Relative Efficacy of Organic Substrates on Maize Root Proliferation under Water Stress

Haroon Shahzad1,*, Muhammad Iqbal1, Safdar Bashir1, Muhammad Farooq2

1 Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan, 38080.
2 Department of Agronomy, University of Agriculture, Faisalabad, Punjab, Pakistan, 38080.

* Corresponding Author: haroon.shahzad_stu@uaf.edu.pk; Tel.: +92-323-603-8220

Abstract: The aggravating threat for today’s agriculture is provision of food security to ever-escalating eating mouths utilizing scarce resources. Water scarcity is restraining humans to produce more from drops of water in place of gallons. Root is present at soil-plant interface and is main water extractor for plant. Its growth pattern varies as soil moisture conditions fluctuates. Present pot study consisting of two factors i.e. organic substrates (Farm manure, Poultry Manure and Molasses) and different water stress levels (50, 75, 100 and 125% of AWCs) using maize as test crop to assess their impact on different growth parameters (especially root growth). The experiment was conducted using CRD under factorial arrangement. Root length (44.55 cm), root fresh & dry biomass (71.10 g and 24.30 g), root diameter (1.73 mm), root volume (0.24 cm³) and root length density (7.4 × 10⁻³ cm cm⁻³) were observed in farm manure treated pots at 75% AWC that was statistically indistinguishable from all other treatments at same water level and 100% water availability but eloquently greater than plants of all treatments at 50% and 125% available water contents. Shoot length, dry and fresh weights were observed greater in plants having 100% available moistures, that were at par with 75% water treated plants. Comparing treatments for all of the parameters in multivariate cluster analysis it was concluded that 75% available water contents produce almost similar to 100% along with the benefit of water security.

Keywords: maize, organic, water

1. Introduction:

Plant roots are major contributors of organic matter and structural stability of soil, directly through root material itself, and indirectly through stimulation of rhizosphere biological activities involved in particle aggregation, more importantly polysaccharide molecules secretion. Glomalin production by mycorrhizae [1] play central role in aggregation that had been explicitly evidenced. Counter production of exopolysaccharides (EPS) by rhizosphere microbiota modifies soil structure of sunflower root surfaces vicinity, counteracting the negative impact of water deficit on plant growth [2].

Water and its movement through soil-plant-atmosphere is crucial for photosynthesis, enzyme activity, metabolite transpiration and productivity of growing grains [3]. Evapotranspiration, is a main component of water balance [4,5] and grain yields can be described as a linear function of total evapotranspiration (ET) for most crops. Scheduled irrigation at different growth stages can improve water use efficiency according to several studies [6,7]. Kang et al. [8] also reported that grain yield and water use efficiency were strongly affected by soil water contents and irrigation schedules.
Arid climate, extensive cultivation, residue burning, exhaustive crop rotation and mismanagement had lead the soils to possess organic carbon less than 1%, that was the reason for conduction of numerous studies with organic substrates. Chief drive was to determine their nutrient equivalence with synthetic fertilizers and their non-nutrient benefits [9]. Long term experiments showed “fatigue” symptoms, witnessing stagnant and declined yields [10-12]. The major reason put forward for this stagnant yield was decline in organic matter quality and quantity [12,13]. Long term fertilizer management, manure and compost application, residue incorporation, green manuring, reduced or zero tillage, crop rotation and waste land restoration enhanced soil carbon buildup and storage [14]. These practices not only sustained the soil carbon but also productivity of crops. Single management strategy won’t be effective for carbon sequestration and yield enhancement [15].

Keeping above facts in mind present study was planned to conserve moisture and to improve plant growth through nutritional management.

2. Results

2.1 Plant Height

Table (1) explicates the variation in plant height of maize with amalgamated application of organic substrates, while soil moisture was kept 50, 75, 100 and 125% of soil available water capacity. Table evidenced increase in length of plants with increasing moisture content upto 100% AWC, that lessened upon further increase.

Highest plant height (90.00 cm) was found in treatment where farm manure was applied (TF1) at 50% moisture level. Plants of TF1 were statistically similar but 7.18, 0.9 and 5% longer in length than TF0, TF2 and TF3 treatments, respectively. Increased soil moisture resulted in more elongated plants as 157.6 cm in (TS2) that was at par with TS1 and TS3 which have only 2.56 and 5.77% dwarfed plants, respectively. All treated soils yielded significantly longer plants than control soil at 75% moisture level. Plant height was observed maximum (158.5 cm) in TH1 that was at par with TH2 and TH3 but was significantly greater than control. At 125% moisture plant height declined to 62.67 cm in TO3 that was at par with all other treated plots at same moisture.

Plant height increased from 83.97 cm at 50% AWC to 135.47 and 138.73 cm at 75 and 100% AWC then decreased to 60.27 cm at oversaturation. Farm manure application had maximum plant height 158.5 cm at 100% available capacity that was 3, 76.1 and 158.7% greater in conditions possessing moisture @ 75, 50 and 125% of available water capacities, respectively. Poultry litter application in soil had given rise 157.6, 155.8, 89.17 and 56.07 cm long plants while the moisture was kept @ 75, 100, 50 and 125% available moistures. Molasses application also had longest 154.9 cm plants where moisture was at 100% of AWC that got declined to 149, 85.73 and 62.67 cm in 75, 50 and 125% AWCS.

2.2 Shoot Fresh Weight

Table (1) overt disparity in fresh weights of plants with application of organic substrates at different (50, 75, 100, 125%) available moistures. It is evidenced from table that increase in moisture yields more plant weights from 50% to 100% AWC that depreciated upon saturation.
At 100% available moisture 106.08 g fresh shoot weight of maize plant was found in pots treated with farm manure, that was statistically at par with other waste treated pots but was significantly greater than untouched control. Poultry manure had yielded 106.13 g fresh weight of plants at 75% available moisture that was 0.3, 12.83 and 33.8% greater in weight than TS0, TS3 and TS0, respectively. 72.94 g fresh weight of plants was there of farm manure treated soils at 50% available moisture capacity that was 1.2, 3.4 and 12.3% greater in content than TF0, TF2 and TF0, respectively. Oversaturation affected the plant biomass in all of the treatments, as 74.97 g biomass was found in pots treated with farm manure that was 3.3, 9.4 and 16.8% greater than TO2, TO3 and TO0, respectively.

Moisture had an impact on plant growth as 100% water availability yielded 77.19 g biomass that was 3.6, 18.8 and 20.25% greater than pots in which soil water content were maintained @ 75, 50 and 125% of AWCs. Combination of farm manure and 100% available water had maximum biomass (106.08 g) production that was statistically like the mass (99.29 g) produced at 75% moisture but was suggestively greater than 74.97 and 72.94 g where water was maintained @ 125 and 50% of AWC. 99.65 g biomass was produced by unified application of poultry and 75% water availability that is suggestively identical to 100% AWC but significantly higher than 72.57 g and 70.54 g, where water was maintained @ 125 and 50% of AWCs.

2.3 Shoot Dry Weight

Table (1) unconcealed discrepancy in shoot dry weights using organic substrates in combination with different (50, 75, 100, 125%) available moistures. It can be demonstrated from figure that moisture increase produces more dry matter upto 100% AWC but oversaturation declines the dry matter addition.

Optimum available moisture (100% AWC) produced 41.66 g dry plant biomass in pots treated with farm manure (TH1), that had not a suggestive alteration from molasses treated (39.05 but pointedly greater than 35.93 g and 30.28 g biomass produced by poultry and untreated plants. TS3 had generated 39.13 g dry biomass which was 0.17, 12.64 and 33.73% greater in weight than TS0, TS3 and TS0, respectively. 28.76 g dry heft was there of farm manure treated soils at 50% available moisture capacity that was 1.5, 3.64 and 12.6% greater in content than TF3, TF2 and TF0, respectively. Dry matter addition was declined in each treatment with oversaturation generating only 29.43 g in farm manure treated pots that was 2.21, 9.4 and 17.11% greater than TO2, TO3 and TO0, respectively.

Maximum dry matter 39.13 g was produced by farm manure and 100% water retention combination engendering 8.9, 41.00 and 37.00% greater biomass than plants grown @ 75, 50 and 125% of AWCs. Control produced (30.28 g) dry shoot matter at 100% AWC that was statistically at par with 75% moisture but was provocatively, greater than dry weights produced @ 125 and 50% of AWC. 39.13 g biomass was produced by application of poultry @ 75% water availability that is defiantly indistinguishable from 100% AWC but wittingly higher than 28.50 g and 27.75 g, where water was maintained @ 125 and 50% of AWCs.
Table 1. Effect of organic substrates application at different moisture levels on plant height, fresh and dry weights of maize shoot

<table>
<thead>
<tr>
<th>AWC</th>
<th>Organic Waste</th>
<th>Treatments</th>
<th>Shoot Length (cm)</th>
<th>Shoot Fresh Weight (g)</th>
<th>Shoot Dry Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>CTRL</td>
<td>TF₀</td>
<td>83.97±2.27 d</td>
<td>64.96±1.89 e</td>
<td>25.55±0.76 e</td>
</tr>
<tr>
<td></td>
<td>FM</td>
<td>TF₁</td>
<td>90.00±2.76 d</td>
<td>72.94±1.48 de</td>
<td>28.76±0.59 de</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>TF₂</td>
<td>89.17±2.21 d</td>
<td>70.54±2.37 de</td>
<td>27.75±0.97 de</td>
</tr>
<tr>
<td></td>
<td>MO</td>
<td>TF₃</td>
<td>85.73±3.57 d</td>
<td>72.05±6.18 de</td>
<td>28.34±2.41 de</td>
</tr>
<tr>
<td>75%</td>
<td>CTRL</td>
<td>TS₀</td>
<td>135.47±1.99 c</td>
<td>74.49±2.35 c-e</td>
<td>29.26±0.97 cd</td>
</tr>
<tr>
<td></td>
<td>FM</td>
<td>TS₁</td>
<td>153.67±1.97 a-c</td>
<td>99.29±3.40 a-c</td>
<td>39.05±1.36 ab</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>TS₂</td>
<td>157.60±3.27 ab</td>
<td>99.65±3.25 a-c</td>
<td>39.13±1.31 ab</td>
</tr>
<tr>
<td></td>
<td>MO</td>
<td>TS₃</td>
<td>148.97±4.30 a-c</td>
<td>88.36±4.02 a-e</td>
<td>34.75±1.61 d</td>
</tr>
<tr>
<td>100%</td>
<td>CTRL</td>
<td>TH₀</td>
<td>138.73±2.50 bc</td>
<td>77.19±4.00 b-e</td>
<td>30.28±1.52 de</td>
</tr>
<tr>
<td></td>
<td>FM</td>
<td>TH₁</td>
<td>158.50±3.42 a</td>
<td>106.08±4.76 a</td>
<td>41.66±1.88 a</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>TH₂</td>
<td>155.80±5.63 ab</td>
<td>91.38±0.99 a-d</td>
<td>35.93±0.39 d</td>
</tr>
<tr>
<td></td>
<td>MO</td>
<td>TH₃</td>
<td>154.90±2.84 ab</td>
<td>99.49±3.32 a-c</td>
<td>39.05±1.28 ab</td>
</tr>
<tr>
<td>125%</td>
<td>CTRL</td>
<td>TO₀</td>
<td>60.27±2.63 e</td>
<td>64.19±3.72 e</td>
<td>25.13±1.44 e</td>
</tr>
<tr>
<td></td>
<td>FM</td>
<td>TO₁</td>
<td>61.27±0.93 e</td>
<td>74.97±8.31 c-e</td>
<td>29.43±3.25 de</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>TO₂</td>
<td>56.07±2.89 e</td>
<td>72.57±7.41 de</td>
<td>28.50±2.97 de</td>
</tr>
<tr>
<td></td>
<td>MO</td>
<td>TO₃</td>
<td>62.67±2.60 e</td>
<td>68.51±2.20 de</td>
<td>26.90±0.80 de</td>
</tr>
</tbody>
</table>
2.4 Root Length

Variation in length of plant root with application of organic wastes at different moisture levels has been particularized in table (2). 11.29 cm long roots were measured for the plants treated with molasses where moisture was maintained at 50% AWC, that was 13.47, 17.11 and 21.92% longer than TF2, TF1 and TF0. 44.55, 41.69 and 40.10 cm long roots in TS1, TS2 and TS3 treatments evidenced 4.62, 4.2 and 3.55 times elongation than 50% available moisture. Slight and non-suggestive diminution in length of roots (43.06 (TH1), 40.39(TH2) and 40.03(TH3) cm) was found with increase in available water contents to 100%, and are challengingly stretched by 39.53, 30.88 and 29.7% than control. Strong decrement (7.81, 6.93, 7.84 and 7.23 cm) in root proliferation was observed upon saturation in non-treated and treated soils.

2.5 Root Fresh and Dry Weight

Effect of different organic substrates at different moisture levels on weight of plant roots is elucidated in table (2). It is evident from figure that combination of farm manure at 75% available water yielded highest root fresh and dry weights (71.1 and 24.3 g) that were only (0.88 and 4.24 g) and (0 and 1.19 g) greater than weights of roots in molasses and poultry treated plants. All of the treated roots have significantly greater fresh and dry biomasses than control. Plant roots in TH2, TH1 and TH3 have fresh and dry weights of order (63.54, 63.00 and 60.57 g) and (21.92, 21.71 and 20.95 g) that were statistically similar but were significantly greater than control (42.03 and 14.47 g), (20.43 and 7.02 g) and (14.31 and 4.97 g) fresh and dry weights of roots were found at 50 and 125% AWCs that were at par with all of the treatments.

Table 2. Effect of organic substrates application at different moisture levels on length, fresh and dry weights of maize root

<table>
<thead>
<tr>
<th>AWC</th>
<th>Organic Waste</th>
<th>Treatments</th>
<th>Root Length (cm)</th>
<th>Root Fresh Weight (g)</th>
<th>Root Dry Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>CTRL</td>
<td>TF0</td>
<td>9.26±1.43 c</td>
<td>20.43±1.83 g-i</td>
<td>7.02±1.10 c</td>
</tr>
<tr>
<td></td>
<td>FM</td>
<td>TF1</td>
<td>9.64±1.23 c</td>
<td>22.32±1.19 gh</td>
<td>7.67±1.10 c</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>TF2</td>
<td>9.95±0.97 c</td>
<td>23.63±1.11 g</td>
<td>7.78±0.86 c</td>
</tr>
<tr>
<td></td>
<td>MO</td>
<td>TF3</td>
<td>11.29±0.55 c</td>
<td>24.32±1.42 g</td>
<td>7.13±1.17 c</td>
</tr>
<tr>
<td>75%</td>
<td>CTRL</td>
<td>TS0</td>
<td>34.74±0.87 b</td>
<td>47.16±1.04 f</td>
<td>16.31±1.17 b</td>
</tr>
<tr>
<td></td>
<td>FM</td>
<td>TS1</td>
<td>44.55±1.11 a</td>
<td>71.10±1.27 a</td>
<td>24.30±2.39 a</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>TS2</td>
<td>41.69±0.70 a</td>
<td>66.96±1.84 a-d</td>
<td>23.11±2.73 a</td>
</tr>
<tr>
<td></td>
<td>MO</td>
<td>TS3</td>
<td>40.10±0.46 a</td>
<td>70.29±1.30 ab</td>
<td>24.30±3.09 a</td>
</tr>
<tr>
<td>100%</td>
<td>CTRL</td>
<td>TH0</td>
<td>30.86±1.05 b</td>
<td>42.03±1.01 f</td>
<td>14.47±1.45 b</td>
</tr>
<tr>
<td></td>
<td>FM</td>
<td>TH1</td>
<td>43.06±0.79 a</td>
<td>63.00±1.72 c-e</td>
<td>21.71±2.99 a</td>
</tr>
</tbody>
</table>
2.6 Root Length Density

Root length density is one of the authoritative parameter that determines plant anchorage, crop stand, water and nutrient uptake from soil. Disparity in length density of plant roots in organic substrate pot cultures at several moisture levels is presented in figure (1). It is illustrated that 75 and 100% moisture yielded denser long roots than other two moisture levels. Farm manure yielded maximum $7.40 \times 10^{-3}$ cm cm$^{-3}$ root length density at 75% moisture that was at par with 100% moisture ($7.13 \times 10^{-3}$) cm cm$^{-3}$ but was 4.6 and 6.54 folds denser than 50 and 125% moistures, respectively. $6.9 \times 10^{-3}$ cm cm$^{-3}$ root length density was found in poultry blended cultures at 75% moisture that was statistically analogous to 100% moisture but was 4.23 and 5.3 times denser than roots in 50 and 125% available moistures. Molasses mixture yielded $6.3 \times 10^{-3}$ cm cm$^{-3}$ length density of roots at 100% moisture availability that was statistically indistinguishable to 75% moisture level. Their combination yielded only $1.87 \times 10^{-3}$ and $1.2 \times 10^{-3}$ cm cm$^{-3}$ denser roots at 50 and 125% moistures that were 3.57 and 5.56 times lesser than root length density in 75% moisture level.

Farm manure had $7.4 \times 10^{-3}$ cm cm$^{-3}$ root length density @ 75% moisture that was 7.2, 11.61 and 28.2% greater than TS2, TS3 and TS0. At 100% available water, maximum root length density ($7.13 \times 10^{-3}$ cm cm$^{-3}$) was found in TH1 that was statistically at par with TH2 ($6.73 \times 10^{-3}$) and TH3 ($6.67 \times 10^{-3}$) but was 1.35 times extra than control ($5.13 \times 10^{-3}$) cm cm$^{-3}$. $1.97 \times 10^{-3}$ cm cm$^{-3}$ dense roots were found in TF3 at 50% AWC that was 20.86, 23.12 and 28.76% lager in content than TF2, TF1 and control, respectively. Plants treated with poultry manure had $1.3 \times 10^{-3}$ cm cm$^{-3}$ dense roots @ 125% AWC that was 3.17, 8.33 and 15% denser than control, TO3 and TO1, respectively.
Figure 1. Effect of different organic substrates on root length density (cm cm\(^{-3}\)) at different water stress levels

2.7 Root Volume

Figure (2) enlightens the vicissitudes in volume of roots upon application of organic substrates at different soil moistures. Roots of untreated control at 75\% AWC occupied 0.15 cm\(^3\) space that was alluringly lower than 0.22, 0.21 and 0.206 cm\(^3\) in TS1, TS2 and TS3, respectively. Volume of roots in molasses treated pots (0.21 cm\(^3\)) was appealingly akin farm manure (0.20 cm\(^3\)) and poultry (0.194 cm\(^3\)) blends but meaningfully greater than control (0.145 cm\(^3\)) at 100\% available moisture. 0.12 cm\(^3\) volume was covered by roots of untreated plants at 50\% moisture that was enticingly similar with TF1, TF2 and TF3, respectively. Molasses blend of soil @ 125\% moisture had occupied 0.11 cm\(^3\) volume in soil that is statistically similar with 0.11, 0.10 and 0.10 cm\(^3\) in farm manure, poultry and control, respectively.

Soil kept at 50\% supported plant to extend its roots to occupy volume of 0.12 cm\(^3\) that was 20\% greater than pots in which moisture was maintained @ 125\% AWC but volume was 25 and 20.8\% lesser than pots in which water was maintained at 75\% and 100\% of available water capacities. Plant roots of farm manure blended soil had covered 0.22 cm\(^3\) volume @ 75\% available water that was at par with 100\% moisture but was pointedly greater than plants in 50 and 125\% water retaining soils. 0.21 cm\(^3\) volume was occupied by plants at 75\% moisture in poultry amended soils that was analogous to 0.194 cm\(^3\) at 100\% moisture but was pointedly more than root volume at 50 and 125\% available moistures. Plants grown in soil treated with molasses @ 100\% AWC have root volume of 0.21 cm\(^3\) that was equal to volume at 75\% AWC but possessed 50 and 91\% more volume than soils at 50 and 125\% available moistures.
Figure 2. Effect of different organic substrates on root volume (cm³) at different water stress levels

2.8 Root Diameter

Figure (3) elucidates the changes in average diameter of root with application of organic substrates while soil water content was maintained at different levels. Data regarding water content reveals roots of 100% water retained soil having 1.1 mm diameter was statistically similar to 75% but was 1.86 and 2.11 times messier than 125% and 50% moisture levels. Blend of farm manure with soil had roots with average diameters of 1.73 mm at 75% moisture that was only 2.7% messier than roots in 100% moisture but had 2.92 and 3.14 times more diameter than 125 and 50% available moistures, respectively. Combination of poultry manure and M19 had managed to formulate roots of 1.65 mm diameter at 75% available water that possessed 0.02, 1.05 and 1.14 mm more diameter than 100, 50 and 125% moisture. Plant roots of molasses treated soils had 1.68 mm average diameter at 75% available soil moisture that was statistically alike to that of 100% moisture level but had 2.95 and 3.3 times more diameter than pots having 50 and 125% moistures. 75% moisture in combination with farm manure give rise the thicker roots of average diameter 1.73 mm that were statistically at par with TS1 and TS2 but was significantly more thick than control. At 100% moisture roots of TH1 had 1.68 mm diameter which was only 0.3, 0.3 and 0.5 mm more than TH3 and TH2, respectively, but was suggestively thicker than control (1.1 mm). Roots of plants in treated as well as control at 50 and 125% moisture were observed to be statistically similar.
Figure 3. Effect of different organic substrates on root average diameter (mm) at different water stress levels

3. Discussion

Plant growth is dependent upon the soil nutritional value, more obviously the nutrients in solution contribute towards growth. The nutrient availability and uptake is dependent upon soil physicochemical health, especially water content of soil, organic carbon and the soil biological activities. Different organic manures at maintained moistures have contributed differently to plant growth as presented in results of plant growth parameters. Shoot growth i.e. plant height, leaf area, chlorophyll contents and shoot dry matter increased significantly due to better root growth that promoted water and nutrient uptake. Plant root is the main soldier present at that border having access to these obstacles. N incorporation increases protein and enzyme contents enduring plants better physiological activism. Greater N contents also contributes towards chlorophyll formation that consequently enhances photosynthesis [16].

Organic substrates (farm manure or crop residues) affect crop growth and yield by direct nutrient supplementation and indirectly by amending soil physical characteristics i.e. soil structure and water retention capacity [17], bulk density, penetration resistance and porosity [18], infiltration rate [19] that improves root environment and stimulate plant growth [20]. However, organic manures alone can’t sustain productivity [21], sensible use of organic manures along with synthetic fertilizers, bio-inoculants and irrigation are essential to safeguard soil health and augment input use efficacy and productivity [22, 23]. Positive response of productivity with integrated application of manure and synthetic fertilizers have been reported by many researchers [24-27]. Plant growth criterion imitate the net flux of resources in and out of
plant and its various organs. However, each resource may be invested differently and provide different insights into plant’s adaptive mechanisms and physiological balance. Ritchie et al. [28] proposed that plant growth and development can be measured by accumulated dry matter in different organs. Several workers [29, 30] analyzed biomass accumulation and growth patterns with respect to plant variety, spacing, nutrient, organics and water management regimes.

Soil moisture is one of the most important factor for poor growth and yield of crops. One possible mean to exploit growth per water drop is deficit irrigation [31]. Saving of water is more beneficial than reduced yields by regulated deficit irrigation, specifically in water limited areas [32]. A linear relation is present in crop growth and irrigation levels and the deficit irrigation at booting and heading delays reproduction resulting into 25% increase in yield of wheat crop [33]. Moisture deficit reduces yield but increases biomass as well the water use capacity of plants [34, 35].

Imran et al. [36] had reported more root length density at 70-80% of available water capacity at different crop growth stages. A provocative change in root penetration pattern, increase in root length density was observed with irrigation at different crop growth stages [37] and the reduced irrigation yielding highest length density of roots in deeper soil [38]. Drying of soil during early crop growth stages stimulate root growth especially in deeper soil profile [39]. Variances in soil moisture storage and uptake under different organic and inorganic applications is more evident during dry spell [24]. The incorporation of organic substrates increases soil organic carbon pool increasing biological activities that results in improved soil physical health leading to more proliferation of roots making water availability much easier for plants, that ultimately results in more growth [40]. Roots mostly prevailed in upper 15 cm depth because of more nutrition and especially loose soil profile, but organic matter addition in deeper profile not only loosen the soil in deeper soil but also enhances root penetration [41]. Allmaras et al. [42] reported increase in root length densities in deeper soil with application of farm manure that maybe attributed to nutrient supply and creation of better soil physical environments due to lowering of soil bulk density and penetration resistance and increased porosity. Decreased crop penetration resistance because of applied manures increase root length density up to 97% [22].

4. Materials and Methods

A pot experiment was carried out at wire house Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad, Pakistan. Experimental site has typical tropical monsoon climate with 30 °C and 705 mm mean annual temperature and precipitation, respectively. Mean annual accumulated temperature above 10 °C is 33.5 °C. A polythene sheet was placed at 7 feet height to protect from rainfall. Soil for the experiment was collected from field area of Institute of Soil & Environmental Sciences (Latitude 31°26′0″N and longitude 73°08′0″E), University of Agriculture, Faisalabad, Pakistan. Soil was sandy clay loam, semi-active, isohyperthermic Typic Calciargids (FAO Classification). The bulk density of soil was maintained as 1.36 Mg m⁻³ during pot filling. Soil samples were collected from depth of 0-15 cm, crop roots and other debris were removed from samples and soil was air dried prior to pass through 2 mm sieve. Soil samples contained 9 g kg⁻¹ SOC, 1.2 g kg⁻¹ N, 7.5 (C: N), 8.2 units of pH. Soil water retention capacity was measured by pre-defined matric potential [43] with the help of suction plates at 0.3, 0.6, 1.0, 3.0 and 4.5 bar pressure and a linear regression equation was calculated by taking ln (h) versus ln θ/ θ₀ to find water contents at
field capacity ($\theta_{FC}$) and permanent wilting point ($\theta_{PWP}$) of soil [44]. Following equation was developed by taking $\ln (h)$ versus $\ln \frac{\theta}{\theta_s}$ to get ($\theta_{FC}$) and ($\theta_{PWP}$) etc.

$$P = \ln P_e + b \ln \left(\frac{\theta}{\theta_s}\right)$$

$P$ is matric potential (kPa), “$P_e$” (intercept) is air entry value/ bubbling pressure that has inverse relation with “$\alpha$”, and “$b$” is slope of $\ln P$ vs $\theta/\theta_s$ of water retention curve. The linear relationship between $\ln \theta/\theta_s$ [-] and $\ln (P)$ [kPa] were observed for experimental soil with intercept (0.26) and a negative slope -6.9283 (Figure 4). Water retention properties of experimental soil are presented in Table (3).

### Table 3. Water Retention properties of soil used for pot filling

<table>
<thead>
<tr>
<th>Water Retention Properties</th>
<th>$\theta_s$</th>
<th>$\theta_{FC}$</th>
<th>$\theta_{PWP}$</th>
<th>$\theta_{AWC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>(%)</td>
<td>23.12±0.94</td>
<td>10.89±0.67</td>
<td>12.25±0.42</td>
</tr>
<tr>
<td>Data is average of three replicates with standard error</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A pot experiment was laid out in CRD under split plot arrangement with water stress levels as main plot factor and treatment (Farm Manure, Poultry Manure and Molasses) as sub plot factor with three replications. Four water stress levels [50, 75, 100 and 125% of Available water contents (AWC)] were designed to subject maize crop to water stress and the other treatments (organic substrates) were mixed with soil at the time of filling of pots. Each treatment was replicated thrice. During the whole study, controlled irrigation was applied to each pot by weighing pot on daily basis using weighing balance, so as to accurately maintain water stress level followed by said experimental design. Locally manufactured digital balance was used for weighing that had weighing capacity in range from 200-30000 ± 5g. Data was collected according to Dwyer et al. [45] and irrigation amount was calculated to replace depleted water content from each pot according to designed treatments. Hybrid maize Shahnshah was planted on 9th of
March 2014. Urea was applied @ 120 kg ha⁻¹ in two splits while phosphorus and potash were applied @ 60 kg ha⁻¹ at the time of sowing. Seedling density after germination was controlled to one plant per pot and weeds were removed by hand. At 25th of April soil from the pots was evacuated using water to take out the roots at the time of harvest. Plant height and fresh weight of root and shoot were measured using weight balance. Shoot was subjected to drying at 70 °C in oven till constant weight and then calculated using weighing balance. Plant roots were separated using dissection needle in water filled glass container and the sketch of these extended roots is being taken using root scanner (hp-scanjet 2700). These scanned roots then inserted to root scanning software (RootSnap) to find average root length, root volume and root diameter [46]. Then again these roots were oven dried at 70 °C to take their dry mass. Root length density (cm cm⁻³) was calculated by equation

\[
\text{Root Length Density} = \frac{\text{Average Root Length}}{\text{Volume of the Pot}}
\]

Average of all of the treatment replicates was calculated and all treatments were tested for significance at (p>0.05) using analysis of variance technique. Significance of individual treatments was tested using Tuckey’s Honestly Significant Difference (HSD) test [47].

**Conclusion**

This study explores the effectiveness of limited water supply in combination with mixture of organic substrates on maize in semi-arid climate. The optimum level of irrigation proved to be 75% of available water contents in combination with all organic substrates.
References


