Performance of selected sorghum (*Sorghum bicolor* L. Moench) genotypes under water stress condition

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DEDICATION

TO THE SOUL OF MY SISTER

AMEL

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ABSTRACT

A field experiment was conducted in autumn 2003 in the Demonstration Farm of the Faculty of Agriculture at Shambat in order to study and evaluate the performance of five sorghum genotypes grown under water stress .The plants were subplot to two watering treatments viz; well- watered (the pants received irrigation water every 14 days) and stressed-plant(received irrigation water every 21 days). Sorghum genotypes used in this study include: Feterita Abu Gumi (G1), Tabat (G2), Feterita Wad Aker (G3), Mugud (G4) and Debakeri (G5).The experiment was laid in a split –plot design with four replications. The watering treatments were allotted to the main plots and the genotypes to the subplots. Results showed that water stress affected almost all the parameters measured in this study. The stressed plants were larger, had greater number of nodes, internodes length, leaves/plant and fewer branches/plant.

Similarly, water stress hastened all the phonological characters studied in this experiment and reduced seed yield and harvest index. Also the data of the present study clearly demonstrated that there is great genetic variability among the tested sorghum genotypes. In this regard, the early maturing genotype (Debakeri) had vigorous growth and greater seed yield compared to the late maturing genotypes (Mugud) in response to water stress.

خلاصة الأطروحة

أجريت تجربة حقلية في خريف 2003 بالمزرعة التجريبية بكلية الزراعة بشمبات لدراسة وتقييم أداء خمسة أصناف من الذرة الرفيعة تحت تأثير الإجهاد المائي.

استخدم مستويين من معاملات الري وهي جيدة الري (الرية كل ١٤ يوم (W)) والري تحت تأثير الإجهاد المائي (الرية كل ٢١ يوم (S)) وكانت الأصناف المدروسة هي فتريتة ابوقمي(G1) طابت (G2)، فتريتة ودعكر (G3)، مقد (G4) و دبيكري (G5) استخدم في هذه التجربة نظام القطاعات المنشطرة بأربعة مكررات . واحتلت معاملات الري القطاعات الرئيسية بينما الأصناف احتلت القطاعات الثانوية.

أوضحت النتائج إن للإجهاد المائي تأثيرعلي كل الصفات المدروسة. فالنباتات المجهدة لها اعلي طول للنبات، عدد العقد/النبات، طول السلاميات، عدد الأوراق/النبات ، الوزن الرطب ، اقل عدد للاشطاء.

الإجهاد المائي أيضا اثر علي كل الصفات المظهرية المدروسة في هذه التجربة كما أدي إلى تقليل إنتاجية البذور ومعامل الحصاد. إضافة إلى ذلك فان النتائج المتحصل عليها من هذه التجربة أوضحت أن هنالك تباين وراثي عالي بين الأصناف المقيمة وعلي ضوء ذلك فان الصنف المبكر دبيكري له معدل نمو عالي واعلي إنتاجية مقارنة بالصنف المتأخر مقد في استجابتهما للإجهاد المائي.

CHAPTER ONE

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is the fifth most important cereal grain in the world and it comes after rice (*Oryza sativa*); maize (*Zea mays*); wheat (*Triticum aestivum*) and barley (*Hordeum vulgare* L.). The crop belongs to the family Gramineae, tribe Andropogoneae and sub tribe Sorghastrae. Generally, there were five basic races of Sorghum viz; bicolor, guinea, candatum, durra and kafir (Harland and de Wet, 1972). Archaeological evidence suggests that early domestication of sorghum occurred 8,000 years ago (Wendorf *et al.,* 1992). The crop occurred in an area extending from near the Ethiopian border in the East, through Sudan up to Lake Chad in the West. In this area there is great diversity as well as the presence of the primitive race bicolor (Harland and de Wet, 1972).

The crop has many common names such as Durra in Sudan, Matama in East Africa, Guinea Corn in West Africa, Jowl in India, Milo in USA and Koaliago in China. The dry grain of sorghum contains approximately about 8-10% water, 68-74% carbohydrate, 8-15% protein, 2-5% fat, 1-2% fiber and 1.5-2% Ash.

In Africa and India sorghum is mainly used for human consumption. In Sudan, sorghum is the major food crop and the majority of the people considered it as the national bread of the country. Also sorghum can be used for beer, as live stock feed, as fuel and many other forms.

The importance of sorghum comes largely from its ability to produce in harsh environments, which are unfavorable to other cereals. The crop for example, can be adapted and successfully grown where annual rain fall varies from 400-700 mm and on a wide range of soil pH

(5-8.5). The optimum temperatures, however, for sorghum growth range from 27°-32 °C.

Over the past 25 years, sorghum production in Africa has increased steadily from 11.6 million tonnes in 1976 to 20.9 million tonnes in 2001. This increase, however, is due to an increase in the total amount of land used for cultivation and not to an overall improvement in crop yield. This is because sorghum produced in Africa is mainly grown using traditional farming practices, with no use of inorganic fertilizers, pesticides or improved hybrid varieties. On the other hand the productivity of sorghum is very low, typically less than one tonne per hectare and can be increased up to 3-5 tonnes/hectare in high input farming systems. This suggests that there is considerable potential for increased sorghum production in Africa, resulting in higher levels of food security.

World-wide, sorghum represents about 5.5% of total cereal production and Africa as a whole amounts up to 17.6% (Dendy, 1995). The countries where it's of great importance include Botswana (84.4%), Sudan (71.6%), Burkina Faso (52.8%), Rwanda (51.5%), Chad (41%), and Cameroon (39.9%). According to statistics of The Ministry of Agriculture Sudan occupied in season 1991 an area of about 5.1 million hectars, 88.8% of this area was under rainfed and 11.2% under irrigated conditions.

From previous research, water stress affects most aspects of plant growth and reduced grain yield (Chaudhuri *et al.,* 1980; Wenzel, 1999). Great yield reduction in sorghum was reported when drought stress occurred between panicle development and physiological maturity (Manjarrez-Sandoval *et al.,* 1989; Craufurd and Peacock, 1993).

In view of lack information on specific drought resistance mechanisms, plant selection for this trait is still largely guided by grain yield and its stability under dry condition (Ficher and Mourer, 1978). In view of increasing spread of drought belt and the high variation in the pattern of rain distribution, there is an increasing need for selecting cultivars adapted to water stress. The objective of this study is to evaluate the performance of contrasting sorghum genotypes under different watering regimes.

CHAPTER TWO

Literature Review

2-1 Definition:

Drought usually refers to a deficiency of available soil moisture, which produces water deficits in plants sufficient enough to cause reduction in growth and yield. Kramer and Boyer (1995) reported that atmospheric factors such as high temperature, low humidity and wind may intensify the injurious effects of drought through an increased rate of transpiration.

Plant can be adapted in a limited way to drought by the operation of escape or tolerance mechanisms (Kramer, 1980). He defined tolerance as the mechanisms that enable a plant to either postpone or endure dehydration or a lowering of water content. Levitt (1980) defined tolerance mechanisms as the ability of the crop to survive and maintain all metabolic functions under water stress. Turner and Kramer (1980) declared that the agronomic definition of drought resistance requires that plants have sufficient growth to an economically harvestable yield. Rosielle and Hamblin (1981) defined drought tolerance as the difference in yield between stress and non-stress environment. Hall *et al.,* (1993) defined drought tolerance as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Blum (1988) reported that drought tolerance comprises drought escape, dehydration avoidance and dehydration tolerance mechanisms.

Drought escape is a particular important strategy of matching phonological development with the period of soil moisture availability to minimize the impact of drought stress on crop production in environments where season is short and terminal drought stress predominates (Turner, 1986). This can be achieved through early flowering and/or a short growth duration which is advantageous in environments with terminal drought stress and where root growth is inhibited by physical or chemical barriers (Turner, 1986; Blum, 1988; Blum *et al.,* 1989). Dehydration avoidance can be defined as the ability of the plant to retain a relatively higher level of moisture content under conditions of soil or atmospheric water stress (Blum, 1988). Important features are root characteristics, leaf, stomata and osmotic adjustment to lower the osmotic potential (Acevedo and Fereres, 1993). The usefulness of dehydration tolerance can be realized when it is placed in a genetic background that has other mechanisms related to maintenance of production under moisture-deficit environment (Subbarao *et al.,* 1995).

2-2The effect of moisture stress on vegetative growth:

2-2-1 Plant height:

Ibrahim *et al.,* (1999) reported that water stress increased the plant height of drought tolerant varieties than non-tolerant ones. Ahmed (1989) found that water stress during GS3 resulted in 20.4% reduction in plant height. In wheat several investigations from different parts of the world reported that plant height increased with more frequent irrigation (Hussein *et al.,* 1978).

2-2-2 Number of leaves per plant:

Kabbashi (1991) showed that in sorghum the number of leaves per plant was not affected by water stress, while Nimir, (1993) found that the number of leaves in wheat was affected under different irrigation intervals.

2-2-3 Leaf area index (LAI):

Nimir, (1993) agreed with this result and he found that LAI of wheat decreased with increasing watering interval. Kabbashi (1991) found that water stress decreased LAI when sorghum cultivated alone compared with sorghum was cultivated with clitoria. Sorghum cultivars attained their maximum LAI during early flowering and early milk stage, respectively (Ibrahim *et al.,* 1999).

2-2-4 Number of tillers/plant:

In most plants, tillering is regulated by apical dominance, moisture stress and nutrition of seedlings may also play a role. Tillering induced by moisture stress can't be viewed as drought resistance mechanism. Under severe moisture stress, especially during the flowering period, excessive tilllering may have a negative effect on grain yield (Wenzel, 1999). Ahmed (1989) found that water stress reduced the number of productive tillers/plant. Similar results were reported by Nimir, (1993) in wheat, who found that the number of tillers decreased under prolonged irrigation interval.

2-3-5 Total shoot biomass per plant :

Hoshino *et al.,* (1978) showed that the tall lines of sorghum were superior in net assimilation rate, crop growth rate and dry matter production compared to the short lines. Eck and Musick (1979) reported similar results and concluded that in unstressed plants, the dry matter accumulation proceeded at near constant rate from about 40 days after sowing till physiological maturity. Ibrahim *et al.,* (1991) and Wenzel (1999) showed that dry matter per plant decreased by increase in water stress.

2-3 The effect of moisture stress on phenological aspects:

Crop phenology refers to the timing of major developmental events such as germination, floral initiation, flowering, seed maturity, leaf fall, etc. Three distinct phonological stages are recognized in sorghum as described by Estain (1972). These stages are as follows:

GS1 from planting to panicle initiation.

GS2 from panicle initiation to bloom.

GS3 from bloom to physiological maturity.

The transition from the vegetative to the reproductive stage occurs with acropetal initiation of primary branch primordia. The importance of this stage is that, by its end, seed number (as a component of yield) has already been fixed and any further yield increase would only come from increases in seed weight.

The effects of water stress on the phenology of sorghum depend upon the severity of stress itself and on the stage of development of the crop at the time of stress. When stress is not severe, as often observed under near optimum environments, the phenological responses are not apparent, and the effects are mainly on growth and yield. In variable moisture environments, however, effects on phenology can be very evident, particularly when stress occurs before flowering.

Seetharama and Bidinger (1979) studied a set of 33 germplasm lines under well irrigated and mid-season stress conditions and found that the number of days to flowering under stress conditions could be either hastened by a day or delayed as long as by 33 days. Kaigama (1982) showed that flowering was delayed when higher temperatures were coupled with water stress.

O'Neill *et al.,* (1983) showed that anthesis occurred earlier under water stress as reported by Hermus *et al.,* (1982) who indicated that in the majority of sorghum varieties, anthesis was hastened by water stress. In contrast, Abdlrahman (1985) and Ahmed (1989) found that there were no differences between stressed and non-stressed sorghum genotypes in number of days to 50% anthesis.

Ahmed (1989) found that water stress during the grain filling period (GS3), which represents the last critical stage of the plant life cycle, resulted in 14.7% reduction in days to 50% physiological maturity.

2-4 The effect of moisture stress on yield and yield components:

Grain yield per plant is determined by the number and size of the grains. In sorghum, although the grain filling stage is less sensitive to water stress than the panicle development and expansion stage, yield reduction occurs as a result of reduced seed weight. This is because seed weight is a function of both seed size and degree of grain filling and moisture stress can affect both yield determinants (Kreig, 1993).

Bakhiet (1990) working with 22 grain sorghum genotypes showed that moisture stress during flowering reduced the mean grain yield/plant, panicle weight and 1000 grain weight and these characters are most severely affected by moisture stress during grain filling and before flowering, respectively.

The number of grains/panicle at harvest depends upon a number of environmental factors and water stress is the important one especially during panicle differentiation and anthesis stage. Wright *et al.,* (1983) noticed a degree of sorghum floral abortion in the early boot stage which reduced the number of grains/panicle, although yield compensation was achieved through tillering and an increase in seed size. Musick and Dusek, (1980) indicated that stress developed at floral initiation and continued into grain filling in wheat reduced yield by reducing the number of heads/m^2 and grain seeds per head. Similar results were reported by Wenzel, (1999) and Ahmed (1989). They found that water stress reduced the number of seeds/head, 1000 seed weight, seed yield/plant and seed yield/ha.

CHAPTER THREE

Materials and Methods

3-1 General:

A field experiment was conducted during 2003 season in the Demonstration Farm of the Faculty of Agriculture at Shambat (lat. 15° 39′, N; Long. 32° 31′; Alt. 375 m above sea level). The soil is heavy clay with pH of 8.5 and the monthly rainfall and temperature during the experimental period were obtained from Shambat Metrological Station, as shown in Appendix table (1).

The objective of the experiment is to study the performance of some selected sorghum genotypes under water stress conditions.

3-2 The experimental treatments:

The experiment was designed to study the effect of two watering intervals applied as follows: well-watered (W) treatment where the plants received irrigation every 14 days and stressed treatments (S) where the plants received water every 21 days. Five sorghum genotypes, namely Fatarita Abu Gumi (G_1), Tabat (G_2), Fatarita Wad Akar (G_3), Mugud (G_4) and Debakri (G_5) were evaluated in the experiment.

3-3 Lay out:

The experiment was arranged in 2X5 split plot design with four replications. The main plots were allotted for the watering intervals and the sub-plot to the genotypes. The land was pre irrigated and prepared by disc ploughing, harrowing and ridging at 80 cm apart. Spacing between plants was 10 cm, and the size of individual plot was 3X3m^2 consisting of four ridges each.

3-4 Husbandry:

Sowing was done manually on the shoulder of the ridges on 10th of July 2003. Seeds were sown at a spacing of 10 cm between holes. The plants were thinned to one plant/ hole two weeks after sowing. A basal dose of nitrogen was applied at a rate of 40 kg N/ha two weeks after sowing. Weeding was done manually 3 times during the season. Furidan was applied 3 times to the experiment to protect the plants from stem borer (*Sesmia critica*). Shortly before milking stage, the heads were covered by bags to guard against birds.

3-5 Characters studied:

3-5-1 Growth attributes:

From the two inner ridges, 5 plants were randomly selected and tagged in each plots to monitor the following characters:

3-5-1-1 Plant height (cm):

Measured from the base of the main stem to the tip of the panicle.

3-5-1-2 Number of nodes/plant

3-5-1-3 Internode Length (cm):

Measured from central internodes of the main stem.

3-5-1-4 Number of leaves/plant

3-5-1-5 Leaf area

3-5-1-6 Leaf area index:

Measured from the third leaf and determine as the ratio of leaf area to unit ground area using the following formula:

$$\text{Leaf area index} = \frac{\text{Leaf area X average number of leaves/plant}}{\text{Ground area}}$$

3-5-1-7 Number of tillers/plant

3-5-1-8 Total shoot biomass (g):

The tagged plants were cut and weighed and the average weight per plant was obtained.

3-5-2 Phonological attributes:

3-5-2-1 Number of days to 50% booting stage

3-5-2-2 Number of days to 50% flowering stage

3-5-2-3 Number of days to 50% milking stage

3-5-2-4 Number of days to physiological maturity.

3-5-3 Reproductive attributes:

3-5-3-1 Number of grains /head

3-5-3-2 1000- Grain weight (g)

3-5-3-3 Grain yield /plant (g/plant)

3-5-3-4 Grain yield /area (Kg/ha)

3-5-3-5 Harvest index:

Determine as a ratio of economical yield to biological yield.

3-5-4 Statistical analysis:

Analysis of variance (ANOVA) appropriate for spilt plot design was used according to SAS program. Means separation was carried out using the least significant differences (LSD) for the different characters.

CHAPTER FOUR

Results

4-1 Growth attributes:

4-1-1 Plant height:

Analysis of variance showed that watering treatments had no significant effect on mean plant height particularly at the first sampling occasions. However, at the end of the season, stressed plants were significantly taller compared to the well-watered plants (Fig. 1a). In contrast, cultivars differ significantly on mean plant height ($P<0.01$) under both treatments (Fig. 1b). In this regard, Mugud (G_4) and Debakri (G_5) were consistently and significantly taller compared to the other genotypes. No significant interaction on mean plant height was recorded in this study (Appendix table 2).

4-1-2 Number of nodes/plant:

Analysis of variance showed that watering treatments had no significant effect on mean number of nodes/plants. However, stressed plants had greater number of nodes compared to well-watered plants (Fig. 2-a). In contrast, genotypes differ significantly on mean number of nodes ($P< 0.05$) under both treatments. In this regard, Mugud (G_4) and Debakri (G_5) had a significantly higher number of nodes compared to the other genotypes (Fig. 2b). No significant interaction on mean number of nodes/plant was observed in this study (Appendix table 3).

Figure (1): Effect of watering treatment (a) and genotypes (b) on mean plant height(cm) of sorghum plants grown during 2003 season. At each sampling occasion means with similar letters are not significantly different from each other according to LSD.

a

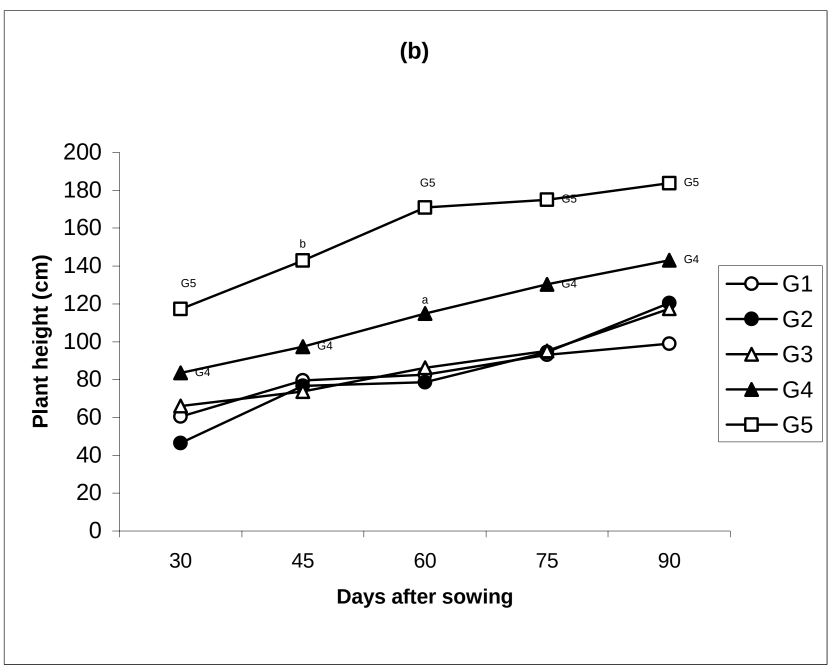
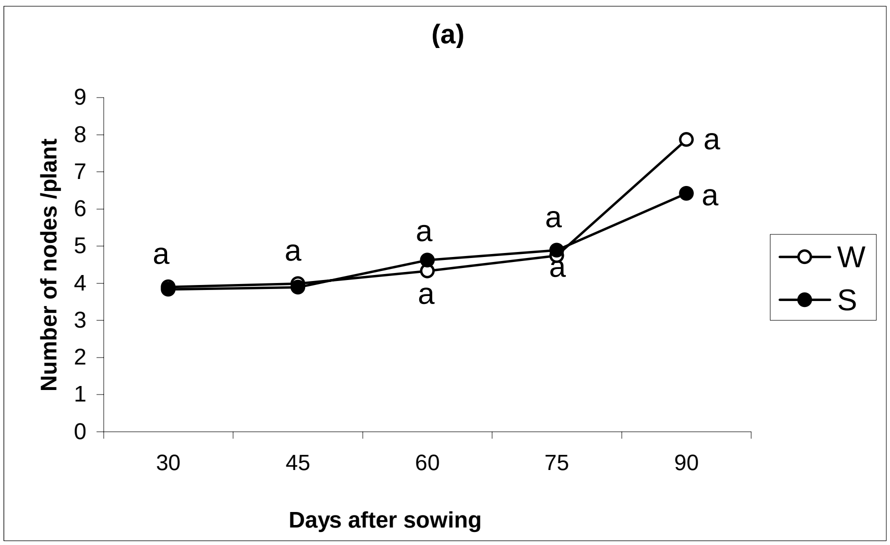
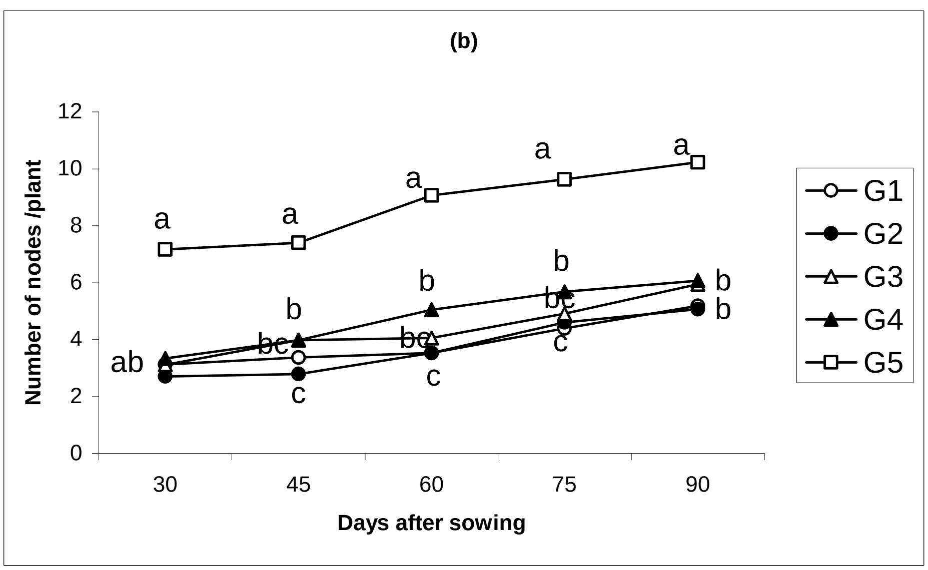

(b)
Plant height (cm)
200
180
160
140
120
100
80
60
40
20
0
30
45
60
75
90
Days after sowing
G5
b
G5
G5
G5
G4
a
G4
G4
G4
G1
G2
G3
G4
G5

Figure (2): Effect of watering treatment (a) and genotypes (b) on mean number of nodes of sorghum plants grown during 2003 season. At each sampling occasion means with similar letters are not significantly different from each other according to LSD.


(a)
Number of nodes /plant
Days after sowing
W
S


(b)
Number of nodes /plant
Days after sowing
G1
G2
G3
G4
G5

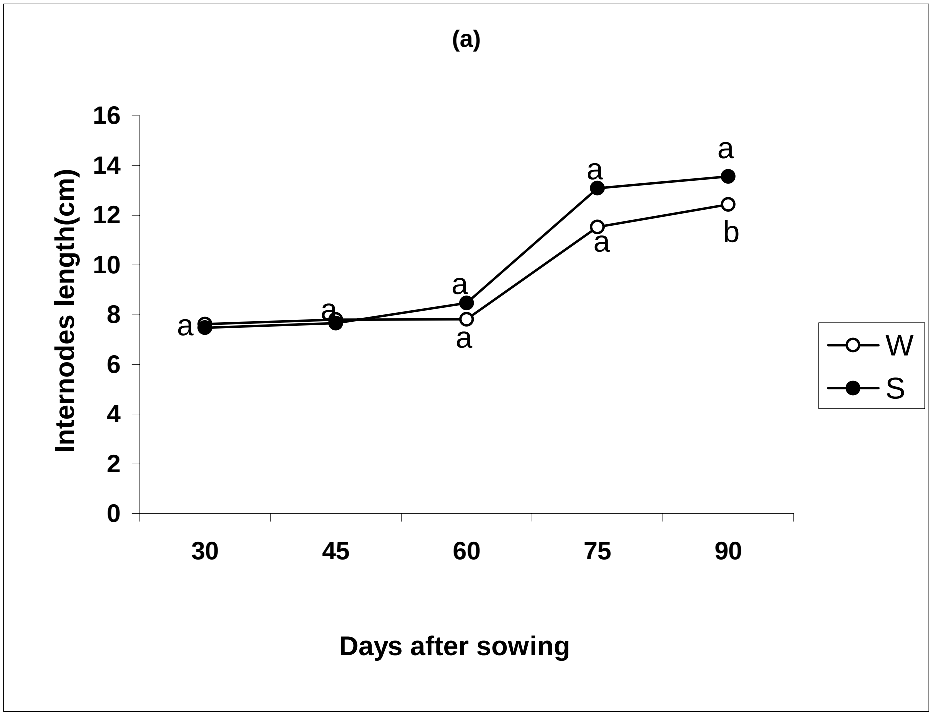
4-1-3 Internodes length (cm):

Watering treatments had significant effect on mean internodes length of plants particularly at the end of the season (Fig. 3a). In this regard, the stressed plants showed an increase in internodes length compared to well-watered plants .Also, genotypes were significantly different on mean length of internodes ($P< 0.01$) in both treatments (Fig. 3b). From the results, Mugud (G4) and Debakri (G_5) had significantly greater length of internodes compared to other genotypes. No significant interaction on mean length of internodes was observed in this study (Appendix table 4).

4-1-4 Number of leaves per plant:

Analysis of variance showed that watering treatments had no significant effect on mean number of leaves per plant (Fig.4a). However, the well-watered plants had consistently greater number of leaves compared to stressed plants. Although Feterita Wad Akar (G_3) consistently had greater number of leaves compared to the other genotypes, there were no significant differences between the genotypes on mean number of leaves/plant under both treatments (Fig. 4b). No significant interaction on mean number of leaves per plant was observed in this study (Appendix table 5).

Figure (3): Effect of watering treatment (a) and genotypes (b) on mean internode length of sorghum plants grown during 2003 season. At each sampling occasion means with similar letters are not significantly different from each other according to LSD.


(a)
Internodes length(cm)
Days after sowing
W
S
0
2
4
6
8
10
12
14
16
30
45
60
75
90

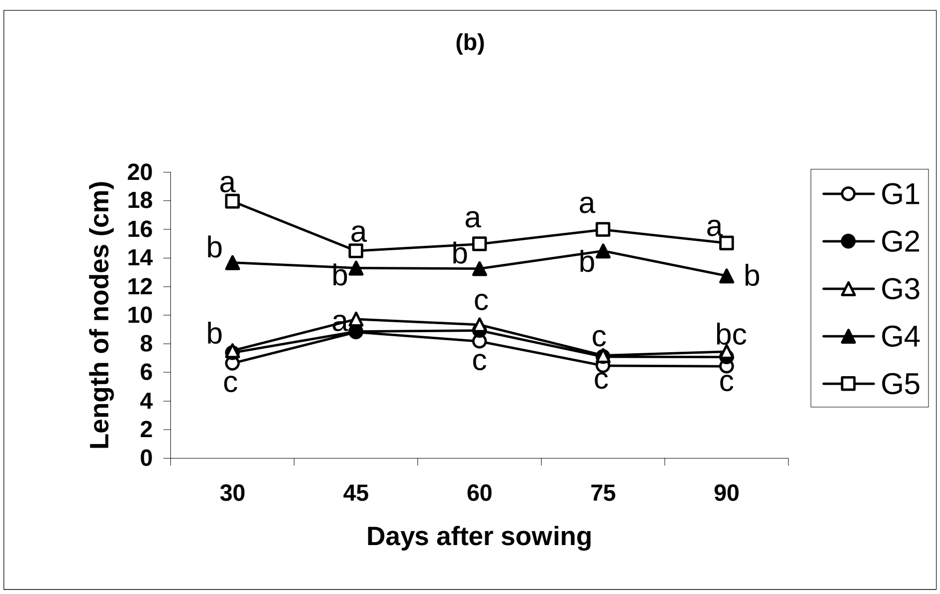
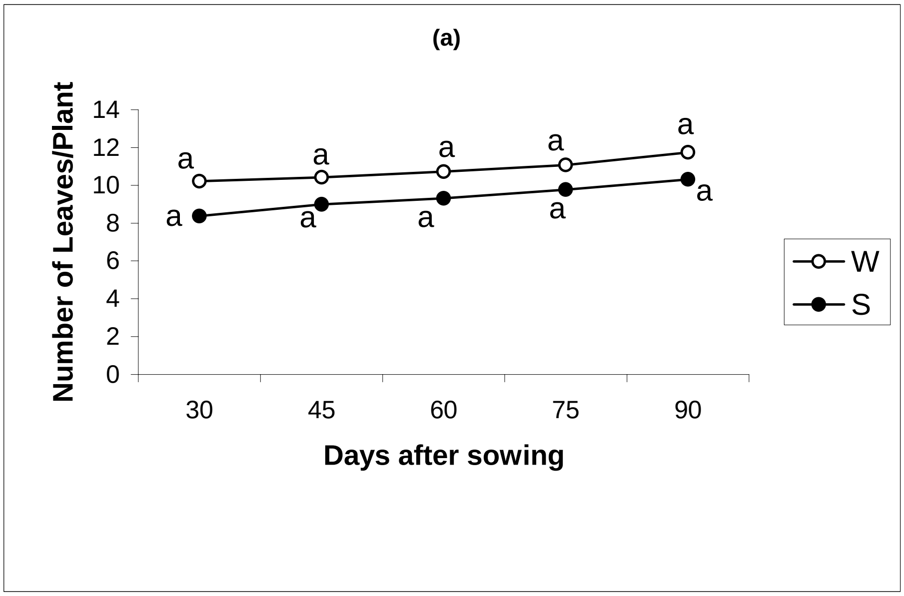
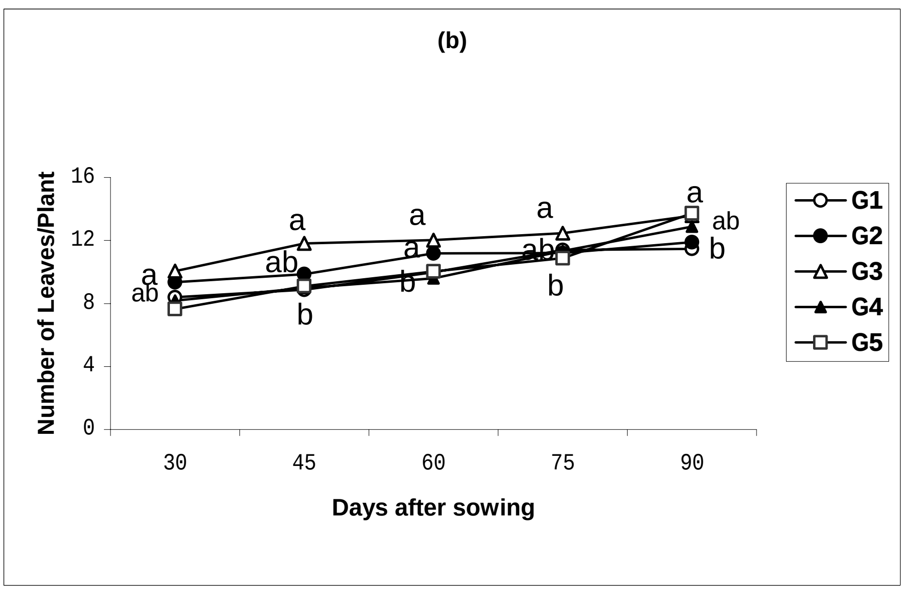

(b)
Length of nodes (cm)
Days after sowing
G1
G2
G3
G4
G5
0
2
4
6
8
10
12
14
16
18
20
30
45
60
75
90

Figure (4): Effect of watering treatment (a) and genotypes (b) on mean number of leaves per plant of sorghum grown during 2003 season. At each sampling occasion means with similar letters are not significantly different from each other according to LSD.


(a)
Number of Leaves/Plant
Days after sowing
14
12
10
8
6
4
2
0
30
45
60
75
90
W
S
a


(b)
Number of Leaves/Plant
Days after sowing
16
12
8
4
0
30
45
60
75
90
G1
G2
G3
G4
G5
a
ab
b

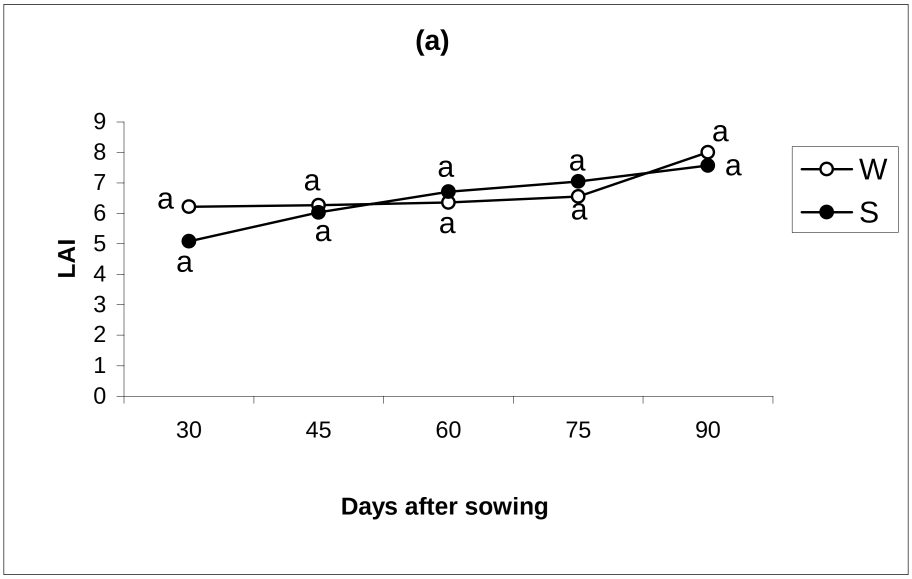
4-1-5 Leaf area index:

Analysis of variance showed that watering treatments had no significant effect on mean leaf area index (Fig. 5a) but stressed plants had a lower leaf area index compared to the well-watered plants. On the other hand, genotypes did not differ significantly on mean leaf area index (Fig. 5b). However, Feterita Wad Akar (G_3) and Mugud (G_4) showed more leaf area index on this aspect than the other genotypes. No significant interaction on mean leaf area index was observed in this study (Appendix table 6).

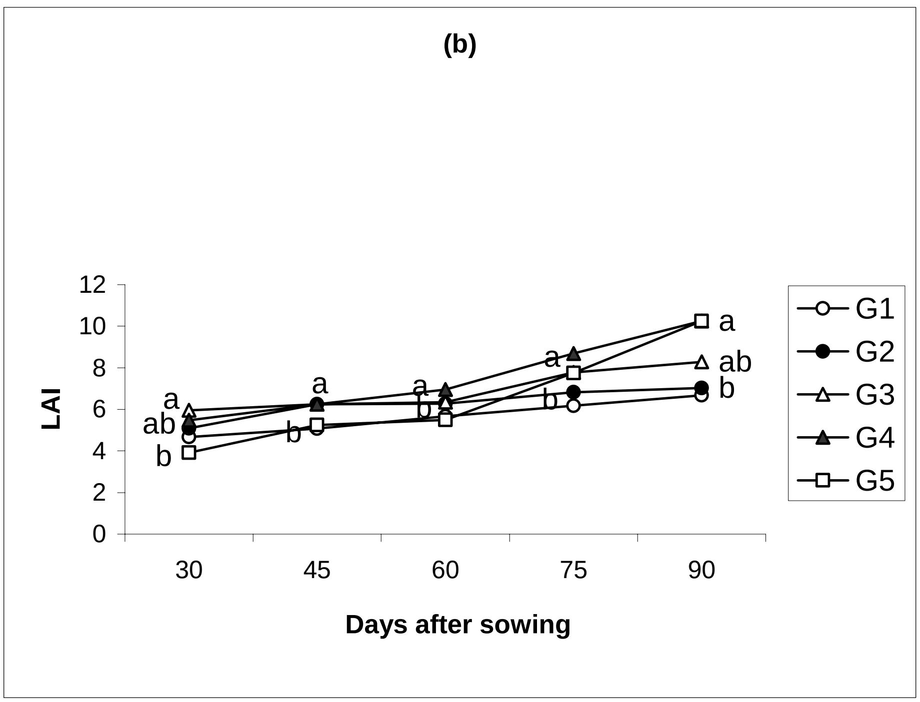
4-1-6 Number of tillers/plant:

Statistical analysis showed that watering treatments had significant effect on mean number of tillers per plant particularly at the last sampling occasions (Fig. 6a). In this regard, the well watered plants had greater number of tillers compared to stressed plants. Similarly, genotypes differed significantly on mean number of tillers per plants (Fig. 6b). In this aspect, Feterita Wad Akar (G_3) and Mugud (G4) consistently had more number of tillers/plant compared to the other genotypes. There was no significant interaction on mean number of tillers/plant in this study (Appendix table 7).

Figure (5): Effect of watering treatment (a) and genotypes (b) on mean leaf area index of sorghum plants grown during 2003 season. At each sampling occasion means with similar letters are not significantly different from each other according to LSD.

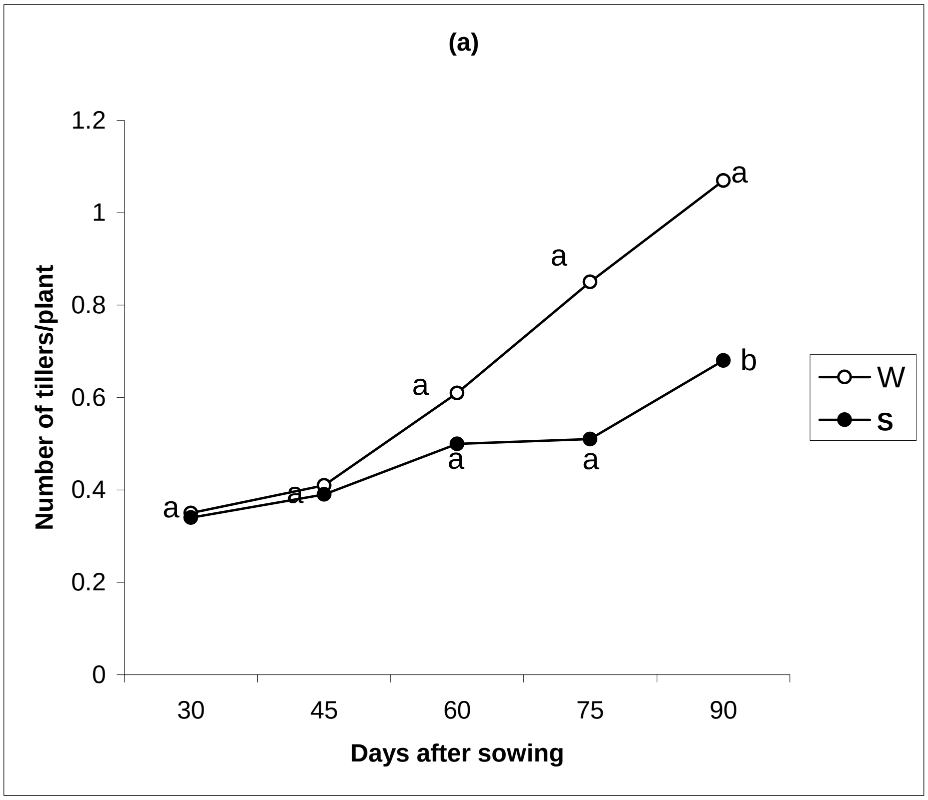


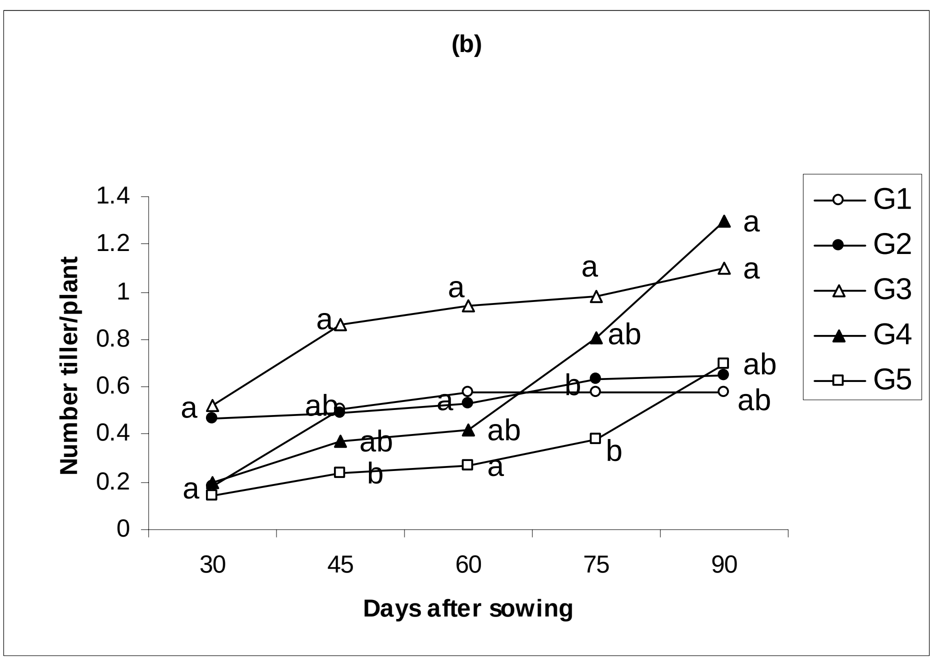
(a)
LAI
Days after sowing
W
S



(b)
LAI
Days after sowing
G1
G2
G3
G4
G5

Figure (6): Effect of watering treatment (a) and genotypes (b) on mean number of tillers per plant of sorghum grown during 2003 season. At each sampling occasion means with similar letters are not significantly different from each other according to LSD.


(a)
Number of tillers/plant
1.2
1
0.8
0.6
0.4
0.2
0
30
45
60
75
90
Days after sowing
W
s
a
b


(b)
Number tiller/plant
1.4
1.2
1
0.8
0.6
0.4
0.2
0
30
45
60
75
90
Days after sowing
G1
G2
G3
G4
G5
a
ab
b

4-1-7 Shoot biomass (kg):

Analysis of variance showed that watering treatments had a significant effect on mean shoot biomass ($P<0.05$), and the well-watered plants had a higher mean shoot biomass compared to stressed plants (Table 1). Likewise, genotypes and the interaction had a highly significant effect on mean shoot biomass (Table 1). In this regard, Feterita Wad Akar (G3) scored the highest shoot biomass under well-watered condition and Debakri (G5) scored the highest shoot biomass under water stress condition (Table 1).

4-2 Phonological attributes:

4-2-1 Number of days to 50% booting:

Watering treatments had no significant effect on mean number of days to booting stage, but it tended to decrease in stressed plants compared to well-watered ones (Table 2).

In contrast genotypes had a highly significant effect on mean number of days to booting ($P<0.01$). In this regard, Mugud (G4) took greater days to reach this stage, while Debakri (G5) was the first one to reach the booting stage. There was a highly significant interaction on mean number of days to booting stage (Table 2).

4. 2.2 Number of days to 50% flowering:

Table (3) showed the effect of treatments on over all mean number of days to 50% flowering stage. Analysis of variance showed that stressed plants significantly had taken fewer days to reach this stage compared to well- watered plants. Likewise, genotypes showed highly significant differences between them in this character ($P<0.01$) . In this regard, Debakeri(G5) took fewer days to flowering stage, whereas Mugud (G4) took longer days to reach this stage (Table 3). No significant interaction was observed in this study.

Table (1) Effect of watering treatments, genotypes and their interaction on mean shoot biomass (kg/ha) of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plants	310.5	246.4	417.9	429.8	235.7	328.1
Stressed-plants	160.7	246.4	316.1	289.3	316.1	265.7
Mean	235.6	246.4	367.0	359.6	275.9	
C.V. For W	17.8 %					
C.V. for G	8.5 %					
LSD $_{5\%}$ for W	5.7*					
LSD $_{5\%}$ for G	4.8**					
LSD $_{5\%}$ for W x G	6.8**					

LSD : Least Significant Difference.
Ns, **, * Means Not Significant and Significant at 0.01, 0.05 level of probability, respectively.

Table (2). Effect of watering treatments, genotypes and their interaction on mean number of days to 50% booting stage of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plants	42.5	41.8	41.5	59.6	26.3	42.1
Stressed-plants	38.8	44.9	42.1	51.5	25.0	40.5
Mean	40.7	43.3	41.8	55.5	25.7	
C.V. for W	0.44%					
C.V. for G	1.4%					
$LSD_{5\%}$ for W	16.2^{ns}					
$LSD_{5\%}$ for G	19.9**					
$LSD_{5\%}$ for W x G	28.2**					

All abbreviation and symbols as in table(1)

Table (3) Effect of watering treatments, genotypes and their interaction on mean number of days to 50% flowering stage of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plants	46.6	44.3	44.3	62.6	40.1	47.6
Stressed-plants	39.1	43.9	43.9	63.0	28.0	43.6
Mean	42.9	44.1	44.1	62.8	34.1	
C.V. For W	0.5 %					
C.V. for G	0.8 %					
$LSD_{5\%}$ for W	3.5*					
$LSD_{5\%}$ for G	3.9**					
$LSD_{5\%}$ for W x G	5.5**					

All abbreviation and symbols as in table 1

4-2-3 Number of days to 50% milking stage:

Watering treatments had no significant effect on mean number of days to milking stage, but the well- watered plants took more days to reach this stage compared to stressed ones (Table 4). In contrast, there were highly significant differences between genotypes($P<0.01$) . In this regard, Mugud(G4) took significantly more days to reach milking stage, while Debakeri (G5) took fewer days to reach this stage (Table 4). A highly significant interaction($P<0.01$) on mean number of days to milking stage was observed in this study (Table 4).

4-2-4 Number of days to 50% physiological maturity:

The effect of treatments on mean number of days to physiological maturity followed similar pattern as described in the previous stages(Table5). Analysis of variance showed that stressed plants took significantly less days to reach this stage compared to well-watered ones (Table 5).

Genotypes showed a highly significant differences ($P<0.01$) on mean number of days to physiological maturity (Table 5). From the results, Debakeri(G5) took fewer days while Mugud(G4) took more days to reach this stage compared to other genotypes (Table5). There was a remarked highly significant interaction ($P<0.01$) on mean number of days to physiological maturity.

4-3 Yield and yield components:

4-3-1 Number of grains/head:

Watering treatments had a highly significant effect on mean number of grains/head, but it tended to increase in well watered plants compared to stressed ones (Table 6).

Table (4) Effect of watering treatments, genotypes and their interaction on mean number of days to 50% milking stage of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plants	53.7	52.5	52.1	70.0	33.6	52.3
Stressed-plants	46.8	47.8	29.4	71.5	33.6	49.9
Mean	50.4	50.2	40.8	70.8	33.6	
C.V. For W	2.3%					
C.V. for G	0.7%					
$LSD_{5\%}$ for W	5.4^{ns}					
$LSD_{5\%}$ for G	10.7^{**}					
$LSD_{5\%}$ for W x G	15.1^{**}					

All abbreviation and symbols as in table (1).

Table (5) Effect of watering treatments, genotypes and their interaction on mean number of days to 50% physiological maturity stage of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plants	61.6	59.3	59.4	77.4	47.3	61.0
Stressed-plants	54.5	58.0	48.1	76.9	42.4	56.0
Mean	58.1	58.7	53.8	77.2	44.9	58.1
C.V. For W	0.5 %					
C.V. for G	1.2 %					
$LSD_{5\%}$ for W	5.7*					
$LSD_{5\%}$ for G	7.2**					
$LSD_{5\%}$ for W x G	10.2**					

All abbreviation and symbols as in table (1).

In contrast, genotypes showed a highly significant differences on mean number of grains/head ($P<0.01$).In this regard, Mugud (G4) and Debakeri(G5) had greater number of grains/head compared to the other genotypes. No significant interaction was observed in this study.

4-3-2 1000 – grain weight (g):

Table (7) showed the interactive effect of wateng treatments and genotypes on mean thousand grain weight of sorghum plants.

The analysis of variance showed that watering treatment had significant effect on mean 1000-grain weight .In this regard, the well-watered plants had higher mean 1000- grain weight compared to stressed plants. Genotypes had significant effect on mean 1000- grain weight($P<0.05$) and, Debakri (G5) had significantly higher grain weight compared to the other genotypes.

There was no significant interaction on mean 1000- grain weight observed in this study (Table 7).

4-3-3 grain yield / plant (g):

Although, the well-watered plants, exhibited higher mean grain yield/plant compared to stress plants. There was no significant difference between treatments (Table 8). In contrast, genotypes had a highly significant effect on mean grain yield/plant ($P<0.01$), where Debakri (G5) showed higher grain yield/plant compared to other genotypes.

A highly significant interaction on mean grain weight/head was observed in this study ($P<0.01$).

Table (6) Effect of watering treatments, genotypes and their interaction on mean number of grains/head of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plant	416	495	684	851	1184	726.0
Stressed-plant	510	480	308	625	736	531.8
Mean	463	487.5	496	738	960	
C.V. For W	8.8%					
C.V. for G	7.0%					
$LSD_{5\%}$ for W	11**					
$LSD_{5\%}$ for G	19**					
$LSD_{5\%}$ for W x G	36**					

All abbreviation and symbols as in table (1).

Table (7) Effect of watering treatments, genotypes and their interaction on mean thousand grain weight (g) of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plants	16.1	15.3	17.5	24.4	36.7	22.0
Stressed-plants	16.7	16.1	14.0	21.5	31.6	20.6
Mean	16.4	15.7	17.7	23.0	34.6	
C.V. For W	10.1 %					
C.V. for G	3.1 %					
$LSD_{5\%}$ for W	2.1*					
$LSD_{5\%}$ for G	1.7*					
$LSD_{5\%}$ for W x G	2.4*					

All abbreviation and symbols as in table (1).

Table (8) Effect of watering treatments, genotypes and their interaction on mean grain yield/ plant(g) of sorghum grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plants	17.9	18.9	22.0	26.2	49.9	27.0
Stressed-plants	17.3	16.4	19.8	24.3	40.8	23.5
Mean	17.6	17.1	20.9	25.2	45.5	
C.V. For W	3.1 %					
C.V. for G	7.7 %					
$LSD_{5\%}$ for W	8^{ns}					
$LSD_{5\%}$ for G	8**					
$LSD_{5\%}$ for W x G	12**					

All abbreviation and symbols as in table (1).

4-3-4 Grain yield/area (kg/ha):

Watering treatments had no significant effect on mean grain yield, but it tended to increase in well-watered plants compared to stressed ones (Table 9).

Genotypes showed highly significant differences on mean grain yield($P<0.01$), In this respect Mugud(G4) and Debakri (G5) had greatest grain yield compared to the other genotypes. A highly significant interaction on mean grain yield was seen in this trail($P<0.01$).

4-3-6 Harvest index (HI):

Watering treatments had no significant effect on mean harvest index but it tended to increase in well-watered plants compared to stressed one (Table 10).

Similarly genotypes had a highly significant effect on mean harvest index($P<0.01$)., In this regard, Debakri (G5) giving greater harvest index compared to the other genotypes. A highly significant interaction on mean HI was seen in this trial($P<0.01$).

Table (9) Effect of watering treatments, genotypes and their interaction on mean grain yield (Kg/ha) of sorghum plant grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plant	4500	4840	4750	7150	7980	5844
Stressed-plant	3680	4080	4570	6100	6990	8040
Mean	4090	4460	4660	6363	7485	
C.V. For W	7.4 %					
C.V. for G	3.5 %					
$LSD_{5\%}$ for W	16^{ns}					
$LSD_{5\%}$ for G	20**					
$LSD_{5\%}$ for W x G	28.2**					

All abbreviation and symbols as in table (1).

Table (10) Effect of watering treatments, genotypes and their interaction on mean harvest index (%)of sorghum plant grown during 2003 season.

Treatment	G1	G2	G3	G4	G5	Mean
Well watered plant	28.0	19.6	11.4	16.6	33.9	21.9
Stressed-plant	11.9	16.6	14.5	21.1	22.1	17.0
Mean	20.0	18.1	13.0	18.9	28.0	
C.V. For W	35.1%					
C.V. for G	19.1%					
$LSD_{5\%}$ for W	16^{ns}					
$LSD_{5\%}$ for G	4**					
$LSD_{5\%}$ for W x G	4**					

All abbreviation and symbols as in table (1)

CHAPTER FIVE

Discussion

In the present study, the performance of some selected sorghum genotypes were evaluated under two different watering regimes. The results showed that most of the parameters measured in this study were affected under water stress. The increase in plant height under prolonged watering interval was associated with significant increase in number of nodes and internodes length. Similar results were reported by Ibrahim *et al*., (1999) who showed that water stress increased the height of the drought tolerant genotypes. In wheat, however, Hussien *et al*., (1968) and Cooper (1980) reported that plant height increased with more frequent irrigation and decreased with less frequent irrigation. Similarly, the number of tillers/plant decreased significantly under prolonged watering interval. Supporting evidence was reported by Nimir (1986) and Ahmed (1989).Moreover, the higher shoot biomass of the well-watered plants observed in this study may be attributed to the greater number of leaves and number of tillers/plant. Similar findings were observed by Steiner *et al*., (1985) and Nimir (1986). However, Parashar,(1979) reported that the reduction in stover yield of sorghum was largest when water stress occurred during heading and grain filling stage. Water deficit during the growing season decreased the number of days to phonological attributes measured in this study. In this regard, the number of days to 50% booting, although insignificant, decreased under water stress. A similar result was reported by Ahmed (1989) who observed no significant difference between watering treatments on mean number of days to panicle initiation. Similarly, water stress significantly hastened the number of days to 50% flowering as was reported by Ahmed (1989).

The grain filling period represents the last and very critical stage of the plant's life cycle and lasts from anthesis to physiological maturity of the grain. In the present study, water stress significantly reduced the number of days to milking and physiological maturity. This result agrees with Seetherma *et al*., (1986) findings. They suggested that physiological maturity was hastened by drought stress, thus curtailing the length of the grain filling period.

In sorghum the potential grain number is determined during the stage of floral initiation and inflorescence development and water stress during this stage resulted in substantial reduction in number of seeds per head. This might explain the significant difference on mean number of grain per head among watering treatments observed in this study. This result is similar to those reported by Ahmed (1989), Ibinidress (1993) and Wright *et al*., (1983). They noticed a degree of floral abortion which severely reduced the number of grain per panicle due to water stress during the booting stage. However, Eck and Musick (1980) suggest that when water stress was initiated at heading or later, only the grain size was reduced while the reduction in seed number probably resulted from some seed not being filled and are more likely to be lost during the threshing process.

Although the grain filling stage, in sorghum, is less sensitive to water stress than the panicle development and expansion stage, yield reduction occurs as a result of reduced seed weight. This is because seed weight is a function of both seed size and degree of seed filling, and moisture stress affect both yield determines. This probably is because without adequate water during the final stages of seed formation, maximum accumulation of carbohydrates, greater seed size and seed density can not be attained. Larson (1975) showed that in addition to reduction in photosynthesis water stress had been shown to reduce translocation from leaves to other plant parts. As a consequence, grain yield per plant and grain yield per unit area were decreased by water stress in this study. Similar results was shown by Evans (1975) who reported that grain yield per head under water stress represents an integrated response of genotype to both grain set and grain filling.

Data from previous research clearly demonstrated the existence of diverse genetic variability among sorghum genotypes. This might explain the consistent variation in the performance of the selected genotypes in response to different watering regimes observed in this study. In this regard, the early maturing genotype (Debakri) was taller, had more nodes and number of leaves per plant and greater internode length compared to the late (Mugud) and medium (Fatarita Wad Akar, Fatarita Abu Gumi and Tabat) maturing genotypes. This vigorous growth may be attributed to the ability of the early maturing genotype to escape drought. This hypothesis was supported by the results of Nimir (1986) and Ibrahim *et al.*, (1999). They indicated that the early maturing varieties of sorghum are more vigorous and drought tolerant. In contrast, the early maturing genotype, as expected, developed less tillers compared to the late genotypes in this study. Similar results were reported by Ahmed (1989). Surprisingly, both Debakri (early maturing) and Mugud (late maturing) outyielded the other genotypes in both grain yield and shoot biomass under both watering regimes. In this respect, both genotypes had greater number of grains per head and grain weight compared to other genotypes. The high yield of the early maturing genotype may be attributed to its ability to complete its life cycle before the onset of severe drought. In addition, the early flowering genotype had a lower leaf area index which could be another mechanism whereby the plant can maintain its water potential under mild water stress. Similar results were reported by Nimir (1986) and Ibrahim *et al*.,(1999). On the other hand, the high yield of the late maturing genotype may be attributed to its high tillering capability which resulted in yield compensation in response to watering regimes. Similar results were reported by Ahmed (1989) and Wenzel (1999) who indicated that severe water stress reduced both yield components. The intermediate performance of Tabat cultivar observed in this study further confirm the previous findings that it was improved as an irrigated cultivar (Nimir, 1986; Ibrahim *et al*., 1999). Similarly, the early maturing genotypes had a higher harvest index compare to other genotypes. This results agreed with Omanya *et al.*,(1996) who found that there were positive correlations between harvest index and grain yield under drought conditions. In conclusion, the early maturing genotypes of sorghum had potential as a grain crop for dry land areas.

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Appendix table (1) Mean Temperature, relative humidity, hours of sun shine and rain fall of Shambat area during 2003 season.

Months	Temperature		Rainfall (mm)	RH%	Sun shine (hours)
	Min	Max			
June	40.9	27.0	6	33	0.79
July	37.3	25.2	40	65	0.73
August	35.8	25.3	74.4	73	0.71
September	38.4	25.2	124.0	61	08.8
October	39.9	22.9	43.4	39	09.5
November	36.1	20.4	___	37	10.1
December	32.6	15.6	___	41	10.0

Appendix table (2) mean squires plant height of sorghum genotypes and their interaction affected by watering treatment grown during 2003 season.

source	d.f	mean squares plant height (cm) days after sowing				
		30	45	60	75	90
Treatment	1	219.02^{ns}	2877.1^{ns}	514.5^{ns}	922.56*	2075.04**
Block	3	674.7^{ns}	2169.1^{ns}	384.99^{ns}	353.65^{ns}	279.58*
Error(a)	3	561.9	5532.4	466.73	39.16	22.85
Variety	4	5421.4*	7464.2^{ns}	11984.67**	14207.47**	10295.77**
Interaction	4	901.8^{ns}	5420.97^{ns}	317.27^{ns}	355.48^{ns}	814.38^{ns}
Error(b)	24	517.9	5336.3	275.29	574.8	945.33

Appendix table (3): mean squires number of leaves/plant of sorghum genotypes and their interaction affected by watering treatment grown during 2003 season.

source	d.f	mean squares number of leaves/plant days after sowing				
		30	45	60	75	90
Treatment	1	2.20^{ns}	11.24^{ns}	13.81^{ns}	2.86^{ns}	13.8^{ns}
Block	3	11.30^{ns}	5.64^{ns}	18.46^{ns}	16.29^{ns}	18.46^{ns}
Error(a)	3	1.23	1.19	9.33	6.11	9.33
Variety	4	5.14^{ns}	33.37^{ns}	11.07	24.93^{ns}	11.07^{ns}
Interaction	4	3.96^{ns}	2.51^{ns}	10.7^{ns}	5.78^{ns}	10.7^{ns}
Error(b)	24	11.12	5.14	4.9	5.7	4.9

Appendix table (4): mean squires number of LAI of sorghum genotypes and their interaction affected by watering treatment grown during 2003 season.

source	d.f	mean squares LAI days after sowing				
		30	45	60	75	90
Treatment	1	11.34^{ns}	3.91^{ns}	2.12ns	0.96^{ns}	0.01^{ns}
Block	3	0.43^{ns}	4.80^{ns}	8.99^{ns}	14.93^{ns}	4.20^{ns}
Error(a)	3	3.89	7.96	1.1	4.64	4.48
Variety	4	15.86^{ns}	42.72*	0.94^{ns}	7.11^{ns}	8.67^{ns}
Interaction	4	1.55^{ns}	0.36^{ns}	9.66^{ns}	1.81^{ns}	10.76^{ns}
Error(b)	24	10.91	5.34	3.31	4.62	3.93

Appendix table (5): mean squires number nodes/plant of sorghum genotypes and their interaction affected by watering treatment grown during 2003 season.

source	d.f	mean squares number of nodes/plant days after sowing				
		30	45	60	75	90
Treatment	1	0.7	0.55^{ns}	4.29ns	1.69**	0.14^{ns}
Block	3	1.78^{ns}	7.11**	0.46^{ns}	0.24^{ns}	0.88^{ns}
Error(a)	3	0.17	0.56	0.63	0.1	1.996
Variety	4	4.83^{ns}	26.3**	43.11**	1.28^{ns}	42.84**
Interaction	4	0.18^{ns}	1.40^{ns}	0.90^{ns}	33.27**	0.75^{ns}
Error(b)	24	0.37	1.13	0.64	0.74	2.55

Appendix table (6): mean squares inter nodes length of sorghum genotypes and their interaction affected by watering treatment grown during 2003 season.

source	d.f	mean squares inter-nodes length days after sowing				
		30	45	60	75	90
Treatment	1	0.53^{ns}	0.03^{ns}	0.65ns	0.53^{ns}	8.74^{ns}
Block	3	3.66^{ns}	13.56^{ns}	4.45^{ns}	39.27^{ns}	3.6^{ns}
Error(a)	3	2.06	6.57	2.59	16.83	0.67
Variety	4	188.62^{**}	56.9*	71.84^{*}	674.27^{ns}	121.32^{**}
Interaction	4	5.59^{ns}	2.22^{ns}	6.59^{ns}	12.97^{ns}	1.91^{ns}
Error(b)	24	3.01	4.26	3.73	137.05	2.98

Appendix table (7): mean squires number of tillers/plant of sorghum genotypes and their interaction affected by watering treatment grown during 2003 season.

source	d.f	mean squares LAI days after sowing				
		30	45	60	75	90
Treatment	1	0.014^{ns}	2.65^{ns}	0.05^{ns}	0.58^{ns}	0.27^{ns}
Block	3	0.22^{ns}	1.47^{ns}	8.99^{ns}	1.53*	0.38^{ns}
Error(a)	3	0.07	2.08	1.1	0.05	0.41
Variety	4	0.29^{ns}	1.68^{ns}	0.94^{ns}	0.54^{ns}	0.93^{ns}
Interaction	4	0.12^{ns}	0.78^{ns}	9.66^{ns}	0.15^{ns}	0.07^{ns}
Error(b)	24	0.4	0.95	3.31	0.18	0.49

Appendix table (8): mean squares yield components of sorghum genotypes and their interaction affected by watering treatment grown during 2003 season.

source	d.f	Number of grain/head	1000 grain weight	Grain yield/plant	Grain yield/area
Treatment	1	212^{ns}	514.5^{ns}	4.29^{ns}	650*
Block	3	899^{ns}	384.49^{ns}	0.46^{ns}	4450*
Error(a)	3	1105	466.73	0.63	2590
Variety	4	941^{ns}	11984.6	43.1^{ns}	7180**
Interaction	4	9662^{ns}	317.3	0.89^{ns}	6580
Error(b)	24	3314	275.29	0.641	3730