Effect of Different Irrigation Levels on Growth and Photosynthetic Capacity of Four Pearl Millet Genotypes

Running Title: Growth and Photosynthetic Capacity of Pearl Millet

Manal A. M. Salih[†1], Abdalwahab H. Abdallah[2],Sayadat El-Tigani[1], Marc J. Janssens[3]and Farhina Pasha[4*]
1 Department of Botany, faculty of Science, University of Khartoum P.O.Box 321 Sudan
2 Department of Agronomy, Faculty of Agriculture, University of Khartoum,P.O.Box 321 Sudan
3. Institute of Horticulture, University of Bonn Auf demHugel 6, D-53121 Bonn Germany

4. *Department Of Biology, College of Science, University of Tabuk 71491 Saudi Arabia
(Corresponding Authors email-farhinabpl@gmail.com Contact -+971507954155)

Author's contribution:

Name of the author	Types of contribution
Manal A. M. Salih	Idea and experimental work
Abdalwahab H. Abdallah	Manuscript and data analysis
Sayadat El-Tigani	Manuscript and data analysis
Marc J. Janssens	Idea and experimental work
Farhina Pasha	Manuscript and data analysis

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Abstract

Background and Objective: Millet is the most important cereal crop in Western Sudan (Kordofan and Darfur provinces), which has a long-term conflicts and drought periods resulted in breakout of famines and hungers. There are many genotypes of local millet which responded differently to stress. This study aimed to compare the growth performance & physiological parameters of selected pearl millet genotypes under different levels of irrigation systems.
Materials and Method: The transpiration rate, stomatal conductance, photosynthetic rate &carbon dioxide assimilation were recorded by portable Portameter (CIRAS). Growth performance i.e.: plant height, stem diameter, no. of leaves, leaf area, no. of tillers and days to inflorescence were recorded at different intervals.
Results: The physiological, morphological and agronomical parameters were affected by the different levels of the irrigation system. The transpiration rate, photosynthetic rate and stomatal conductance were found to increase with the increase in water level. The four genotypes did not vary greatly considering the transpiration and photosynthetic rates. However, varied greatly in stomatal conductance. The morphological and agronomic parameters responded positively with the increase in

the water level of irrigation. Number of tillers, branches and days to 50% flowering initiation had no clear response with the increase in water levels.

Conclusion: All the physiological and morphological parameters had a clear and positive response to the increase in the water level of irrigation systems.

Keywords: Drip irrigation, Pearl millet,stomatal conductance, photosynthetic rate, Carbon dioxide assimilation.

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INTRODUCTION

Knowledge of the physiological characteristics of a crop plant is helpful in its improvement programs. Information on different phases of growth, water use efficiency and fertilizer responsiveness, physiological basis of hybrid vigor, photoperiodic requirement and photosynthetic efficiency should help in maximizing yields[1].

Millet is grown mostly as the main grain crop in the drier Western Parts of Sudan (Darfur and Kordofan States) where climatic conditions permit only millet production. Also there is a limited cultivation of millet in the Eastern region of the country. Pearl millet is grown as a rain fed crop in Africa. It can grow in dry regions with as little as 250mm of annual rainfall[2]. It is a dual-purpose crop; its grain is used for human consumption and its fodder for animal. In Africa and Asia more than 95% of the crop is produced and it is grown mainly for its grain. This study aimed to compare the selected genotypes in growth parameters under different water levels of irrigation.

The importance of water to crop plants had been studied by many physiologists[3,4,5].In the absence of irrigation, drought eventually results in the sustained plant water stress, but transient water stress often develops on hot sunny days in the absence of drought [6].Availability of water contributed largely to the variability in higher plants with respect to morphology, life cycle, internal water economy and metabolism [7]. Apparent photosynthesis may also be influenced by the reduction in turgor and by the increased respiration, which can be expected during the reaction phase of stress imposition [8]. The reduction in leaf water potential by water stress affects turgor and consequently leads to stomatal closure [9]. Several investigators reported that stomatal closure is better correlated with soil water status than with leaf water status[9]. Stomatal closure induced by water deficits causes a depletion of carbon dioxide in the intercellular space.

Plants regulate transpiration through the opening and closing of stomata. Transpiration also regulates leaf temperature. Prolonged stomatal closure will also lead to rapid increase of leaf temperature.It is also observed that stomatal conductance of leaves of pearl millet at flowering largely operates to maximize assimilation rather than to minimize water loss[10].

Water-use efficiency and drought resistance in pearl millet-Pearl millet is mainly grown in rain fed areas in Asia and Africa. It can grow in regions of low rainfall, as 250mm of annual rainfall. Based on their studies of irrigation effects on pearl millet, Gregory and Squire suggested that the grain yield of the crop might be increased in three ways, by: i) Increasing leaf area and the duration of maximum leaf area index. ii) Increasing the size of the root system. iii) By increasing number of tillers that produce panicles[11].

Photosynthesis exploits solar energy to provide the energy of the complex physiochemical reactions of living organisms. High photosynthetic efficiency is essential for high productivity of a plant [12] and the potential rate of CO_2 assimilation depends on the development of an effective metabolic system. Many factors influence photosynthesis, the

factor most limiting photosynthesis in higher plants is the availability of water. Plants possessing the well-known Calvin cycle of CO_2 fixation are referred to as C_3 plants because the early product of the sequence is the C-3 compound, 3-phosphoglyceric acid. A more efficient C_4 pathway metabolism has been reported. Several of the desert plants adapted to high temperatures and high light intensity exhibit the C_4 pathway [13].

C_4 plants generally have higher rates of CO_2 assimilation than C_3 plants. In summer, the temperature range (35-45°c); C_3 and C_4 plants have similar P_{max} (maximum rate of photosynthesis) at appropriate temperatures. C_4 photosynthesis is inherently more productive even in the extreme habitat. C_4 plants have a two-step mechanism of CO_2 fixation, which may help to overcome part of the deleterious effects of water deficiency i.e. starvation of assimilates. The C_4 plants have the preponderance of PEP (Phospho-enol pyruvate) carboxylase and the relatively higher chlorophyll a: b ratio, in contrast to the predominance of RuBp (ribulose-1, 5-bisphosphate) carboxylase and low chlorophyll a: b ratio of C_3plants.Other important characteristics of the C_4 include a low (<10 ppm) CO_2 compensation concentration[13].Pearl millet has a C-4-dicarboxylic acid pathway of photosynthesis .The leaves of pearl millet possessed several fold higher activities of such enzyme as phosphoendpyruvate carboxylase and pyruvate phosphate dikinase than those of the C_3 plant, *Oryzasativa* (rice) compared the photosynthetic carbon metabolism with the anatomical features of cultivated pearl millet leaves[14]. In the mesophyll cells, two enzymes functioned to reduce oxaloacetate, the primary product of CO_2 fixation. These enzymes were:i) The light-activated chloroplast NADP-malate dehydrogenase, and ii)The cytoplasmic NAD-malate dehydrogenase.They also found that like malic acid, aspartic acid participated in the transport of CO_2 from the mesophyll to the bundle sheath cells.Photoperiodism is the developmental response of a plant to the relative duration of day and night [15].The growth and the development of the cultivated species (*Pennisetumglaucum* cultivar Ugandi) and the wild species (*Pennisetumvioloceum*), seemed to be greatly affected by the environmental conditions, particularly the photoperiod.

MATERIALS AND METHODS

Effect of Irrigation level on Growth and Photosynthetic Capacity of four pearl millet genotypes

The experimentswereperformedin the green house at Marhof Experimental Station of the Institute of Horticulture at University of Bonn, Wessling, Germany; during the period May – October, 2001.

Sowing and Germination -Pearl millet fifty seeds, were sown of each genotype in compost, in 46×26×5 cm3 seedling trays.The planting medium constituted of compost (92% organic matter), sand and soil in the ratio of (1:1:1, $^{v}/_{v}$).

Transplanting- was done after approximately 30 days after sowing with seedlings having 4 true leaves.The experiment was laid out in a spilt-split block design with three replicates, with drip irrigation. The main blocks consisted of four water regime treatment (T1, T2, T3 and T4), eachsplittedvertically to accommodate four genotypes (G1, G2, G3 and G4), i.e. total number of pots were 48 (4×4×3). The drip irrigation system was built and each drip supplied water to the pot at a rate of 50ml/minute.The four different water regimes were constructed were T_1: First level, minimum water level was 500ml per irrigation per pot.T_2: Second level was 1000ml per irrigation per pot.T_3: Third level was 1500ml per irrigation per pot.T_4: Fourth level, maximum water level was 2000 ml per irrigation per pot.

Irrigation was conducted twice a week during the normal conditions and altered to three times per week in hot conditions with well water.Fertilizer was applied once every three weeks (Hakaphosblau (BASF), Austria) which contains: 10% P_2O_5, 15% N, 15% K_2O, 2% MgO, 0.05% Mn, 0.01% Zn, 0.01% B, 0.01% Cu, 0.05% Fe, and 0.001% Mo.The water level was adjusted using water meter, time and tensiometer (Tensio-Check TC 1020). The tensiometer readings were recorded at regular

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intervals before and after irrigation. The parameters recorded in this experiment were grouped into two, these were: Physiological and Morphological & agronomic parameters.

Physiological parameters **-**were recorded by means of CIRAS portable Portameter, which were: Transpiration in mmol H_2O $m^{-2}s^{-1}$; Stomatal conductance in mmol $m^{-2}s^{-1}$; Respiration in CO_2 in ppm andPhotosynthesis in mmol CO_2 $m^{-2}s^{-1}$.Analyses of gas exchange were conducted with the portable Portameter type CIRAS-1 differential CO_2/H_2O infra-red analyzer (pp system, Hitchin, Herts, England) with integrated automated gas supply. The plant leaves were clamped in a broad Parkinson leaf chamber, which was connected to the CIRAS-1.Net photosynthesis (A) and transpiration rate (E) as well as stomatal conductance (G_s) and leaf intercellular CO_2 concentration (C_i) were measured at about $\geq 35^{\circ}$C and 360 ppm, CO_2, 70-80% relative humidity and 400-600 umol $m^{-2}s^{-1}$photo synthetically active radiation (PAR) in the glass house. Temperature, relative humidity and radiation of the glass house were recorded automatically through a computerized system.

Morphological and Agronomic parameters studies were, (a) Plant height (cm): from the soil surface to the tip of the main panicle. (b)Stem diameter (cm): measured after panicle exertion at 10 cm above the soil level. (c) Leaf area (cm^2): leaves at the 4, 5 or 6 internodes were measured. Then the leaf area was calculated as follows: Maximum length $\times$ maximum width $\times$ 0.75. (d) Number of leaves per plant: recorded as an average after panicle exertion. (e)Total leaf area (cm^2): calculated as an average leaf area times the average number of leaves per plant. (f) Total number of tillers: calculated as an average of total number of tillers including productive and nonproductive tillers after panicle exertion. (g)Total number of branches: recorded as an average of total number of branches including productive and nonproductive, after panicle exertion. (h) Days to initiation of panicle exertion: the number of days recorded from the sowing date to the time when plants within a pot just started panicle emergence. (i) Main panicle length (cm): the length of the head beard on the main stem. (j)Main panicle diameter (cm): the average diameter of the middle of the main panicle.

The collected data were then analyzed statistically following Gomez and Gomez using the Computer program SPSS[17].

RESULTS AND DISCUSSION

1. Photosynthesis Capacity and Growth Parameters as affected by Irrigation Levels

The Physiological Parameters-The tensiometer readings reflecting the root suction pressure (HPA) were recorded at intervals of 45, 75 and 90 days before and immediately after irrigation. The average tensiometer readings ± standard deviations were recorded in table (1). Considering the first irrigation level, at the age of 45 days the root suction pressure ranged between 20.0 and 23.0 HPA before irrigation and drops to the range of 6.0 and 9.3 HPA immediately after irrigation. The readings at the age of 75 days and 90 days ranged between 79.5 -110.0 HPA and between 221.5 –312.5 HPA respectively.When considering the second level of irrigation; at 45 days, the root pressure ranged between 13.0-19.3 HAP, and 59.5- 90.5 HPA at the age of 75 days. At the age of 90, it ranged between 140.0- 170.0 HPA. At the third level of irrigation (T3), the suction pressure ranged between (10.0 -17.6HPA), (41.0-44.0HPA) and (52.0- 60.5) for the ages 45, 75 and 90 days respectively. It is clear that root suction pressure increased with age and decreased with the increase in water level of irrigation. This was true for the four genotypes. Knowing the change in the root suction pressure with the different levels of water can help in increasing yield as well as reducing the loss of water of irrigation [18].

1.2 *The PortameterReadings*:were recorded at the age of 3 months (Table 2).

The transpiration rate, increases with the increase in water level from T_1 up to T_4 for all genotypes (table 2). Under the second level of irrigation, the transpiration rate ranged between 2.40-2.90 mmol $H_2O/m^2/s$ for the four genotypes. At the third irrigation level, the four genotypes had similar ranges 3.11-3.72 mmol $H_2O/m^2/s$, with the highest rate recorded for

genotypeDarmasa. Under the highest level of water treatment (T_4) the four genotypes had similar rates of transpiration, 4.30-4.60 m mol $H_2O/m^2/s$. (Table 2).

The photosynthetic rate in µmol $CO_2/m^2/s$ also increased with the increase in water level for the different genotypes (Table 2). Under (T_1) irrigation level, the photosynthetic rate ranged between 4.00 – 4.47 µmol $CO_2/m^2/s$. Under level two of irrigation (T_2), the genotypes Bauda and Madlkawia increased with a non-significant value, while Darmasa and Ugandi increased their transpiration rate with a high value. Ugandi had no clear increment in the transpiration rate between T_2 to T_3. The other three genotypes had a noticeable increment in the transpiration rate from T_2 to T_3. The highest water level (T_4) had the highest photosynthetic rates for the four genotypes. Darmasa had the minimum value 7.70 µmol $CO_2/m^2/s$ while the other genotypes: Bauda, Ugandi and Madlkawia had almost the similar or a very close value of photosynthetic rate (8.50 µmol $CO_2/m^2/s$).

The stomatal conductance increased with water levels from T_1 to T_2 up to T_3, but decreased under the highest level of irrigation for the four genotypes (Table 2).Under the first irrigation level (T_1), the stomatal conductance varied greatly between the four genotypes although Bauda and Ugandi had close values; Darmasa and Madlkawia had also close values. Under the second water level (T_2), also the four genotypes varied greatly but Bauda and Madlkawia had more or less close values of stomatal conductance. Under level three (T_3), also the different genotypes varied greatly in their stomatal conductance. The increase in the value of the stomatal conductance with the increase in water level (up to T_3) also varied for the different genotypes (Table 2). In Bauda there was no increase from T_1 to T_2 but a small decrease. From T_2 to T_3 the increase was almost two and half times. For Darmasa, the increase was almost three times from T_1 to T_2 and almost only a little increase from T_2 to T_3. In Ugandi the increase was gradual form T_1 to T_2 to T_3. Madlkawia had almost an increase of more than one and half times from T_1 to T_2, and almost two and half times increasement from T_2 to T_3. All of the four genotypes decreased in their stomotal conductance from T_3 to T_4.In general the respiration rate increased with the increase in water level except in Darmasa and Madlkawia there was a decline in the respiration rate (CO_2 ppm) from T_3 to T_4 of water level. The four genotypes varied in their respiration rate (table 3).

2 Morphological and Agronomic Parameters: 1.1.Plant Height (cm)-The results obtained by the stem height under the different irrigation levels were recorded in table (3). The replicates (R_1, R_2 and R_3) are averages of three readings. The average values were analysed statistically by means of Box Plots cluster bars (Fig.1). Form table 3, table 4, figure 1 and figure 2 the stem height increased with the increase in water level. The genotype Bauda had the highest stem height under the fourth level of irrigation (248.0 cm) followed by Ugandi then Madlkawia and finally Darmasa. Some plants in Bauda reached almost three and half meters in height under level four of irrigation. Under the lowest level of irrigation (T_1), Bauda and Darmasa (88.2 and 86.5 cm respectively) had the minimum stem height then Ugandi (142.8cm) and finally Madlkawia (166.4cm) with the highest stems. From the length of the bars, Madlkawia had high variation within the genotype itself opposite to the other 3 genotypes where there is no clear variation within the genotype itself concerning plant height.Under level two of irrigation (T_2), Ugandi had the highest value followed by Madlkawia, Bauda and finally Darmasa. Also from the length of the bars, the variation within the genotypes themselves is not big. In Bauda, Darmasa and Ugandi there is a jump between T_1 and T_2 plant height, unlike Madlkawia where the difference in stem height between T_1 and T_2 is not so big.Under level three of irrigation (T_3), also the genotype Ugandi had the highest stems (258 cm) followed by Madlkawia, then Bauda and Darmasa which were very close to each other. There is variation within the genotype itself especially in Bauda and Madlkawia. It is clear that the plant height

values were coinciding for T_3 and T_4 in Darmasa, Ugandi and Madlkawia.

1.2 *Stem Diameter (cm)*-The results obtained by the stem diameter under the different irrigation levels were recorded in table (5). Statistical analysis by means of Box plot cluster bars results were illustrated in figure (3).High levels of irrigation resulted in high values of stem diameter. Under level one of irrigation, the stem diameter ranged from 2.87 – 5.17cm for the four genotypes. Darmasa and Madlkawia had the highest value of stem diameter and they were close to each other followed by Ugandi and finally Bauda which had high variation within the genotype itself compared to the other genotypes under level one of irrigation.Under level two of irrigation, the stem diameter values ranged from3.90 – 5.80 cm for the four genotypes. From figure (3) it is clear that among thefour-pearl millet genotypes the highest was in Ugandi, followed by Darmasa and then Bauda.Under level three of irrigation (T_3), Madlkawia and Ugandi had values close to each other except that the variation within the genotype Madlkawia was high. These were little higher than Bauda and Darmasa which had values close to each other (fig.3). The fourth water treatment (T_4) had high values for the stem diameter only in the genotype Darmasa. The values obtained by Bauda were coinciding with the values obtained for T_3. Ugandi and Madlkawia had values of stem diameter less than those obtained under T_3 of irrigation.

1.3 Single Leaf Area (cm^2)-Leaf area (cm^2) was recorded from leaves in nodes 4-6. The average leaf area was recorded in table (6). By means of Box plots cluster bars, the results were analysed and illustrated in figure (4). Generally, it is obvious from figure (4), there is a noticeable variation in the leaf area between the different pearl millet genotypes. The effect of water levels of irrigation on the leaf area of the genotype Bauda (figure, 4), was not high. The leaf area values under T_1, T_2 and T_3were coinciding with each other. Under T_4 of irrigation level there was a small decline in leaf area compared to the value of T_3. In Darmasa the leaf area values were of close values to Bauda. There was an increase in the leaf area from $T_1$to T_2 (figure 4), then a decline in leaf area under T_3 of irrigation and another decline under T_4 of irrigation. The leaf area increased with a small value from T_1 to T_2 in Ugandi. Then a clear increase under T_3 of irrigation and a highest value of leaf area under T_4 of irrigation. This means that increasing water level treatment results in an increase in the leaf area of Ugandi.The fourth genotype Madlkawia, reacted differently to the increase in water level. The values of leaf area under T_1, T_2 and T_3 were coinciding, although there was a small decline in leaf area under T_2 of irrigation.The variation within the genotype itself was clear particularly in T_1. Under T_4 of irrigation level, the area increased with a high value.

1.4 Number of Leaves-The number of leaves per main stem was recorded as an average in table (7). Using statistical analysis , box plots cluster bars; the number of leaves was illustrated in figure (5).Generally speaking different water levels affected the number of leaves per main stem clearly (fig5). In Bauda, increasing water level, increase the number of leaves, with a considerable increase from T_1 to T_2 and a small increase from T_2 to T_3 to T_4.InDarmasa, increasing water level resulted in increasing number of leaves per plant. T_2showedslight increase. A large increase from T_2 to T_3 and but a small increase in number of leaves from T_3 to T_4 (fig.5).InUgandiincreasing water level, increases the number of leaves per main stem except for the highest water level (T_4) reduced the number of leaves. The variation in Ugandi itself is clear in T_3 results (Figure 5and Table 7).Madlkawia reacted similarly to Ugandi towards increasing water levels, except that the values of increase or declining are small compared to that of Ugandi. The pattern of bars for the number of leaves is similar to that of the stem height, this indicates that the stem height is increased due to the increase in number of nodes which is reflected by the increase in number of leaves.

1.5 Total Leaf Area (cm^3)- The results are tabulated in table (8). Box plots cluster bars obtained from the statistical analysis are illustrated in figure (6). Under T_1, from figure (6), Ugandi had the smallest total leaf area which

ranged between 1065 – 2033 cm^2. Madlkawia had high value of total leaf area almost close to the value obtained by the other two genotypes: Bauda and Darmasa the variation within the genotype itself varied greatly (1731.66 – 4060.10 cm^2). The four pearl millet genotypes reacted differently to the increase in water level. In the genotype Bauda the total leaf area increased with the increase in water level from T_1 to T_2 up to T_3, then decline in the total leaf area under T_4 of irrigation. Darmasa more or less, followed the same pattern of Bauda, even the total leaf area values were close to each other.Ugandi which had the smallest values of total leaf area, always increased its total leaf area with the increase in water level, although the range of the value under T_3 was large.Increasing water level resulted in an increase in total leaf area of the genotype.Madlkawia which had the highest value of leaf area under T_4 of irrigation. It is clear that there is an increase in the total leaf area with the increase in the water level, (up to T_3 in Bauda, Darmasa and Ugandi).If we compared figure: 4, 5 and 6 with each other, we can observe that the pattern of the bars of the genotypes Darmasa, Ugandi, Bauda and Madlkawia are more or less similar in figure 4 and figure 6. This might illustrate that the increase in total leaf area is a result of the increase in the leaf dimensions (single leaf area) and not from the number of leaves increment.

1.6 Total Number of Tillers-Total number of tillers included the vegetative as well as reproductive ones. This was recorded after main stem panicle exertion. The results were tabulated as averages in table (9). Again, box plots cluster bars obtained by statistical analysis are illustrated in Figure (7). Different water levels have no clear effect on the number of tillers of the four pearl millet genotypes except in Ugandi. The number of tillers decreased with the increase in water level up to T_3, then a noticeable increment under T_4 of irrigation (fig.7). Pattern of the plot bars was similar between the four genotypes and within the genotype itself. The variation within the group itself was large so the different values were coinciding together (table 9). In Bauda, T_2 level of irrigation increased the average number of tillers then decreased under T_3 and T_4. inDarmasa, $T_2$and T_3 average values were similar less than T_1 ad again increased under T_4. Madlkawia had the same average of tillers under T_1, T_2 and T_3 then an increaseunder T_4.

1.*6-Total number of branches*- were recorded for the four pearl millet genotypes under the different water levels after the main panicles exertion and recorded in averages in table (10). Statistical analysis reflected the results in the form of box plots cluster bars (fig.8). Level four (T_4) did not result in an increase in the total number of branches for the four genotypes. The four genotypes reacted differently with the increase in water level in producing branches level one gave the highest number for Bauda and Ugandi, while Madlkawia had the highest number of branches (4.33) under level two of irrigation, and Darmasa had high branches (2.33) under level three (T_3) of irrigation. Under level four of irrigation, Bauda, Darmasa and Madlkawia had values of zero branches.

1.7 Days to Flowering Initiation-Table (11) illustrates days to flowering initiation taken by the four pearl genotypes under the different irrigation levels. From the duration recorded in the table, the irrigation level did not affect days to inflorescence but the pearl millet genotypes themselves varied greatly in the time taken to initiate inflorescence. The genotypes Bauda and Darmasa took between 133 – 139 days to flowering initiation while Ugandi and madlkawia took between 102-110 days to flowering initiation. The water level has no effect on the period of each genotype. Table (12) shows the length of the days and nights in Bonn, Germany during the period of the experiment (May – November 2001).

1.8 Panicle Dimensions-The length and the width of the main stem panicles for the four pearl millet genotypes under different irrigation levels are recorded in table (12). It is clear from the results obtained, that the genotypes Ugandi and Madlkawia showed increase in panicle dimensions (length and width) with the increase in water level, while it is not clear in the other two genotypes Bauda and Darmasa. These two (Bauda and Darmasa) had delayed flowering

initiation (133-139 days) and this might be confirmation for the conclusion derived; long hours of day light resulted in an enhanced vegetative phase for Bauda and Darmasa where plants reached height of more than 350cm. This was on the expense of the reproductive phase which was reflected on delay on flower initiation and decreased panicle size.

Considering plant height and main stem diameter, both parameters responded positively and very clearly to the increase in water level of irrigation in the four pearl millet genotypes. The high atmospheric humidity and long day length of the green house contributed together with the high-water levels to give very high stems which reached length of more than three and half meters. These findings confirm that the increase in the amount of water affects all the physiological and biochemical processes. This is reflected by the increase in the rate of cell division and also in cell expansion which is then reflected in the growth rate[19,20].The four genotypes varied among each other in their response to the water level. The genetic variance expressed under dry conditions and well water conditions was also reported in other crops[21].The leaf dimension; expressed in single leaf area, number of leaves per plant and total leaf area; also showed clear response to the water levels. Again variation among the different pearl millet genotypes was noticed. The variation was high in the number of leaves per plant compared to the leaf area. The increase in number of leaves with the increase in the level of water of irrigation is similar to the response and increase in the main stem height with the increase in the irrigation level[22]. This states that the increase in the main stem height resulted from increasing the number of nodes more than from the increase in the length of internodes[1,14].

There was also an increase in the single leaf area and total leaf area with increasing the water level except in the genotypes Bauda, Darmasa and Ugandi which experienced a small decrease under level four of irrigation. Again, it is worth mentioning here that there was also a significant decrease in the stomatal conductance under level four of irrigation.The increase in the total leaf area with increasing the water level resulted from the increase in the number of leaves per plant more than for the increase in the leaf dimensions.The increase in leaf area with the increasing in water level is a result of increasing growth rates, and these findings agree with[23].Considering the number of tillers and branches, no positive response was noticed with the increase in water level, except a very small increase for the number of tillers in Ugandi and Madlkawia. Although the high growth of the vegetative parts, high stem, large leaf area was expected to increase the number of tillers and branches since the capacity of tillering and branching is known to be very high in these genotypes of pearl millet. The only explanation is the restricted area i.e. the size of pots formed an obstacle and restricted the process of tillering and branching.

Considering days to flowering initiation, the results obtained reflected that water level has no effect on days to flowering initiation for the four pearl millet genotypes. The genotypes varied greatly in the period taken to change from vegetative to the reproductive stage. Naturally under field conditions these genotypes took almost a period of 35-45 days to change into the reproductive phase, but under the green house conditions they took between 102-139 days to flowering initiation. The long day period and irrigation level interacted to enhance the vegetative phase. The growth and development of pearl millet were affected greatly by the photoperiod[10,18]. When planted in October both the two pearl millet species (wild and cultivated) took 40 days for panicle exertion, while they took only 28 days for the panicle exertion when planted on December. Hence flowering was enhanced by the short photoperiod. In this experiment the long day in Germany enhanced the vegetative state and resulted in very delayed initiation of inflorescence, which only started with the decreasing in day length (October 2001).Again, these findings agree with other workers[7,15]. The delayed onset of the reproductive state affected the panicle size. The size obtained was

less than that under normal field conditions; even the increase in size with the increase in the water level of irrigation was not high and inconsistent[24,25].

Conclusion: The physiological, morphological and agronomical parameters were affected by the different levels of the irrigation system. The transpiration rate, photosynthetic rate and stomatal conductance were found to increase with the increase in water level. The four genotypes did not vary greatly considering the transpiration and photosynthetic rates. However, they varied greatly in stomatal conductance. The morphological and agronomic parameters responded positively and very clearly to the increase in the water level of irrigation. Number of tillers, number of branches and days to 50% flowering initiation had no clear response with the increase in water levels. As adaptation to drought is all about corresponding supply and demand of water for crop survival.

Significance statement: This study discovers the responses of different varieties of different millet genotypes to different level of irrigation. The four genotypes reacted differently with the water level. This study will help in deciding the suitable genotype to be cultivated according to the condition available. Thereby making millet production in arid and semiarid region an opportunity rather than a challenge for economic prosperity.

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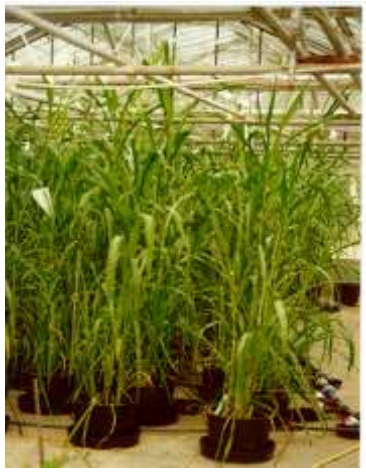

Figure 1. Boxplot bars for the plant height as affected by different irrigation levels

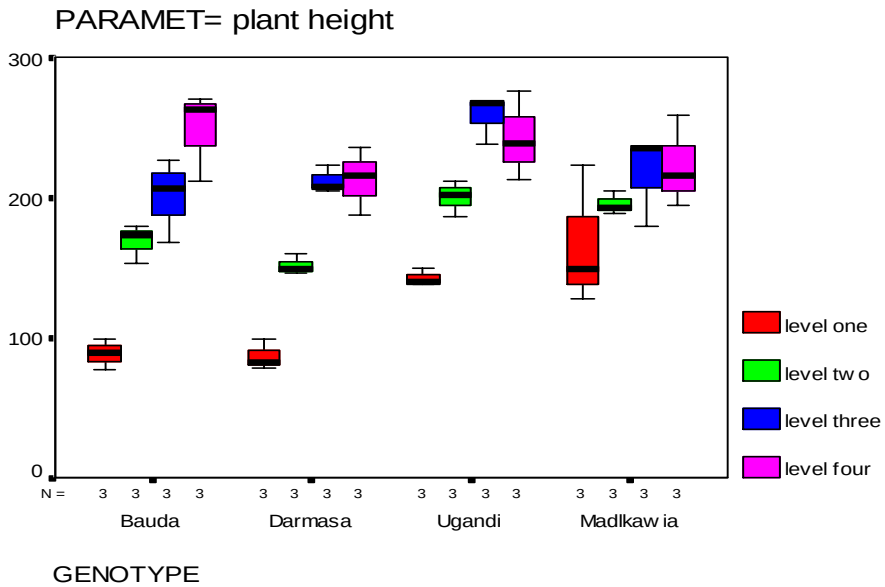

Figure 2. Variation in stem height under different water levels

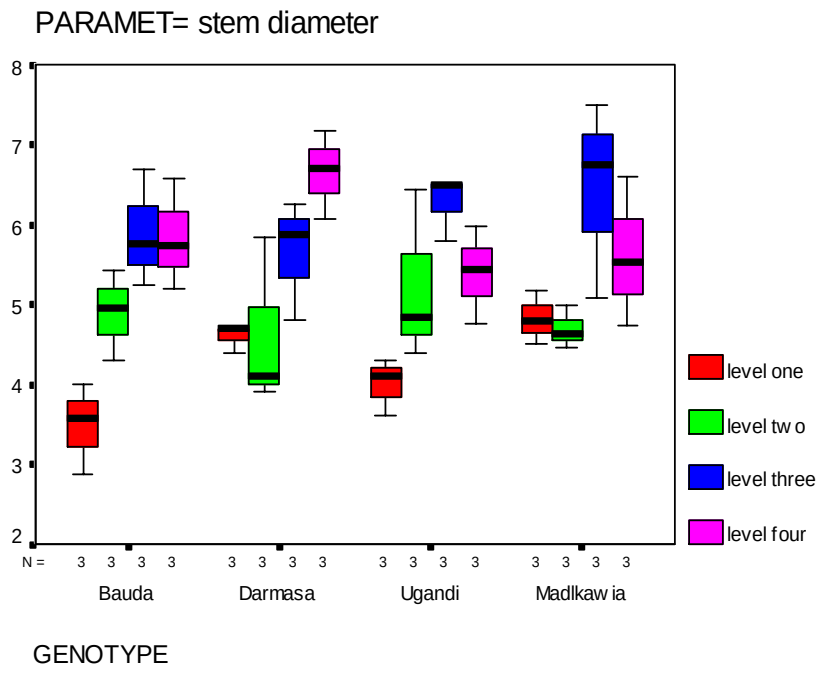

Figure 3 Boxplot bars for the stem diameter as affected by different irrigation

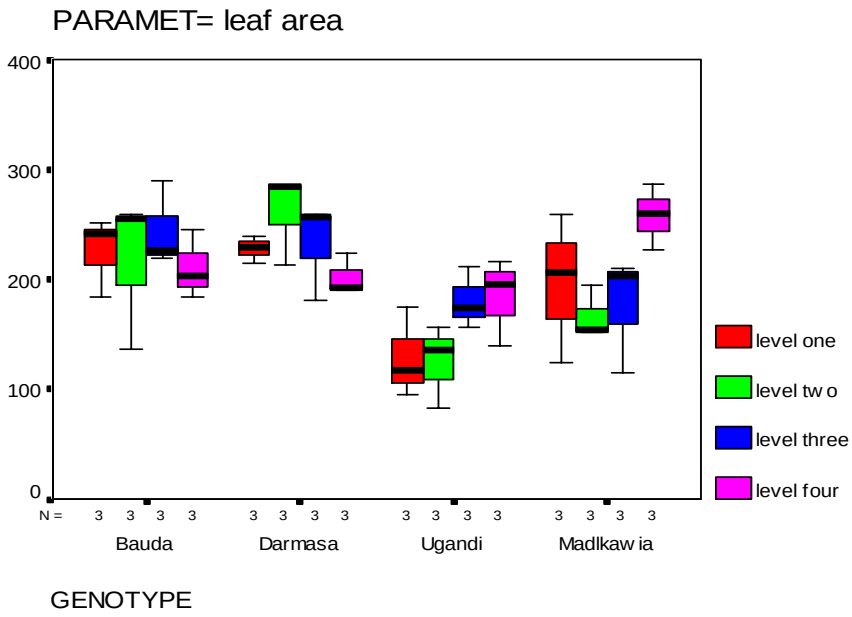

Figure 4. Boxplot bars for the single leaf area as affected by different irrigation levels

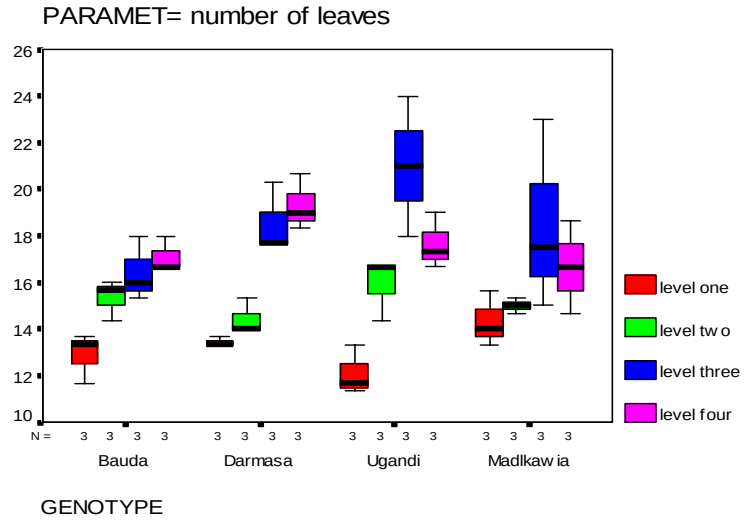

Figure 5 Boxplot bars for the number of leaves as affected by different irrigation levels

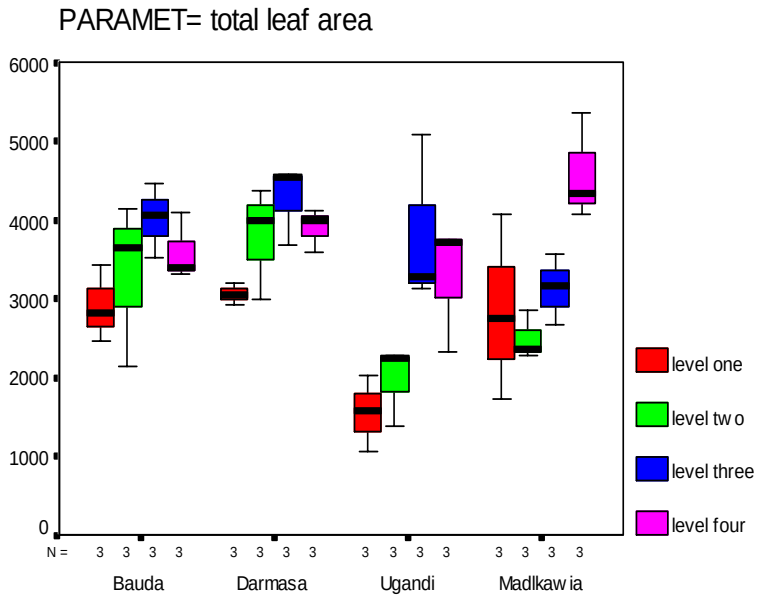

Figure 6. Boxplot bars for the total leaf area as affected by different irrigation levels

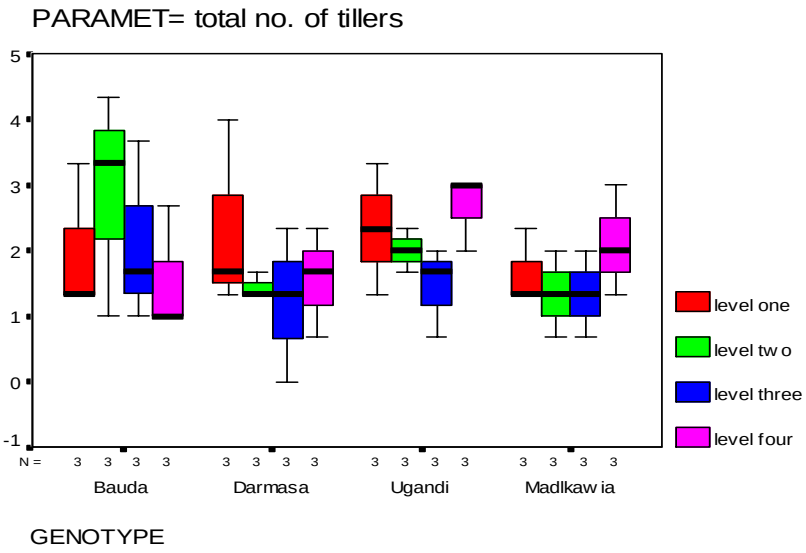

Figure 7. Boxplot bars for the number of tillers as affected by different irrigation levels

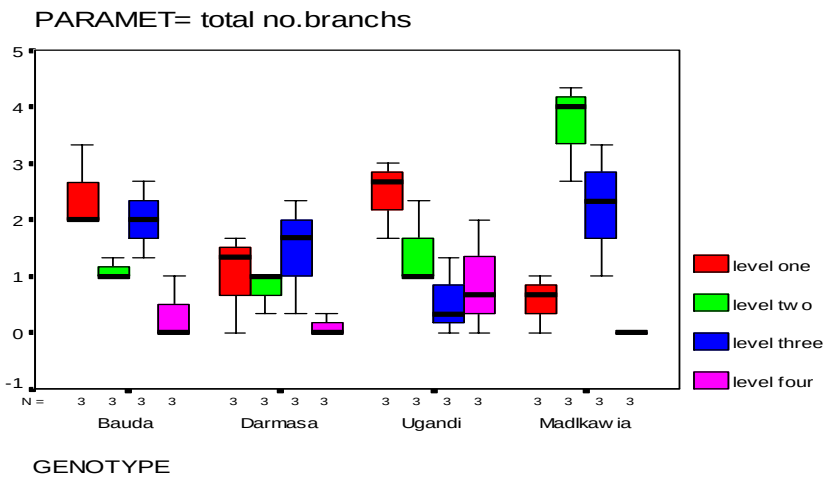

Figure 8. Boxplot bars for the number of branches as affected by different irrigation levels

Table (1) Root suction pressure (HPA) ± S.D. for the four pearl millet genotypes as affected by the four irrigation levels at different intervals

Root suction pressure (HPA)						
Treatment	45 days old		75 days old		90 days old	
	Before irrigation	After irrigation	Before irrigation	After irrigation	Before irrigation	After irrigation
T_1B	21.0 ± 3.0	8.0 ± 2.5	88.5 ± 11.0	7.0 ± 4.3	312.5 ± 33.3	72.7 ± 10.7
T_2B	17.0 ± 2.5	6.0 ± 2.7	74.0 ± 9.3	5.7 ± 2.5	150.7 ± 20.6	62.3 ± 8.3
T_3B	12.0 ± 3.5	3.0 ± 1.3	41.0 ± 9.0	3.0 ± 1.7	72.0 ± 21.3	14.0 ± 6.0
T_4B	8.0 ± 2.0	0.0 ± 0.0	34.0 ±6.0	0.9 ± 0.7	33.3 ± 9.0	2.5 ± 2.0
T_1D	20.0 ± 2.0	7.0 ± 2.0	80.0 ± 13.3	6.5 ± 3.6	211.5 ± 30.7	73.3 ± 10.5
T_2D	15.0 ± 2.5	5.0 ± 3.0	70.5 ± 7.0	5.0 ± 1.7	140.0 ± 21.0	62.3 ± 9.7
T_3D	10.0 ± 2.0	2.5 ± 1.5	44.0 ± 6.5	2.5 ± 1.3	60.5 ± 18.7	15.0 ± 11.5
T_4D	8.0 ± 3.0	0.0 ± 0.0	40.5 ± 6.3	1.0 ± 0.9	14.0 ± 10.5	5.0 ± 3.7
T_1U	20.0 ± 2.5	6.0 ± 2.5	79.5 v 14.5	6.0 ± 3.7	273.0 ± 28.5	65.0 ± 13.3
T_2U	13.0 ± 3.0	5.0 ± 1.7	59.5 ± 6.7	4.5 ± 3.0	170.5 ± 19.5	50.0 ± 11.0
T_3U	11.0 ± 2.5	3.0 ± 0.7	47.0 ± 6.5	2.0 ± 0.7	60.5 ± 15.0	13.5 ± 7.5
T_4U	7.0 ± 2.0	0.0 ± 0.0	40.0 ± 5.3	1.3 ± 0.6	29.5 ± 11.7	3.5 ± 2.7
T_1M	23.0 ± 2.5	9.3 ± 3.0	104.0 ± 27.0	7.0 ± 4.5	221.5 ± 21.7	66.7 ± 9.7
T_2M	19.3 ± 3.9	7.5 ± 3.0	90.5 v 19.0	5.5 ± 3.7	170.7 ± 19.0	55.5 ± 6.0
T_3M	17.6 ± 2.5	2.7 ± 1.3	43.0 ± 11.3	3.0 ± 2.5	62.5 ± 9.1	11.3 ± 2.5
T_4M	9.0 ± 1.7	0.7 ± 0.5	33.0 ± 7.0	1.5 ± 1.3	14.3 ± 5.7	2.0 ± 0.67

(*T_1, T_2, T_3 and T_4 stands for the first, second, third and fourth irrigation level. B, D, U and M stands for Bauda, Darmasa, Ugandi and Madlkawia.SD : Standard Deviation. HPA: Root suction pressure)

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Table (2): Transpiration rate (E), photosynthetic rate (A), stomatal conductance (G) and respiration rate (Ci) for the four pearl millet genotypes under four levels of irrigation

Treatment	Transpiration (E) µmol $H_2O/m^2/s$ ± S.D.	Photosynthetic rate (A) µmol $CO_2/m^2/s$ ± S.D.	Stomatal conductance (G) µmol/m^2/s ± S.D.	Respiration rate (Ci) in CO_2 ppm ± S.D.
T_1B	0.80 ±0.05	4.00 ± 0.80	27.33 ± 2.03	120.00 ± 31.00
T_2B	2.77 ± 0.11	4.20 ±1.50	25.67 ± 6.00	215.00 ± 31.00
T_3B	3.40 ± 0.11	5.80 ± 1.00	67.33 ± 7.00	232.00 ± 6.70
T_4B	4.31 ±0.06	8.60 ± 0.80	27.00 ± 4.67	273.67 ± 25.30
T_1D	0.95 ± 0.20	4.10 ± 05.0	16.33 ± 7.67	100.00 ± 30.00
T_2D	2.85 ±0.08	5.40 ± 0.50	50.00 ± 13.33	191.30 ± 37.33
T_3D	3.72 ± 0.20	6.50 ± 2.00	59.67 ± 10.00	317.00 ± 64.00
T_4D	4.46 ± 0.33	7.70 ±1.30	42.00 ± 11.33	131.00 ± 24.00
T_1U	0.89 ± 0.10	4.47 ± 2.00	26.67 ± 7.00	230.00 ± 34.0
T_2U	2.41 ±0.01	5.30 ± 1.40	34.67 ± 10.67	244.00 ± 54.00
T_3U	3.11 ± 0.05	5.50 ± 1.00	45.33 ± 9.00	243.00 ± 18.67
T_4U	4.60 ± 0.06	8.50 ± 2.40	18.00 ± 7.33	256.38 ± 8.33
T_1M	0.82 ± 0.12	4.30 ± 1.20	12.00 ± 5.00	172.50 ± 24.50
T_2M	2.92 ± 0.07	4.40 ± 2.50	21.67 ± 3.33	297.00 ± 99.00
T_3M	3.69 ± 0.04	5.80 ± 1.70	52.33 ± 16.33	327.50 ± 54.50
T_4M	4.47 ± 0.14	8.40 ± 1.00	23.67 ± 6.67	267.67 ± 13.30

(*T_1, T_2, T_3 and T_4 stands for the 1st, 2nd, 3rd, and 4th irrigation level. B, D, U and M stands for Bauda, Darmasa, Ugandi and Madlkawiarespectively.**µmol $H_2O/m^2/s$.: micromole water per meter square per square, S.D S.:tandard deviation**)

Table 3: Plant height (cm) results, under different water levels for the four pearl millet genotypes

Treatment	Plant height R_1 (cm)	Plant height R_2 (cm)	Plant height R_3 (cm)	Mean value (cm)
T_1B	76.50	89.40	98.70	88.2
T_2B	152.80	172.80	179.00	168.2
T_3B	167.70	226.70	206.70	200.4
T_4B	211.30	270.30	262.30	248.0
T_1D	78.20	98.70	82.70	86.5
T_2D	146.00	148.50	159.30	151.3
T_3D	208.00	205.00	223.30	212.1
T_4D	187.00	215.30	236.00	212.8
T_1U	138.30	150.00	140.00	142.8
T_2U	186.50	211.30	201.70	199.8
T_3U	267.50	268.00	238.50	258.0
T_4U	276.00	212.70	239.00	242.6
T_1M	127.70	148.30	223.30	166.4
T_2M	204.20	188.80	193.00	195.3
T_3M	179.00	235.00	235.00	216.3
T_4M	215.00	259.00	194.00	222.7

(*T_1, T_2, T_3 and T_4 stands for the first, second, third and fourth irrigation level respectively. B, D, U and M stands for the genotypes: Bauda, Darmasa, Ugandi, Madlkawia. R_1, R_2 and R_3 stands for the 1st replicate, 2nd and 3rd replicates respectively. Cm: centimeter)

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Table 4: ANOVA results for the different growth parameters of the four pearl millet genotypes (F Ratio) as affected by different water levels

Parameter	Source	F ratio
Plant height	Treatment	13.55
	Water	52.13
	Genotypes	8.95
	WXG interaction	2.21
Stem diameter	Treatment	4.55
	Water	17.65
	Genotypes	0.69
	WXG interaction	1.47
Single leaf area	Treatment	2.91
	Water	0.77
	Genotypes	8.38
	WXG interaction	1.80
Number of leaves	Treatment	6.55
	Water	26.19
	Genotypes	1.23
	WXG interaction	1.78
Total leaf area	Treatment	4.50
	Water	11.00
	Genotypes	5.80
	WXG interaction	1.90
Total tillers	Treatment	0.75
	Water	1.01
	Genotypes	0.64
	WXG interaction	0.70
Total branches	Treatment	5.88
	Water	9.98
	Genotypes	2.65
	WXG interaction	5.60
Days of flowering initiation	Treatment	15.89
	Water	0.34
	Genotypes	77.30
	WXG interaction	0.60

Table 5: Stem diameter (cm) for the four pearl millet genotypes under different irrigation levels

Treatment	Stem diameter cm. R_1	Stem diameter cm. R_2	Stem diameter cm. R_3	Mean cm
T_1B	3.57	4.00	2.87	3.48
T_2B	4.96	5.43	4.30	4.90
T_3B	5.77	5.23	6.70	5.90
T_4B	6.57	5.73	5.20	5.83
T_1D	4.40	4.70	4.70	4.60
T_2D	4.10	5.83	3.90	4.61
T_3D	5.87	4.80	6.25	5.64
T_4D	6.07	7.17	6.70	6.65
T_1U	4.10	3.60	4.30	4.00
T_2U	4.40	6.43	4.83	5.22
T_3U	6.50	5.80	6.50	6.27
T_4U	5.97	4.77	5.473	5.39
T_1M	4.80	4.50	5.17	4.82
T_2M	4.47	4.63	5.00	4.70
T_3M	6.75	5.07	7.50	6.44
T_4M	4.73	6.60	5.53	5.62

(*T_1, T_2, T_3 and T_4 stands for the first, second, third and fourth water levels respectively. B, D, U and M stands for the genotypes Bauda, Darmasa, Ugandi and Madlkawia respectively. R_1, R_2 and R_3 stands for the 1st, 2nd and 3rd replicates. Cm: centimeter)

Table 6: Leaf area (cm2) results under four irrigation levels

Treatment	Leaf area cm^2 R_1	Leaf area cm^2 R_2	Leaf area cm^2 R_3	Mean cm^2
T_1B	240.96	184.20	250.91	225.37
T_2B	258.79	254.62	135.86	216.42
T_3B	290.0	225.51	219.38	245.03
T_4B	244.87	202.90	184.32	210.70
T_1D	239.70	214.11	229.13	227.65
T_2D	213.51	284.68	285.29	261.16
T_3D	259.28	180.81	254.89	232.33
T_4D	189.27	192.58	224.00	201.95
T_1U	117.72	94.81	174.29	128.94
T_2U	156.05	136.23	82.76	125.01
T_3U	173.82	212.06	156.18	180.69
T_4U	195.65	139.35	216.70	183.90
T_1M	205.68	123.69	259.10	196.16
T_2M	194.05	152.10	153.68	166.61
T_3M	203.36	115.46	210.65	176.49
T_4M	227.55	286.98	260.00	258.18

(*T_1, T_2, T_3 and T_4 stands for level one, two, three and four of water treatment. B, D, U and M stands for the genotypes: Bauda, Darmasa, Ugandi and Madlkawia. The three replicates are indicated with R_1, R_2 and R_3. Cm^2: centimeter square)

Table 7: Number of leaves per main stem of the four pearl millet genotypes under different level of irrigation

Treatment	Number of leaves R_1	Number of leaves R_2	Number of leaves R_3	Number of leaves mean
T_1B	11.67	13.33	13.67	12.89
T_2B	16.00	14.33	15.67	15.33
T_3B	15.33	18.00	16.00	16.44
T_4B	16.67	16.67	18.00	17.11
T_1D	13.33	13.67	13.33	13.44
T_2D	14.00	15.33	14.00	14.44
T_3D	17.67	20.30	17.67	18.55
T_4D	19.00	20.67	18.33	19.33
T_1U	13.33	11.33	11.67	12.11
T_2U	14.33	16.67	16.67	15.89
T_3U	18.00	24.00	21.00	21.00
T_4U	19.00	16.67	17.33	17.67
T_1M	13.33	14.00	15.67	14.33
T_2M	14.67	15.00	15.33	15.00
T_3M	17.50	23.00	15.00	18.50
T_4M	14.67	18.67	16.67	16.67

(*T_1, T_2, T_3 and T_4 stands for the four levels of water treatment. B, D, U and M stands for the four pearl millet genotypes: Bauda, Darmasa, Ugandi and Madlkawia. R_1, R_2 and R_3 stands for the three replicates.)

Table 8: Total leaf area (cm^2) of the four pearl millet genotypes as affected by different water levels

Treatment	Total leaf area (cm^2)	Total leaf area (cm^2)	Total leaf area (cm^2)	Mean value

	R_1	R_2	R_3	(cm^2)
T_1B	2812.00	2455.39	3429.80	2899.06
T_2B	4140.64	3648.70	2128.93	3306.09
T_3B	4448.77	4059.18	3510.08	4006.01
T_4B	4081.77	3382.34	3317.76	3593.96
T_1D	3195.20	2926.88	3054.30	3058.79
T_2D	2989.14	4364.14	3994.06	3762.11
T_3D	4581.48	3670.44	4539.25	4263.72
T_4D	3596.13	3980.44	4105.92	3894.16
T_1U	1569.21	1065.02	2033.96	1556.06
T_2U	2236.20	2270.95	1379.61	1962.44
T_3U	3128.76	5089.44	3279.95	3832.72
T_4U	3717.35	2322.96	3755.41	3265.24
T_1M	2741.71	1731.66	4060.10	2844.49
T_2M	2846.71	2281.50	2355.91	1494.71
T_3M	3558.80	2655.58	3159.75	3124.71
T_4M	4071.66	5357.92	4334.20	4587.93

(*T_1, T_2, T_3 and T_4 are the four water levels. B, D, U and M are the four pearl millet genotypes. R_1, R_2 and R_3 are the three replicates. Cm^2: centimeter square)

Table 9: Total number of tillers of the four pearl millet genotypes under the four irrigation levels

Treatment	Number of tillers R_1	Number of tillers R_2	Number of tillers R_3	Tillers mean value
T_1B	3.33	1.33	1.33	2.00
T_2B	3.33	1.00	4.33	2.89
T_3B	3.67	1.00	1.67	2.11
T_4B	2.67	1.00	1.00	1.56
T_1D	1.67	1.33	4.00	2.33
T_2D	1.67	1.33	1.33	1.44
T_3D	2.33	0.00	1.33	1.22
T_4D	2.33	0.67	1.67	1.56
T_1U	2.33	1.33	3.33	2.33
T_2U	2.33	2.00	1.67	2.00
T_3U	2.00	1.67	0.67	1.45
T_4U	3.00	2.00	3.00	2.67
T_1M	1.33	1.33	2.33	1.66
T_2M	3.67	1.33	2.33	2.44
T_3M	0.67	1.33	2.00	1.33
T_4M	1.33	2.00	3.00	2.11

(*T_1, T_2, T_3 and T_4 stands for level one, two, three and four of water treatment. B, D, U and M stands for Bauda, Darmasa, Ugandi and Madlkawia pearl millet genotypes. R_1, R_2 and R_3 stands fro the three replications.)

Table 10: Total number of branches of the four pearl millet genotypes under the four water treatments

Treatment	Total number of branches			
	R_1	R_2	R_3	Mean value
T_1B	3.33	2.00	2.00	2.78
T_2B	1.00	1.33	1.00	1.11
T_3B	1.33	2.00	2.67	2.00
T_4B	1.00	0.00	0.00	0.33
T_1D	1.67	1.33	0.00	1.00
T_2D	1.00	0.33	1.00	0.78
T_3D	1.67	0.33	2.33	1.44
T_4D	0.00	0.00	0.33	0.11
T_1U	2.67	3.00	1.67	2.45
T_2U	1.00	1.00	2.33	1.44
T_3U	0.33	1.33	0.00	0.55
T_4U	0.67	2.00	0.00	0.89
T_1M	1.00	0.00	0.67	0.55
T_2M	4.00	4.33	2.67	3.67
T_3M	1.00	2.33	3.33	2.22
T_4M	0.00	0.00	0.00	0.00

(*T_1, T_2, T_3 and T_4 are the four water levels. B, D, U and M are the four pearl millet genotypes Bauda, Darmasa, Ugandi and Madlkawia. R_1, R_2 and R_3 are the three replications.)

Table 11 Days to flowering initiation of the four pearl millet genotypes under the four water levels

Treatment	Days to flowering initiation			
	R_1	R_2	R_3	Mean value 3R
T_1B	140.0	135.0	136.0	137.0
T_2B	135.0	138.0	137.0	136.7
T_3B	134.0	133.0	132.0	133.0
T_4B	132.0	133.0	129.0	131.3
T_1D	134.0	133.0	135.0	134.0
T_2D	134.0	136.0	134.0	134.7
T_3D	136.0	140.0	138.0	138.7
T_4D	137.0	140.0	138.0	138.3
T_1U	106.5	114.5	100.3	107.1
T_2U	98.0	95.0	113.0	102.0
T_3U	106.0	95.0	120.0	107.0
T_4U	111.0	109.0	112.0	110.7
T_1M	109.0	120.0	92.0	107.0
T_2M	96.5	114.4	106.0	105.3
T_3M	101.0	98.0	114.5	104.5
T_4M	109.0	109.0	110.0	109.3

(*T_1, T_2, T_3 and T_4 stands for the 1st, 2nd, 3rd and 4th irrigation level. B, D, U and M stands for Bauda, Darmasa, Ugandi and Madlkawia. R_1, R_2, R_3 are the three replicates.)

Table 12: The duration of light and darkness in Bonn, Germany during (June – November 2001)

Date	Day hours	Night hours
1st June	17.50	6.50
15th June	17.50	6.50
30th June	17.00	7.00
1st July	17.00	7.00
15th July	16.25	7.75
31st July	15.50	8.50
1st August	15.50	8.50
15th August	15.00	9.00
31st August	13.50	10.50
1st September	13.50	10.50
15th September	12.25	11.75
30th September	11.75	12.25
1st October	11.75	12.25
15th October	10.50	13.50
31st October	10.00	14.00
1st November	10.00	14.00
15th November	9.00	15.00

Table 13: Main panicle length, main panicle width, longest panicle length and the highest width value for the four pearl millet genotypes under the four water levels

Treatment	Average panicle length (cm) ± S.D.	Average panicle width (cm) ± S.D.	Longest panicle length (cm)	Highest panicle width (cm)
T_1B	12.07 ± 0.83	4.14 ± 0.86	12.50	8.00
T_2B	10.12 ± 0.87	5.40 ± 1.75	11.00	6.50
T_3B	9.50 ± 2.50	7.50 ± 2.00	11.50	13.00
T_4B	11.50 ± 2.50	8.40 ± 1.90	13.00	8.50
T_1D	7.58 ± 2.30	4.67 ± 1.77	10.50	5.00
T_2D	8.00 ± 1.50	5.50 ± 0.75	10.00	7.00
T_3D	8.20 ± 1.64	6.00 ± 0.67	12.00	6.00
T_4D	6.00 ± 1.20	8.40 ± 1.90	13.00	8.50
T_1U	13.85 ± 3.70	6.00 ± 1.00	21.00	7.00
T_2U	14.38 ± 3.736	7.25 ± 0.25	19.50	7.50
T_3U	18.60 ± 5.30	8.00 ± 0.75	26.00	8.00
T_4U	17.67 ± 3.80	8.50 ± 2.67	22.00	9.00
T_1M	15.67 ± 2.00	7.50 ± 1.50	20.00	7.50
T_2M	18.38 ± 3.20	8.00 ± 2.67	24.00	10.50
T_3M	17.50 ± 3.00	9.00 ± 1.67	20.00	9.00
T_4M	19.00 ± 3.20	10.50 ± 1.67	24.00	10.50

(*T_1, T_2, T_3 and T_4 are the four water levels. B, D, U and M are the four genotypes: Bauda, Darmasa, Ugandi and Madlkawia. Cm: centimeter, S.D. :Standard Deviation)