Response of maize genotypes to reduction in substrate moisture during early vegetative development

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ABSTRACT

Ten varieties of maize (Zea mays L.) were considered for the comparative study of early growth of roots and shoot in pots (30cm x 15cm) under different moisture regimes: (e.g. saturated (100% of field capacity), moderate (75%), mild (50%) and sever (25%) stress treatments. Pots were filled with sand and clay-soil mixtures (8:1 w/w) initially treated with half strength Hoagland solutions (200 ml pot⁻¹). The rest of the higher moisture contents were maintained by adding fresh water for the desired treatments. Experiment was conducted in a glass house in completely randomized design with six replications. Results revealed by reducing moisture from saturated to sever stress decreased both root and shoot. Saturated treatment showed highest leaf number plant⁻¹ (9.18), dry matter (DM) of shoots (10.89 g plant⁻¹), roots (1.31 g plant⁻¹), leaf area (140.24 cm²) and root-volume (0.63 cm³). A reduction in moisture has reduced (P<0.05) all the observed traits but shoot and roots DM and their ratio did not differ (P<0.05). Among the varieties, Pahari showed the maximum leaves (8.44 plant⁻¹) but No. 974 the highest shoot DM (5.75 g plant⁻¹). Roots DM were observed the maximum (1.13 g plant⁻¹) in Azam. Okmas showed the highest leaf area (107.48 cm²). Root-volume was observed greater (0.57 cm³) in Karak local. The study suggests that commercial varieties showed larger leaf area and biomass, however, local varieties have potentials for roots DM and root volume that can be used for improvement of maize to cope with expected future climate changes for the optimum maize production in the region.

Keywords: Maize Varieties, moisture regimes, root and shoot mass, leaf area, roots-volume

INTRODUCTION

In many tropical and subtropical areas, drought is an emerging factor of crop production. Drought response has become visible under the climate change scenario. Drought limits production of field crops, particularly the summer crop e.g. maize, which contributes significantly in global food security (Asim et al., 2013). Maize in Pakistan is planted in a hot summer dry months (e.g. July-Aug.). The young plant is adversely affected by drought stress that resulted in a significant loss of DM and the desired density at harvest (Akmal et al., 2010) resulting a considerable loss in yield (Saini and Westgate, 2000). Right after emergence, drought considerably affects germination and results to impotent re-seeding the crop. Literature has reported that yield loss in maize due to post-emergence drought spells are as high as those caused by drought at flowering (Edmeades et al., 1989). Selection of resistant variety has been considered an economic and efficient source to sustain the seeding
growth (Mukharjee et al., 1991). Nonetheless, drought resistant is a complex trait resulting from contributing numerous factors. Among several putative characters, water status of soil at sowing (Wahbi and Gregory, 1995; Thomas et al., 1995) and root response to soil moisture availability (Malik et al., 2002) are interesting traits to tolerate drought of young seedlings. It is known that crop water use efficiency depends on extent and effectiveness of crop rooting system at the time of seedling establishment (Jackson et al., 1986). Development of an extensive root system at establishment phase might contribute in drought tolerance (Murphy et al., 1982; Mukharjee et al., 1991).

Variability has been observed in many species and its varieties for root characters and their responses against drought (Sahnoune et al., 2004). Response of maize crop to drought is related to development of the root system, which might influence water uptake in early establishment phase of the plant growth (Aina and Fapohunda, 1986). Most studies have therefore focused on roots volume, length, number and especially the root to shoot DM ratio. The available water is generally localized in soil but depleted at a faster rate from upper soil profile when sowing is done in high temperature in the summer. Low and moderate water treatments have slightly affected the roots-volume in top and middle soil layers, which is quite possible and expected to be done so. Previous studies conducted on wheat and barley has reported that 60-90% of roots were confined in top surface layers (Sahnoune et al., 2004). Significant differences were observed between water treatments for root and shoot DM of plants (Adda et al., 2005). Values of both roots and shoot DM have shown an increase in 100% field capacity in relation to water deficits. The ratio between roots and shoot has been measured in several studies and with an increase of the ratio was noted under drought (Sahnoune et al., 2004). It is known that maize is highly sensitive and generally the root development is less inhibited than shoot in drought (Akmal and Hirasawa, 2004) but the trait could not be used to discriminate the cereal varieties (Sahnoune et al., 2004). Elongation rate and volume of roots and roots to shoot DM ratio have been considered as efficient character to evaluate genotype response against drought (Merah, 2001). Roots and shoot growth under drought is therefore essential to study for initial stage of growth of a plant because maize is known as highly sensitive crop than any other cereal (Sharp and Davies, 1979). We compare Varieties growth for initial development phase to save crop from future climate change effects.

**MATERIALS AND METHODS**

Pot experiment was conducted in summer 2008 under greenhouse conditions, Institute of Biotechnology and Genetic Engineering (IBGE), University of Agriculture Peshawar, Pakistan. Root and shoot growth of maize Varieties were studied for early development phase of growth. Sowing was done in plastic pots (D = 15cm; H 30cm), filled with homogeneous sand and clay-soil (8:1 v/v) mixture prepared for the experiment (Sahnoune et al., 2004). Pre-determined measured quantity of water was added gradually until substrate was saturated with no further absorptions (Shah et al., 2011). This state of moisture regimes is termed as saturated (M1 = 100% moisture of the field capacity). For rest of the treatments, added quantity of water per pot (M1) was reduced to 75%, 50% and 25% as M2 (Moderate), M3 (Mild), and M4 (Severe) stresses, respectively. Different maize varieties; consist of 5 commercial open pollinated varieties (OPV), 3 hybrids and 2 local (landraces) were collected and planted on 12.07.2008; initially with 5 seeds pot−1 and thinned-out to 3 seedling pot−1 at emergence. Names of varieties with collection sources are shown in Table 1 above.

The experiment was conducted in completely randomized design (CRD). Each treatment was repeated

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Name</th>
<th>Type</th>
<th>Source/Origin</th>
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<tbody>
<tr>
<td>V1</td>
<td>Azam</td>
<td>OPV</td>
<td>CCRI, Nowshera</td>
</tr>
<tr>
<td>V2</td>
<td>Jalal</td>
<td>OPV</td>
<td>CCRI, Nowshera</td>
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<tr>
<td>V3</td>
<td>Pahari</td>
<td>OPV</td>
<td>CCRI, Nowshera</td>
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<tr>
<td>V4</td>
<td>Sarhad white</td>
<td>OPV</td>
<td>CCRI, Nowshera</td>
</tr>
<tr>
<td>V5</td>
<td>Local farmer</td>
<td>OPV</td>
<td>Hangu City</td>
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<tr>
<td>V6</td>
<td>Local farmer</td>
<td>OPV</td>
<td>Karak City</td>
</tr>
<tr>
<td>V7</td>
<td>Okmas</td>
<td>OPV</td>
<td>CBFB, Okara</td>
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<tr>
<td>V8</td>
<td>No. 974</td>
<td>Hybrids</td>
<td>Monsanto Pvt. Ltd</td>
</tr>
<tr>
<td>V9</td>
<td>Babar</td>
<td>Hybrids</td>
<td>CCRI, Nowshera</td>
</tr>
<tr>
<td>V10</td>
<td>No. 3025</td>
<td>Hybrids</td>
<td>Pioneer Pvt. Ltd</td>
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OPV = Open Pollinated Genotype
CCRI = Cereal Crop Research Institute, Nowshera.
CBFB = Cattle Breeding Farm Bahaulnagar, Okara.
six times. Uniform standard procedure was adopted for substrate mixture preparation, filling and irrigation (Shah et al., 2011; Khan et al., 2012). The desired moisture regimes were maintained initially for all pots and subsequently maintained during the study by weighing three additional pots on daily basis for a desired moisture level that was subsequently maintained by added with a desired water quantity. Each pot was manually added with water quantity as per treatment requirements with care that in no case extra water dropped-out from pots. Half strength Hoagland solution (Arnon and Hoagland, 1950) was added at the starts at a rate of 200 ml pot⁻¹. The amount of water added as nutrient solution was adjusted accordingly for the moisture treatment. Plants were allowed to grow for 35 days. At harvest, all leaves of plant from a pot were counted and averaged for a single reading. Likewise, fresh weight of shoot and roots were recorded and oven dried at 80°C for about 72 h. Root to shoot ratio was determined on DM basis. Leaf area was measured by passing all leaves from a leaf area’s measuring machine (LI-3000A, LI-COR, USA). Fresh root volume was estimated by dipped all roots of a plant in a known water volume taken in a graduated cylinder. The displacement of water quantity in that cylinder was recorded by dipping all roots as root volume. To get an accurate reading, the procedure repeated three times and averaged for a common reading.

All data were subjected to ANOVA using General Linear Model (GLM) procedure of SAS (SAS Institute, 1987, Cary, NC, USA). Comparisons were made between mean of the moisture treatments, varieties and their interaction using Least Significant Difference (LSD) test (P<0.05).

RESULTS

Leaf number plant⁻¹

Leaf number plant⁻¹ of maize varieties was significantly influenced by moisture regimes (Figure 1). Favorable (100%) moisture resulted in the highest (9.18) leaf number plant⁻¹, which significantly decreased to 8.78 leaf plant⁻¹ for moderate (75%) to (8.19 plant⁻¹) for mild (50%) treatment. The lowest (6.95) leaf number was recorded for severe (25%) treatment. Varieties were also found significantly different for leaf number (Figure 1b above). Pahari produced the higher (8.44) leaf number, followed...
Shoot and roots dry matter (g plant$^{-1}$)

Shoot DM (g plant$^{-1}$) is shown in Figure 2. The low moisture (50%) showed maximum shoot DM (6.23 g plant$^{-1}$) with a significant decrease (6.02 g plant$^{-1}$) in moderate (75%), followed by a further reductions (5.83 g and 4.32 g plant$^{-1}$) at favorable (100%) and severe (25%) stresses, respectively (Figure 2a). Varieties were also found different (P<0.05) for shoot DM (Figure 2b). No. 974 was the highest (5.75 g plant$^{-1}$), followed by Babar (5.74 g plant$^{-1}$) and Azam (5.74 g plant$^{-1}$) in shoot DM. The shoot DM was significantly higher for Karak local (5.45 g plant$^{-1}$), but Pahari (5.44 g plant$^{-1}$) and Hangu (5.35 g plant$^{-1}$) was non-significant to each other. Treatment interactions (moisture x Varieties) were also found significant (P<0.05) for shoot DM (Figure 2c). A decrease in moisture from 100% to 75% showed relatively moderate changes in shoot DM and similarly did for 75% to 50%. However, a considerable reduction was observed in shoots DM when moisture decreased from 50 to 25%. Sarhad white was found relatively stable in shoot DM between 100% and 50% moisture as
Roots dry weight (g) per plant of maize Varieties at vegetative stage under different soil moisture regimes. Different boxed of the figure showed different treatments e.g. moisture regimes (top right box), Varieties (top left box) and their interactions (the lower box).

Root DM (g plant$^{-1}$) of different Varieties showed significant responses ($P<0.05$) with moisture reductions (Figure 3a). Contrary to shoot DM, mild stress (50%) showed high roots DM (1.31 g plant$^{-1}$). It was significantly decreased (1.28 g) by increase in moisture (100%). A significant reduction of 1.01 g plant$^{-1}$ was observed at moderate (75%) moisture. The severe moisture (25%) treatment showed the minimum (0.78 g) roots DM. Different maize Varieties were also found significantly different for roots DM (Figure 3b). Azam showed the highest (1.13 g) roots DM, followed by No. 3025 (1.12 g) and Jalal (1.11 g). Both Varieties were not significantly different from each other but differed ($P<0.05$) from Babar (1.06 g) and Hangu (1.06 g). Treatments interaction (moisture x Varieties) has shown a significant ($P<0.05$) effect on roots dry DM. Both favorable (100%) and low (50%) moisture showed relatively the highest roots DM for almost all Varieties (Figure 3c). A moderate reduction in roots DM was noticed when moisture dropped to moderate (75%) compare to mild (50%). The severe moisture treatment was not comparable to any of the observed moisture regimes.

Roots to shoot ratio

Roots to shoot DM ratio (RSDR) of Varieties was significantly influenced by moisture regimes (Figure 4a below). Favorable (100%) moisture showed the highest (0.22) RSDR, which was significantly decreased to 0.21 at mild (50%), followed by a further significant decrease...
Figure 4. Roots to shoot ratio of maize Varieties at vegetative stage under different soil moisture regimes. Different boxed of the figure showed different treatments e.g. moisture regimes (top right box), Varieties (top left box) and their interactions (Lower box).

Leaf area

Leaf area (cm$^2$) of Varieties and moisture are shown in Figure 5. Leaf area was affected (P<0.05) by moisture (Figure 5a). Favorable moisture (100%) showed the maximum (140.24 cm$^2$) leaf area that decreased (99.86 cm$^2$) significantly under moderate (75%), followed by a further reduction (89.74 cm$^2$) at mild (50%). The minimum (47.51 cm$^2$) leaf area was observed at severe (25%) moisture. Varieties were also found different for leaf area (Figure 5b) with a maximum (107.48 cm$^2$) for Okmas, followed by No. 3025 (104.80 cm$^2$) with a non-significant difference form each other. Babar (99.08 cm$^2$), No. 974 (98.75 cm$^2$) and Pahari (93.85 cm$^2$) were almost similar in leaf area. Azam (93.27 cm$^2$) and Jalal (90.82 cm$^2$) were similar in leaf area. Hangu local (86.80 cm$^2$), Sarhad White (85.90 cm$^2$) and Karak (82.62 cm$^2$) were
lower in leaf area. The interactive effects (Figure 5c) revealed a change (P<0.05) in leaf area (cm$^2$). Favorable (100%) showed relatively high leaf area (cm$^2$) in all Varieties. Moderate (75%) showed lower leaf area than favorable moisture (75%). A further decrease from moderate to mild reduction in moisture showed a decrease in leaf area (P<0.05) in all Varieties. The strong reduction in leaf area was observed in severe (25%) stress for all Varieties (Figure 7c). Varieties (No. 974, Babar, Okmas and No. 3025) were markedly affected than rest of the Varieties when moisture reduced from 100% to 75%. Moderate to low moisture treatments were relatively less affected the plant leaf area as compared to severe (25%) stress.

Root’s volume (cm$^3$)

Root’s volume (cm$^3$) of maize plant in moisture regimes was different (Figure 6) and showed a strong significant effect (Figure 6a below). The favorable (100%) showed optimum (0.63 cm$^3$) roots volume that significantly decreased to 0.57 cm$^3$ in moderate (75%) stress. A significant decrease (0.52 cm$^3$) in mild (50%) stress was recorded with a minimum (0.35 cm$^3$) root volume in severe (25%) stress treatment. Different Varieties were found different (P<0.05) in root’s volume (Figure 6b below). Optimum (0.57 cm$^3$) roots volume was recorded in Karak local that significantly declined to 0.55 cm$^3$ in Hangu local and No. 974 (0.53 cm$^3$). Jalal and Babar have reflected almost the same roots volume (0.52 cm$^3$). Sarhad White and Azam also showed the same roots volumes (0.51cm$^3$). Okmas and No.3025 showed roots volumes of 0.50 cm$^3$ that was non-significantly different from Pahari (0.49 cm$^3$). The interactive effects of moisture and Varieties were significant (P<0.05) for root volume (Figure 6c below). The favorable (100%) treatment showed relatively higher root-volume for all Varieties, followed by moderate (75%) stress. Further reduction from moderate (75%) to mild stress (50%) reduced root volume considerably.
Figure 6. Roots volume (cm$^3$) per plant of maize Varieties at vegetative stage under different soil moisture regimes. Different boxed of the figure showed different treatments e.g. moisture regimes (top right box), Varieties (top left box) and their interactions (Lower box).

for all Varieties. Compared to the others, root's volume in Pahari was influenced mildly from 100, 75 and 50% stresses. Genotype No. 974, Babar, Okmas and No. 3025 were also found relatively uniform in roots volume at 75% and 50% moistures.

DISCUSSION

Young maize plant showed greater leaf elongation, which was inhibited (P<0.05) by increasing water stress. Maize roots and shoot growth have strongly influenced by decreasing water (Sharp and Davies, 1979). Competition between transpiration stream and leaf growth including roots have explained contrasting responses to deficient water for growth (Malamy, 2005). As compare to the plant roots, shoot growth was also found sensitive to limited water for maize in the young development phase. It is indicated that growth inhibited rather metabolically regulated as a consequence of changing plant water status under the drying soil in early establishment phase of a plant growth. Research has shown that both stem and leaf growth can severely be inhibited at reduced moisture availability despite of the complete maintenance of turgor in growing regions of a plant as a result of osmotic adjustment (Khan et al., 2012). Furthermore, shoot growth could be sensitive to the soil drying process which caused substantial inhibitions in aerial parts of a plant. Such observations have led to much interest in involvement of non-hydraulic regulatory signals from root to shoot (Mehmood-ul-Hassan et al., 2012). It is believed that root growth is less subdued than shoot growth and in
some reports root growth has promoted by drought stress. Plant grows in a drying soil has obviously benefits to maintain adequate water supply (Sharp et al., 2004). The important feature of root growth is the roots ability to sustain elongation in low water regime and/or sustain growth over the complete inhibition of shoot (Westgate and Boyer, 1985). A range of species have potential through rooting system to sustain shoot growth under dry conditions of the soil and to ensure water supply for the emerging seedling for a healthy plant (Spollen et al., 1993).

Kiran and Tewari (2004) has studied growth and water relation in drought and observed that young plants failed to survive for 28 days drought in summer. However, growth of plant was positively related to moisture availability in the soil. By decreasing moisture root to shoot ratio improved and leaf weight ratio declined (p<0.05). Other plant characters for example leaf number, leaf area ratio, specific leaf area etc. were also adversely affected by limiting soil moisture. Plants have special mechanism to avoid stress situations by maximizing water uptake and/or minimizing water losses (Mehmood-ul-Hassan et al., 2012). Most plants have responded to stress through making some kind of special modification in the morphological and physiological characteristics. Even in same species the size of individual plants may vary several folds due to water shortages (Qayyum et al., 2012). The distribution and regeneration of species are based on water relation at the time of plant growth; the well distributed moisture during the growth will ensure the uniform plant density from emergence to harvest. In maize the density once marinated after emergence has drastically declined at harvest due to higher temperatures and/or moisture fluctuations in the soil during the crop growth (Asim et al., 2013). Smaller seed size, shallow roots and minimal capacity for reserve storage have made plants less tolerant to the unfavorable oscillations (Shah et al., 2011). Among plant organs, leaf number is highly sensitive to moisture loss and severely inhibited the rate of assimilates production in sources that affect the growth. Leaf area also has a similar response under drought. A positive relationship is, therefore, reported for leaf area and soil moisture. Literature has also confirmed the role of leaf water potentials in plant development under stresses (Qayyum et al., 2012). Leaf area ratio (cm² seedling⁻¹) has also shown a fluctuating response to soil moisture. However, the specific leaf area (SLA) has increased with increase in stress showing that plant at stress conditions requires higher leaf area g⁻¹ leaf weight and might resulting poor net photosynthetic rate per unit leaf area growth. Drought is a critical factor limiting growth and development of crops. Species have mechanisms to cope with stresses for a shorter period but may fail to sustain longer the yield potential (Khan et al., 2012). Increased in root DM under drought might be advantageous to plants in drying soil and might be important for the establishment of the young plant that are generally vulnerable to drying soil surface under the field conditions. Researchers have suggested that roots depth and density are important parameters to study for facing stress conditions by depletion of higher moisture from the soil (Yoshida and Hasegawa, 1982; Inanaga et al., 1996) and/or moderately moist soils (Hirasawa et al., 1994). Important is to clarify the mechanisms responsible for growth of roots that support shoot growth. Root in stresses has a substantial capacity for osmotic adjustment in growing regions (Serraj and Sinclair, 2002). It helps to maintain turgor under the stress. Healthy root system of plants has a significant effect on cereals production especially in moisture deficient soils (Mehmood-ul-Hassan et al., 2012).

The study of root elongation, number, DM and volume are significant parameters to compare different Varieties. Seminal roots length and elongation rates have been reported different for the different Varieties with non-significant change in numbers (Asad et al., 2011). Reduction in soil moisture from 100% to 75% did not show any significant change in root and shoot but further decrease from 75% has shown a strong loss of both root and shoot. Maize is found sensitive to moisture fluctuation in early growth (Mehmood-ul-Hassan et al., 2012). Moderate to severe reduction has shown significant change in shoot DM. Shoot is observed mild affected by reduction moisture form saturated (100%) to mild (50%) state but thereafter a significant decrease observed in roots and shoot DM when moisture decreased further. It was due to limited leaf area which restricted assimilates for the growth of roots and shoot. Varieties showed variations to moisture rates, showing that resistant markers does exist to be taken in consideration for further improvement of the high yielding varieties (Qayyum et al., 2012). One can also conclude that moisture fluctuations from 100% to 75% did not make any significant (p<0.05) loss in growth of hybrid and/or OPV varieties but thereafter drought stress caused marked decreases in root and shoot DM which might affect the final growth and production. Lower shoot DM can be due to limited leaf area, which restricts sinks sources accordingly. The study concluded that plants should adequately be irrigated from emergence to sustain healthy plants stand. Local genotype has potentials to take in consideration for improvement of the existing high yielding maize varieties to cope with future climate change hazards.

CONCLUSIONS

The study suggests that local genotypes as compare to exotic hybrids or improved synthetic have a great potential to perform better roots dry matter as well as roots volume that enables crop better to survive in partial drought. This root character shall have to be taken in consideration for further improvements of new cultivars.
that are high yielding with efficient resource capturing efficiency for climate changes expected in the region. Leaf is highly sensitive part in maize plant that affected more in partial drought and hence adversely reflects the biomass and yield.

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LITERATURE CITED


