Asian Journal of Plant Sciences

ISSN 1682-3974

ANSInet
an open access publisher
http://ansinet.com

Asian Journal of Plant Sciences 4 (3): 284-292, 2005
ISSN 1682-3974

Responses of Some Bread Wheat (*Triticum aestivum* L.) Germplasm to Varying Drought Stress Conditions under Rainshelter

[1]P.K. Kimurto, [2]M.G. Kinyua, [3]J.B.O. Ogolla, [4]J.M. Macharia and [2]P.N. Njau
[1]Department of Agronomy, Egerton University, P.O. Box 536, Njoro, Kenya
[2]National Plant Breeding Research Center, Njoro, P.O. Njoro, Kenya
[3]Department of Plant Production, University of Venda, Private Bag X5050, South Africa
[4]Department of Botany, Egerton University, P.O. Box 536, Njoro, Kenya

Abstract: A better understanding of factors limiting and/or regulating grain yield can provide an opportunity to identify and then select for traits that increase the efficiency of water use and yield under drought stress conditions. The main objective of this study was to assess response of some bread wheat genotypes to varying moisture levels in a tropical environment. In two experiments, twelve bread wheat cultivars were evaluated under the rain shelter in the year 2002 at three simulated moisture regimes (210, 240 and 270 mm). Cultivars differed in their response ($p<0.001$). The differential responses of the cultivars were mainly due to differences in Evapotranspiration Rates (ET), Harvest Index (HI), kernel number and seeds/head ($p\leq 0.001$). Although early seedling vigor and biomass accumulation ensures drought escape, it is affected by early-seedling stage drought because genotypes can't recover later with supply of water. Other traits identified for selection were longer flag leaf and longer growth cycles. The study provides evidence that under moisture stress, adaptive traits contribute significantly to superior performance and during selection, yield potential and adaptive traits need to be combined, because neither alone will provide superior germplasm or explain superior performance. There was sufficient intraspecific variation in these morphological attributes to suggest their use as selection tools.

Key words: Drought stress, wheat, selection criteria, rain shelter, watering regimes

INTRODUCTION

There is evidence that drought is increasingly becoming more serious due to shortages of plant-available water[1]. In developing world, wheat yields are reduced by 50-90% of their irrigated potential by drought stress[2], with yield variability of up to 16% in tropical drylands[3]. In Kenya wheat yield reduction of up to 62% was reported under terminal stress in drought simulated conditions[4], while in many instances it may be up to 100% in farmers conditions. Furthermore progress in genetic gain in yield potential is very slow in rainfed environments[5] and almost nil gain in marginal environment. This is because in most breeding programs, genetic variation in yield is masked by large genotypes x year and/or genotype x location and genotype x year x location interactions[5,6]. A major challenge to breeders and physiologists in these environments is to devise the most effective strategies for maximizing genetic gain and increase production. In Kenya, domestic wheat production currently meets only 50% of the annual national demand of approximately 600,000 tons[7], while the rest is imported at a cost of about US$ 90 million which drains the country of enormous and scarce foreign exchange. Therefore, there is need to increase domestic wheat production by intensifying production in traditional high potential areas and expanding wheat production into marginal areas which is approximately 83% of total land area[4,8]. Complete crop failure, reduced establishment or reduced yield may result if drought occurs at seedling, flowering or grain filling stages in bread wheat[9] and maize[10]. There is therefore, need to develop cultivars that are early-season and/or pre- and post-anthesis drought stress resistant for growing in these areas. Specific targeting of morphological characters that enhance yield particularly in early generations, may be more cost effective. This study was therefore carried out with the objective of assessing responses of some bread wheat genotypes to varying drought stress conditions and also to identify the morphological traits associated with drought tolerance in wheat that may be used by breeders to increase genetic gain and increase production.

Corresponding Author: P.K. Kimurto, Department of Agronomy, Egerton University, P.O. Box 536, Njoro, Kenya
E-mail: pkimurto@yahoo.co.uk

MATERIALS AND METHODS

Site description: The study was carried out under rain shelter at National Plant Breeding Research Centre, Njoro. National Plant Breeding Research Centre (2160 m a.s.l., latitude 0°20'S, longitude 35°56'E) receives average annual rainfall of 931 mm. Mean maximum and minimum temperature are 22.7 and 7.9°C, respectively. The soils are well drained Mollic Andosols with sandy loam[11].

Plant material: Twelve bread wheat genotypes (R963, R965, R962, R960, R966, R970, 94B01, R917, KM20, Chozi, Duma and Heroe) were evaluated under the rain shelter. Seven lines among these were introductions from CIMMYT and other international nurseries with different phenotypic, maturity periods, yield potential and have shown resistance to drought as shown in Table 1.

Design of experiments: The shelter used for drought simulation excludes rainfall is similar to that earlier described[12,13]. It measures 15.5 m long x 7.5 m wide and the roof is covered by translucent sheets, which allow up to 90% of photosynthetic photon flux density to pass through. Drip irrigation was used to water the plots[14]. Randomized Complete Block Design (RCBD) with split-plot arrangement of treatments in three replications was used. Each experimental unit consisted of 4 wheat rows, 1 m long and spaced 20 cm between the rows. Recommended seed and fertilizer rates of 125 and 150 kg ha^{-1} DAP (46-18-0) (supplying 70 kg P_20_5 and 37 kg N), respectively, was applied. Plots were shielded from rainfall by covering with the rain shelter at all rainy times and at night. To ensure good germination and stand establishment before imposing irrigation treatments, the crop received 30 mm of moisture up to field capacity (30-32 % moisture content) at planting as determined by Neutron probe readings. In additional the crop received 60 mm water in two equal general irrigation's, at emergence and 7 Day After Emergence (DAE), respectively. Moisture stress was then created by withholding water supply for a period of 2, 4 and 6 weeks, respectively (up to 21, 35 and 49 DAE, respectively. Total water applied included low (210 mm), medium (240 mm) and high water regimes (270 mm) depending on the treatment. Sowing was done on 15th Sept 2001 (season I) and 5th Jan 2002 (season II). The amount and frequency of water application simulates the amount and natures of rainfall pattern usually received in most marginal areas during cropping season[10,11]. Aphids were controlled by application of Metasystox at the rate of 1 L ha^{-1}. The experiments were manually kept weed-free throughout the growing season.

Measurement of soil moisture: Changes in volumetric moisture content were monitored at approximately 7 to 9-day interval with neutron probe (Troxler Model 4300, New York). At sowing, a single PVC access tube was installed to a depth of 110 cm midway in each plot between the four rows of wheat. The 110 cm depth was considerably below the maximum depth of roots as deduced from inflections in the progress of soil drying[15]. On each occasion, the probe was lowered into the access tubes (3.9 cm internal diameter) and fifteen-second counts in the soil were taken. Soil moisture readings were taken at 0.1 m intervals between 0.1 and 0.4 m depth and 0.2 m intervals between 0.4 and 1 m depth. On each day of measurements, standard count was taken as 240 sec counts in air. Volumetric water content (mm/m) at each depth was calculated using calibration equations developed on the site[16] as shown below:

$$Y= 0.6739x-0.0345 \qquad \text{0-20 cm depth} \qquad (1)$$

$$Y= 0.5894x-0.0295 \qquad \text{30-60 cm depth} \qquad (2)$$

$$Y= 0.4592x+0.0639 \qquad \text{>80 cm depth} \qquad (3)$$

where, Y is soil moisture content (mm) and x is the intercept. Total crop evapo-transpiration (ET) was estimated using water balance equation:

$$ET = -\Delta S + I (+ P) -D-R. \qquad (4)$$

where, Δ is the change in storage (the difference in volumetric water content of the entire profile between the start and the end of the experiment), I is irrigation (plus P, precipitation), D the drainage and R is the runoff. The soil moisture content of the deepest layer (1.0 m) showed little change during the crop-growing season. However, when the volumetric moisture content at 1.0 m increased above that at the beginning of the season, Drainage (D) was assumed to have occurred. Previous studies[15,17] have shown runoff in the area (rain shelter) to be generally negligible. The land surrounding the rain shelter was cropped every year with rainfed wheat. This minimized advection currents.

Measurement of yield and yield components: The following parameters were taken from each plot: Ear length (measured from the base of the spike to the tip of the apical spikelet, exluding the awns) on 10 spikes selected randomly in each experimental unit at maturity, spikelets per head (as individual number of mature florets) was counted on spikes measured for ear length. Seeds per head was counted on 10 spikes selected randomly in each experimental unit at maturity, plant height (cm) at maturity

Table 1: Name, origin, pedigree and drought responses of wheat genotypes used in study

Name of genotype	Origin	Pedigree	Drought tolerance response
Chozi variety	Kenya	F12.71/COC//GEN	Tolerant check
Duma variety	Kenya	SW 53 = BUCK BUCK 'S'	Tolerant check
Kenya Heroe variety	Kenya	MBUNI/SRPC 64//YRPC1	Susceptible check
R917	CIMMYT Mexico	URES/BOW/OPATA	Moderately tolerant
R960	CIMMYT Mexico	PASTOR	Moderately tolerant
R962	CIMMYT Mexico	KLEIN CHAMACO	Moderately tolerant
R963	CIMMYT Mexico	BOW//URES//KEA	Moderately tolerant
R965	CIMMYT Mexico	BOW//BUC/BUL/3/KAUZ	Moderately tolerant
R966	CIMMYT Mexico	FILIN	Moderately tolerant
R970	CIMMYT Mexico	PIPED/5PATIO/ALD//PAT 72300/3PUN/4/BOW/6BAW 898	Moderately tolerant
KM20	Kenya	PASA MUTANT	Moderately tolerant
94B01	Kenya	PUN// BOW/BAW	Susceptible

measured from the soil surface to tip of spike, excluding the awns and number of tillers at maturity as tillers with spikes or heads. 1000-kernel (g) weight was obtained by counting one thousand grains from each plot and weighed. At final harvest, all plants in the four rows were cut at ground level and heads threshed to obtain the seed, then seed weighed from each plot. Final grain yield (kg ha^{-1}) was calculated by converting the grain yield per plot into yield/ha at 13.5% moisture content. Harvest Index (HI) was obtained by dividing grain yield with total aboveground biomass in each plot. Plant tissues were first dried at 70°C for at least 24 h and dry matter content determined. Data was taken from two centre rows, but biomass and final yield were determined from all the four rows. Other parameters measured were; biomass accumulation over time was determined by destructive harvesting of two plants at 14 DAE interval, length of flag leaf (cm) was measured as the length from the base of stem to the tip of the flag leaf at anthesis and heading and maturity dates recorded as the dates when 50% of the heads and vegetative plant parts had completely emerged from the flag leaf and dried through the normal physiological processes, respectively.

Statistical analysis: Analysis of variance was used to evaluate the treatments using general linear model (GLM), SAS package[18]. Statistical differences among treatment means for all variables were evaluated using Fisher's Least Significance Test (LSD) at $p<0.05$.

RESULTS AND DISCUSSION

Crop water use: The main effects of moisture regimes and test germplasm were significant for all traits in the analysis of variance (Table 2). The interaction between water regimes and wheat genotypes affected total crop ET, grain yield and biomass (Table 2). There was no interaction between moisture regimes and other traits measured (Table 2). Soil moisture content was almost similar for all water regimes at the beginning of the planting season for all watering regimes, ranging between 20-78 mm of water at 10 and 60 cm depth. This was expected because at planting uniform amount of water was applied to field capacity to enable the seeds germinate uniformly. Drainage below 100cm was not noticed because moisture content started decreasing below this depth instead of increasing if drainage occurred (Fig. 1, 2 and 3). This indicates the high efficiency of the drip irrigation. Cultivars progressively extracted moisture from the soil such that after 56 DAE, most plants especially at low and medium soil moisture regimes (Fig. 1) had absorbed most water below depth of 30 cm. This was tillering stage and root development for most plants was well developed and water requirement had also increased significantly. Soil moisture below 60 cm was relatively high during vegetative stage suggesting that genotypes did absorb moisture below 50 cm depth. There was also possibility of drainage from upper layers to 60 cm depth. Anthesis occurred on average at 69 DAE after sowing, suggesting that cultivars utilized most of the supplied moisture up to a depth of 50 cm and they experienced drought stress at flowering. As moisture stress increased and crop water requirement increased at 70 DAE, soil moisture depletion also increased below depth increasing to >50 cm (Fig. 2). This was more pronounced under low and medium water regimes.

At 84 DAE, most of the cultivars had significantly depleted most of water at between 50-60 cm depth, especially under low and medium water regimes (Fig. 3). This shows that the test genotypes were capable of adjusting osmotically under water deficits to meet their water requirement, which could have been achieved through two mechanisms. They may have produced greater root length, thus allowing soil moisture extraction in deeper layers, or they may simply have had a greater capacity to extract water from dry soil at this depth (Fig. 2 and 3). These findings are consistent with those reported earlier[19] in sunflower. Below this depth (>60 cm) increased moisture was due to incomplete utilization of additional water supply, as the crop had

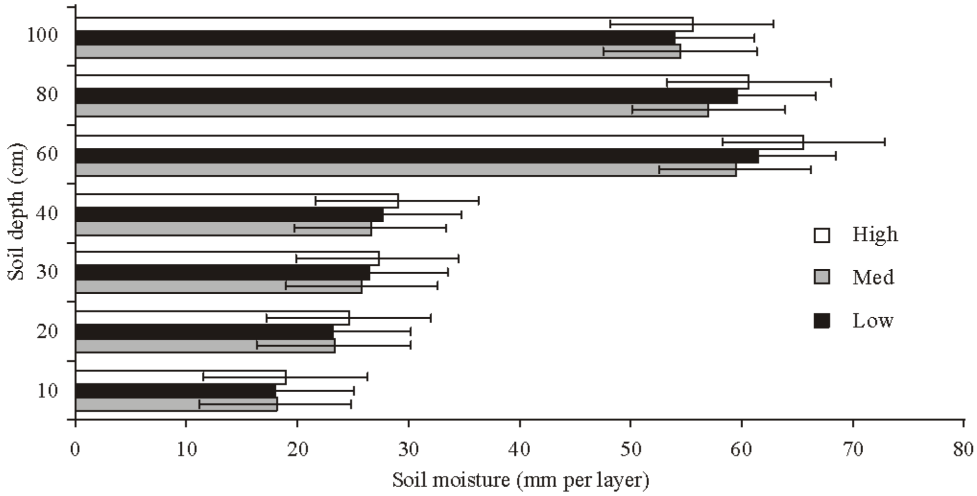

Fig. 1: Change in soil moisture content of soil layers (0-100 cm depth) 56 DAE for 12 wheat genotypes tested

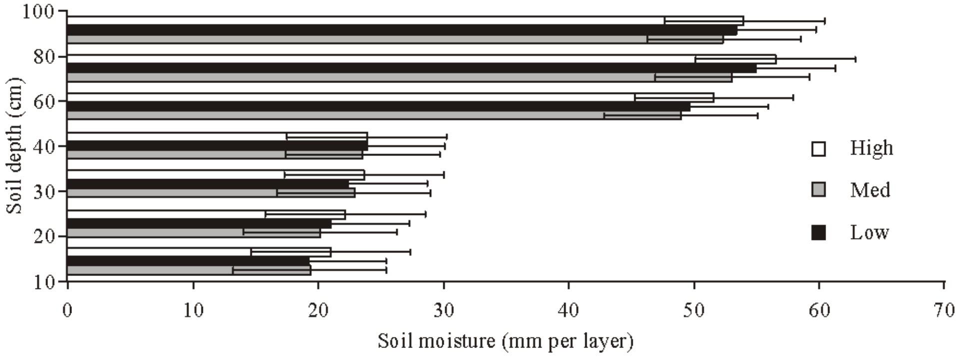

Fig. 2: Change in soil moisture content of soil layers (0-100 cm depth) 70 DAE for 12 wheat genotype tested

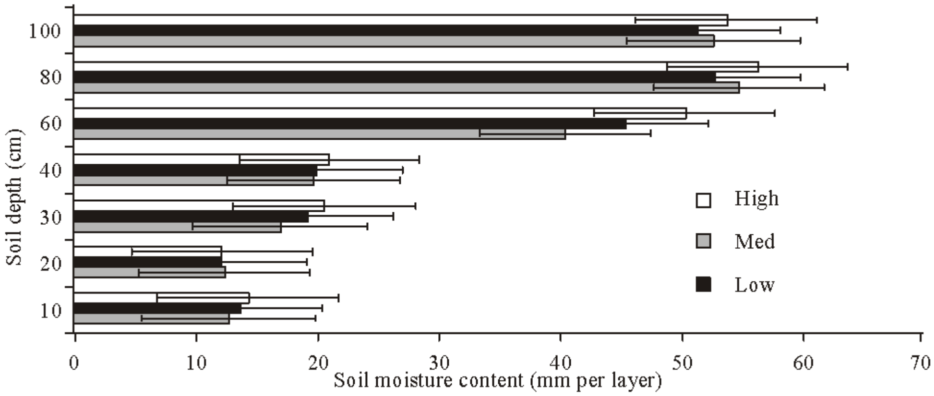

Fig. 3: Change in soil moisture content of soil layers (0-100 cm depth) 84 DAE for 12 wheat genotype tested

started maturing. Despite the moisture treatments the effective maximum rooting depth for water extraction was about 20-40 cm (Fig. 3). This could have been influenced by the soil characteristics of the site, mainly attributed to hard pan (bulk density 1.69 g cm^{-3}) at this depth[15]. Probably, this could have impeded deeper penetration and proliferation of roots and caused most of them to confine in the top <60 cm layer for a larger period of the growing season. Insufficient oxygen in the lower soil layers may also have reduced root growth despite moisture deficient at upper soil layers. This agrees with earlier reports that when air-filled porosity of soil decreases to 10% or below root development is severely hampered[20]. Increasing moisture supply from medium to high regimes and from low to medium levels increased crop ET by 32 and 29%, respectively. ET also accounted for 56, 48 and 42% of the

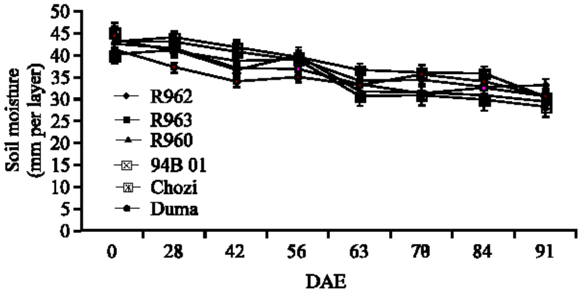

Fig. 4: Soil moisture depletion for tolerant wheat genotype under lowest moisture regime

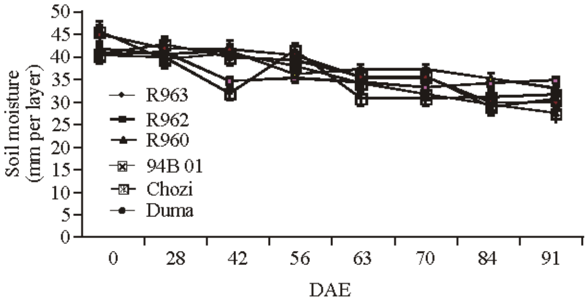

Fig. 5: Soil depletion for tolerant wheat genotype under highest moisture regime

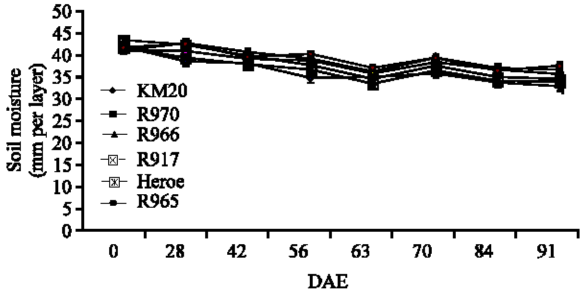

Fig. 6: Soil moisture depletion for susceptible genotype under high moisture regime

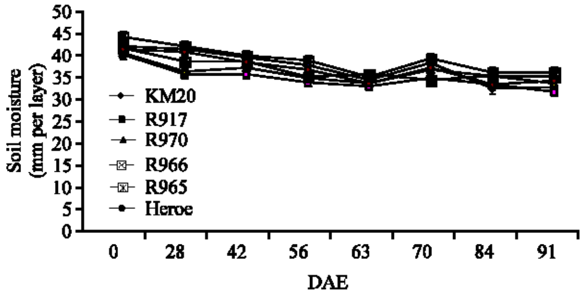

Fig. 7: Soil moisture depletion for susceptible wheat genotype under high moisture regime

total water supplied in high, medium and low water regimes, respectively (Table 2). This indicates that as water supply is increased, water loss through evaporation and transpiration increases proportionately. A significant loss through surface evaporation could have occurred for high and medium levels because water supply was during early growth period, when soil was already wet from previous irrigation while consumption by the crop was still low (Table 2). Evaporation values of between 18-20% of the ET in soil fully covered by mature crop of maize under stress have been reported earlier[21]. Similar findings indicate that as rainfall increased so as the loss components of ET and D in maize and bean trials at Kiboko, Kenya[22].

Genotypes tested differed in rates of moisture extraction (ET) at different moisture regimes (Table 2). Chozi, R965, R962, R963, Heroe and KM20 had the highest ET values resulting in depletion of soil moisture to lower levels in the profile in both lowest and highest moisture regimes (Fig. 4 and 5). Genotypes R960, Duma, 94B01, R970 and R917 had the lowest quantities of ET resulting from low moisture extraction from soil profile under both lowest and highest moisture regimes (Fig. 6 and 7). Heroe and KM20 had high ET but they had very low yield, indicating that most of the water could have been lost through evaporation beneath canopy (E_{sc}) (due to poor canopy grown cover). Esc was not measured in this study. Duma, R960 and 94B01 had low ET but high yield, suggesting that most of the extracted water was lost through the transpiration component of ET. Chozi had high ET and high yield suggesting that it had high yield potential which maximizes on available water. R970 and R917 had low ET and yield indicating that they have low yield potential and low capacities to utilize available moisture. This shows that these genotypes can be classified into three groups; those that are tolerant due to their ability to extract large volumes of water from the soil profile (e.g. Chozi) and those that are tolerant due to their capacities to extract adequate moisture and utilize it efficiently to produce yield (e.g. Duma, R960 and 94B01). The third group consists of susceptible genotypes due to low volume of water extraction (e.g. R970 and R917) and/or low yield despite high ET, probably due to high E_{sc} (e.g. Heroe and KM20). Efficiency in water extraction among the first and second group of genotypes increased the total volume of water that was extracted from the soil by intercepting water that would otherwise be lost in drainage resulting in increased yield. Chozi for example had 21% higher ET than R970 which had the lowest ET. These could have been achieved by producing greater root length, thus allowing soil moisture extraction in deeper layers, or they may simply have had a greater

Table 2: Response of evapo-transpiration (ET), dry matter (DM), grain yield and yield components for 12 wheat genotypes to three moisture regimes for two seasons (2001/2002) under rain shelter

Geno type	ET (mm)	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Kernel weight (g)	Harvest index	Plant height (cm)	Flag leaf length (cm)	Days to heading	Days to PM
Low moisture									
Chozi	97.4	2993.3	703.2	16.9	0.34	58.7	14.0	57.6	101.0
94B01	83.2	1199.2	685.6	15.7	0.40	46.0	12.2	63.6	102.0
Duma	93.9	1480.8	652.8	15.7	0.32	51.5	13.1	55.3	100.6
Heroe	86.0	2033.3	394.9	12.9	0.18	47.2	14.1	62.0	103.6
KM20	75.8	1420.0	494.4	11.3	0.21	45.5	13.1	60.0	104.3
R917	81.7	1454.2	622.7	9.5	0.17	46.3	10.6	62.0	101.6
R960	80.1	1200.8	681.9	16.1	0.38	49.8	15.1	59.0	101.6
R962	93.6	2311.3	570.6	12.5	0.27	52.8	10.5	56.6	100.3
R963	79.1	1470.8	522.9	13.5	0.30	51.3	15.5	54.0	98.0
R965	108.9	2060.0	680.1	13.4	0.22	51.0	12.0	57.3	100.0
R966	100.9	2171.2	598.1	13.8	0.27	57.0	15.1	58.6	102.6
R970	85.3	1407.5	447.7	14.1	0.26	65.5	14.4	51.6	97.6
Mean	88.8	1766.9	585.4	13.6	0.27	51.9	13.5	58.1	101.1
Medium moisture									
Chozi	131.0	3831.3	1061.1	18.3	0.35	61.8	14.4	61.3	102.0
94B01	110.7	2125.8	783.3	15.7	0.44	57.8	13.3	61.3	103.3
Duma	107.7	2277.9	1049.1	17.7	0.43	60.3	14.0	56.6	101.0
Heroe	111.9	3242.9	820.4	13.3	0.23	50.8	16.0	63.3	106.6
KM20	117.2	2612.9	709.7	13.4	0.28	51.8	16.5	62.6	104.6
R917	120.9	1933.3	535.6	12.0	0.20	54.5	12.5	62.6	101.6
R960	104.9	2003.7	1089.4	19.5	0.49	60.0	18.0	57.0	101.0
R962	127.3	3342.5	1023.8	14.2	0.31	61.6	13.8	57.6	102.6
R963	115.4	2372.1	943.0	15.8	0.37	58.6	17.3	55.3	98.6
R965	116.2	3261.3	946.3	15.5	0.31	65.3	16.4	57.3	102.0
R966	112.5	2582.9	861.6	16.1	0.32	59.3	15.2	59.6	103.0
R970	107.3	2650.0	952.3	16.1	0.33	76.6	16.5	53.3	100.1
Mean	15.3	2686.4	899.6	15.6	0.34	59.9	15.3	59.0	102.3
High moisture									
Chozi	165.8	5337.9	1616.8	22.1	0.41	69.3	21.0	64.6	106.3
94B01	149.3	3057.5	1405.1	19.7	0.41	57.0	18.2	63.6	107.0
Duma	127.8	3143.3	1323.1	23.9	0.55	66.6	18.6	57.3	102.6
Heroe	157.1	4194.6	960.2	16.9	0.26	64.3	17.0	65.0	106.0
KM20	180.4	3502.9	1056.9	17.2	0.27	62.6	19.1	65.0	107.3
R917	131.0	3244.2	704.6	15.8	0.25	61.5	13.8	64.3	103.3
R960	134.4	2868.3	1405.7	24.1	0.53	67.0	16.5	59.0	102.3
R962	158.0	5060.4	1298.2	17.9	0.32	72.6	18.9	61.3	104.0
R963	179.5	3082.9	1346.1	20.6	0.44	68.1	22.1	57.6	104.3
R965	155.7	4638.7	1184.7	18.3	0.41	71.0	16.7	58.3	105.3
R966	158.8	3758.6	1229.2	18.1	0.35	62.0	17.5	57.6	102.6
R970	132.4	2855.0	995.7	20.2	0.39	81.3	21.5	55.0	102.0
Mean	152.5	4712.0	1210.5	19.6	0.38	66.9	19.6	60.6	105.2
Grand Mean	118.9	3055.1	895.2	16.3	0.33	59.6	15.7	59.2	102.9
CV%	20.78	34.6	37.85	8.91	24.44	10.02	16.69	4.09	3.84
LSD	438.19	458.9	3410.1	1.3	0.07	5.6	2.4	2.2	3.7
Genotype	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.02$
Water	$p<0.001$	$p<0.005$	$p<0.001$	$p<0.05$	$p<0.008$	$p<0.001$	$p<0.001$	$p<0.02$	$p<0.07$
W x G	$p<0.05$	$p<0.05$	$p<0.05$	ns	ns	$P<0.05$	ns	ns	ns

WxG-Water x Genotype Interaction

capacity to extract water from dry soil. This is in agreement earlier findings[23] which showed that crop productivity is proportional to the volume of water transpired by a crop and that increased root length density and/or the extent of the root system by fertilizer application may increase interception of water[24]. Early maturing genotypes like Duma, R963 and R970 depleted the soil profile earlier from 42 DAE as compared to late maturing cultivars, which extracted more water from 56DAE (Fig. 3, 4 and 5). These shows that an increase in the size of crop canopy (tillers and leaf area) resulted in greater crop ET through an increases in Transpiration (T) component of the water balance. Also early maturing and short stature genotypes can escape drought by utilizing initial available moisture to develop smaller leaf area and complete their growth cycles when environment is still cool. These findings are comparable to those reported elsewhere[25] that the rates of ET of short season hybrid maize were consistently less than those of full season hybrids for 27 days preceding anthesis and partly attributed this reduction in the ET rate to the smaller LAI in the short season hybrid.

However, as irrigation increased from low to high regime, ET also increased and in high yielding drought tolerant genotypes (like R960, Duma and Chozi), it is postulated that the T component increased proportionately because of decreased E_{sc}. Transpiration could have been increased because of larger evaporative crop leaf surface while increases in E_{sc} could be due to maintenance of a wet soil surface for longer periods, because a dry surface leads to very low E_{sc} rates irrespective of the degree of canopy cover. These results are in agreements with those reported earlier[26]. Similarly Kisele *et al.*[27] also observed that irrigation (30 and 100% of weekly ET) increased cumulative ET of maize despite no effects on LAI. Those results and the present study agree with earlier conclusions[28,298] that ET will proceed according to atmospheric demand as long as soil water is adequate.

Measurement of ET clearly shows that one indictor of drought tolerance is efficient water extraction from the soil which could be is associated with adequate root distribution in the upper and lower layers of the soil profile as was the case for the tolerant cultivars. Similar observations were reported earlier that more extensive and dense root system ensures the maintenance of plant turgor and efficient transpiration from the canopy and final yield[30]. However genotypes with high yield potential like Heroe could have been disadvantaged because of inhibited transpiration and low turgor due to low extractable soil moisture.

This is in agreement with earlier findings that when soil moisture is very limited, the high-yielding genotype might be at a disadvantage because of its high stomatal conductance, which doesn't support high yield[30]. It appears therefore that, drought tolerant cultivars used a combination of efficient water extraction in low moisture profile (due to superior root growth characteristics in terms of length and density) and osmotic adjustment to maintain higher yields.

Grain yields and yield components: The performance of the test genotypes decreased with decreasing water levels up to lowest moisture, showing that increasing the duration of drought resulted in significant in grain yield and yield components (Table 2). The interaction between water regimes and wheat genotypes significantly affected yield, ET, biomass and plant height only and it didn't affect other yield components (Table 2). Chozi, R960, Duma, 94b01, R962, R963 and R965 produced the highest in mean grain yield across water regimes in decreasing order, while R917, Heroe, KM20 and R970 produced the lowest yields (Table 2). However, genotypes, which produced the highest biological yield didn't produce the highest HI, suggesting that higher DM accumulation does not guarantee higher yield. This was the case of 94b01 and Duma, which had higher harvest index due to low biomass and short growth duration for Duma. Medium to late maturing genotypes like Chozi, R962 and R960 had high biomass and yield because they have greater potential productivity and the developmental attributes to achieve that potential in terms of their capacity for resource capture. This is in agreement with previous work that longer growth duration is associated with greater biomass, both above and below grown, leading to greater root length density, but they lack in their HI, as compared with earlier genotypes[30]. Chozi, R962 and R963 also had high ET and DM, suggesting that they extracted more water from the soil which where utilized to produce more biomass than grain yield (Table 2). Highest grain yield was recorded in Duma, R960 and 94b01, indicating that they utilized more water for grain production and less biomass (Table 2). Early growth rate and vigour where desirable traits under dry conditions because it would allow more efficient water use during cooler part of growing season. This was clearly demonstrated by Duma and R963 in this study, suggesting that high seedling vigor and faster biomass accumulation enhance drought survival. However there should be an optimum balance of pre- and post-anthesis growth to maximize yield, since too much early growth will overly reduce water availability at and after anthesis and produce sink size that is not filled under stress conditions[6]. Vigorous early growth when vapor pressure deficits are low will enable these genotypes attain sufficient quantities of biomass and fast recovery rates after stress. They also had higher kernel weight (e.g Chozi, Duma and R960) (Table 2). These results are consistent with earlier findings[33] that a high HI, many grains per spike and per meter square and high growth rates are all critical to high yield and are considered basic in attaining high yield under drought. Selection of large spikelets/head while maintaining large seeds/head (large sink size) would lead to increased yield, as this has been reported to be the most important component determining wheat grain yield under pre-anthesis drought stress[32].

`Genotypes R970, R963, Duma, R965 took the shortest time to reach heading and maturity except for genotype R965 that took the longest time to mature after heading. Heroe, R917, KM20, 94B01 and Chozi were the latest maturing genotypes in decreasing order (Table 2). R962, R966, R960 were medium in maturity dates. Since highest yielding genotypes under rain shelter were Chozi, R960, 94b01, R962, R963 and R965, it shows that medium to late maturing varieties are high yielding. But it is clear that high yield is supported by longer growth cycle as in the case of Chozi, R962, R965 and 94B01. This shows that there is a conflict between yield potential and stresses adaptation where higher yielding cultivars are mainly medium-to-late maturing. However, while early genotypes like Duma and R970 escape drought, high yielding late maturing genotypes are not necessarily susceptible to drought. The results show some medium to late genotypes like Chozi, R962, R965, R960 and 94B01 have high yield potential than early ones as it had been demonstrated with peanut[33]. Contrasting results have been reported in Mediterranean where climate short grain filling period followed by earlier maturity were shown to be genetically associated with high yields, because earliness allowed the plants to escape extreme moisture stress, which is often accompanied by heat stress[34].

Since the crop in this experiment was subjected to seedling stage stress, early maturing varieties sustained high yield reduction while late flowering and high yielding genotypes sustained less yield reduction. This is possibly because late flowering genotypes like Chozi, R965, R965, 94B01 and R960 had a relatively better capacity for recovery from severe stress. R970, Chozi and R962 were the tallest with low HI while Duma, R960 and 94B01 had highest HI and were amongst highest yielding in driest regime. They also had fewer numbers of tillers (data not shown), which could have resulted in reduced vegetative dry mass and increased HI.

The differential responses of these cultivars to varying moisture levels during early season growth (early season drought) in a semi-arid tropical environment were mainly due to their ability to maximize kernel production with high kernel weights, ET and HI. As moisture stress increased, drought tolerant cultivars used a combination of efficient water extraction in low moisture profile (due to superior root growth characteristics in terms of length and density) and osmotic adjustment to maintain higher yields. Other adaptive traits, which contributed to significant superior performance under drought, were limited tillering capacity and longer flag leaves. To develop new cultivars with improved early vigor and vegetative biomass for long periods and efficient water uptake and use and consequently grain yield, as proved in this study, breeders need access to parents with considerable improvement in these characteristics. In these respects, Chozi, R960, R963 and Duma evaluated in this study appeared to be the most promising candidates. The study shows that in breeding; yield potential and adaptive traits need to be combined, because neither alone will provide superior germplasm. Genotypes R960, R963 and R965 are potential candidates for testing at National Performance Trials (NPTs) and possible release.

REFERENCES

1. Conti, S., P. Landi, M.C. Sanguineti, S. Stefanelli and R. Tuberosa, 1994. Genetic and environmental effects on abscisic acid in leves of field grown maize. Euphytica, 78: 81-89.
2. Skovmand, B. and M.P. Reynolds, 2000. Increasing yield potential for marginal areas by exploring genetic resources collections. The 11th Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia, CIMMYT.
3. Pingali, P.L. and S. Rajaram, 1999. Global Wheat Research in Changing World. In: Pingali, P.L., (Ed.), CIMMYT 1998-99. World Wheat, Facts and Trends: Global Wheat Research in a Changing World; Challenges and Achievements. Mexico, D.F:, CIMMYT.
4. Kasele, I.N., F. Nyirenda, J.F. Shanahan, D.C. Nielsen and D. Andria, 1994. Ethephon alters crop growth, water use and grain yield under drought stress. Agron. J., 86: 283-288.
5. Calhoun, D.S., G. Gebeyehu, A. Miranda, S. Rajaram and M. van Ginkel, 1994. Choosing evaluation environments to increase wheat grain yield under drought conditions. Crop Sci., 34: 673-678.
6. van Ginkel, M., D.S. Calhoun, G. Gebeyehu, A. Miranda, C. Tian-you, R. Pargas Lara. R.M. Trethowan., K Sayre, J. Crossa and S. Rajaram, 1998. Plant traits related to yield of wheat in early, late or continuous drought conditions. Euphytica, 100: 109-121.
7. Ministry of Economic Planning (various issues) 2001-1997. National Development Plan. Government Printers, Nairobi, Kenya.
8. KARI, 2002. Kenya Agricultural Research Institute Annual Report, KARI, Nairobi, Kenya.
9. Kimurto, P.K., M.G. Kinyua and J.M. Njoroge, 2003. Response of bread wheat genotypes to drought simulation under a mobile rain shelter in Kenya. African Crop Sci. J., 11: 16-25.
10. Mugo, S., M. Smith, M. Banzinger and T. Setter, 1998. Performance of early maturing Katumani and Kito composites under drought at the seedling stage and flowering stages. African Crop Sci. J., 6: 329-344.
11. Jefferies, A.R., 1993. Response of potato genotypes to drought I: Expansion of individual leaves and osmotic adjustments. Ann. Applied Biol., 122: 93-104.
12. KARI, 1984. Kenya Agricultural Research Institute Annual Report, KARI, Nairobi, Kenya.
13. Upchurch, D.R., J.T. Ritchie and M.A. Foale, 1983. Design of a large dual-structure rain out shelter, Agron. J., 75: 845-848.
14. Watermatics, 1999. Drip irrigation Kit: Dew-Horse II. Chapin Watermatics Inc. Watertown, USA.
15. Ooro, P., 2004. Use of path analysis to determine water use efficiency in bread wheat under rain out shelter. M.Sc Thesis, Egerton University, Njoro, Kenya.

16. Ooro, P., M.G. Kinyua, J.B.O. Ogolla, P.K. Kimurto and M. Mwangi, 2002. Manual Report: Characterization and analysis of Soil Profile of KARI-Njoro Field Station.
17. Kimurto, P.K., 2000. Selection of bread wheat germplasm by simulation of drought stress under rain shelter in Kenya. M.Sc. Thesis, Egerton University, Njoro, Kenya.
18. SAS, 1996. SAS Intistute Inc.; SAS/STAT Users Guide. Release 6.13. Cary N.C., USA.
19. Chimenti, C.A. and A.J. Hall, 1993. Genetic variation and changes with ontogeny of osmostic adjustment in sunflower. Euphytica, 71: 201-210.
20. Howell, T.A., J.A. Tolk, A.D. Schneider, S.R. Evett, 1998. Evapotranspiration, yield and water use efficiency of corn hybrids differing in maturity. Agron. J., 90: 3-9.
21. Fernandez, J.E., F. Moreno, J. M. Murillo, J.A. Cayuela, E. Fernandez and F. Cabrera, 1996. Water use and yield of maize with two levels of nitrogen fertilization in South west Spain. Agric. Water Manage., 29: 215-233.
22. Pilbeam, C.J., L.P. Simmonds and A.W. Kavilu, 1995. Transpiration efficiencies of maize and beans in Semi-arid Kenya. Field Crops Res., 41: 179-188.
23. Sinclair, T.R., C.B. Tanner and J.M. Bennett, 1984. Water use efficiency in crop production. Bioscience, 34: 40-60.
24. Cooper, P.J.M., P.J. Gregory, J.D.H. Keatinge and S.C. Brown, 1987. Effects of fertilizer, variety and location on barley production under rainfed conditions in Northern Syria. II. Soil water dynamics and crop water use. Field Crops Res., 16: 67-84.
25. Jaetzold, R. and H. Schimdt, 1983. Farm management Handbook of Kenya. Natural conditions and farm management information Vol. II/B. Central and Western Kenya. Government Printers, Nairobi.KARI, 1984. Kenya Agric. Res. Institute Annual Report. KARI, Nairobi, Kenya.
26. Wallace, J.S., C.R. Lloyd and M.V.K. Sivakumar, 1993. Measurements of soil, plant and total evaporation from millet in Niger. Agric. For. Meteorol., 63: 149-169.
27. Kasele, I.N., F. Nyirenda, J.F. Shanahan, D.C. Nielsen and D. Andria, 1994. Ethephon alters crop growth, water use, and grain yield under drought stress. Agron. J., 86: 283-288.
28. Ogola, J.B.O., T.R. Wheeler and P.M. Harris, 2002. Effects of nitrogen and irrigation on water use of maize crops. Field Crops Res., 4096: 1-13.
29. Rosenberg, N.J., B.L. Blad and S.B. Verma, 1983. Microlimate: The Biological Environment. 2nd Edn., Wiley-Interscience, NY.
30. Blum, A., 1996. Crop responses to drought and the interpretation of adaptation. Plant Growth Regulation, 20: 135-148.
31. Fisher, R.A., 1979. Growth and water limitation to dryland wheat in Australia: A physiological framework. J. Aust. Instit. Agric. Sci., 45: 83-89.
32. Kinyua, M.G., B. Otukho and O.S. Abdulla, 2000. Developing wheat varieties for the drought-prone ares of Kenya: 1996-1999. In: CIMMYT, 2000. The 11th Regional Wheat Workshop for Eastern, Central and South Africa. Addis Ababa, Ethiopia, CIMMYT.
33. Nageswara Rao, R.C., J.H. Williams and M. Singh, 1989. Genotypic sensitivity to drought and yield potential of peanuts. Agron. J., 81: 887-893.
34. Fisher, R.A., 1981. Optimizing the the use of water and nitrogen through breeding of crops. Plant and Soil, 58: 249-278.