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Analysis of Adaptive Response of Maize (*Zea mays*) Varieties from DR-Congo to Water Stress

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Abstract

Maize production in tropical Africa is often negatively affected by drought. The main objectives of the present study were to 1) analyze the impact of water stress on the agro-morphological performance of two varieties of Quality Protein Maize (QPM) compared to two normal maize varieties and 2) assess their adaptive response in contrasting water environments. Agro-morphological responses to water deficiency of maize (*Zea mays* L.) were assessed in controlled experiments using four maize varieties, two normal maize (Zm725 and Mus1) and two quality protein maize (Mudishi1 and Mudishi3) varieties. They were subjected to three water regimes (100%, 60%, 30% water retention capacity) at the beginning of the bloom stage, using a Fischer block design with four replications. Significant differences ($p < 0.05$) among varieties, water regimes and their interactions for plant growth and production parameters were observed. Reduction of water supply to plants caused changes in aerial and underground plant growth. Plant stem height, foliar expansion, and root system development characterizing vegetative growth showed variation in varietal response to water regimes. Mus1 (normal maize variety) was the best adapted to variations in water regimes because they developed an important root volume to adapt to the effects of water deficit while maintaining their morphological and productive characteristics.

Keywords

Maize (*Zea mays* L.), Drought Resistance, Water Stress, Leaf Area Index (LAI), Quality Protein Maize (QPM), DR-Congo

1. Introduction

Drought is one of the limiting factors inmaize (*Zea mays* L.) production. Indeed, maize growth and yield like most tropical plant species are often negatively affected by drought. Even in areas where rainfalls provide an annual average of 2600 mm of water, soil water reserves can decrease sharply during the dry season and limits vegetation growth [1]. Maize is sensitive to environmental stresses during flowering period [2] [3] [4].

Several studies have described to the effects of drought on plants [5] [6]. The effects drought on an annual scale depends on its starting period in relation to the crop stage and its duration. Water stress affects several physiological and morphological traits such as leaf temperature regulation [6] [7], stomatal conductance, leaf area [8], as well as photosynthesis [5] [9].

Decrease in water content in plant results in reduced growth of different organs, even before the photosynthesis process is affected [10]. In maize (*Zea mays* L.), the decrease of 50% in grain yield is associated with a water deficit during male flowering.

Analysis of agro-morphological characteristics, might contribute to our understanding of crop coping mechanism(s) to water deficit. Hence the objectives of the present study were to 1) analyze the impact of water stress on the agro-morphological performance of two varieties of QPM compared to two normal maize varieties and 2) assess their adaptive response in contrasting water environments.

2. Materials and Method

2.1. Experimental Site

The study was conducted from June to October 2014 at the National Institute of Agronomic Research and Studies (INERA) at Mvuazi research center in the DR-Congo. This center, located at 470 m altitude, 14˚54' east longitude and 5˚21' latitude south, is characterized by Aw4 climate type with annual rainfalls ranging from 800 mm to 1200 mm and temperature ranging between 22˚C and 30˚C.

2.2. Plant Material

Four maize (*Zea mays* L.) varieties including two genetically improved varieties of Quality Protein Maize (QPM) named Mudishi1 and Mudishi 3, one genetically improved variety of normal maize (Mus1) and an exotic variety (ZM725) were used for this study. These seeds were obtained from INERA (for Mudishi 1, Mudishi 3, and MUS 1) and the International Center of Maize and Wheat Improvement (CIMMYT) of Zimbabwe (for ZM725). The ZM725 variety has been tested in semi-arid areas for its drought tolerance and was used as a reference.

2.3. Experimental Method

All the varieties were grown under shelters in a transparent polyvinyl roof, in PVC pots of 50 cm in depth and 25 cm in diameter. These pots were filled with a

non-leached tropical ferruginous soil with an apparent density of 1.64 g/cm^3 and a retention capacity (RC) of 130 mm per meter of depth.

Sowing of two maize seeds per pot took place after application of 500 ml of a solution of the mineral fertilizer NPK (17-17-17) at a concentration of 2 g/L in each pot. The spacing was carried out at 14 days after sowing and consisted in maintaining one vigorous plant per pot.

Prior to the application of treatments (water regime—WR), each pot received 1500 ml of water every week until the beginning of the blooming stage. The pots were then separated into three batches corresponding to the following water regimes:

-100% retention capacity (RC): the plants were regularly watered at 100% RC.

-60% retention capacity (RC): the plants were watered regularly at 60% RC,

-30%retention capacity (RC): the plants were watered regularly at 30%RC.

The experimental design consisted in four Fisher blocks with 3 replications and three water regimes resulting in 48 experimental units (pots). Each block was repeated twice, which allowed the destructive measurements to be conducted on one of the two replications.

Maximum temperature (T$_{max}$) varied from 26.0˚C to 29.7˚C and the minimum temperature (T$_{min}$) from 16.5˚C to 19.6˚C during the growing period. Relative humidity varied from 68% to 97%. The photoperiod was 12 h of light and 12 of dark for most of the days during the trial.

2.4. Data Collection

During the growth phase, the following parameters were measured: plant height, green leaf number, leaf area index, root volume, and grain yield. These measurements were made at different growing stages including stem elongation (A), 50% male flowing (B), 50% female flowering (C), 50% ear formation (D), ear filling (silk spike) (E), 50% ear maturity(F), husk senescence (G), 50% leaf senescence (H), total senescence (leaves and stems) (I), and grain desiccation (J).

Plant heights were measured using a flat ruler placed between the collar and the sheath of the last fully extended leaf. The number of visible green leaves was determined by counting the leaves with less than 50% senescent surface. The leaf area index (LAI) was estimated as the one-sided green leaf area per unit ground surface area (LAI = leaf area/ground area, m^2/m^2). Root volume was measured by comparing the water levels before and after immersing all the roots in a known volume of water. The total biomass was measured with a precision balance after drying all plant (stem, leaves, husk and roots) in an oven for three days. The grain yield was the weight adjusted to 14% of moisture after harvest.

2.5. Statistical Analysis

Data were analyzed using Excel 2007 software. The means were separated ($p \leq 0.05$) using ANOVA followed by multiple comparison tests for each growth stage using the R and Statistix 8 software for Windows.

3. Results

3.1. Plant Height (HP)

Plant growth (Figure 1(a)) shows almost the same elongation at the beginning of the upstream period up to 50% female flowering for Mus1, and reached its maximum (202 cm) at 50% of ear maturity. This variety had a fast growth and therefore a higher stem length than the other three varieties during all stages of growth. ZM725 variety with moderate growth before ears maturity reached its
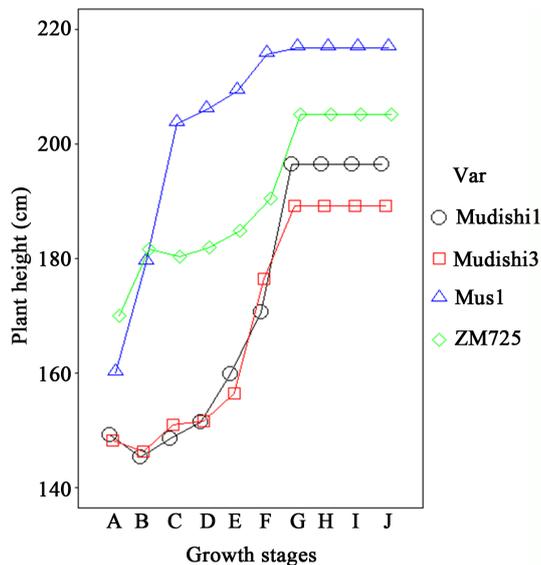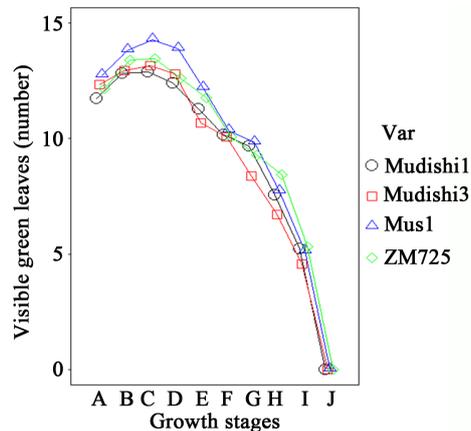

(a)
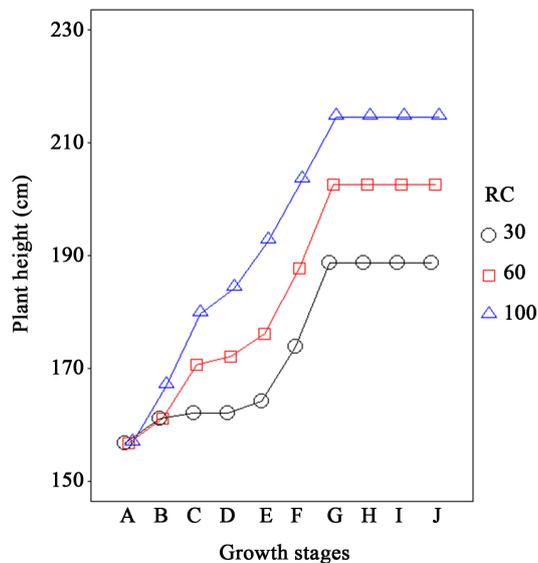
(b)

Figure 1. (a) Evolution of stem growth by varieties in all water regimes combined; (b) Evolution of stem growth by water regime for all varieties. Stem elongation (A), 50% male flowing (B), 50% female flowering (C), 50% ear formation (D), ear filling (silk spike) (E), 50% ear maturity (F), husk senescence (G), 50% leaf senescence (H), total senescence (leaves and stems) (I), and grain desiccation (J).

maximum value (189.10 cm) at the senescence of husk. The QPM varieties (Mudishi1 (169.19 cm) and Mudishi3 (166.78 cm), showed a slow development, reaching their maximum height at the senescence of husk.

Figure 1(b) decrypts plant height by water regime (WR). The mean of heights by WR at the end of the assay ranged from 168.27 cm to 194.15 cm. Analysis of the variance showed a highly significant difference ($p < 0.05$) among the WRs. The treatments were ranked in the following order: 100% > 60% > 30% RC.

3.2. Number of Visible Green Leaves (NGL)

The number of visible green leaves per variety (**Figure 2(a)**) was similar for all varieties (up to 50% female flowering). After this stage, the onset of foliar senes-


(a)
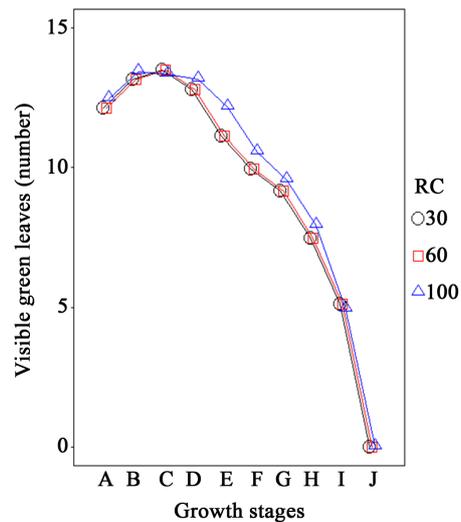
(b)

Figure 2. (a) Evolution of the number of visible green leaves by variety in all water regimes combined; (b) Evolution of the number of green leaves visible by regime for all varieties. RC represents retention capacity. Stem elongation (A), 50% male flowing (B), 50% female flowering (C), 50% ear formation (D), ear filling (silk spike) (E), 50% ear maturity (F), husk senescence (G), 50% leaf senescence (H), total senescence (leaves and stems) (I), and grain desiccation (J).

cence was observed. The NGL of Mus1 variety remained significantly higher until ears maturity. After this stage, the NGL for ZM725 became higher until total senescence. The QPM varieties (Mudishi1 and Mudishi3) showed significantly lower NGL throughout the entire growing period. No significant difference ($p <$ 0.05) was observed between varieties at ear maturity.

Analysis of water regime (**Figure 2(b)**) showed that the 100% RC regime has the highest NGL from the phase of 50% of ear formation until senescence. Plants treated with 60% RC and 30% RC regimes showed identical NGLs.

3.3. Leaf Area Index (LAI)

The LAI of each variety under all regimes (**Figure 3(a)**) was estimated as a function of leaf area and density during the test. Mus1 variety recorded the highest LAI values throughout the trial. However, Mudishi 3 showed the lowest LAI from the 50% female flowering stage until the end of the assay.
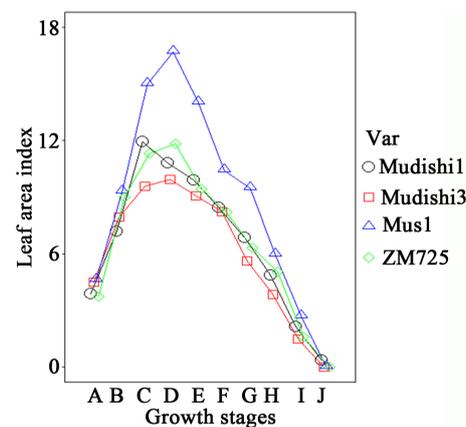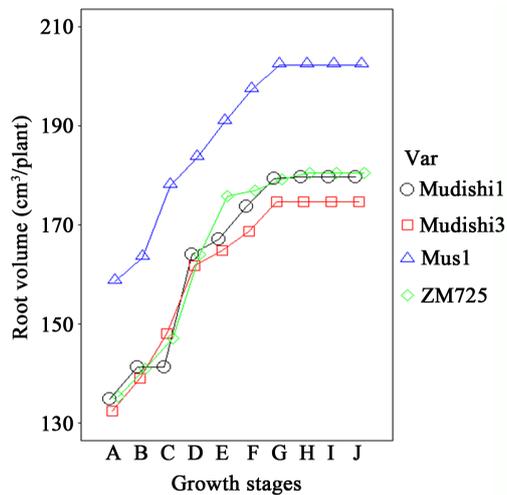

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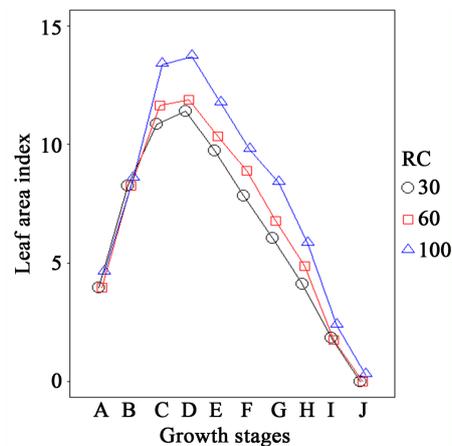
(b)

Figure 3. (a) Evolution of Leaf Area Index (LAI) of variety in all water regimes; (b) LAI evolution by water regime for all varieties. RC represents retention capacity. Stem elongation (A), 50% male flowing (B), 50% female flowering (C), 50% ear formation (D), ear filling (silk spike) (E), 50% ear maturity (F), husk senescence (G), 50% leaf senescence (H), total senescence (leaves and stems) (I), and grain desiccation (J).

For plants in pots that were watered at 100% RC, the maximum LAI was recorded at 50% of ear formation for all varieties. The LAIs were significantly influenced by the water regime (**Figure 3(b)**). The 100% RC regime resulted in the formation of large LAIs compared to other water regimes. **Figure 3(b)** shows that LAIs were similar at 50% of male flowering and decreased significantly at ears maturation and husk senescence and remained at the same level until the end of the crop.

3.4. Root Volume (RV)

Root volume of plants per variety (**Figure 4(a)**) varied substantially among different growing stages (GS). Mus1 had the highest root volume until the end of

(a)
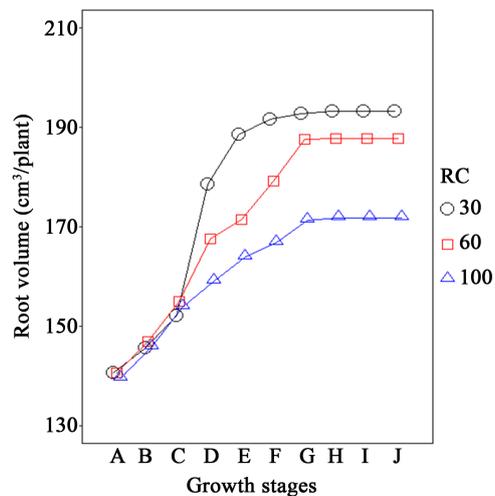
(b)

Figure 4. (a) Evolution of root volume by variety for all water regimes combined; (b) Evolution of root volume by water regime for all varieties. RC represents retention capacity. Stem elongation (A), 50% male flowing (B), 50% female flowering (C), 50% ear formation (D), ear filling (silk spike) (E), 50% ear maturity (F), husk senescence (G), 50% leaf senescence (H), total senescence (leaves and stems) (I), and grain desiccation (J).

the assay. For all varieties, significant increases in root volume were recorded between 50% female flowering and ear maturing before reaching the final volume.

Variation in root volume based on water regime is described in Figure 4(b). Two subgroups can be identified. In the first group, characterized by the 30% RC regime, there is first a linear increase in all plants before female flowering, then an exponential phase pushing the plants to the maximum production until the beginning of the senescence. In the second group that includes the 100% RC and 60% RC, the trends are similar from the beginning of male flowering to the senescence of husk. A significant difference ($p < 0.05$) was observed among the water regimes; the 30% RC regime with 195 cm^3/plant positively influenced root production, followed by the 60% RC regime with 185.15 cm^3/plant and then the 100% RC with 170 cm^3/plant at the end of the test.

3.5. Grain Yield (g/m^2)

Since the test was carried out in a pot, the yield was determined per volume of soil per unit of area. Figure 5(a) shows grain yields recorded for each water regime. In general, significant differences were observed among water regimes. The 100% RC regime resulted in an average production of 2101.7 g/m^2 followed by the 60% RC regime with 1858 g/m^2 and the 30% RC regime with 1372 g/m^2.

All varieties were significantly affected by the amount of water during the test. Figure 5(b) shows that when 100% RC was applied, Mus 1 and ZM725 produced the highest yields compared to the two QPM varieties. The switch to lower WR significantly reduced the ZM725 yield by more than 25% in 60% RC and more than 40% in 30% RC. While QPM varieties have almost retained their yield in 60% RC, there was a decreaseof grain yields in the 30% RC regimen.

3.6. Biomass (BM)

Figure 6(a) shows the levels of biomass production for each water regime. Analysis of variance of biomass by water regime revealed significant differences ($p < 0.05$) among treatments. The 100% RC regime resulted in the highest biomass (151 g/plant) followed by 60% RC (142.85 g/plant) and 30% RC (116.67 g/plant).

A significant difference was found between ZM725 and the other three varieties for the water regimes of 60% RC and 30% RC. Its biomass production remained lower than that of Mus1 and the two QPMs. However, no significant difference was observed between Mus1 and the two QPMs in 60% RC and 30% RC (Figure 6(b)).

4. Discussion

Application of the three water regimes (100% RC, 60% RC, and 30% RC) on the four varieties revealed the actual impact of drought on maize growth and the critical plant development phases during which plants are more vulnerable. It
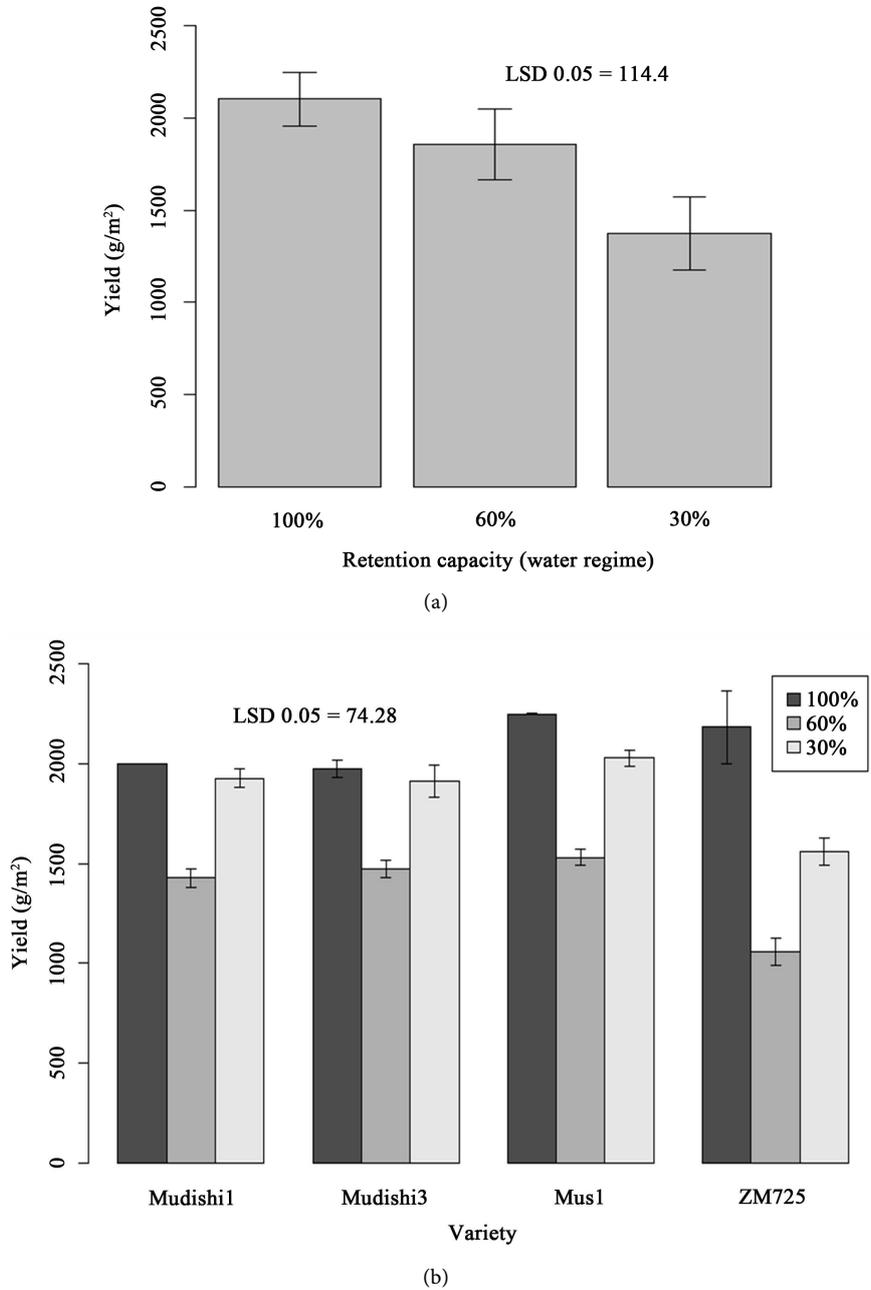
(a)

(b)

Figure 5. (a) Average yield by water regime (retention capacity) for all varieties; (b) Yield average per variety by water regimes or retention capacity.

also helped determine if plant's response to water shortage has been specific. Our results showed varietal differences for plant growth and grain yield, two groups of parameters that characterize plant development and production. Hence these four maize varieties have different adaptation mechanism to water availability. A significant decrease in these parameters was observed in the plants at 30% RC for all the varieties.

Stem length varied according to the water regime. Similar results were reported by Attia (2007) on cotton crop [11]. They also observed a decrease in
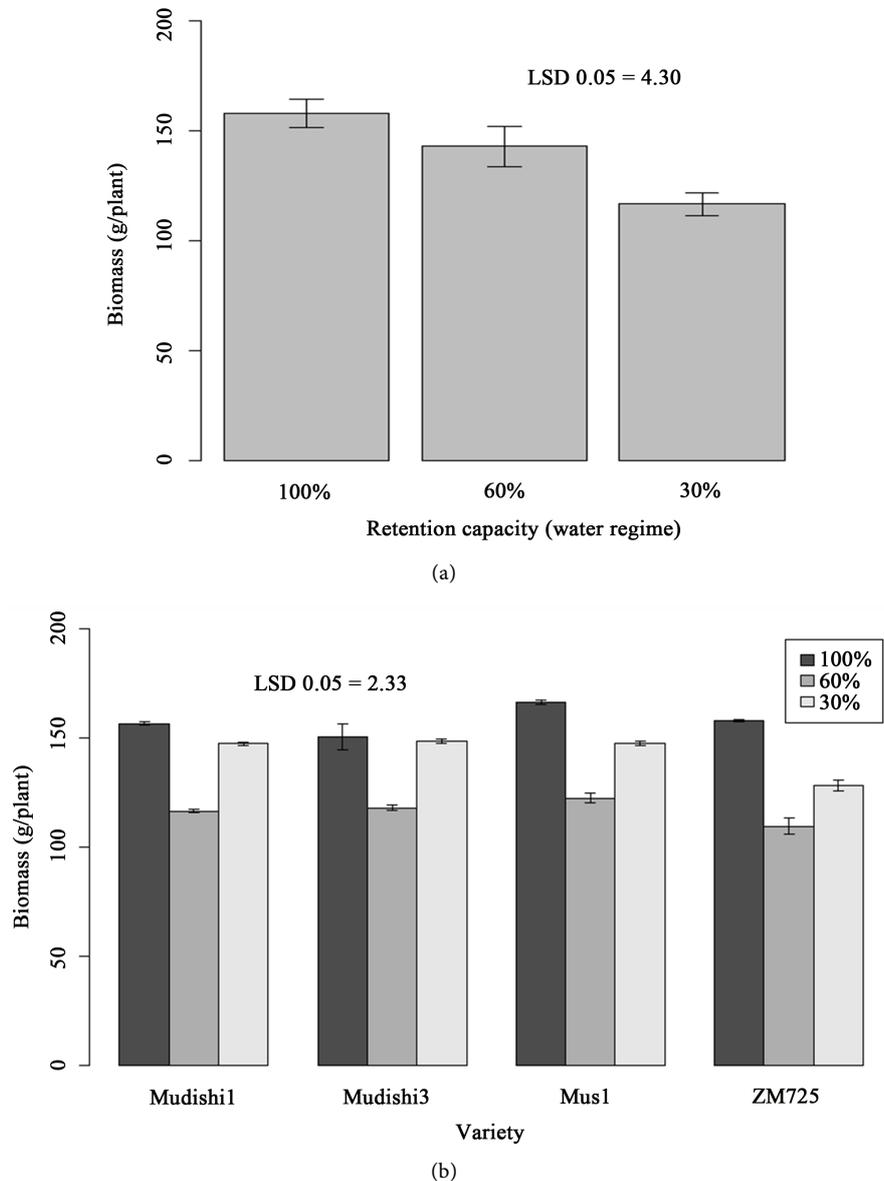
(a)

(b)

Figure 6. (a) Biomass average by water regime (retention capacity) for all maize varieties; (b) Biomass average by variety by water regime or retention capacity.

plant size that was associated with irrigation doses of 50% and 25% compared to the control that was irrigated at 100%. Stem length and root volumes, two parameters associated with plant growth, showed, firstly, a varietal effect at the end of the test and secondly, a water regime effect. Mus1 and ZM725 varieties showed the longest stem and the largest root volume. These two maize varieties, with good vegetative growth, appeared to be better suited to the normal water regimen, however QPM varieties respond better to stress conditions. A decrease in the amount of water resulted in a significant increase of the root system from male flowering. Magorokosho *et al.* (2003) showed that this phase of growth is the most vulnerable for maize [12]. Edmeades *& et al.* (1995) reported that the estimated loss of yield could range from 21% to 50% [13]. Under conditions of

water deficit, plants increase their water resource through root mining.

Salah and Tardieu, (1997) and Cakir, (2004) showed that leaf surfaces of maize plants subjected to water deficits were smaller than those of well-watered plants [3] [14]. These findings are consistent with those reported by Matthews (1986) and Chartzoulakisa *et al.* (2002) [15] [16]. Reduction of leaf area by water stress may be due to a decrease in mitotic activity of epidermal cells which results in a reduction in the total number of leaf cells [15]. It may also be due to a reduction in the size of the cell due to anatomical changes [16]. The decrease in leaf area under the limiting water regime is an adaptive plant mechanism to limit leaf transpiration when water conditions become unfavorable. The weak development of the leaf area from the ear filling stage, observed in all the plants, could be explained by a low need of water at the beginning of maturity of the cobs. The reduction in leaf area is less marked when stress is imposed at the vegetative stage. Normal foliar development resumes when plants are watered again.

Significant correlations among different parameters measured were found for different water regimes. This suggests that switching to stress induces variations in different parts of the plant [17] [18] [19]. These results are similar to those reported by Kimani *et al* (1994), who showed that severe water stress reduced plant biomass in *Cajanus cajan* from 34% to 54% [20]. Sustained growth of the root system under stress would be a factor of resistance to water stress. This phenomenon is explained by the fact that soil usually dries on the surface and roots sink more into the soil in search of water. Indeed, grain yield depends closely on the quantities of water available during the period from an thesis to maturity. The maintenance of high yield under water deficit conditions in certain varieties such as Mus1 and Mudishi3 can be explained by the ability to pump deeply water because of their important root system development. According to Passioura (1977), root system ability to exploit soil water reserves under stress is an effective response to sustain grain production [21]. Kabongo *etal.,* (2016a, 2016b) reported that Mus1 and Mudishi3 varieties were among maize accessions that were moderately sensitive to changes in soil water potential in a field study [22] [23]. Their stress sensitivity index was <1.

It has been demonstrated that the most critical period of water supply is between 14 days before and 14 - 21 days after silking [24] [25]. During this period, grain yield is determined and the longer the duration of water stress the more severe is the crop failure [25] [26]. Other studies have demonstrated specific effects of water stress on maize phenology, leaf production, and grain yield varied with varieties [26] [27] [28].

5. Conclusion

The objective of this study was to analyze the impact of water stress on the agro-morphological performance of two varieties of QPM compared to two other normal maize varieties, and to assess their adaptive response in contrasting water environments. The four varieties that were characterized showed different

adaptation mechanisms to various water regimes. The results revealed that water deficit accentuated at the beginning of flowering influences plant growth and its development. However, this early flowering deficit reduces yield. MUS 1 variety was more adapted to variation to water availability. High-performance varieties will sustain its growth and productivity in areas with low or irregular rainfalls. Hence, the QPM varieties tested in the present study grown in the savanna of southwestern DRC are less vulnerable to the effects of moderate water stress that occurs during plant growing cycle.

Acknowledgements

Competing Interest

Authors have declared that no competing interests exist.

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