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RELATIVE EFFICACY OF ORGANIC SUBSTRATES ON MAIZE ROOT PROLIFERATION UNDER WATER STRESS

EFICÁCIA RELATIVA DE SUBSTRATOS ORGÂNICOS NA PROLIFERAÇÃO DE RAÍZES DE MILHO SOB ESTRESSE HÍDRICO

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ABSTRACT: The aggravating threat for today's agriculture is provision of food security to ever-escalating population 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 available water contents (AWCs)} using maize as test crop to assess their impact on different growth parameters (especially root growth). The experiment was conducted using completely randomized design CRD under factorial arrangement. Root length (44.5 cm), root fresh & dry biomass (71.1 g and 24.3 g, respectively), root diameter (1.73 mm), root volume (0.24 cm^3) and root length density (7.4 x 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. They were statistically at par with 75% water treated plants. Comparing treatments for all 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: Organic. Maize. Root. Proliferation. Drought.

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. They are involved in particle aggregation, more importantly polysaccharide molecules secretion. Glomalin production by mycorrhizae (RILLIG et al., 2002) play central role in aggregation that had been explicitly evidenced (SCHREINER et al., 1997). 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 (ALAMI et al., 2000).

Water and its movement through soil-plant-atmosphere is crucial for photosynthesis, enzyme activity, metabolite transpiration and productivity of growing grains (NACEU et al., 1999). Evapotranspiration, is a main component of water balance (GENTINE et al., 2007; PARASURAMAN et al., 2007) and grain yields can be described as a linear function of total evapotranspiration (ET) for most crops (VAUX; PRUITT, 1983). Scheduled irrigation at different growth stages can improve water use efficiency according to several studies (WANG et al., 2002; FANG et al., 2010). JIN et al. (1999) also found that over irrigation can decrease crop water use efficiency, while deficit irrigation may result in more production and WUE. Kang et al. (2002) 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 (TANDON, 1997). Long term experiments showed "fatigue" symptoms, witnessing stagnant and declined yields (DAWE et al., 2000; DUXBURY et al., 2000; LADHA et al., 2003). The major reason put forward for this stagnant yield was decline in organic matter quality and quantity (DAWE et al., 2000; YADAV et al., 2000; LADHA et al., 2003). 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 (KIMBLE et al., 2002). These practices not only sustained the

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soil carbon but also productivity of crops. Single management strategy won’t be effective for carbon sequestration and yield enhancement (LAL, 2004).

Based upon above facts it was hypothesized that artificial organic materials decompose to boost nutritional capacity of soil. Therefore, this experiment was envisaged to assess the impact of organic substrates addition in soil on maize vegetative growth under water stress.

MATERIAL AND METHODS

A pot experiment was carried out at wire house Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad, Pakistan. Experimental site, which has typical tropical monsoon climate with 30 ºC and 705 mm mean annual temperature and precipitation, respectively. Mean annual accumulated temperature above 10 °C is 33.5 °C. Approximately, 80% annual precipitation comes during March to September. 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). Each pot had 45 cm height and 20 cm diameter and was filled with 10 kg soil. 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} soil organic carbon (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 (DANE; HOPMANS, 2002) 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/θ_s to find water contents at field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}) of soil (WILLIAMS et al., 1983). Following equation was developed by taking ln (h) versus ln θ/θ_s to get (θ_{FC}) and (θ_{PWP}) etc.

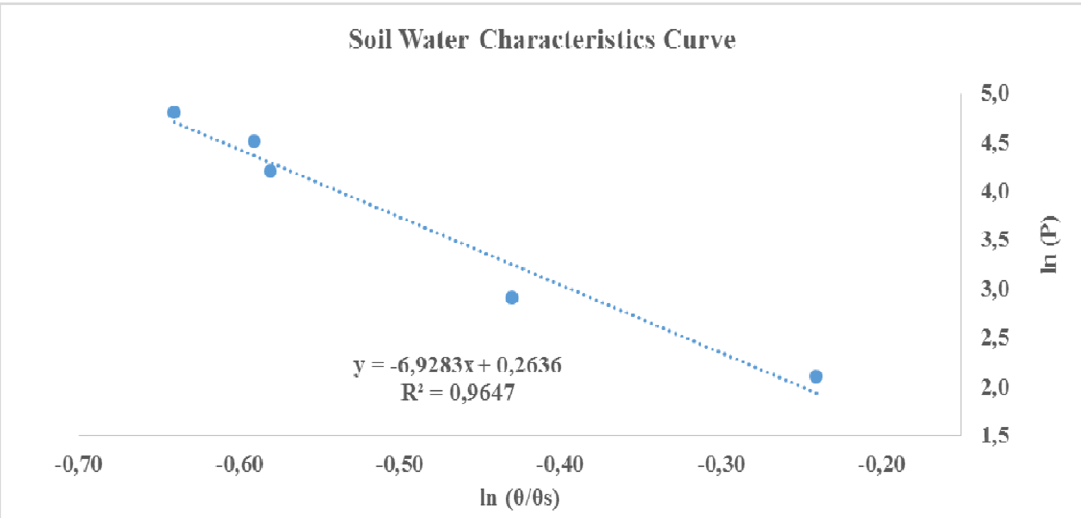


Figure1. Water characteristics curve

$\ln P = \ln P_\alpha + b \ln(\theta/\theta_s)$

P is matric potential (k Pa), “P_e” (intercept) is air entry value/ bubbling pressure that has inverse relation with “α”, and “b” is slope of ln *P vs* θ/θ_s of water retention curve. The linear relationship between *ln* θ/θ_s [-] and *ln* (P) [kPa] were observed for experimental soil with intercept (0.26) and a negative slope -6.9283 (Figure 1). Water retention properties of experimental soil are presented in Table 1

The experiment was laid out in CRD under factorial arrangement with water stress levels as one factor and organic amendments (Farm Manure, Poultry Manure and Molasses) as other factor with three replications. Four water stress levels (50, 75, 100 and 125% of 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 as being described in treatment plan.

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.

Table1. Water Retention properties of soil used for pot filling

Water Retention Properties	Θ_S	Θ_{FC}	Θ_{PWP}	Θ_{AWC}
Units	(%)			
	45.4±1.32	23.1±0.94	10.9±0.67	12.3±0.42

Data is average of three replicates with standard error

Treatment Plan

50% AWC	**100% AWC**
$CTRL_{50}$= Control	$CTRL_{100}$ = Control
FM_{50} = Farm Manure	FM_{100} = Farm Manure
PM_{50} = Poultry Manure	PM_{100} = Poultry Manure
MO_{50} = Molasses	MO_{100} = Molasses
75% AWC	**125% AWC**
$CTRL_{75}$ = Control	$CTRL_{125}$ = Control
FM_{75} = Farm Manure	FM_{125} = Farm Manure
PM_{75} = Poultry Manure	PM_{125} = Poultry Manure
MO_{75} = Molasses	MO_{125} = Molasses

Data was collected according to Dwyer et al. (1987) 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 (at the time of 1st and 2nd irrigation) 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 was measured with meter rod and fresh weight of root and shoot was measured using weight balance. Shoot was subjected to drying at 70 ºC 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 (Dannoura et al., 2008). Then again these roots were oven dried at 70 ºC to take their dry mass. Root length density (cm cm^{-3}) was calculated by equation

$$Root\ Length\ Density = \frac{Average\ Root\ Length}{Volume\ of\ the\ Pot}$$

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 (Montgomery, 2013). Better performing treatments were categorized using multivariate (Cluster analysis) technique.

RESULTS

Plant Height

Table 2 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 up to 100% AWC that lessened upon further increase.

Tallest plants (90.0 cm) were found in treatment where farm manure was applied (FM_{50}) at 50% moisture level. Plants of FM_{50} were statistically similar but 7.18, 0.9 and 5% longer in length than $CTRL_{50}$, PM_{50} and MO_{50} treatments, respectively. Increased soil moisture resulted in more elongated plants as 157.6 cm in (PM_{75}) that was at par with FM_{75} and MO_{75} 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 FM_{100} that was at par with PM_{100} and MO_{100} but was significantly greater than control. At 125% moisture plant height declined to 62.7 cm in MO_{125} that was at par with all other treated plots at same moisture.

Plant height increased from 84.0 cm at 50% AWC to 135.5 and 138.7 cm at 75 and 100% AWC then decreased to 60.3 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, 89.2 and 56.1 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, 85.7 and 62.7 cm in 75, 50 and 125% AWCs.

Shoot Fresh Weight

Table 2 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.

Table 2. Effect of organic substrates application at different moisture levels on plant height, fresh and dry weights of maize shoot

AWC	Organic Amendments	Treatments	Plant Height (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)
50%	CTRL	$CTRL_{50}$	84±2.27 d	65±1.89 e	25.6±0.76 e
	FM	FM_{50}	90.0±2.76 d	72.9±1.48 de	28.8±0.59 de
	PM	PM_{50}	89.2±2.21 d	70.5±2.37 de	27.8±0.97 de
	MO	MO_{50}	85.7±3.57 d	72 ±6.18 de	28.3±2.41 de
75%	CTRL	$CTRL_{75}$	135.5±1.99 c	74.5±2.35 c-e	29.3±0.97 cd
	FM	FM_{75}	153.7±1.97 a-c	99.3±3.40 a-c	39 ±1.36 ab
	PM	PM_{75}	157.6±3.27 ab	99.6±3.25 a-c	39.1±1.31 ab
	MO	MO_{75}	149±4.30 a-c	88.4±4.02 a-e	34.8±1.61 d
100%	CTRL	$CTRL_{100}$	138.7±2.50 bc	77.2±4.00 b-e	30.3±1.52 de
	FM	FM_{100}	158.5±3.42 a	106.1±4.76 a	41.7±1.88 a
	PM	PM_{100}	155.8±5.63 ab	91.4±0.99 a-d	35.9±0.39 d
	MO	MO_{100}	154.9±2.84 ab	99.5±3.32 a-c	39±1.28ab
125%	CTRL	$CTRL_{125}$	60.3±2.63 e	64.2±3.72 e	25.1±1.44 e
	FM	FM_{125}	61.3±0.93 e	75±8.31 c-e	29.4±3.25 de
	PM	PM_{125}	56.1±2.89 e	72.6±7.41 de	28.5±2.97 de
	MO	MO_{125}	62.7±2.60 e	68.5±2.20 de	26.9±0.80 de

Abbreviations: AWC (Available water contents), CTRL (Control), FM (Farm Manure), PM (Poultry Manure) and MO (Molasses)

At 100% available moisture 106.1 g fresh shoot weight of maize plant was found in pots treated with farm manure, which was statistically at par with other waste treated pots but was significantly greater than control. Poultry manure had yielded 106.1 g fresh weight of plants at 75% available moisture that was 0.3, 12.8 and 33.8% greater in weight than FM_{75}, MO_{75} and $CTRL_{75}$, respectively. 72.9 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 MO_{50}, PM_{50} and $CTRL_{50}$, respectively. Oversaturation affected the plant biomass in all the treatments, as 75 g biomass was found in pots treated with farm manure that was 3.3, 9.4 and 16.8% greater than PM_{125}, MO_{125} and $CTRL_{125}$, respectively.

Moisture had an impact on plant growth as 100% water availability yielded 77.2 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 (106.1 g) production that was statistically like the mass (99.3 g) produced at 75% moisture but was suggestively greater than 75 and 72.9 g where water was maintained @ 125 and 50% of AWC. 99.6 g biomass was produced by unified application of poultry and 75% water availability that is suggestively identical to 100% AWC but significantly higher than 72.6 g and 70.5 g, where water was maintained @ 125 and 50% of AWCs.

Shoot Dry Weight

Table 2 unconcealed discrepancy in shoot dry weights using organic substrates in combination with different (50, 75, 100, 125%) available moistures. It can be demonstrated from Table that moisture increase produces more dry matter up to 100% AWC but oversaturation declines the dry matter addition.

Optimum available moisture (100% AWC) produced 41.7 g dry plant biomass in pots treated with farm manure (FM_{100}), that had not a suggestive alteration from molasses treated (39.0) but pointedly greater than 35.9 g and 30.3 g biomass produced by poultry and untreated plants. Poultry manure @ 75% AWC had generated 39.1 g dry biomass which was 0.17, 12.6 and 33.7% greater in weight than FM_{75}, MO_{75} and $CTRL_{75}$, respectively. Farm manure yielded 28.8 g dry heft at 50% AWC that was 1.5, 3.64 and 12.6% greater in content than MO_{50}, PM_{50} and $CTRL_{50}$, 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 17.1% greater than PM_{125}, MO_{125} and $CTRL_{125}$, respectively.

Maximum dry matter 39.1 g was produced by farm manure and 100% water retention combination engendering 8.9, 41.0 and 37.0% greater biomass than plants grown @ 75, 50 and 125% of AWCs. Control produced (30.3 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. 39.1 g biomass was produced by application of poultry @ 75% water availability that is defiantly indistinguishable from 100% AWC but wittingly higher than 28.5 g and 27.7 g, where water was maintained @ 125 and 50% of AWCs.

Root Length

Variation in length of plant root with application of organic amendments under different moisture levels has been particularized in Table 3. Roots of 11.29 cm length were measured for the plants treated with molasses where moisture was maintained at 50% AWC that was 13.5, 17.1 and 21.9% longer than PM_{50}, FM_{50} and $CTRL_{50}$. 44.6, 41.7 and 40.1 cm long roots in FM_{75}, PM_{75} and MO_{75} treatments evidenced 4.62, 4.2 and 3.55 times elongation than 50% available moisture. Slight and non-suggestive diminution in length of roots (43.1 (FM_{100}), 40.4 (PM_{100}) and 40.0 (MO_{100}) cm) was found with increase in available water contents to 100%, and are challengingly stretched by 39.5, 30.9 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.

Root Fresh and Dry Weight

Effect of different organic substrates at different moisture levels on weight of plant roots is elucidated in Table 3. It is evident from this table 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 PM_{100}, FM_{100} and MO_{100} have fresh and dry weights of order (63.5, 63 and 60.6 g) and (21.9, 21.7 and 21 g) that were statistically similar but were significantly greater than control (42 and 14.5 g). (20.4 and 7.02 g) and (14.3 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 3. Effect of organic substrates application at different moisture levels on length, fresh and dry weights of maize root

AWC	Organic Amendments	Treatments	Root Length (cm)	Root Fresh Weight (g)	Root Dry Weight (g)
50%	CTRL	$CTRL_{50}$	9.26±1.43 c	20.4±1.83 g-i	7.02±1.10 c
	FM	FM_{50}	9.64±1.23 c	22.3±1.19 gh	7.67±1.10 c
	PM	PM_{50}	9.95±0.97 c	23.6±1.11 g	7.78±0.86 c
	MO	MO_{50}	11.3±0.55 c	24.3±1.42 g	7.13±1.17 c
75%	CTRL	$CTRL_{75}$	34.7±0.87 b	47.2±1.04 f	16.3±1.17 b
	FM	FM_{75}	44.6±1.11 a	71.1±1.27 a	24.3±2.39 a
	PM	PM_{75}	41.7±0.70 a	67±1.84 a-d	23.1±2.73 a
	MO	MO_{75}	40.1±0.46 a	70.3±1.30 ab	24.3±3.09 a
100%	CTRL	$CTRL_{100}$	30.9±1.05 b	42±1.01 f	14.5±1.45 b
	FM	FM_{100}	43.1±0.79 a	63±1.72 c-e	21.7±2.99 a
	PM	PM_{100}	40.4±0.68 a	63.5±0.80 b-e	21.9±2.62 a
	MO	MO_{100}	40±1.02 a	60.6±1.41 de	20.9±2.81 a
125%	CTRL	$CTRL_{125}$	7.81±0.55 c	14.3±1.65 ij	5.00±0.88 c
	FM	FM_{125}	6.93±0.30 c	15.2±1.18 ij	5.08±0.22 c
	PM	PM_{125}	7.84±0.31 c	15.1±0.95 ij	5.18±0.65 c
	MO	MO_{125}	7.23±0.38 c	12.2±1.12 j	4.10±0.47 c

Abbreviations: AWC (Available Water Contents), CTRL (Control), FM (Farm Manure), PM (Poultry Manure) and MO (Molasses)

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 2. It is illustrated that 75 and 100% moisture yielded denser long roots than other two moisture levels. Farm manure yielded maximum 7.40 x 10^{-3} cm cm^{-3} root length density at 75% moisture that was at par with 100% moisture (7.13 x 10^{-3}) cm cm^{-3} but was 4.6 and 6.54 folds denser than 50 and 125% moistures, respectively. 6.9 x 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 x 10^{-3} cm cm^{-3} length density of roots at 100% moisture availability that was statistically undistinguishable to 75% moisture level. Their combination yielded only 1.87 x 10^{-3} and 1.2 x 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 x 10^{-3} cm cm^{-3} root length density @ 75% moisture that was 7.2, 11.61 and 28.2% greater than PM_{75}, MO_{75} and $CTRL_{75}$. At 100% available water, maximum root length density (7.13 x 10^{-3} cm cm^{-3}) was found in FM_{100} that was statistically at par with PM_{100} (6.73 x 10^{-3}) and MO_{100} (6.67 x 10^{-3}) but was 1.35 times extra than $CTRL_{100}$ (5.13 x 10^{-3}) cm cm^{-3}. 1.97 x 10^{-3} cm cm^{-3} dense roots were found in MO_{50} at 50% AWC that was 20.9, 23.1 and 28.8% lager in content than PM_{50}, FM_{50} and $CTRL_{50}$, respectively. Plants treated with poultry manure had 1.3 x 10^{-3} cm cm^{-3} dense roots @ 125% AWC that was 3.17, 8.33 and 15% denser than $CTRL_{125}$, MO_{125} and FM_{125}, respectively.

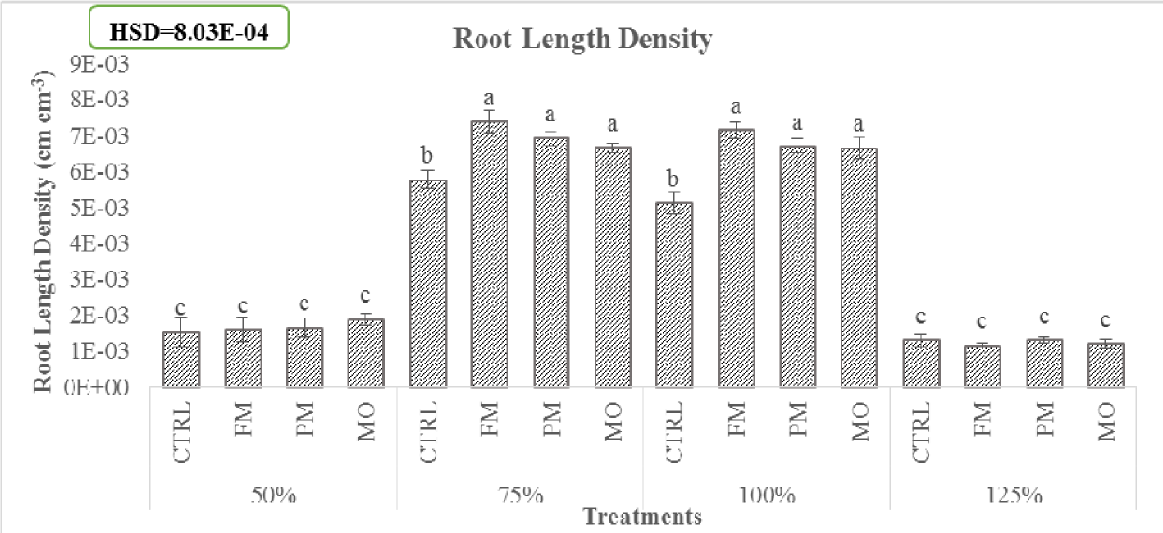


Figure 2. Effect of different organic substrates on root length density (cm cm^{-3}) at different water stress levels

Root Volume

Figure 3 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 FM_{75}, PM_{75} and MO_{75}, respectively. Volume of roots in molasses treated pots (0.21 cm^3) was appealingly akin farm manure (0.20 cm^3) and poultry (0.19 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 FM_{50}, PM_{50} and MO_{50}, 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 75and 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.

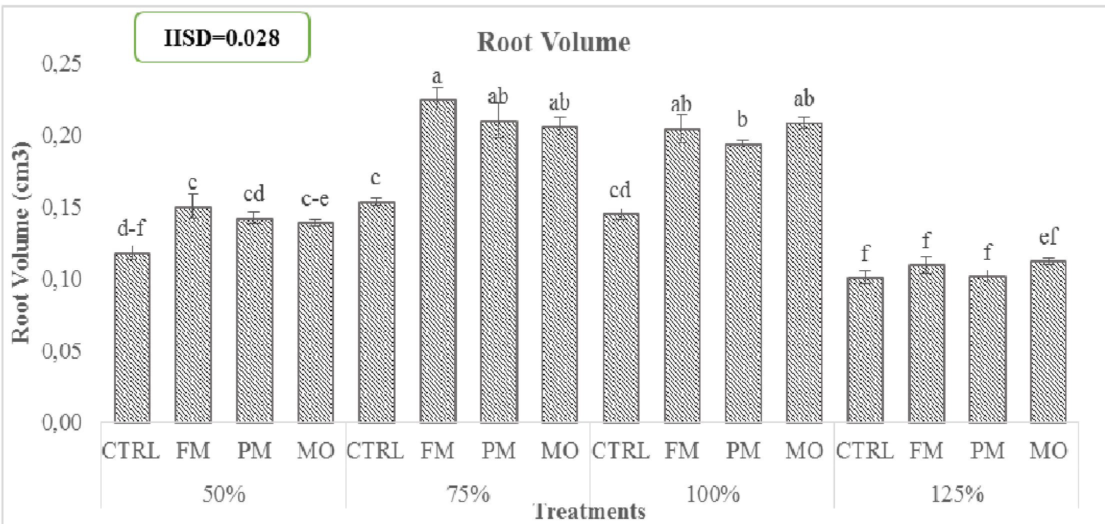


Figure 3. Effect of different organic substrates on root volume (cm^3) at different water stress levels

Root Average Diameter

Figure 4 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 with soil 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 PM_{75} and MO_{75} but was significantly more thick than $CTRL_{100}$. At 100% moisture roots of FM_{100} had 1.68 mm diameter which was only 0.3, 0.3 and 0.5 mm more than MO_{100} and PM_{100}, respectively, but was suggestively thicker than $CRRL_{100}$ (1.1 mm). Roots of plants in treated as well as control at 50 and 125% moisture were observed to be statistically similar.

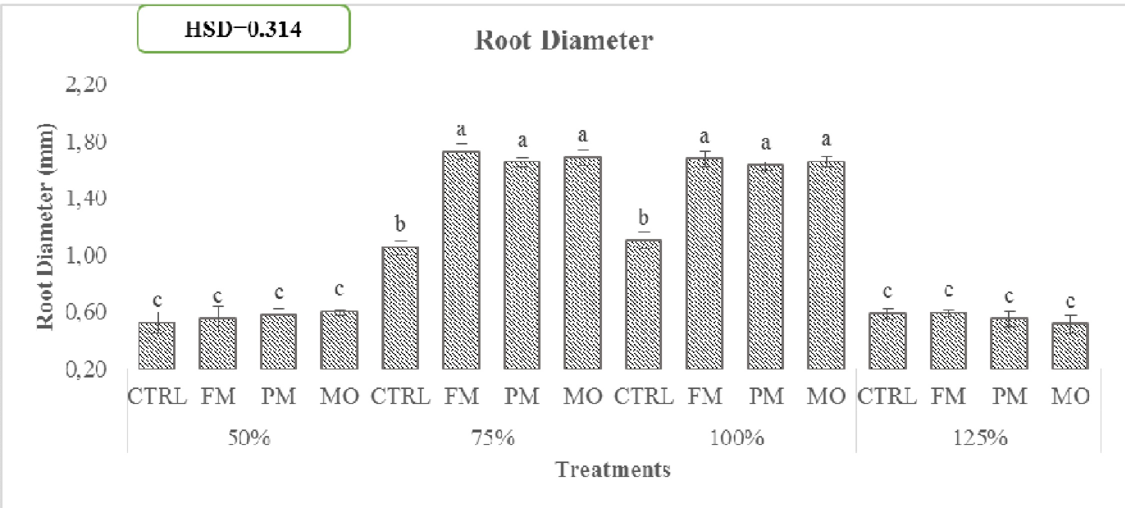


Figure 4. Effect of different organic substrates on root average diameter (mm) at different water stress levels

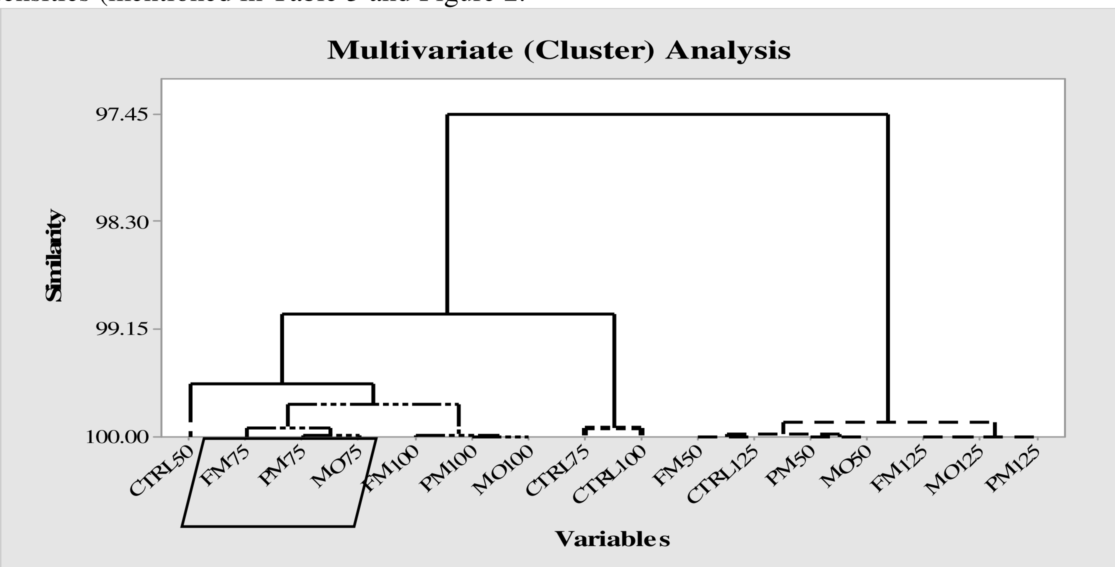
DISCUSSION

Plant growth is dependent upon the soil nutritional value, more obviously, the nutrients in solution contribute towards growth. The nutrient availability and uptake are 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, shoot fresh 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 (Mia *et al.*, 2005).

Organic substrates addition resulted in improved plant vegetative (height, fresh and dry biomass of maize plants) growth (Table-2). This improvement maybe due to direct nutrient supplementation or by indirect amendment of soil physical characteristics i.e. soil structure and water retention capacity, bulk density, penetration resistance and porosity, infiltration rate (HATI et al., 2008). Improved soil health provides conducive environment for root development that stimulate plant growth. Sensible use of organic manures along with synthetic fertilizers and irrigation are essential to safeguard soil health and augment input use efficacy and productivity (HATI et al., 2006;

BHATTACHARYYA et al., 2008). Positive response of productivity with integrated application of manure and synthetic fertilizers have been reported by many researchers (BANDYOPADHYAY et al., 2003; GHOSH et al., 2006; HATI et al., 2000; MANDAL et al., 2000; SINGH et al., 1999). Plant growth criterion imitate the net flux of resources in and out of plant and its various organs. However, each resource maybe invested differently and provide different insights into plant's adaptive mechanisms and physiological balance (HAMANN et al., 2017). Several workers (EL-DARIER et al., 2002; POSPISIL et al., 2006) 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 (English and Raja, 1996). Saving of water is more beneficial than reduced yields by regulated deficit irrigation, specifically in water limited areas (KIRDA, 2002). 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 (ALDERFASI; REFAY, 2010). The present experiment also indicates statistically similar growth pattern where soil moisture was kept @ 75% of AWC (Table-2 & 3). Moisture deficit reduces yield but increases biomass as well the water use capacity of plants (MAHAMED et al., 2011; HAMED et al., 2015). Limited water supply up to 75% of AWC massive growth of plant roots was observed yielding higher root masses and length densities (mentioned in Table 3 and Figure 2. Imran et al. (2015) 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 (XUE et al., 2003) and the reduced irrigation yielding highest length density of roots in deeper soil (QUANQI et al., 2010). Drying of soil during early crop growth stages stimulate root growth especially in deeper soil profile (ZHANG et al., 2006). Variances in soil moisture storage and uptake under different organic and inorganic applications is more evident during dry spell (BANDYOPADHYAY et al., 2003). 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 (CORBEELS et al., 1998). Roots mostly prevailed in upper 15 cm depth because of more nutrition and especially loose soil profile, but organic matter addition not only loosen the soil in deeper region but also enhances root penetration (BANDYOPADHYAY et al., 2010). Huang (2000) reported increase in root length densities in deeper soil with application of farm manure 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% (HATI et al., 2006).



CONCLUSION

In arid and semi-arid areas of world, limited water application in combination with organic substrates has a significant impact on plant growth. 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 (Multivariate Analysis) in combination with all organic substrates.

RESUMO: A ameaça agravante para a agricultura atual é a provisão de segurança alimentar para populações cada vez maiores, utilizando recursos escassos. A escassez de água está restringindo os seres humanos a produzir mais a partir de gotas de água no lugar de galões. A raiz está presente na interface solo-planta e é o principal extrator de água para a planta. Seu padrão de crescimento varia conforme as condições de umidade do solo flutuam. O presente estudo em vaso é constituído por dois fatores, ou seja, substratos orgânicos (esterco bovino, esterco de aves e melaço) e diferentes níveis de stress hídrico {50, 75, 100 e 125% do teor de água disponível (AWCs)} utilizando milho como cultura de teste para avaliar o seu impacto em diferentes parâmetros de crescimento (especialmente crescimento de raiz). O experimento foi conduzido utilizando delineamento experimental inteiramente casualizado, em arranjo fatorial. Raiz radicular (44,5 cm), biomassa seca e fresca da raiz (71,1 ge 24,3 g, respectivamente), diâmetro radicular (1,73 mm), volume radicular (0,24 cm3) e densidade radicular (7,4 x 10-3 cm cm-3) foram observados em vasos tratados com esterco de fazenda a 75% AWC que foi estatisticamente indistinguível de todos os outros tratamentos no mesmo nível de água e 100% de disponibilidade de água, mas eloqüentemente maior que plantas de todos os tratamentos a 50% e 125% de conteúdo de água disponível. O comprimento do rebento, peso seco e fresco foram maiores nas plantas com 100% de umidade disponível. Eles foram estatisticamente equivalentes a 75% de plantas tratadas com água. Comparando os tratamentos para todos os parâmetros na análise multivariada de clusters, concluiu-se que 75% do conteúdo de água disponível produz quase o mesmo que 100%, juntamente com o benefício da segurança hídrica.

PALAVRAS-CHAVE: Orgânica. Milho. Raiz. Proliferação. Seca.

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