of crop growth (46, 67, and 80 days from planting) in 15 cm depth increments in the plots down to a depth of 90 cm for gravimetric determination of moisture.

3.6.1.2 Soil matric potential

Tensiometer gauge readings were taken daily at around 9.00 a.m. Where necessary, flushing of tensiometers was done only after readings had been recorded. From these readings the weighed soil matric potential (ψ_m weighted) in 15 - 105 cm depth was calculated using following relationship:

$$\psi_m \text{ (weighted)} = \frac{\sum_{n=1}^{n=3} \psi_{mi} D_i}{90}$$

Where ψ_m (weighted) = Weighted soil matric potential
in 15 - 105 cm profile depth

n = number of soil layers varying
from 1 to 3

ψ_{mi} = Soil matric potential at 30,
60 and 90 cm depths in soil

D_i = thickness of different soil
layers in which soil matric

potential is supposed to be constant corresponding to the soil ψ_m observed at a point in that particular layer. Each layer was 30 cm thick.

3.6.2 On plants

3.6.2.1 General observations

Germination was after 7 to 8 days. Tasselling was observed 45 and 60 days after planting for Katumani and Ilonga Composite respectively.

3.6.2.2 Plant height

Plant height was determined 54 days from planting (here after DFP only). A tape measure was used.

3.6.2.3 Plant diameter

Stem diameter was measured with a vernier calliper on the 3rd internode from the soil surface 54 DFP. Five plants randomly selected from center row were measured for plant height and stem diameter.

3.6.2.4 Leaf area

Leaf area was measured on 5 plants for both cultivars at 54 days and only for Ilonga Composite at 74 DFP using Electronic planimeter (Model: Paton Electronic Planimeter, Australia).

3.6.2.5 Number of leaves

Number of leaves per plant was counted while leaf area was being measured.

3.6.2.6 Dry-matter yield

Five plants from guard rows at 54 and 74 DFP were taken for dry-matter (DM) and leaf area measurement. The above ground plant parts (leaves and stems) were oven-dried at 70°C and weighed for DM yield.

3.6.2.7 Leaf water potential

Plant water status at selected stages of growth was estimated from leaf water potential (ψ_l) on leaf samples taken at various times of the day using a pressure bomb (Model: Arimad - 2, Israel) - (Boyer, 1967). To minimize loss of leaf area, about 15 cm lengths of leaves from the apex of one of the three uppermost fully opened leaves were cut.

3.6.2.8 Root length

After harvesting, 3 cores (5.5 cm x 4.0 cm) were collected in 15 cm depth increments in the plots down to a depth of 90 cm. Root length was estimated using Newman's (Newman, 1966) technique.

3.7 Harvesting and Grain Yield

Katumani was harvested on February 17, 1986, 87 days from planting when all plants were dry. Ilonga Composite was harvested on both sites on March 20, 1986, 113 DFP. An area of 12 m² in each plot (3 center rows) free of border effects was harvested.

Maize ears were sundried then shelled after which the grain was air-dried and then weighed.

3.8 Yield Components

3.8.1 Percentage of barren plants

At harvesting time, barren plants and those with partially filled cobs were counted and expressed as a percentage of the total number of plants per plot (treatment).

3.8.2 Number of kernels per cob

From the bags containing maize cobs harvested from each treatment, 3 cobs were randomly picked, hand-shelled and the number of kernels/cob counted.

3.8.3 Thousand kernel weight

After shelling and air-drying, 1000 kernels were counted from each treatment and their weight determined.

3.9 Water Use Efficiencies

3.9.1 Total water use efficiency (TWUE)

Total water use efficiencies for DM or grain yield were separately computed as follows:

$$\text{TWUE (irrigated plot)} = \frac{\text{Yield (kg/ha)}}{(\text{Seasonal Rainfall} + \text{Irrigation}) \text{ cm}}$$

$$\text{TWUE (rainfed plot)} = \frac{\text{Yield (kg/ha)}}{(\text{Seasonal Rainfall}) \text{ cm}}$$

Note: (1) For DM yield, Seasonal rainfall or irrigation water refer to amounts received up to the date of sampling.

- (11) For grain yield, seasonal rainfall or irrigation water refer to amounts received up to 2 weeks before harvesting date when maize had already attained physiological maturity.

3.9.2 Irrigation water use efficiency (IWUE)

Irrigation water use efficiencies for DM and grain yield were calculated as follows:

$$\text{IWUE} = \frac{(\text{Yield (irrigated)} - \text{Yield (rainfed)}) \text{ kg/ha}}{\text{*Irrigation water (cm)}}$$

*As explained under TWUE.

3.10 Statistical Analysis

The data obtained from this study were analysed statistically by a pocket calculator (Model: fx-180p Casio Scientific calculator) using the analysis of variance technique and mean comparison were by LSD method (Little and Hills, 1978).

Table 4.1. Effects of soil water holding capacity cultivars, and water regimes on the frequency of irrigation and total irrigation water

Treatments	Days from										Total Irrigation Water
	Planting	13	32	36	40	65	71	76	95		
Soil 1 (High WWC)											
Rainfed Katumani	0	0	0	0	0	0	0	0	0	0	0
Irrigated Katumani	10	10	10	10	10	0	NA	NA	NA	NA	40
Rainfed Ilonga Comp.	0	0	0	0	0	0	0	0	0	0	0
Irrigated Ilonga Comp.	10	10	10	10	10	0	0	10	0	0	50
Soil 2 (Low WWC)											
Rainfed Katumani	0	0	0	0	0	0	0	0	0	0	0
Irrigated Katumani	10	10	10	10	10	10	NA	NA	NA	NA	50
Rainfed Ilonga Comp.	0	0	0	0	0	0	0	0	0	0	0
Irrigated Ilonga Comp.	10	10	10	10	10	10	10	10	10	10	80

NA = Not applicable as Katumani had already reached physiological maturity

* Day 13 = 5/12/1985

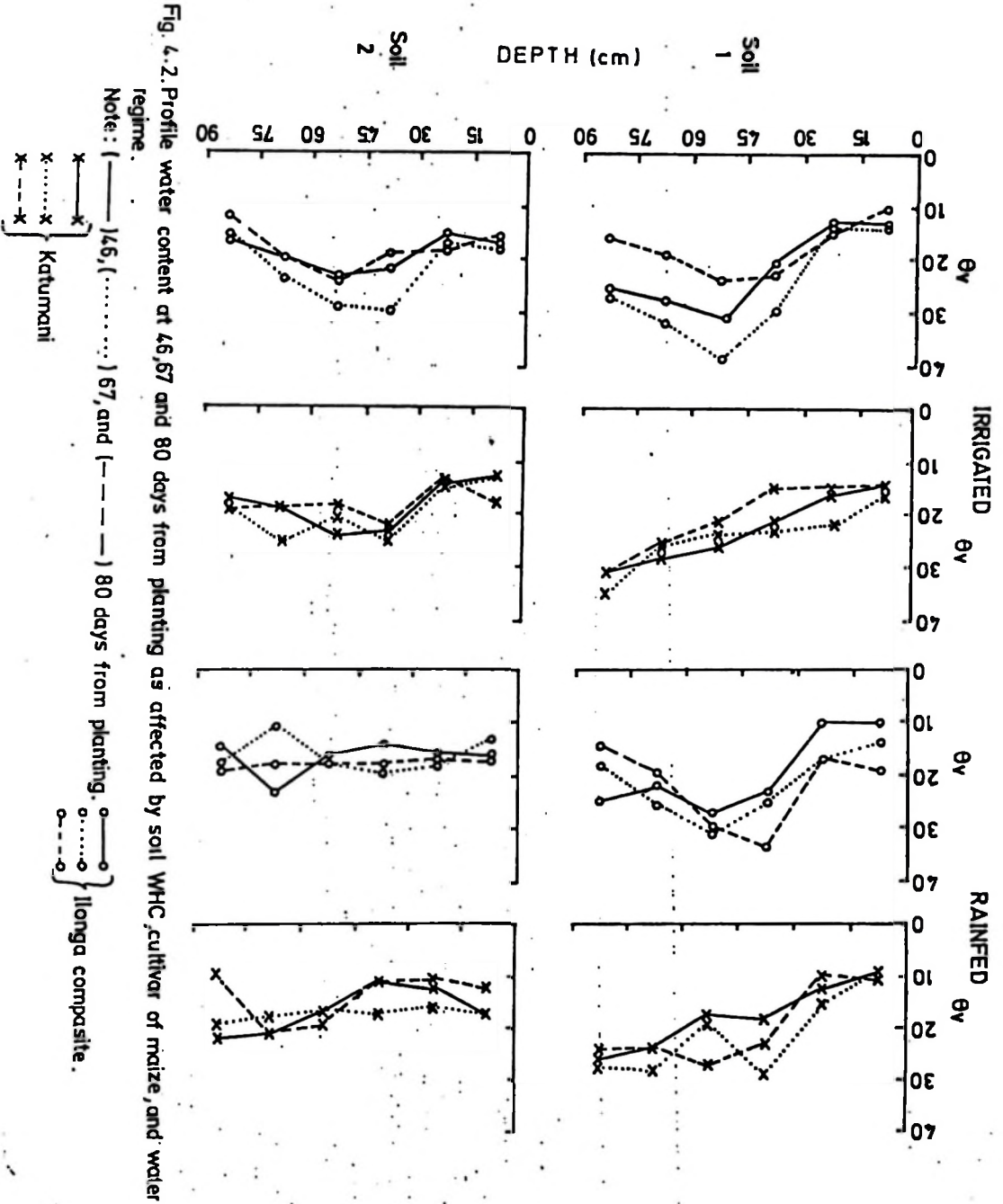


Fig. 4.2. Profile water content at 46, 67 and 80 days from planting as affected by soil WHC, cultivar of maize, and water regime.

are usually high in total water retention (Jamison and Kroth, 1958).

The absence of marked difference amongst treatments and the low values in profile water content in the surface 30 cm of soil stems from the fact that most roots were concentrated in this layer as was evident from Figure 4.5 which is discussed later in the section dealing with root length density. Thus, more water was extracted from within this than any other layer leading to low water contents.

A glance at figure 4.2, shows a uniform depletion of profile water in a soil with low WHC and under rainfed conditions. The tendency is for plants to send their roots deep into the soil when subjected to conditions of limited moisture supply (Mayaki et al., 1976). The resulting root system enables the plants to extract water uniformly from the entire soil profile. The distribution of roots as is evident from RLD (Figure 4.5) makes this conclusion logical.

Apart from soil WHC, profile water content also seems to have been affected by water regimes. For example, irrespective of soil WHC, irrigated plots contained more water within the profile than the corresponding rainfed plots. Assuming that the same amount of water would have been extracted by the crop in each plot, the difference in profile water content should be attributed to water applied through irrigation. For example, at 56 DFP, irrigated plots had received 30 mm of irrigation water in the preceeding 15 days on top of 20 mm of rain. A succession of heavy rains amounting to 114.7 mm between day 56 and day 67 from planting accounts for the high profile water content at 67 days as compared to either that

at 56 or 80 DFP.

Very low values of profile water content (as low as 8% v/v) in rainfed plots at 80 DFP could be explained by a prolonged dry spell from around day 67. As a result, most soil water held in the soil had, by that time, been depleted by evapotranspiration.

4.2.2 Weighted soil matric potential (ψ_m)

The seasonal march in soil matric potential for treatments in soil 1 (high WHC) is shown in Figure 4.3(a) while that for soil 2 (low WHC) in Figure 4.4(a). Each curve represents weighted ψ_m values in each treatment in the depth of 15 - 105 cm. The weighted matric potential values over the entire period of determination are given in Appendix 1a & b.

A glance at the figures shows that soil 1 has a high ψ_m . From day 41 to day 70, ψ_m did not fall below - 0.29 bars and - 0.14 bars for rainfed and irrigated treatments respectively. On the other hand, ψ_m values as low as - 0.39 bars for rainfed and - 0.25 bars for irrigated plots were registered in soil 2 during the same period. Being sandy and hence free draining, soil 2 lost more incoming water (rain or irrigation) from within 15 - 105 cm depth leading to low ψ_m values.

The soil ψ_m fluctuated with the distribution of rains and irrigation. A succession of rainy days as from day 40 from planting giving 128.7 mm within 10 days might have saturated the soils leading to zero ψ_m .

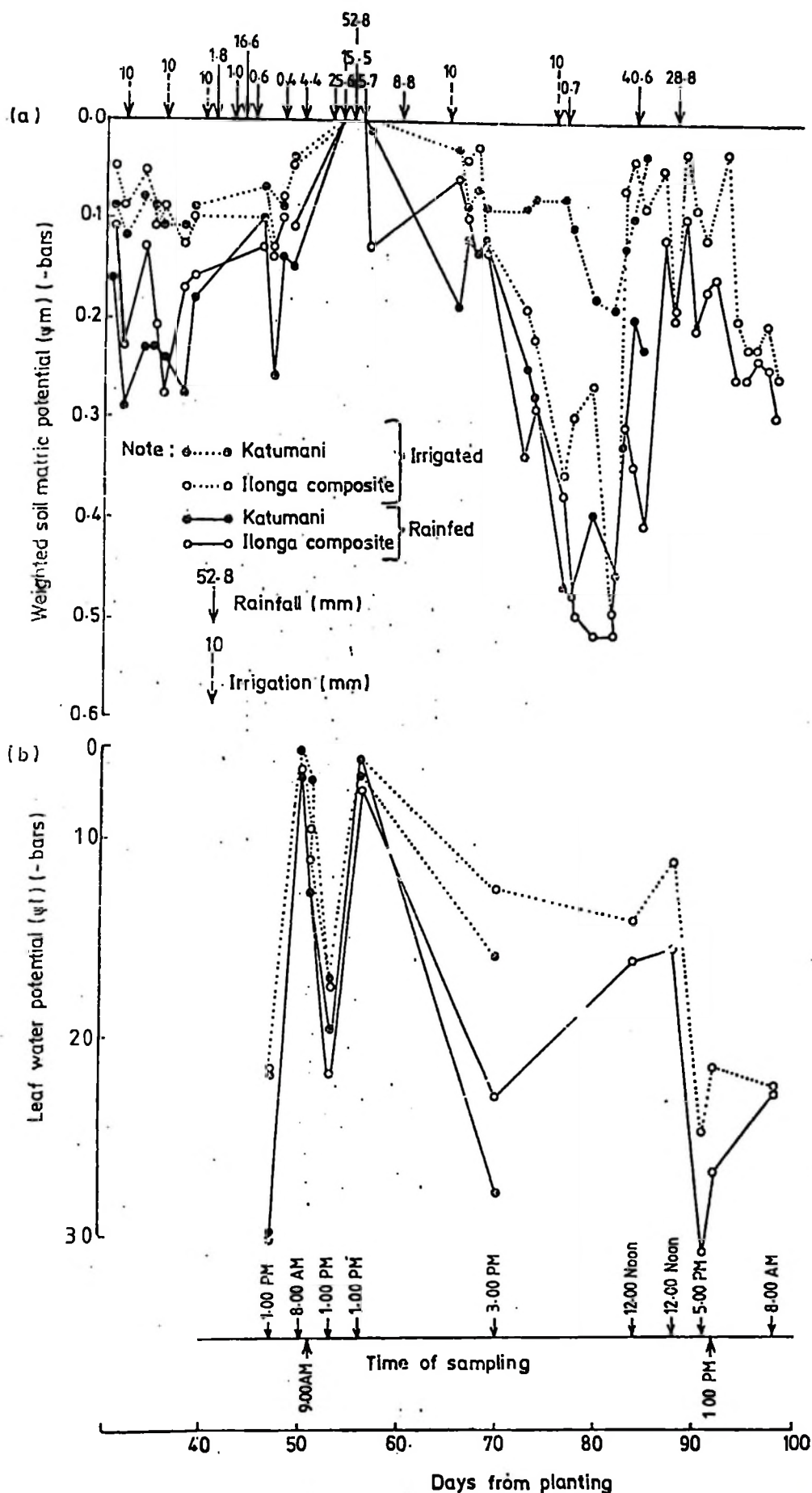


Fig. 4.3. Changes in (a) weighted soil matric potential and (b) leaf water potential in a soil with high WHC as affected by cultivar of maize and water regime.

In both soils, ψ_m was at its lowest during a 14-day dry spell beginning 60 DFP. The explanation is two-fold. First, the high temperature prevailing at that period (Table 2.2) might have increased the loss of water through evapotranspiration. Second, apart from the normal increase in ETo under dry conditions, this period coincided with tasseling-silking stage for Ilonga Composite and grain filling for Katumani during which water requirements for maize are much higher (Hall et al., 1981; Harder et al., 1982; Stegman, 1982; Bennett and Hammond, 1983). Thus, more water was lost through evapotranspiration leading to the lower ψ_m .

As physiological maturity approached, there was an increase in ψ_m in all plots, especially in irrigated treatments. It is considered that ETo had declined following the general senescence of leaves thus making the plants a less effective tool in the loss of water. As a result, soils might have retained more of the added water which brought about an increase ψ_m .

Early in the season, rainfed plots planted with Katumani had lower ψ_m values as compared to similar plots planted with Ilonga Composite. The difference in the duration of the crop and phenological stages of the two cultivars could explain this variation. Also, Katumani being a short duration cultivar might have established a prolific root system faster than the Ilonga Composite to match the above ground development. Katumani tasseled 15 days earlier than Ilonga Composite. Thus, early better root development and increased demand for water at tasseling stage (Bennett and Hammond, 1983) leading to increased water uptake might

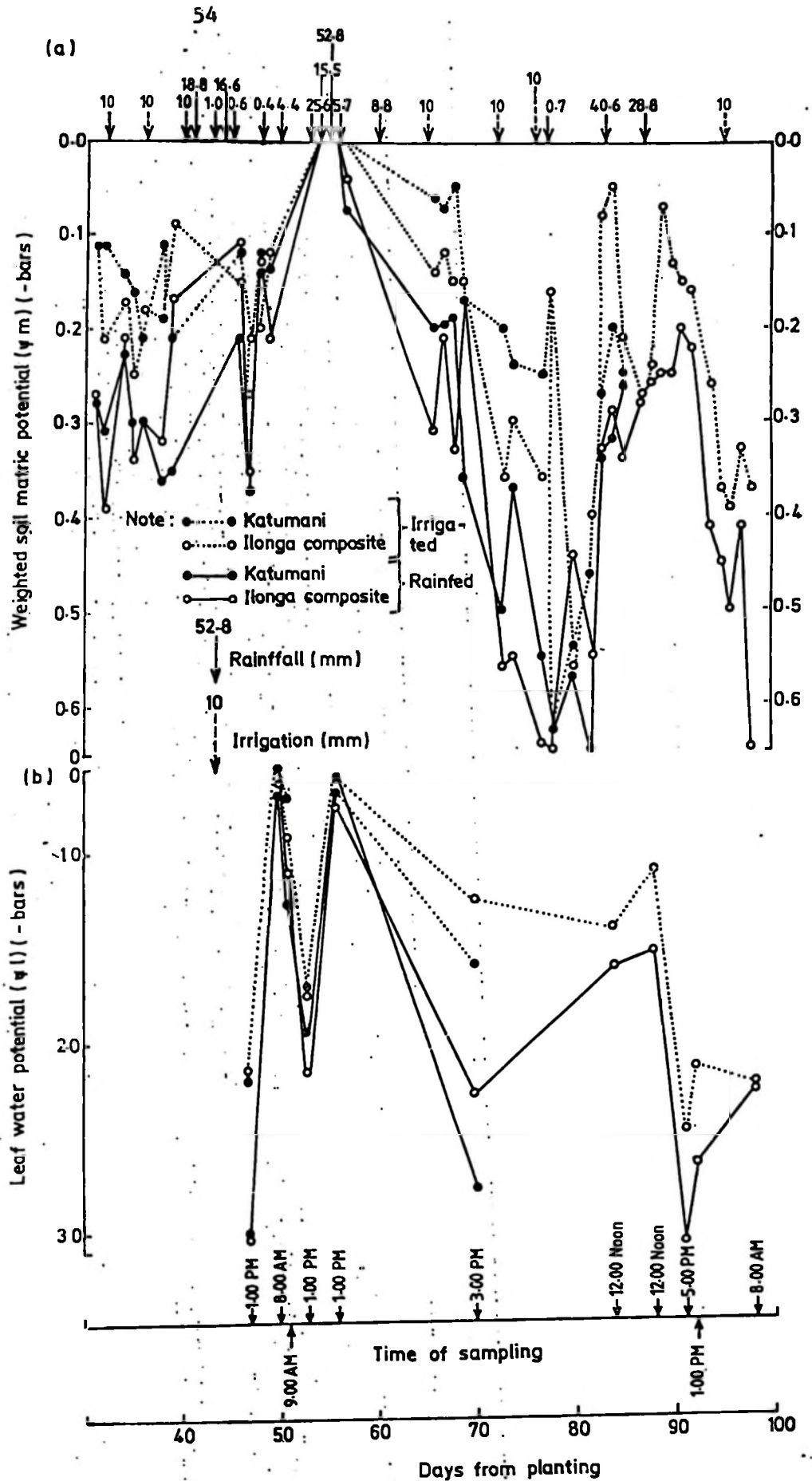


Fig.4.4. Changes in (a) weighted soil matric potential and (b) leaf water potential in soil with low WHC as affected by cultivar of maize and water regime.

be responsible for lower ψ_m in plots planted with Katumani.

4.2.3 LEAF water potential

Trends in leaf water potential (ψ_l) for all treatments at certain stages of crop development measured at various times of the day are shown in Figure 4.3(b) for soil 1 (high WHC) and Figure 4.4(b) for soil 2 (low WHC). Leaf water potential values over the entire period of measurement are given in Table 4.2 and means for main effects in Table 4.3.

As from day 47 to day 56 from planting, no marked differences in ψ_l were observed amongst the various treatments. This tendency was more pronounced for ψ_l values determined before noon. Given the fact that all plants had had the whole night to readjust from water deficit experienced the previous day this observation seems logical.

High ψ_l values observed during this period (day 47 to day 56) relative to those observed during the entire season (Figures 4.3b and 4.4b), are attributed to the frequent and heavy rains amounting to 128.7 mm which were received in 10 days as from day 40. During this period, soil ψ_m was at its highest (Zero ψ_m) thus collaborating the high values of ψ_l .

Averaged over the entire period of measurement, plants in soil 1 had higher ψ_l values (- 15.16 bars) than those in soil 2 which had a mean value of - 17.38 bars (Table 4.3). The storage of more water in soil 1 relative to soil 2 resulted in the supply of more water to the plants with consequential maintenance of high ψ_l values.

Table 4.2. Effects of soil water holding capacity, cultivars, and water regimes on leaf water potential of maize

Treatments	Days from planting														
	47	50	51	53	56	70	84	88	91	92	98				
	Time of sampling	1.00 P.M.	8.00 A.M.	9.00 A.M.	1.00 P.M.	1.00 P.M.	3.00 P.M.	12.00 Noon	12.00 Noon	5.00 P.M.	1.00 P.M.	8.00 A.M.			
		----- Leaf water potential (- bars) -----													
Soil 1 (high WHC)															
Rainfed Katumani		21.2	5.5	6.3	16.0	6.7	23.6	*	-	-	-	-	-	-	
Rainfed Ilonga Comp.		27.5	7.0	7.0	19.0	6.3	21.5	14.6	12.8	34.0	22.0	20.7			
Irrigated Katumani		19.0	5.5	6.5	15.5	5.5	14.8	*	-	-	-	-	-	-	
Irrigated Ilonga Comp.		19.8	6.5	6.9	17.0	6.0	12.0	11.7	9.9	20.0	16.0	20.5			
Soil 2 (low WHC)															
Rainfed Katumani		30.0	6.7	12.7	19.6	6.1	27.8	*	-	-	-	-	-	-	
Rainfed Ilonga Comp.		30.3	7.0	11.0	21.7	7.4	23.0	16.2	15.4	30.9	26.7	23.0			
Irrigated Katumani		22.1	5.5	7.0	17.2	6.9	15.8	*	-	-	-	-	-	-	
Irrigated Ilonga Comp.		21.7	6.5	9.3	17.5	6.2	12.5	14.3	11.0	24.9	21.5	22.6			

* Katumani had already reached physiological maturity

Table 4.3. Effects of soil water holding capacity, cultivars, and water regimes on leaf water potential of maize (Main Effect Means)

Date	Sampling Time	Soil		Cultivars			Water Regimes	
		High	Low	Katungani	Ilonga Comp.	Rainfed	Irrigated	
8-1-86 (47)	1.00 p.m.	21.58	26.03	23.08	24.83	27.25	20.65	
11-1-86 (50)	8.00 a.m.	6.13	6.43	5.30	6.75	6.55	6.00	
12-1-86 (51)	9.00 a.m.	6.68	10.00	8.13	8.55	9.25	7.43	
14-1-86 (53)	1.00 p.m.	16.88	19.00	17.08	18.80	19.06	16.80	
17-1-86 (56)	1.00 p.m.	6.13	6.65	6.30	6.48	6.63	6.15	
31-1-86 (70)	3.00 p.m.	17.96	19.78	20.5	17.25	23.98	13.78	
14-2-86 (84)	12.00 Noon	13.15	15.25	*	14.20	15.40	13.0	
16-2-86 (88)		11.35	13.2	*	12.28	14.10	10.45	
21-2-86 (91)	5.00 p.m.	27.09	27.9	*	27.45	32.45	22.45	
22-2-86 (92)	1.00 p.m.	19.00	24.1	*	21.55	26.35	18.75	
28-2-86 (98)	8.00 a.m.	20.6	22.8	*	21.7	21.85	21.55	
		$\bar{x} = 15.16$	$\bar{x} = 17.38$	$\bar{x} = 13.48$	$\bar{x} = 16.35$	$\bar{x} = 18.26$	$\bar{x} = 14.27$	

* Katungani had already reached physiological maturity

(47) Numbers in parenthesis indicate days from planting

Average over soils and water regimes, Katumani had higher ψ_1 values (- 13.48 bars) than Ilonga Composite (- 16.35 bars). Thus, Katumani had the ability to maintain a higher ψ_1 under similar moisture regime as Ilonga Composite. In a way, this indicates that Katumani has drought tolerance characteristics (Turner, 1979). Further evidence for drought tolerance comes from the general appearance of the crop stand in rainfed treatments which showed healthy plants for Katumani while those of Ilonga Composite showed wilted leaves, accounting for the low values of ψ_1 registered for this latter cultivar.

Irrigation increased ψ_1 markedly. Under rainfed conditions, ψ_1 values were on the average, lower by 4 bars when compared with those for plants under irrigation. Leaf water potential was - 14.27 and - 18.26 bars for plants under irrigation and rainfed conditions respectively. This is in conformity with the findings of other workers (Inuyama, 1978; Aparicio-Tejo and Boyer, 1983).

4.3 Effect of Soil Water Holding Capacity, Cultivars, and Water Regimes on Plant Growth, Yield Components and Grain Yield of Maize

The effect of soil water holding capacity (WHC), cultivars and water regimes on plant growth, yield components and grain yield was assessed in a field experiment. The parameters examined were: plant height, stem diameter, number of leaves per plant, leaf area per leaf, leaf area index (LAI), root length density (RLD), dry-matter yield (DM), percentage of barren plants, number of kernels set per cob, thousand kernel weight, and grain yield.

4.3.1 Plant height

Except for cultivars, soil type, moisture regimes and their interactions had no significant effect on plant height (Table 4.4 and Appendix 2). On the average, Katumani was significantly ($P = 0.05$) shorter than Ilonga Composite. Plants measured 67 and 78 cm in height respectively for Katumani and Ilonga Composite at 54 DFP. Compared with Ilonga Composite, Katumani is a short type of maize and hence the difference in height is quite logical.

Despite the lack of statistical significance, consistent trend was shown by plants of both cultivars to be shorter under rainfed and on soil with low WHC than under irrigated conditions and on soil with high WHC. These results are comparable with those reported by Denmead and Shaw (1960), Claassen and Shaw (1970a) and Bennett and Hammond (1983) for maize subjected to moisture stress during vegetative growth stage. All rainfed plots experienced a 16 - day dry spell starting from day 24 (December 17th 1985). This affected plant growth resulting in reduction in plant height. Plants of rainfed Katumani were 6.4 cm (9.1%) shorter and those of Ilonga Composite 5.8 cm (7.2%) shorter than the average height attained by plants under irrigated conditions. Similarly, plants were shorter in soil 2 (low WHC) than in soil 1 (high WHC). This was due to the ability of the latter soil to retain and release more water to growing plants long after rains had ceased. Such a phenomenon has long been recognized by Jamison and Kroth (1958) and Hillel (1971).

Table 4.4. Effects of soil water holding capacity, cultivars, and water regimes on plant height of maize (54 days from planting)

Soil type(s)	Maize cultivars (M)	Water regimes (W)	
		Rainfed	Irrigated
Plant height cm S x M x W means			
Soil 1 (High WMC):	Katwani	67.0	74.5
	Ilonga Composite	77.8	81.1
Soil 2 (Low WMC):	Katwani	60.3	65.6
	Ilonga Composite	72.6	81.0
Maize cultivar (main effects means) ^a			
	Katwani	66.36	78.12
	Ilonga Composite		

^aLSD, 5% (cultivars): 5.4

4.3.2 Stem Diameter

Like plant height, stem diameter was affected only by the type of cultivar (Table 4.5 and Appendix 3). In all treatments, stems of Katumani were significantly ($P = 0.05$) thinner than those of Ilonga Composite. On the average, stem diameter of Katumani measured 1.8 cm as that of Ilonga Composite 2.3 cm. Genetically, Katumani is a small cultivar of maize which explains its smaller stem diameter than Ilonga Composite. Soil WMC and water regime had no significant ($P = 0.05$) effect on stem diameter. Furthermore, the two factors lead to no consistent trend. Very little evidence is available in literature either to support or contradict the present findings.

4.3.3 Number of leaves

The type of cultivar significantly ($P = 0.05$) affected the total number of leaves. Significant interactions were observed between soil type and water regimes ($S \times W$) as well as between maize cultivars and water regimes ($M \times W$) (Appendix 4).

At 54 days from planting, Katumani had 9.4 leaves where as Ilonga Composite had 11.0 leaves on the average (Table 4.6.). This difference should be considered to be an inherent property of the cultivars as is evident from other plant parameters such as plant height and stem diameter mentioned earlier. Failure of different water regimes to lead to significant effect on the number of leaves was also reported by Bennett and Hammond (1983).

Table 4.5. Effects of soil water holding capacity, cultivars, and water regimes on the stem diameter of maize (54 days from planting)

Soil type	Maize cultivars	Water regimes	
		Rainfed	Irrigated
Stem diameter cm/plant			
S x M x W means			
Soil 1			
(High WHC):	Katumani	1.91	1.87
	Ilonga Composite	2.34	2.23
Soil 2			
(Low WHC):	Katumani	1.70	1.74
	Ilonga Composite	2.07	2.43
Maize cultivar (main effect means) ^a			
	Katumani	1.81	2.27
	Ilonga Composite		

^a LSD, 5% (cultivars): 0.10

Table 4.6. Effects of soil water holding capacity, cultivars, and water regimes on the number of leaves of maize (54 days from planting)

Soil type(s)	Maize cultivars (M)	Water regimes (W)		Main effect Maize cultivars (Means) ^a
		Rainfed	Irrigated	
(Number of leaves/plants) S x M x W means				
Soil 1 (High WHC):	Katumani	8.3	10.1	
	Ilonga Composite	10.5	11.2	
Soil 2 (Low WHC):	Katumani	9.4	9.5	
	Ilonga Composite	11.9	10.3	
Soil Type x Water Regime (Means) ^b				
Soil 1		9.4	10.7	
Soil 2		10.7	9.9	
Maize Cultivar x Water Regime (Means) ^c				
	Katumani	8.9	9.9	9.4
	Ilonga Composite	11.2	10.7	11.0

^aLSD, 5% (cultivars): 1.56

^bLSD, 5% between soils for the same or different water regime: 1.60

^cLSD, 5% (1) Between water regime means for the same cultivar: 0.89
(11) Between cultivars for same or different water regime: 1.70

The significant ($P = 0.05$) interaction between soil type and water regime disappeared when means were separated for Least Significant Difference (LSD) test. This could be traced to the failure of the main effects (soil WHC and water regimes) to show a significant ($P = 0.05$) effect on the parameter under consideration. Furthermore, the interaction of soil type x water regimes did not show any consistent trend with respect to the number of leaves.

Under both water regimes, Katumani had fewer leaves than Ilonga Composite. However, the difference was significant ($P = 0.05$) only under rainfed conditions. This is a departure from the expected trend because rainfed plants of Ilonga Composite had a poorer stand than those of Katumani. Between water regimes, within each cultivar the number of leaves was affected in a complex way. Fewer leaves were produced under rainfed condition for Katumani but under irrigation, fewer leaves were produced for Ilonga Composite. The leaf number for Katumani was significantly different ($P = 0.05$) under the two water regimes but for Ilonga Composite, it did not differ significantly.

At 74 DFP, all leaves had dried up in plots planted with Katumani. Ilonga Composite still had leaves but lower leaves had senesced especially in rainfed plots. Irrigation lead to more leaves per plant. Though slight in magnitude, the tendency is attributed to more water supply which delayed leaf senescence. As a result, in all treatments, the cultivar had fewer leaves (<10) at 74 (Table 4.7) than at 54 days (>10).

Table 4.7. Effects of soil water holding capacity, cultivar, and water regime on the number of leaves of maize (74 days from planting)

Soil type(s)	Maize cultivar (M)	<u>Water regime (W)</u>		(Number of leaves/plant)
		Rainfed	Irrigated	
Soil 1				
(High WHC):	*Katumani	-	-	
	Ilonga Composite	8.9	9.3	
Soil 2				
(Low WHC):	*Katumani	-	-	
	Ilonga Composite	8.0	8.7	

*Katumani had all its leaves dried at 74 days

S x M x W means

4.3.4 Leaf area

4.3.4.1 Leaf area per leaf

Both cultivars had larger leaves in soil 1 than in soil 2 (Table 4.8). However, the difference was marginal for Katumani. Larger leaves in soil 1 were a product of a better soil moisture regime created by its high WHC.

Averaged over soils and water regimes, Ilonga Composite had larger leaves (323.4 cm^2) than Katumani (207.5 cm^2). This trend was similar to those shown for plant height, stem diameter and number of leaves discussed earlier, thus suggesting varietal difference to be the cause of the observed trend.

Plants of both cultivars had larger leaves under irrigated (275.93 cm^2) than under rainfed (254.93 cm^2) conditions on the average. Several workers (Boyer, 1970; Hsiao *et al.*, 1970; Acevedo *et al.*, 1971) have reported increased expansion of leaves of maize following irrigation and the general decline in leaf area when plants are subjected to water stress.

After seventy four (74) DFP, all leaves for Katumani had dried up in all treatments. Consequently, leaf area could not be determined. As for Ilonga Composite, leaves were smaller at this stage than at 54 DFP. This was despite substantial rains (68.7 mm within 20 days) received between the two sampling stages. The inevitable senescence with age of lower and usually larger leaves of the plant leaving smaller upper leaves explains the observed decline in leaf area (Aparicio-Tejo and Boyer, 1983). The decline

Table 4.8. Effect of soil water holding capacity, cultivars, and water regimes on leaf area of maize

Soil type(s)	Maize cultivars (M)	Water regimes (W)		Area/leaf (cm)		
		Rainfed	Irrigated	Rainfed	Irrigated	
----- Area/leaf (cm) -----						
S x N x W means						
		(54 days from planting)		74 days from planting)		
Soil 1						
(High WHC):	Katumani	188.8	220.4	-	-	
	Ilonga Composite	322.8	358.9	288.0	350.9	
Soil 2						
(Low WHC):	Katumani	207.0	213.6	-	-	
	Ilonga Composite	301.1	310.8	208.0	237.0	
Main Effect Means (54 days from planting)						
	<u>Soil Type</u>	<u>Maize cultivars</u>		<u>Water Regimes</u>		
	Soil 1	Soil 2	Katumani	Ilonga Composite	Rainfed	Irrigated
	272.73	258.13	107.45	323.4	254.93	275.93

in the number of leaves with age of the plant especially toward the end of the life cycle as reported by Aparicio-Tejo and Boyer (1983) is also supported by the data generated from this study (Tables 4.6 and 4.7).

4.3.4.2 Leaf area index (LAI)

At 54 days from planting, cultivars and water regimes had significant ($P = 0.05$) effect on leaf area indices (Table 4.9 and Appendix 5). Leaf area indices varied between 0.67 to 0.93 for Katumani and ranged between 1.33 to 1.63 for Ilonga Composite. Averaged over all the factors, LAI was 0.82 for Katumani and 1.47 for Ilonga Composite. This represented a 79% superiority in LAI of Ilonga over Katumani. More and larger leaves produced by Ilonga Composite compared with Katumani explains this varietal difference in LAI (Tables 4.6 and 4.8).

On the average, irrigation led to a 17% increase in LAI. Leaf area index was 1.23 and 1.05 under irrigated and rainfed conditions, respectively. Since the number of leaves produced by either cultivar was not significantly affected by any of the water regimes (Appendix 4), lower leaf area indices under rainfed conditions resulted from smaller leaves and to some extent increased leaf senescence due to moisture stress. Similar observations have been reported by other workers (Aparicio-Tejo and Boyer, 1983; Bennett and Hammond, 1983).

At 74 DFP, all leaves of Katumani had senesced and dried up in all treatments. As a result, leaf area and LAI could not be determined (Table 4.10). Ilonga Composite, on the other hand,

Table 4.9. Effects of soil water holding capacity, cultivars, and water regimes on the leaf area index (LAI) of maize (54 days from planting)

Soil type (S)	Maize cultivars (M)	Water regimes (W)		Main effects means
		Rainfed	Irrigated	
S x M x W means				
Soil 1 (High VHC):	Katumani	0.67	0.93	<u>Maize cultivars</u> ^a
	Ilonga Composite	1.37	1.63	
Soil 2 (Low VHC):	Katumani	0.83	0.83	<u>Water regimes</u> ^b
	Ilonga Composite	1.33	1.53	
		Rainfed	Irrigated	
		1.05	1.23	

^aLSD 5% (cultivars): 0.33

^bLSD 5% (water regimes): 0.15

still had a large number of green leaves at 74 days from planting. On the average, LAI for Ilonga Composite had declined by 29% compared with the value at 54 days. Over all, plants had 2.3 leaves less per plant than at 54 DFP. Fewer and smaller leaves coupled with damaged leaf blades due to water stress lead to the decline in LAI at a later stage of 74 DFP. Despite the general decline in magnitude of LAI, irrigation increased LAI as was the case at 54 DFP. Leaf area index was observed to be 1.22 and 0.88 under irrigated and rainfed conditions respectively showing an increase of 39% under irrigated conditions. Likewise, the WRC of soil had a decisive effect on LAI. Leaf area indices for soil with high WRC were higher than corresponding LAI values for soil with low WRC. The ability of soil having high WRC to store and avail more rain and/or the water supplied through irrigation accounts for the higher leaf area indices in this soil. Water stressed plants are generally stunted (Kramer, 1972) and usually have smaller leaves (Bennett and Hammond, 1983) leading to lower LAI values. A rapid decline in leaf enlargement due to moisture stress has also been reported by Boyer (1970).

4.3.5 Root length density

Mean root length density (RLD) values within 0 - 90 cm of surface soil as affected by soil WRC, cultivars, and water regimes are presented in Table 4.11. Variation with depth in RLD values is shown in Figure 4.5 and the data is presented in Appendix 6.

Table 4.10. Effects of soil water holding capacity, cultivars, and water regimes on the leaf area index of maize (74 days after planting)

Soil type(s)	Maize cultivars (M)	Water regimes (W)		Cultivars (rain effect means)	
		Rainfed	Irrigated	Katumani	Ilonga Composite
(LAI)					
S x M x W means					
Soil 1					
(High WHC):	*Katumani	-	-	-	1.05
	Ilonga Composite	0.99	1.28		
Soil 2					
(Low WHC):	*Katumani	-	-	-	
	Ilonga Composite	0.76	1.15		
	Average	0.88	1.22		

*Katumani had all its leaves dry at 74 days, hence leaf area could not be measured

The difference in WHC of soil caused major variations in RLD values. On the average, RLD was 0.605 cm/cm^3 for soil 1 (high WHC) and 0.426 cm/cm^3 for soil 2 (low WHC). This represented a 42% superiority in RLD of plants in soil 1 over those in soil 2, and it suggests that more root development was encouraged by a better moisture regime created by the high WHC in soil 1. On the other hand, bulk density (BD) values which were generally high for soil 1 and low for soil 2 (Table 2.3) would seem to suggest otherwise. Compacted layers of soils (with high BD) usually act as physical barriers to root penetration (ASAE, 1971). Bulk density values given in this study are from profiles located 5 meters from the field. Thus after ploughing the surface BD values should have changed especially for soil 1 which had a high clay content.

Averaged over soils and water regimes, Ilonga Composite had 10% more length of roots/unit volume of soil than Katumani. Respective RLD values were 0.539 cm/cm^3 for Ilonga Composite and 0.490 cm/cm^3 for Katumani. However, this was true only under conditions of relatively high water supply as was the case in soil 1 (high WHC) for in soil 2 (low WHC), the trend was reversed irrespective of the water regime. Furthermore, in both soils (low and high WHC) RLD values for Katumani did not show big variations thus indicating that this cultivar was less affected by water regime and soil WHC with regard to RLD. This character, in a way explains the ability of Katumani to perform satisfactorily under relatively dry conditions as was evident from lower response to irrigation in relation to grain yield. On the other hand, failure of Ilonga composite to increase its RLD substantially under

Table 4.11. Effects of soil water holding capacity, cultivars, and water regimes on root length density (RLD) of maize (in cm/cm³)

Soil type(s)	Maize cultivars (M)	Water regimes (W)		
		Rainfed	Irrigated	
S x M x W means*				
Soil 1				
(High WHC):	Katumani	0.487	0.520	
	Ilonga Composite	0.651	0.753	
Soil 2				
(Low WHC):	Katumani	0.466	0.483	
	Ilonga Composite	0.318	0.436	
	Main effect means			
	<u>Maize cultivars</u>		<u>Water regimes</u>	
	<u>High</u>	<u>Low</u>	<u>Rainfed</u>	<u>Irrigated</u>
	0.605	0.426	0.481	0.550
		<u>Katumani</u>	<u>Ilonga Composite</u>	
		0.490	0.539	

* Each figure is a mean of six RLD values of 15 cm depth increments from 0 - 90 cm depth of soil

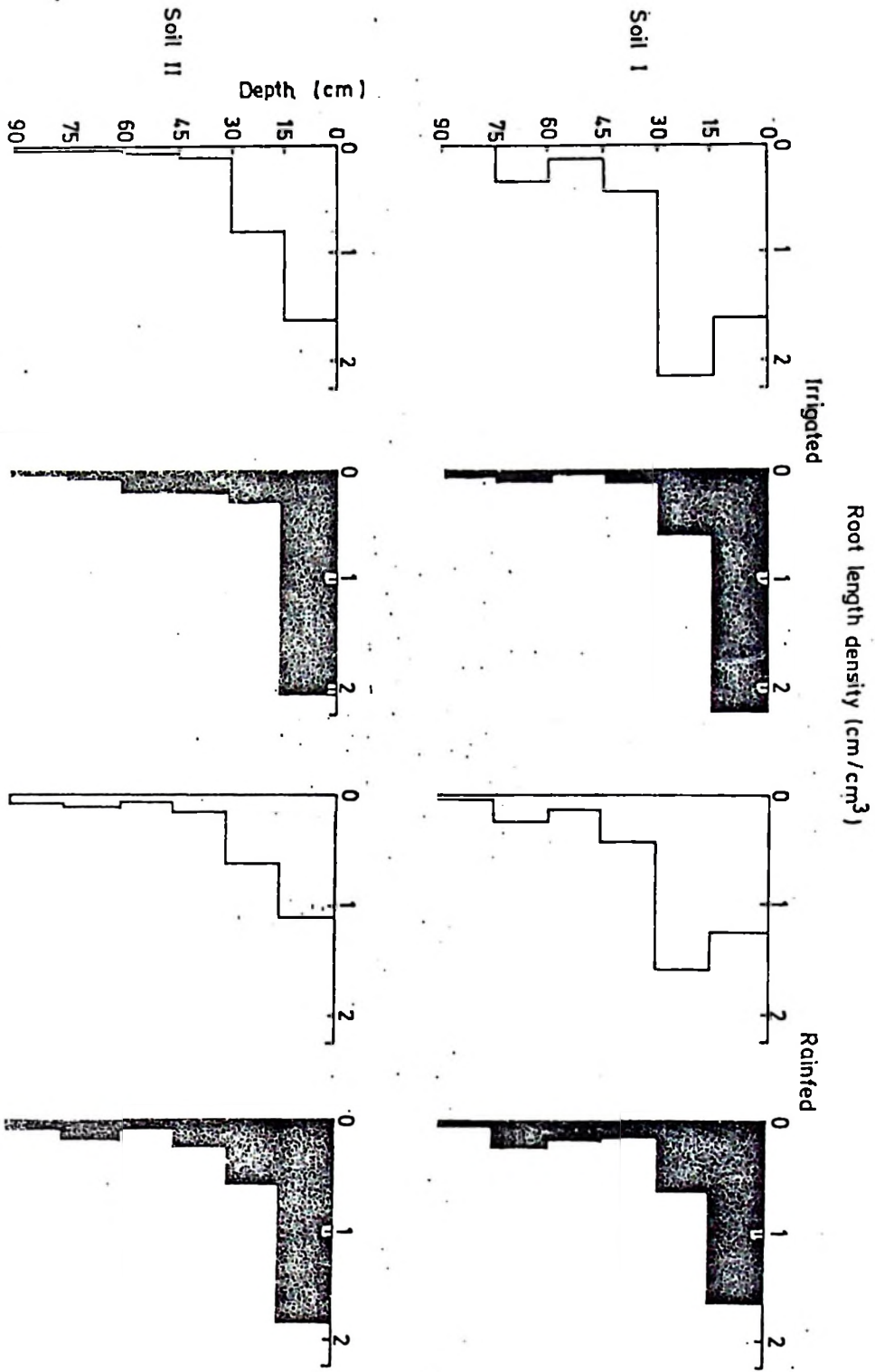


Fig. 4.5 Root length densities as affected by soil WRC, cultivar of maize, and water regime.

Note:- Cultivars : Hanga composite Katurani.

conditions of limited water accounts for its sensitivity to water stress and hence its poor performance with regard to grain production under such conditions. It should be mentioned here that, under rainfed conditions Katumani had higher TWUE (grain yield) than Ilonga Composite (Table 4.19) thus implying that Katumani extracted more water from the soil.

Under irrigation, plants had an average RLD of 0.550 cm/cm^3 , 14.5% higher than the value of 0.481 cm/cm^3 obtained under rainfed conditions. This further underlines the role of water in enhancing root growth. It is also known that moist soil encourages more root development as it is easily dislodged by advancing roots.

The surface 30 cm of soil housed most of the plant roots (Figure 4.5) and more so in irrigated treatments. This is in line with the findings by Mayaki et al. (1976). The loosening of surface soils through ploughing, the abundance of mineral nutrients (added fertilizers) and rain and/or irrigation water wetting the surface soil create an ideal environment for root development.

From the Figure 4.5, it is seen that relatively more roots penetrated beyond a 30 cm soil depth under rainfed than under irrigated conditions. This indicates that rainfed maize will expand its root system deeper in the soil during periods when soil water is at less than optimum, thereby tapping water reserves located deeper in the soil compared with irrigated maize (Mayaki et al., 1976).

Table 4.12. Effects of soil water holding capacity, cultivars, and water regimes on dry-matter yield of maize (54 days from planting)

Soil type(s)	Maize cultivars (M)	Water regimes		Main effects means	
		Rainfed	Irrigated	Cultivars ^a	Water regimes ^b
DM yield, kg/ha S x M x W means					
Katumani Ilonga Composite Rainfed Irrigated					
Soil 1					
(High WHC):					
Katumani		943	1452.7	1166.25	2368.75
Ilonga Composite		1715.3	3373.7		1284.75
					2250.25
Soil 2					
(Low WHC):					
Katumani		955.7	1313.6		
Ilonga Composite		1525	2861		
Maize cultivar x water regime means ^c					
Katumani		549.3	1383.2		
Ilonga Composite		1620.2	3117.3		

^aLSD, 5% (cultivars): 463.10

^bLSD, 5% (water regimes): 249.20

^cLSD, 5% (1) Between water regime means for the same cultivar: 351.14
 (11) Between cultivar means for same or different water regime: 523.71

4.3.6 Dry matter yield

Maize cultivars and water regimes significantly ($P = 0.05$) affected dry matter (DM) yield both at 54 and 74 days from planting (Tables 4.12 and 4.13). However, the interaction between the two factors (cultivars x water regimes) was significant ($P = 0.05$) only at 54 days from planting (Appendices 7 and 8). The mean DM yield at 54 and 74 DFP was respectively 1166.3 and 2001 kg/ha for Katumani, 2369 and 4465 kg/ha for Ilonga Composite. This represented an increase (over a short period of 20 days) of 72 and 88% over DM yield at 54 days for Katumani and Ilonga Composite respectively. This increase was due to increased growth of plants and the formation of ears encouraged by a favourable soil water regime caused by 68.7 mm of rain received during this short period. This was more than one-half of the amount of rainfall received during the first 54 days of the crop cycle.

Ilonga Composite outyielded Katumani in DM production by a factor of almost two (2). This difference is explained by larger plant size (height), stem diameter, and more leaves as well as larger cobs (Plate 1) produced by Ilonga Composite. Katumani is a short and smaller plant (Acland, 1971).

Compared with the DM yield obtained under rainfed conditions, irrigation increased DM yield by 75 and 28% at 54 and 74 DFP respectively. Heavy rains received after day 54 (68.7 mm within 20 days) reduced water deficits (Figures 4.3a and 4.4a) in rainfed plots, consequently, the vegetative growth following the good rains

Table 4.13. Effects of soil water holding capacity, cultivars and water regimes on dry-matter yield of maize (74 days after planting)

Soil type(s)	Maize cultivars (M)	Water regimes (W)		Main effect means	
		Rainfed	Irrigated	Katumani	Ilonga Composite
(DM yield, kg/ha)					
S x M x W means					
maize cultivars ^a					
Water regimes ^b					
Soil 1					
(High WHC):	Katumani	1641.3	2509.3	2001.2	4465.2
	Ilonga Composite	4171.3	5134		
Soil 2					
(Low WHC):	Katumani	1532.3	2321.7	Rainfed	Irrigated
	Ilonga Composite	4007	4543.3	2838	3628.3

^aLSD, 5% (cultivars): 156.0

^bLSD, 5% (water regimes): 271.5

narrowed the gap in DM yield between rainfed and irrigated treatments.

At 54 DFP, cultivars and water regimes interacted significantly ($P = 0.05$). Each cultivar produced more DM (Table 4.12) under irrigation than under rainfed conditions. Irrigation increased DM by 92 and 46% for Ilonga Composite and Katumani respectively. The relatively smaller increase in DM yield for Katumani shows low response to applied water and thus underlines its drought tolerance. Within each moisture regime, Katumani was significantly ($P = 0.05$) outyielded by Ilonga Composite. Dry matter yield for Ilonga Composite was higher by 70 and 125% than that for Katumani under rainfed and irrigated conditions, respectively. The ability of Ilonga Composite to produce more dry matter when supplied with water is evident from the data on other plant growth parameters discussed earlier.

Although there was no significant ($P = 0.05$) interaction amongst soils, cultivars and water regimes, in all treatments, DM yield was higher in soil 1 than in soil 2. Given the fact that similar management practices were carried out in both soils, the higher DM yield in soil 1 could have been due to its ability to retain and supply more water to the crop. A similar view is shared by Jamison and Kroth (1958), Hillel (1971) and Leeper et al., (1974).

4.3.7 Percentage of barren plants per plot

Katumani was least affected by water regime and WHC of soils with regard to barrenness. No barren plants were observed under irrigated conditions for Katumani. Under rainfed conditions, a

few barren plants (4%) were observed only in plots located in a soil with a low WHC. On the other hand, Ilonga Composite was severely affected in terms of barren plants under rainfed conditions. All treatments involving this cultivar had barren plants (Table 4.14). However, there were fewer barren plants under irrigated (3 to 11%) than under rainfed conditions (26 to 35%). The higher number of barren plants for Ilonga Composite could be explained when its phenological stage and prevailing weather conditions are taken into account. It was continuously dry for 20 days, three days after tasseling was first observed in Ilonga Composite. This was in addition to a 16 - day dry spell experienced prior to tasseling. Water stress at such a critical period lead to the failure of ear formation and reduction in kernel set. By that time, tasseling was already completed for Katumani and hence the effect of the dry spell did not result in barren plants. The percentage of barren stalks in this study fall almost within the range observed by Shaw et al., (1980) (7.3 to 42.7%) for maize stressed just before pollination.

4.3.8 Number of kernels set per cob

Maize cultivars, water regimes and their interactions had a significant ($P = 0.05$) effect on the number of kernels set per cob. Analysis of variance for this parameter is shown in Appendix 9 and Table 4.15 gives the number of kernels set/cob for each treatment. Over all, Ilonga Composite set 294.5 and Katumani 232.2 kernels/cob. The difference represented a 27% superiority of Ilonga Composite over Katumani. In general, Katumani had smaller cobs (Plot 1) a varietal characteristic leading to a smaller number of

Table 4.14. Effects of soil water holding capacity, cultivars, and water regimes on the percentage of partially filled cobs and barren plants

Soil type(s)	Maize cultivars (M)	Water regimes (W)	
		Rainfed	Irrigated
Percent barren plants/plot (S.E.M. x W means)			
Soil 1			
(High WHC):	Katumani	0.0	0.0
	Ilonga Composite	26.3	3.0
Soil 2			
(Low WHC):	Katumani	4.0	0.0
	Ilonga Composite	35.4	11.1

kernels/cob.

Taking averages over soils and cultivars, there were 211.2 and 315.5 grains per cob under rainfed and irrigated conditions respectively. Thus, irrigation caused a significant ($P = 0.05$) increase in the number of grains set/cob. This represented an increase of about 50% as a result of irrigation.

Both cultivars set more kernels/cob under irrigation than under rainfed conditions. Irrigation lead to 7 and 98% increase in the number of kernels set/cob for Katumani, and Ilonga Composite respectively. As a result of irrigation, the number of kernels set per cob in Katumani increased from 224.5 to 239.8 while that for Ilonga Composite increased from 197.8 to 391.2. However, the increase was not significant ($P = 0.05$) for Katumani indicating that kernel setting was least affected by moisture stress. The 98% increase in the number of kernels set/cob for Ilonga Composite underlines the sensitivity of this cultivar to water stress. It is thus obvious that Katumani did not respond to irrigation in terms of number of kernels set/cob whereas Ilonga Composite responded favourably to irrigation. Despite its superiority under irrigation, Ilonga Composite gave the lowest number of kernels/cob under rainfed conditions. The impairment of extrusion of the silks from the husk, the desiccation of silks and pollen before pollination brought on by moisture stress are potential sources of reduction in the number of seeds set on the ear. Similar explanations were given by Hall et al., (1981) and Waldren (1983).

Table 4.15. Effects of soil water holding capacity, cultivars and water regimes on the number of kernels set per cob of maize

Soil type(s)	Maize cultivars (M)	Water regimes (W)		Main effect means
		Rainfed	Irrigated	
S x M x W means				
<u>Maize cultivars^a</u>				
Soil 1				
(High WHC):	Katumani	241	263.7	Katumani
	Ilonga Composite	206	420	Ilonga Composite
Soil 2				
(Low WHC)	Katumani	208	216	<u>Water regimes^b</u>
	Ilonga Composite	189.7	362.3	Rainfed
	Maize cultivar x water regime means ^c			Irrigated
	Katumani	224.5	239.8	211.2
	Ilonga Composite	197.3	391.2	315.5

^aLSD, 5% (cultivars): 31.35

^bLSD, 5% (water regimes): 19.94

^cLSD, 5% (1) Between water regime means for the same cultivar: 28.20
 (11) Between cultivar means for same or different water regime: 37.02

The interaction of soil WHC x cultivars x water regimes had no significant ($P = 0.05$) effect on the number of kernels set/cob. However, a consistent trend in the results was noted. For example, more kernels were set/cob in all treatments in soil 1 (high WHC) than in corresponding treatments in soil 2 (low WHC). This is thought to have been caused by the higher water supply in soil 1 than in soil 2. According to Leeper et al., (1974), the potential of a soil to produce maize under adequate fertility and high level of management is largely determined by the soils' capacity to store and supply water to the crop.

Katumani had more kernels set/cob than Ilonga Composite under rainfed conditions, the opposite being true under irrigation. This trend indicates that Ilonga Composite is severely affected by water stress whereas Katumani is drought tolerant.

4.3.9 Thousand kernel weight

Cultivars and water regime had a significant ($P = 0.05$) effect on the thousand kernel weight. (Table 4.16 and Appendix 10).

A thousand kernels of Ilonga Composite weighed 313.7 g, 23% heavier than those of Katumani which weighed 256 g. Visual observation of the kernels revealed that Katumani had smaller kernels than those of Ilonga Composite and hence the difference in grain weight between the two cultivars.

Irrigation lead to a 43% increase in weight of kernels. On the average, 1000 kernels weighed 234.2 and 335.5 g under rainfed and irrigated conditions respectively. Kernels from rainfed

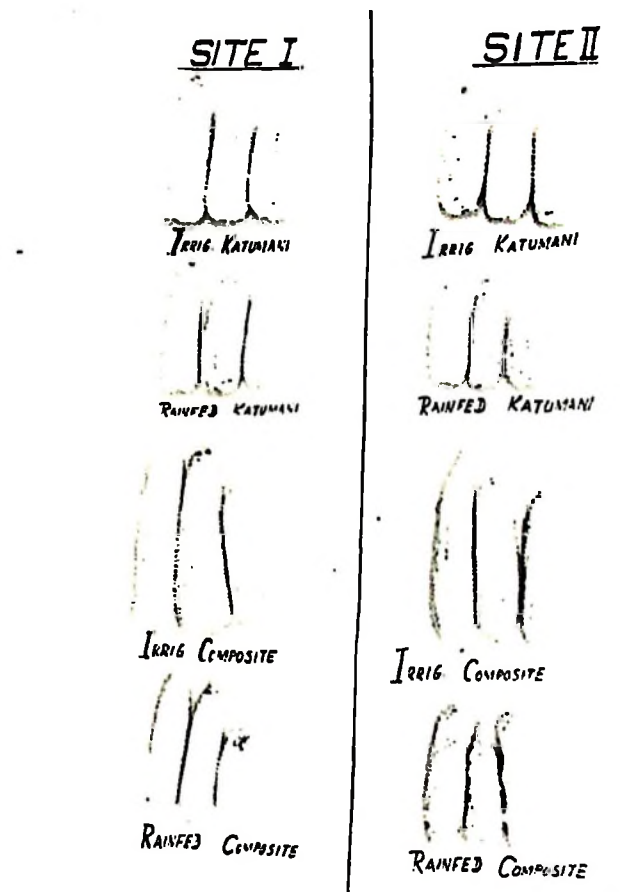


Plate 1: Size of cob as affected
by soil water holding
capacity, cultivars, and
water regimes

Note: Site 1 = Soil 1 (High WHC);
Site II = Soil 2 (Low WHC)

treatments for Ilonga Composite were shrivelled giving a rough outline. A similar tendency toward lower kernel weight in stressed plants has been reported by other researchers (Claassen and Shaw, 1970; Harder et al., 1982). However, in the present study the reduction in kernel weight due to moisture stress was relatively greater than reported by other workers mentioned above. The explanation seems to lie in the degree of stress to which the crop was subjected. Furthermore, the cultivars used in this study especially Ilonga Composite appear to be very sensitive to water stress. Despite the observed high sensitivity of Ilonga Composite to water stress, its kernels (shrivelled kernels) weighed more than those of Katumani even under rainfed conditions. From these results it is obvious that Katumani has smaller kernel size which is an inherent character of the cultivar.

4.3.10 Grain yield

Grain yield (Table 4.17 and Appendix 11) followed a similar trend as did the number of kernels set per cob (Table 4.15 and Appendix 9) except for the type of soil. Independently soil WHC, had a significant ($P = 0.05$) effect on grain yield. The interaction between cultivars x water regimes (M x W) was also significant at the same level.

Averaged over cultivars and water regimes, soil 1 (high WHC) produced 18% more grain weight compared with soil 2 (low WHC). Yield figures were 1322.1 and 1120.4 kg/ha for soil 1 and soil 2 respectively. Likewise, grain yield levels for all treatments in soil 1 were higher but not significantly ($P = 0.05$) different from

Table 4.16. Effects of soil water holding capacity, cultivars, and water regimes on a thousand kernel weight (in g)

Soil type(s)	Maize cultivars (C)	Water regimes (W)		Main effect means
		Rainfed	Irrigated	
S x N x W means				
<u>Maize cultivars</u> ^a				
Soil 1				
(High WHC):	Katumani	202.7	310.0	Katumani
	Ilonga Composite	269.7	358.3	256
				Ilonga Composite
Soil 2				
(Low WHC):	Katumani	207.0	304.3	
	Ilonga Composite	257.3	369.3	Rainfed
				Irrigated
				234.2
				335.5

^aLSD, 5% (cultivars): 21.36

^bLSD, 5% (water regimes): 9.35

from grain yield for corresponding treatments in soil 2. Higher grain yields of maize from soils with high than in soils with low WNC have also been reported by Wahab et al., (1976).

Averaged over soils and water regimes, grain yield was 1410.9 and 1031.5 kg/ha for Ilonga Composite and Katumani, respectively. This 37% superiority in grain yield by Ilonga Composite over Katumani is attributed to larger cobs, higher number of kernels set per cob, and heavier grains produced by the former cultivar as opposed to the latter.

Grain yield, when averaged over soils and cultivars, was observed to be 1527.1 and 915.5 kg/ha under irrigated and rainfed conditions, respectively. Thus, irrigation increased grain yield by 67% with respect to the yield obtained under rainfed conditions. This is in line with established findings that the yield potential in maize is closely related to water availability (Waldren, 1983). Some workers (Stewart et al., 1975; Garrity et al., 1983) have established a linear relationship between water loss through seasonal ETo and DM or grain yield production.

A closer look at cultivars x water regimes (interaction) effect on grain yield data shows that irrigation increased the grain yield from 995 to 1068 kg/ha for Katumani, a non-significant ($P = 0.05$) 7% increase. On the other hand, irrigation increased grain yield of Ilonga Composite by 138%, a significant ($P = 0.05$) increase from 836 to 1986.2 kg/ha. The low grain yield for both cultivars under rainfed and hence water stress conditions can be explained by the high number of barren plants, smaller cobs, smaller and

Table 4.17. Effects of soil water holding capacity, cultivars and water regimes on

Grain yield of maize (in kg/ha)

Soil type(s)	Maize cultivars (M)	Water regimes (W)		Main effect means	
		Rainfed	Irrigation		
S x M x W means					
<u>Soil type means^a</u>					
Soil 1					
(High WHC):					
	Katumant	1040.7	1139	Soil 1	Soil 2
	Ilonga Composite	911.7	2196.7	1322.1	1120.4
<u>Maize cultivars means^b</u>					
Soil 2					
(Low WHC):					
	Katumant	949.3	997	<u>Maize cultivars means^b</u>	
	Ilonga Composite	759.2	1775.7	Katumant	Ilonga Composite
	Maize cultivars x water regimes means ^d			1031.5	1410.9
	Katumant	995	1068	<u>Water regimes means^c</u>	
	Ilonga Composite	836	1986.2	Rainfed	Irrigated
				915.5	1527.1

^aLSD, 5% (soils): 129.7

^bLSD, 5% (cultivars): 48.6

^cLSD, 5% (water regimes): 126.4

^dLSD, 5% (1)

(1) Between water regime means for the same cultivar: 181.6
 (11) Between cultivars for same or different water regime: 137.2

lighter kernels and low number of kernels set/cob as is evident from the data and discussion on these parameters given earlier. Moisture stress is known to affect all these parameters (Robins and Domingo, 1953; Denmead and Shaw, 1960; Claassen and Shaw, 1970a and b; Stewart et al., 1975; McPherson and Boyer, 1977; Shaw, 1977; Shaw et al., 1980; Hall et al., 1981; Harder et al., 1982; Bennett and Hammond, 1983). For example, a period of water stress for 6 to 8 days during tasseling or pollination has been observed to lead to reduction in grain yield by up to 50% (Claassen and Shaw, 1970b). Higher rates of reduction in grain yield of 6 to 7% per day of stress around the tasseling-silking stage have also been reported (Shaw, 1977). The results from the current study tally with the findings quoted above. In the current investigation, rainfed (water stressed) plants of Ilonga Composite experienced a 16 - day dry spell starting from day 3 after tasseling was first observed culminating in drastic grain yield reduction.

Between cultivars, under rainfed conditions, Katumani produced significantly ($P = 0.05$) more grain (995 kg/ha) than Ilonga Composite (836 kg/ha). The explanation of the superiority of Katumani over Ilonga Composite seems to lie in the high percentage of barren plants and the fewer number of kernels set/cob which were associated with Ilonga Composite under rainfed conditions. Following irrigation, the trend was reversed. Despite the fact that there were some barren plants in irrigated plots, Ilonga Composite gave a significantly ($P = 0.05$) higher grain yield (1986.2 kg/ha) than Katumani (1068 kg/ha) which had no barren plants. The general

reduction in the number of barren plants following irrigation, the increase in the size of cobs, the significant ($P = 0.05$) increase in the number of kernels set/cob and the increase in kernel weight relative to Katumani, made Ilonga Composite produce more weight of grain/ha under irrigated conditions.

4.4 Water Inputs and Water Use Efficiencies

4.4.1 Water inputs

By 54 DFP, when the plants were sampled for DM measurement, all treatments had received 197.9 mm of rainfall. During the same period, all irrigated plots had also received 40 mm of irrigation water.

The maize crop was considered physiologically mature at 2 weeks before harvesting. Accordingly, by the time of attainment of physiological maturity the rainfall received amounted to 213.8 mm for Katumani and 288.4 mm for Ilonga Composite. Because Ilonga Composite took a longer period to mature, it received more rain as well as irrigation water.

The amount of irrigation water also varied with the water holding capacity (WHC) of the soil (Table 4.1). In soil 1 (high WHC) the amount of irrigation water was 40 and 50 mm while in soil 2 (low WHC) it was 50 and 80 mm for Katumani and Ilonga Composite respectively. Soil 2, due to its low WHC necessitated relatively more frequent irrigation and hence more volume of irrigation water. The extra water supplied to soil 2 is considered to have been lost either through drainage beyond the root zone or through evaporation.

Table 4.18. Effects of soil water holding capacity, cultivars, and water regimes on water use and

total water use efficiency (TWUE) of maize

Treatments	Dry Matter and Water Use				Grain and Water Use					
	Yield (kg ha)	Water use (cm)	No. of irriga- tion	TWUE kg/ha cm	Change % In TWUE due to irri- gation	Yield (kg ha)	Water use (cm)	No. of irriga- tion	Change % In TWUE due to irri- gation	
Soil 1 (High WHC):										
Rainfed Katumani	943.0	19.79	0	47.65	NA	1040.7	21.38	0	48.68	NA
Irrigation Katumani	1452.7	23.79	4	61.06	+ 28.14	1139.0	25.38	4	44.83	- 7.81
Rainfed Ilonga	1715.3	19.79	0	86.68	NA	911.7	28.84	0	31.61	NA
Irrigation Ilonga	3373.7	23.79	4	141.81	+ 63.60	2196.7	33.84	5	64.91	+ 105.35
Soil 2 (High WHC):										
Rainfed Katumani	955.7	19.79	0	48.29	NA	949.3	21.38	0	44.40	NA
Irrigation Katumani	1313.6	23.79	4	55.16	+ 14.23	997.0	26.38	5	37.79	- 14.89
Rainfed Ilonga	1525.0	19.79	0	77.06	NA	759.2	28.84	0	26.32	NA
Irrigation Ilonga	2861.0	23.79	4	120.26	+ 56.06	1775.7	36.84	8	48.20	+ 83.13

NA - Not applicable as no irrigation was done

4.4.2 Total water use efficiency (TWUE)

4.4.2.1 Total water use efficiency for DM yield (54 DFP)

In both soils, irrigation led to an increase in TWUE for both cultivars (Table 4.18). Water use efficiency was observed to be 47.7 and 61.1 kg/ha - cm for Katumani under rainfed and irrigated conditions respectively in soil 1 (high WHC). Whereas, the values for Ilonga Composite for the same soil were 86.7 and 141.8 kg/ha - cm. In soil 2 (low WHC) TWUE values were 48.3 and 55.2 kg/ha - cm for Katumani and 77.1 and 120.3 kg/ha - cm for Ilonga Composite under rainfed and irrigated conditions respectively. Despite the fact that the same amount of water was used to raise the crop up to this stage (54 DFP) in both soils and in all treatments, TWUE was higher in soil 1 than in soil 2 (Table 4.19). It is possible that soil 1 benefited from its high WHC to store more rain and/or irrigation water which became available to growing plants during the period before subsequent rains or irrigations (Sanchez, 1976) encouraging greater vegetative growth. It is also possible that soil 1 had stored more pre-growing season water than soil 2 which encouraged more vegetative growth in soil 1 than in soil 2.

The TWUEs for DM yield following irrigation were higher by 26.1 and 14.2% for Katumani and 63.6 and 56.1% for Ilonga Composite in soil 1 and soil 2 respectively. The higher TWUEs and response to irrigation shown by Ilonga Composite as compared to Katumani demonstrate the ability of the former to produce more DM per unit of applied water than the latter. Conversely, it is implied that water stress will lead to a drastic reduction in DM yield for

Table 4.19. Effects of soil water holding capacity, cultivars, and water regimes on TWUE of maize

Parameter	Main effect means					
	<u>Soil WHC</u>		<u>Cultivars</u>	<u>Water regimes</u>		
	<u>Soil 1</u>	<u>Soil 2</u>		<u>Rainfed</u>	<u>Irrigated</u>	
Dry-matter yield (kg/ha - cm)	84.30	75.19	53.04	106.45	64.92	94.57
Grain yield (kg/ha - cm)	47.52	39.18	43.94	42.76	37.75	48.95

Ilonga Composite than for Katumani. This reasoning is well supported by the data for DM yield (Tables 4.12 and 4.13).

4.4.2.2 Total water use efficiency for grain yield

With regard to grain yield, TWUE was higher under rainfed than under irrigated conditions for Katumani and vice versa for Ilonga Composite (Table 4.18). Respective TWUE values were 48.68 and 44.88 kg/ha - cm for Katumani in soil 1 (high WHC) under rainfed and irrigated conditions respectively. For Ilonga Composite, values in soil 1 were 31.61 and 64.91 kg/ha - cm respectively under rainfed and irrigated conditions. A similar trend was observed in soil 2 (low WHC) but with TWUE values relatively lower than those in soil 1. For Katumani, the values of TWUE were 44.40 and 37.79 kg/ha - cm and for Ilonga Composite 26.32 and 48.20 kg/ha - cm under rainfed and irrigated conditions respectively. Thus, Katumani made a better use of water under rainfed conditions than Ilonga Composite for grain production. It is implied from the lower TWUE for Katumani under irrigated conditions that the soil moisture reserve resulting from rainfall was nearly able to meet the crop water requirement for this cultivar. It is evident from the data generated from this experiment that Katumani is more drought tolerant than Ilonga Composite. On the other hand, Ilonga Composite showed lowest TWUE values in rainfed treatments demonstrating the sensitivity of this cultivar to water stress compared to Katumani.

At the same level of applied water the TWUE values were higher in case of soil 1 than in soil 2. Even when applied water

was lower compared to that in soil 2, this trend of higher TWUE in soil 1 was maintained. It can be considered that most water was lost through drainage in soil 2 (low WHC). Consequently, less water than that recorded (rain and irrigation) was used by the growing plants culminating in low TWUE values.

Taking averages over soils and cultivars, TWUE values both for DM and grain yield were higher under irrigated than under rainfed conditions (Table 4.19). With regard to cultivars, Ilonga Composite had higher TWUE values for DM yield but lower values for grain yield than Katumani on the average.

4.4.3 Irrigation water use efficiency (IWUE)

4.4.3.1 Irrigation water use efficiency for DM yield

Irrigation water use efficiency values for DM yield at 54 DFP were 127.4 and 414.6 kg/ha - cm respectively for Katumani and Ilonga Composite in soil 1 (high WHC). In soil 2 (low WHC), IWUE values were 89.48 and 334 kg/ha - cm for Katumani and Ilonga Composite respectively (Table 4.20). From these results, two findings are evident. First, at the same level (40 mm) of applied water (Table 4.18) IWUE values were higher in soil 1 than in soil 2. Soils with high WHC are reported to store and avail more water to growing plants long after rains or irrigation have ceased (Sanchez, 1976) than soils with low WHC. Second, Ilonga Composite had higher IWUE values for DM yield than those for Katumani. Thus, Ilonga Composite responded more favourably to irrigation than did Katumani.

It is implied from these data that Ilonga Composite is more sensitive to water stress than Katumani.

When IWUE values for DM yield in rainfed treatments (Table 4.18) are compared with IWUE (DM) values (Table 4.20), it becomes evident from the higher IWUE values that one unit of irrigation water was more efficient, in the production of DM than the same amount of rain water. The observed difference could be explained by the timing of application of water. Rainfall was random giving successive days of heavy rains (Figure 4.1c) which might have saturated the root zone beyond its storage capacity with consequential loss of water. At other times, continuous dry spells (Figure 4.1d) affected crop growth. On the other hand, irrigation water was applied only when absolutely necessary and in amounts which could not lead to wastage.

4.4.3.2 Irrigation water use efficiency for grain yield

Although lower in magnitude, IWUE values for grain yield followed the same trend as that for DM yield (Table 4.20). Irrigation water use efficiency values for Katumani and Ilonga Composite were respectively 24.58 and 257 kg/ha - cm in soil 1 (high WHC). In soil 2 (low WHC), IWUE values were 9.54 and 127.06 kg/ha - cm respectively for Katumani and Ilonga Composite. Explanations given earlier for IWUE (DM yield) are also valid for IWUE (grain yield). Higher IWUE values in soil 1 than those in soil 2 are a product of a greater storage of irrigation water and consequently its greater supply to plants in soil 1 as opposed to soil 2. The superiority of Ilonga Composite to Katumani with respect to IWUE for grain yield is explained by the higher yield potential of Ilonga

Table 4.20. Effects of soil water holding capacity and cultivars on irrigation water use efficiency (IWUE) of maize

Treatments	<u>Irrigation water use efficiency</u>	
	For dry-matter yield	For grain yield
	----- kg/ha - cm -----	
Soil 1 (High WHC):		
Katumani	123.43	24.58
Ilonga Composite	414.6	257.0
Soil 2 (Low WHC):		
Katumani	89.48	9.54
Ilonga Composite	334.0	127.06

Composite as is evident from cultivar x water regime interactions in which irrigation lead to a significant ($P = 0.05$) increase in grain yield for this cultivar but lead to a non-significant increase for Katumani (Table 4.17).

With respect to grain yield, a comparison between values for IWUE (Table 4.20) and TWUE (Table 4.18) shows $IWUE > TWUE$ for Ilonga Composite, and $IWUE < TWUE$ for Katumani. Thus, for Ilonga Composite, one unit of irrigation water resulted in more grain yield than the same amount of rain water and vice versa for Katumani. It is implied by this trend that soil moisture resulting from rainfall was nearly able to meet the crop water requirements for Katumani but not for Ilonga Composite. In fact, following irrigation, TWUE declined for Katumani but increased for Ilonga Composite.

5. SUMMARY AND CONCLUSIONS

Analysis was made of reference crop evapotranspiration (ET_o) and rainfall (R) data on a 10-day basis over a 10-year period (1973/74 - 1982/83) to establish an average trend of these parameters during short rains. On the average, ET_o exceeded R the entire short rain season.

A field study was undertaken to investigate the effects of soil WHC, cultivars, and water regimes on plant-water status, growth, grain yield and yield components of maize (Zea mays L). The results are summarized as follows:

- (i) Soil 1 (high WHC) had higher values of weighted matric potential (ψ_m) than soil 2 (low WHC). At tasseling stage, plots planted with cultivar Katumani had lower ψ_m values than those with Ilonga Composite. In all plots, ψ_m increased with the approach of physiological maturity of crop especially in irrigated plots.
- (ii) Averaged over the entire period of measurements, plants in soil 1 had higher leaf water potential (ψ_l) values (- 15.16 bars) than those in soil 2 which had a mean value of - 17.38 bars. Similarly, Katumani had higher ψ_l (- 13.48 bars) than Ilonga Composite (- 16.35 bars). Under rainfed conditions, ψ_l values were, on the average, lower by 4 bars compared with those for plants under irrigation.
- (iii) Plant height and stem diameter were significantly affected by cultivars. Plants of Ilonga Composite were taller by 16.4% and had stems 25.4% thicker

than those of Katumani. Plants of both cultivars were also consistently but non significantly taller in soil 1 and irrigation than in soil 2 and under rainfed conditions respectively.

- (iv) Ilonga Composite had 11.0 leaves, a number significantly greater than 9.4 for Katumani. Katumani produced significantly fewer leaves under rainfed than under irrigated conditions as well as than that produced by Ilonga Composite under either of the water regimes.
- (v) On the average, leaves were larger by 5.5% in soil 1 than in soil 2. Also, leaves of Ilonga Composite were 55.9% larger than those of Katumani. Similarly, leaves were consistently larger under irrigation as compared to rainfed conditions.
- (vi) Ilonga Composite had leaf area indices (LAI) which were significantly higher (by 79%) than those of Katumani. Cultivars had a significant effect on LAI which was increased significantly by irrigation. Averaged over all the factors, LAI was 0.82 for Katumani and 1.47 for Ilonga Composite. Irrigation lead to 17 and 38.9% increases in LAI over the rainfed plants at 54 and 74 DFP respectively. However, LAI had declined by 29% at 74 days as compared to that at 54 DFP.

- (vii) Average root length density (RLD) in 0 - 90 cm depth was 0.605 cm/cm^3 in soil 1, 42% higher than that in soil 2 which showed a value of 0.426 cm/cm^3 . Averaged over soils and water regimes, Ilonga Composite had RLD of 0.539 cm/cm^3 , 10% higher than 0.490 cm/cm^3 for Katumani.
- (viii) Mean dry-matter (DM) yield at 54 and 74 DFP was respectively 1166.3 and 2001 kg/ha for Katumani; 2369 and 4465 kg/ha for Ilonga Composite. In both cases, the difference in DM yield between the two cultivars was significant. Thus, Ilonga Composite outyielded Katumani in DM production by a factor of almost two (2). Compared with the DM yield obtained under rainfed conditions, irrigation significantly increased DM yield by 75 and 28% at 54 and 74 DFP respectively. Cultivars and water regimes interacted significantly only at 54 DFP with irrigation increasing DM yield significantly for both cultivars. Ilonga Composite outyielded Katumani by 70 and 125% under rainfed and irrigated conditions respectively. However, the yield level for Katumani under irrigation was not significantly different from that of Ilonga Composite under rainfed conditions.

- (ix) All treatments involving cultivar Ilonga Composite had barren plants. However, there were fewer barren plants under irrigated (3 to 11%) than under rainfed conditions (26 to 35%). The highest percentage (35%) of barren plants was in soil 2 and under rainfed conditions.
- (x) Over all, Ilonga Composite set 294.5 and Katumani 232.2 kernels/cobs, the difference being significant. Taking averages over soils and cultivars, irrigation caused a significant increase in the number of kernels set/cob. There were 211.2 and 315.5 kernels set/cob under rainfed and irrigated conditions respectively. As a result of irrigation, the number of kernels set/cob increased from 224.5 to 239.8 for Katumani while that for Ilonga Composite increased from 197.8 to 391.2. However, the increase was not significant for Katumani. Despite the lack of statistical significance, treatments in soil 1 had more kernels set/cob than corresponding treatments in soil 2.
- (xi) Cultivars and water regimes had significant effect on thousand kernel weight. Thousand kernels of Ilonga Composite weighed 313.7 g, 23% heavier than those of Katumani which

weighed 256 g. Irrigation lead to a 43% increase in weight of 1000 kernels. On the average, thousand kernels weighed 234.2 and 335.5 g under rainfed and irrigated conditions respectively.

- (xii) Independently, all factors had significant effect on grain yield. Maize cultivars x water regimes also interacted significantly. Yield figures were 1322.1 and 1120.4 kg for soil 1 and soil 2 respectively. Averaged over soils and water regimes, grain yield was 1410.9 and 1031.5 kg/ha for Ilonga Composite and Katumani respectively. Averaged over soils and cultivars, grain yield was 915.5 and 1527.1 kg/ha under rainfed and irrigated conditions respectively. Irrigation gave a non-significant grain yield increase from 995 to 1068 kg/ha for Katumani and a significant increase from 836 to 1986.2 kg/ha for Ilonga Composite. Under rainfed conditions, Katumani produced significantly more grain/ha than Ilonga Composite, the opposite was true under irrigation. Grain yield figures for all treatments in soil 1 were higher but not significantly different from yield levels for corresponding treatments in soil 2.

- (xiii) The amount of supplementary irrigation water applied until the crop reached physiological maturity was 40 and 50 mm in soil 1 while it was 50 and 80 mm in soil 2 for Katumani and Ilonga Composite respectively.
- (xiv) Soil 1 had higher values of total water use efficiency (TWUE) for both DM and grain yield than soil 2. Total water use efficiency for DM yield was higher for Ilonga Composite than for Katumani in all water regimes. With regard to grain yield, TWUE was higher under rainfed than under irrigated conditions for Katumani and vice versa for Ilonga Composite.
- (xv) Irrigation water use efficiencies (IWUE) both for DM and grain yield were higher in soil 1 than in soil 2. Also, Ilonga Composite showed higher IWUE values for both DM production as well as grain yield than Katumani.

In view of the results obtained in this study, the following conclusions were made:

- (i) Comparison of the two maize cultivars grown showed Katumani to produce more grain weight per hectare than Ilonga Composite under rainfed conditions and vice versa under

irrigation.

- (ii) During short rains, only cultivar Katumani be grown and preferably in soils with high WEC.
- (iii) Cultivar Ilonga Composite be preferred to Katumani when facilities for supplementary irrigation are available.
- (iv) Katumani is drought tolerant/escapes drought whereas Ilonga Composite is severely affected by drought.
- (v) Less supplementary irrigation water is required to produce an economic grain yield for Katumani than for Ilonga Composite.

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Appendix Ia. Effects of soil water holding capacity, cultivars, and water regimes on weighted soil

matrix potential (in bars)

TREATMENTS:	DAYS FROM PLANTING																			
	31	32	34	35	38	39	46	47	48	49	54	55	56	57	66	67	68	69	73	
Soil 1 (high WHC)																				
Rainfed Katumani	0.16	0.29	0.23	.23	.28	.18	.10	.26	.14	.15	.0	.0	.0	.0	.19	.12	.13	.12	.25	
Rainfed Ilonga Composite	0.11	0.23	0.13	.21	.17	.16	.13	.10	.10	.11	.0	.0	.0	.01	.06	.10	.13	.13	.34	
Irrigated Katumani	0.09	0.12	0.08	.09	.11	.09	.07	.14	.09	.04	.0	.0	.0	.0	.03	.09	.07	.09	.09	
Irrigated Ilonga Composite	0.05	0.09	0.05	.11	.13	.10	.10	.14	.08	.05	.0	.0	.0	.0	.03	.04	.03	.12	.19	
Soil 2 (Low WHC)																				
Rainfed Katumani	0.28	0.31	0.23	.30	.36	.35	.20	.37	.14	.14	.0	.0	.0	.07	.20	.20	.19	.36	.50	
Rainfed Ilonga Composite	0.27	0.39	0.21	.34	.32	.17	.11	.35	.13	.21	.0	.0	.0	.04	.31	.21	.33	.17	.56	
Irrigated Katumani	0.11	0.11	0.14	.16	.11	.21	.12	.21	.12	.13	.0	.0	.0	.0	.06	.07	.05	.17	.20	
Irrigated Ilonga Composite	0.11	0.22	0.17	.25	.19	.09	.15	.27	.20	.12	.0	.0	.0	.0	.14	.12	.15	.15	.36	

Appendix 1b. Effects of soil water holding capacity, cultivars, and water regimes on weighted soil
matrix potential (in bars)

TREATMENTS:	DAYS FROM PLANTING																		
	74	77	78	80	82	83	84	85	87	88	89	90	91	92	94	95	96	97	98
Soil 1 (high WHC)																			
Rainfed Katumani	.28	.47	.48	.40	.46	.33	.20	.23											
Rainfed Ilonga Composite	.29	.38	.50	.52	.52	.31	.35	.41	.12	.19	.10	.21	.17	.16	.26	.26	.24	.25	.30
Irrigated Katumani	.08	.08	.10	.18	.19	.13	.10	.03											
Irrigated Ilonga Composite	.22	.36	.30	.27	.50	.07	.04	.09	.05	.20	.03	.09	.12	.03	.20	.24	.24	.20	.26
Soil 2 (Low WHC)																			
Rainfed Katumani	.37	.55	.63	.57	.65	.34	.32	.26											
Rainfed Ilonga Composite	.55	.64	.66	.44	.55	.33	.29	.34	.28	.26	.25	.25	.20	.22	.41	.45	.50	.41	.65
Irrigated Katumani	.24	.25	.63	.54	.46	.27	.20	.25											
Irrigated Ilonga Composite	.31	.36	.16	.56	.40	.08	.05	.21	.27	.24	.07	.13	.15	.16	.26	.37	.39	.33	.37

Appendix 2. Summary of ANOVA for plant height as affected by soil
water holding capacity, cultivars and water regimes

Source of Variation	SS	df	MS ^a	Observed Required F		
				F	5%	1%
Sub-subplots	2573.5333	23				
Subplots	1666.5633	11				
Main plots	776.3483	5				
Blocks, B	378.7233	2	189.36165			
Soil types, S	163.28163	1	163.28163	1.39352	18.51	98.50
Main plot Error, BS	234.34337	2	117.171685			
Maize cultivar, M	759.37496	1	759.37496	33.64532**	7.71	21.20
S x M	40.56004	1	40.56004	1.79708	7.71	21.20
Subplot error, BM + B (S x M)	90.28	4	22.57			
Moisture regimes, W	224.48163	1	224.48163	2.724959	5.31	11.26
S x W	3.2267	1	3.2267	0.039169	5.31	11.26
M x W	0.42671	1	0.42671	0.24037	5.31	11.26
S x M x W	19.80163	1	19.80163	4.4972	5.31	11.26
Sub-subplot error, BW + B (S x W) + B (M x W) + B (S x M x W)	659.03837	8	82.379796			

^aBrackets indicate formation of F - ratios

Appendix 3. Summary of ANOVA for stem diameter as affected by soil water holding capacity, cultivars and water regimes

Source of Variation	SS	df	MS	Observed Required F		
				F	5%	1%
Sub-subplot	2.4097	23				
Subplot	1.7726	11				
Main plots	0.4179	5				
Blocks, B	0.0631	2	0.03155			
Soil types, S	0.05996	1	0.05996	← 0.40672	18.51	98.50
Main plot Error, BS	0.29484	2	0.14742	←		
Maize cultivar, M	1.2973	1	1.2973	← 162.1625	7.71	21.20
S x M	0.0254	1	0.0254	← 3.175	7.71	21.20
Subplot error, BM + B (S x M)	0.032	4	0.008	←		
Moisture regimes, W	0.0240	1	0.0240	← 0.457005	5.32	11.26
S x W	0.11214	1	0.11214	← 2.135357	5.32	11.26
M x W	0.0229	1	0.0229	← 0.436059	5.32	11.26
S x M x W	0.057933	1	0.057933	← 1.10315	5.32	11.26
Sub-subplot error,	0.4201266	8	0.0525158	←		
BW + B (S x W) + B (M x W)						
+ B (S x M x W)						

Appendix 4. Summary of ANOVA for the number of leaves per plant as affected by soil water holding capacity, cultivars and water regimes (54 days from planting)

Source of Variation	SS	df MS ^a		Observed Required F		
				F	5%	1%
Sub-subplots	44.5	23				
Subplots	31.06	11				
Main plots	7.28	5				
Blocks, B	5.43	2	2.715			
Soil types, S	0.3267	1	0.3267	←	0.4289	18.51 98.50
Main plot error, BS	1.5233	2	0.7617	—		
Maize cultivar, M	16.0067	1	16.0067	←	*8.2437	7.71 21.20
S x M	0.0066	1	0.0066	←	0.0034	7.71 21.20
Subplot error, BM + B (S x M)	7.7667	4	1.9417	—		
Moisture regimes, W	0.3267	1	0.3267	←	0.7260	5.32 11.26
S x W	6.4066	1	6.4066	←	14.2369	5.32 11.26
M x W	2.9399	1	2.9399	←	6.53311	5.32 11.27
S x M x W	0.1668	1	0.1668	←	0.37066	5.32 11.26
Sub-subplot error,	3.600	8	0.45	—		
BW + B (S x W) + B (M x W)						
+ B (S x M x W)						

^a Brackets indicate formation of F - ratios

Appendix 5. Summary of ANOVA for leaf area index as affected by soil
water holding capacity, cultivars, and water regimes
(54 days from planting)

Source of Variation	SS	df	MS ^a	Observed Required F		
				F	5%	1%
Sub-subplot	3.6783	23				
Subplot	3.1983	11				
Main plot	0.3183	5				
Blocks, B	0.2058	2	0.1029			
Soil types, S	0.0016	1	0.0016	←	0.028	18.51 98.50
Main plot error, BS	0.1109	2	0.05545	←		
Maize cultivar, M	2.53496	1	2.53496	←	** 30.7298	7.71 21.20
S x M	0.01507	1	0.01507	←	0.1827	7.71 21.20
Subplot error, BM + B (S x M)	0.32997	4	0.08249	←		
Moisture regimes, W	0.20163	1	0.20163	←	* 7.8075	5.32 11.26
S x W	0.0417366	1	0.041736	←	1.6161	5.32 11.26
M x W	0.01504	1	0.01504	←	0.5824	5.32 11.26
S x M x W	0.01493	1	0.01493	←	0.5781	5.32 11.26
Sub-subplot error,	0.2066	8	0.025825	←		
BW + B (S x W) + B (M x W) + B (S x M x W)						

^a Brackets indicate formation of F - ratios

Appendix 6. Effects of soil water holding capacity, cultivars, and water regimes on root length density of maize

<u>Soil type</u>	<u>Depth</u> --cm--	<u>Kainfed</u>		<u>Irrigated</u>	
		<u>Ilonga Composite</u>	<u>Katumani</u>	<u>Ilonga Composite</u>	<u>Katumani</u>
		cm/cm ³			
High WHC (Soil 1)	0 - 15	1.180	1.715	1.511	2.224
	15 - 30	1.844	0.635	2.122	0.603
	30 - 45	0.452	0.133	0.429	0.118
	45 - 60	0.161	0.165	0.118	0.063
	60 - 75	0.236	0.225	0.332	0.102
	75 - 90	0.032	0.051	0.005	0.065
Low WHC (Soil 2)	0 - 15	1.080	1.844	1.590	2.049
	15 - 30	0.599	0.540	0.800	0.298
	30 - 45	0.118	0.187	0.090	0.212
	45 - 60	0.024	0.031	0.066	0.204
	60 - 75	0.046	0.126	0.035	0.078
	75 - 90	0.042	0.067	0.035	0.058

Appendix 7. Summary of ANOVA for dry-matter yield as affected by soil water holding capacity, cultivars, and water regimes (54 days from planting)

Source of Variation	SS	df	MS ^a	Observed Required F		
				F	5%	1%
Sub-subplots	20,933,938	23				
Subplots	12,993,105	11				
Main plots	3,524,558	5				
Blocks, B	3,161,394.25	2	1,580,697.125			
Soil types, S	257,922.66	1	257,922.66	4.901558	18.51	98.50
Main plot error, BS	105,241.09	2	52,620.545			
Maize cultivar, M,	8,676,037.5	1	8,676,037.5	51.967464	7.71	21.20
S x M	124,704.173	1	124,704.173	0.746949	7.71	21.20
Subplot error, DM + B (S x M)	667,805.327	4	166,951.332			
Moisture regimes, W	5,593,141.5	1	5,593,141.5	80.4047	5.32	11.26
S x W	84,253.506	1	84,253.506	1.2	5.32	11.26
M x W	1,696,016.666	1	1,696,016.666	24.3813	5.32	11.26
S x M x W	10,922.655	1	10,922.655	0.15702	5.32	11.26
Sub-subplot error,	556,498.673	8	69,562.334			
BW + B (S x W) +						
B (M x W) + B						
(S x M x W)						

^a Brackets indicate formation of F - ratios

Appendix 8. Summary of ANOVA for dry-matter yield as affected by soil water holding capacity, cultivars, and water regimes (74 days from planting)

Source of Variation	SS	df	MS	Observed Required F		
				F	5%	1%
Sub-subplots	42,590,621.34	23				
Subplots	38,029,232.34	11				
Main plots	1,447,728.34	5				
Blocks, B	774,125.09	2	387,062.545			
Soil types, S	410,816.67	1	410,816.67	← 3.1266	13.51	98.50
Main plot error, BS	262,786.58	2	131,393.29	←		
Maize cultivar, M	36,427,776	1	36,427,776	← ** 1900.7119	7.71	21.20
S x M	77,066.67	1	77,066.67	← 4.02115	7.71	21.20
Subplot error, B _i + B (S x M)	76,661.33	4	19,165.3325	←		
Moisture regimes, W	3,747,760.67	1	3,747,760.67	← ** 44.9487	5.31	11.26
S x W	93,750	1	93,750	← 1.1244	5.31	11.26
M x W	8,816.67	1	8,816.67	← 0.1057	5.31	11.26
S x M x W	44,032.66		44,032.66	← 0.5281	5.31	11.26
Sub-subplot error,	667,029	8	83,378.625	←		
BW + B (S x W) + B						
(M x W) + B (S x M						
x W)						

Appendix 9. Summary of ANOVA for the number of kernels set per cob
as affected by soil water holding capacity, cultivars,
and water regimes

Source of Variation	SS	df	MS ^a	Observed Required F		
				F	5%	1%
Sub-subplots	155499.3334	23				
Subplots	37627.3334	11				
Main plots	11236.8334	5				
Blocks, B	364.5834	2				
Soil types, S	8970.6667	1	8970.6667	←	9.4349	18.51 98.50
Main plot error, BS	1901.5833	2	950.7917			
Maize cultivar, M	23312.6667	1	23312.6667	←	** 30.4625	7.71 21.20
S x M	16.6666	1	16.6666		0.0218	
Subplot error, BM + B (S x M)	3061.1667	4	765.2917			
Water regimes, W	65312.6667	1	65312.6667	←	** 145.5165	5.32 11.26
S x W	1176	1	1176		2.6201	
M x W	47526	1	47526	←	** 105.8879	
S x M x W	266.6667	1	266.6667		0.5941	
Subplot error, EW + B (S x W) + B (M x W) + (S x M x W)	3590.6666	8	448.8333			

^a Brackets indicate formation of F - ratios

Appendix 10. Summary of ANOVA for a thousand kernel weight as affected by soil water holding capacity, cultivars, and water regimes

Source of Variation	SS	df	MS ^a	Observed Required F		
				F	5%	1%
Sub-subplots	85091.3334	23				
subplots	22202.334	11				
Main plots	829.3334	5				
Blocks, B	445.0834	2	222.5417			
Soil types, S	2.6667	1	2.6667	←	0.0140	18.51 98.50
Main plot error, BS	381.5833	2	190.79165	←		
Maize cultivar, M	19952.6667	1	19952.6667	←	** 56.1915	7.71 21.20
S x M	0.0	1	0	←		
Subplot error, BM + B (S x M)	1420.3333	4	355.0833	←		
Water regimes, W	61610.6667	1	61610.6667	←	** 624.6962	5.32 11.26
S x W	66.6666	1	66.6666	←	0.6760	5.32 11.26
M x W	6.0000	1	6.0000	←	0.06084	
S x M x W	416.6667	1	416.6667	←	4.2247	
Subplot error	789	8	98.625	←		
BW + B (S x W) + B (M x W) + + B (M x W) + B (S x M x W)						

Appendix 11. Summary of ANOVA for grain yield as affected by soil water holding capacity, cultivars, and water regimes

Source of Variation	SS	df	MS ^a	Observed			Required F		
				F	5%	1%	F	5%	1%
Sub-subplots	5441825.96	23							
Subplots	1246149.459	11							
Main plots	331727.71	5							
Blocks, B	77016.3338	2	38508.1669						
Soil types, S	243815.0417	1	243815.0417	44.75175	18.51	98.50			
Main plot error, BS	10896.3345	2	5448.16725						
Maize cultivar, M	863742.0416	1	863742.0416	465.96418	7.71	21.20			
S x M	43265.0427	1	43265.0427	23.34026	7.71	21.20			
Subplot error, BM + B (S x M)	7414.6647	4	1853.6662						
Moisture regimes, W	2244205.042	1	2244205.042	120.57947	5.32	11.26			
S x W	43448.7093	1	43448.7093	2.33447	5.32	11.26			
M x W	1746076.042	1	1746076.042	93.81537	5.32	11.26			
S x M x W	13052.0407	1	13052.0407	0.70128	5.32	11.26			
Sub-Subplot error, BW +	148894.667	8	18611.83338						
B (S x W) +									
B (M x W) +									
B (S x M x W)									

^a Brackets indicate formation of F ratios

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