Pak. J. Bot., 52(4): 1251-1265, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-4(38)

MANAGEMENT OF SOIL PHYSICAL HEALTH AND CARBON DYNAMICS IN MAIZE CULTIVATED FIELD THROUGH ORGANIC AMENDMENTS

HAROON SHAHZAD[1,2]*, MUHAMMAD IQBAL[2], SAFDAR BASHIR[2] AND MUHAMMAD FAROOQ[3,4]

[1]Pakistan Agricultural Research Council, Arid Zone Research Center, DI Khan, Pakistan
[2]Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad, Pakistan
[3]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
[4]Department of Plant Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud 123, Oman
**Corresponding author's email: rhs2140@ymail.com*

Abstract

Pakistan is situated in the most intensively colonized zone of the world. With the passage of time, farmer land holdings are decreasing due to the increasing population. To feed this increasing population the available lands had been cultivated intensively even using brackish water. The use of brackish water for this intensified cultivation is the chief cause of soil particle disintegration resulting in a poor structure. To address this problem a series of experiments were conducted using organic amendments [Farm Manure (FM), Poultry Manure (PM) and Molasses (MO)] maintaining soil water level at 75% of available water contents (AWC). The recommended dosage of mineral fertilizers was applied and maize hybrid Shahanshah was used as a test crop. Addition of farm manure as treatment resulted in better water-stable aggregation (40.68 and 39.91%), soil total organic carbon (12.64 and 12.09 g kg^{-1}), saturated field hydraulic conductivity (27.85 and 27.04 mm h^{-1}), infiltration rate (26.07 and 25.38 mm h^{-1}), total porosity (0.49 and 0.48 m^3 m^{-3}). Similarly, plant agronomic parameters i.e. grain yield (9.47 and 9.21 Mg ha^{-1}) and water use efficiency (11.13 and 10.83 kg mm^{-1} yr^{-1}) were calculated highest in farm manure treatment plots that were significantly greater than control but were found statistically at par with other treatments. It was concluded that organic matter addition yields better soil structure that results in proper aeration, water retention, root penetration ultimately achieving yield goals along with saving up to 25% irrigation water as indicated from the correlation analysis.

Key words: Species diversity; Plant community; Soil properties; Mount Lao Nature Reserve

Introduction

Pakistan has mineral soils that are poorly structured due to brackish irrigation water and alkalinity. These soils have higher bulk densities, low water holding capacities (WHCs), and very fewer contents of organic carbon. Mineral fertilization is deadly expensive, and it seriously deteriorates the bio-physiochemical health of the soil. Manures, composts, molasses, farm wastes, and crop residues (wheat straw, rice straw, sugarcane bagasse, etc.) are the organic substrates that remediate soil the bio-physiochemical health and productive quality (Annabi *et al.*, 2007) by slabbing the serious degradation of soil structure and nutrients losses. Soil organic carbon stock and deprived soil structure reestablish with a shallow application of organic substrates (Fallah *et al.*, 2013) that also lowers mineral nutritional cost and nutrient losses by continuous and long-term supply to enhance productivity (Behera *et al.*, 2007). Better particle flocculation with increasing application rates of organic wastes also indirectly reduces soil erosion losses (Parras-Alcantara *et al.*, 2016). Surface application of organic amendments protects soil from radiation and temperature effects and is a nutritional and carbon source for microbial communities (Odlare *et al.*, 2008). Shallow application of organic materials increases the flocculation of soil particles giving rise to a stabilized structure that improves surface entry of water to reduce runoff and evaporative losses of water (Wesseling *et al.*, 2009). Soil physical indices i.e. bulk density, void ratio, porosity, hydraulic retention, and conduction got better, and crop nutrient use efficacy and yields were enchanted with the application of compost (Yazdanpanah *et al.*, 2016). Organic manures have a capricious impact on water stable aggregates (Chivenge *et al.*, 2011) adding carbon to aggregates as glue (Fonte *et al.*, 2009).

Agricultural sustainability is the necessity of the time and is uprightly approached by application of agro-industrial wastes as organic amendments (Scialabba & Mullar-Lindenlauf, 2010) and their biotransformed products manage soil fertility and productivity to provide healthy food and protect soil from being eroded (Vassilev *et al.*, 2007).

Water is a vital factor for plant physiological processes affecting crop productivity by its movement through the soil-plant-atmosphere continuum and is lost through soil surface evaporation and plant transpiration (Liu and Zhang, 2007). Evapotranspiration, main water balance component (Gentine *et al.*, 2007; Parasuraman *et al.*, 2007) linearly related to crop gain yields (Karam *et al.*, 2007).

Well-organized irrigation practices potentially save water restraining the adverse impacts of over-irrigation on-farm returns that deteriorate soil and groundwater systems (Khan & Abbas, 2007). Shahzad *et al.*, (2019) reported decreased crop water use efficiency (WUE) upon over-irrigation, while reported more production and WUE with regulated deficit irrigation. Many agro-management practices have been rehearsed for many years to improve agricultural output (Ali *et al.*, 2014). Managed irrigation has optimistic effects on plant water relations and produces. Scheduled irrigation at different crop growth stages can improve WUE (Fang *et al.*, 2010). Irrigation schedules sturdily affected grain yield and WUE of the crop (Imran *et al.*, 2015).

For this study, it was hypothesized that organic amendments release organic glues on putrefaction by indigenous micro-flora that enhances particle aggregation with entrapped carbon to improve soil physical health. This study was conducted to evaluate the effect of organic substrate addition on soil physical quality indices and maize yield, while the water content was maintained at 75% of available water capacity.

Materials and Methods

Soil and meteorology of experimental site: Two-year field experiment was carried out at field area of the Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad, Pakistan. The experimental site has a typical tropical monsoon climate with 30°C and 705 mm mean annual temperature and precipitation, respectively. The mean annual accumulated temperature above 10°C is 33.5°C. Approximately, 80% of the annual precipitation comes from March to September. Meteorological data during the whole experiment (2014 and 2015) is presented in (Fig. 1).

Experimental field area of Institute of Soil & Environmental Sciences (Latitude 31°26′0″N and longitude 73°08′0″E), University of Agriculture, Faisalabad, Pakistan had sandy clay loam, semi-active, isohyperthermic Typic Calciargids, soil (Anon., 2014-15) Classification. Before the sowing of the crop, soil samples were collected from a depth of 0-15 cm, crop roots and other debris were removed from samples, and soil was air-dried before pass through 2 mm sieve. Soil samples contained 8.4 g kg^{-1} SOC, 1.03 g kg^{-1} N, 8.15 (C: N), 8.2 units of pH.

Soil water retention: 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 were 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.

$$\ln P = \ln P_\alpha + b \ln (\theta/\theta_s)\text{-----------------------(i)}$$

P is matric potential (k Pa), "P_e" (intercept) is air entry value/ bubbling pressure that has an inverse relation with "α", and "b" is the 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 (0.0211) and a negative slope -7.2615 (Fig. 2). Water retention properties of experimental soil are presented in Table 1.

Manure composition: Organic substrate samples (< 2 mm) were examined for organic carbon, water retention, and nutritional (NPK) contents using standard analytical procedures. For nitrogen determination, dried and homogenized organic material was digested with H_2SO_4, while K_2SO_4 was added to increase temperature. Copper sulphate ($CuSO_4$) was used as a catalyst and NaOH added to digestion solution to evaporate N as ammonia that was condensed in boric acid solution and titrated against indicator with H_2SO_4 (Bremner & Mulvaney, 1982). Samples were then digested using di-acid (HNO_3 and $HClO_4$) mixture and digested material was run on the spectrophotometer to analyze phosphorus while flame photometer was used for potash determination (Kuo, 1996). The physiochemical characteristics of these organic substrates have been presented in Table 2.

Experimental design: Two-year field experiment was laid out using randomized complete block design (RCBD) maintaining water level @ 75% of AWC along with farm manure, poultry manure, and molasses as organic substrate treatments. Plot size was 5 x 5 m^2, while organic substrates were added @ of 30 Mg ha^{-1} and each treatment had three replicas.

Irrigation: During the whole study, controlled irrigation was applied to each plot after measuring water contents using a time domain reflectometer (TDR), to accurately maintain soil moisture followed by said experimental design. The irrigation depth was calculated by

$$AD = Qt\text{------------------------------(ii)}$$

where Q is flow (L^3 T^{-1}), t is time in hours, A is the area of the plot in hectare and d is the depth of irrigation in cm. The amount of water available through rainfall during the growing seasons are given in figure 1.

Agricultural practices: Hybrid maize Shahanshah was planted on the 21st of July 2014. Urea was applied at 150 kg N ha^{-1} in two splits (at the time of 1st and 2nd irrigation) while phosphorus and potash were applied at 90 kg ha^{-1} 60 kg ha^{-1} as basal dose using di-ammonium phosphate and muriate of potash as source fertilizers. Seedling density after germination was controlled through thinning in each plot maintaining 20 cm distance between plants. Weeds and insect pests were controlled chemically in time.

Chlorophyll and gas exchange parameters: Chlorophyll contents (µg L^{-1}) were measured at the time of flower initiation from the flag leaf using SPAD meter (Minolta SPAD-502 DL meter Japan). Gas exchange parameters including photosynthetic rate (A) (µmol $m^{-2}sec^{-1}$), transpiration rate (E) (mmol $m^{-2}sec^{-1}$), CO_2 intake rate (µmol $m^{-2}sec^{-1}$) and substomatal CO_2 (Ci) (µmol mol^{-1}) were recorded using Infrared Gas Analyser (CI-340).

Plant growth and yield attribute: Growth parameters (Plant Height (cm), shoot fresh & dry weights (g), shoot water contents, grain yield (t ha^{-1}) were agronomically recorded at crop harvest (Azevedo Neto *et al.*, 2004). Crop water use efficiency and harvest index were measured using the equation.

$$IWUE = \frac{Grain\ yield}{Irrigation\ water\ applied}\text{-------------(iii)}$$

$$HI = \frac{Grain\ yield}{Biological\ yield} \times 100\text{-------------------(iv)}$$

Soil organic carbon fractionation: Organic carbon fractions were separated as per the method described by (Six *et al.*, 1998). 5 gram (<2 mm) soil sample was immersed in 35 mL of 1.85 g mL^{-1} NaI solution in centrifuge tube of 50 mL volume and tubes were gently shaken by hand several times and remained materials on the inside of wall were washed with 10 mL of NaI to make 50 mL volume. Air was exhausted by placing in a vacuum for 10 minutes, equilibrated for 15 minutes, and centrifuged for one hour at 2000× *g*. The supernatant was passed through 0.45 µm membrane and the remaining NaI was washed with DI water and floating substance on the filter is fine light organic carbon (fLOC) while samples passed through the filter was dispersed in 5 gL^{-1} Na-hexametaphosphate for 18 hours continuous shaking on the reciprocal shaker. The dispersed segment was passed through 250 and 106 µm sieves to collect coarse particulate organic carbon (cPOC), >250 µm, fine particulate organic carbon (fPOC), 250-53 µm and mineral associated organic carbon (mSOC), <53 µm. All the SOC fractions were dried at 60°C, weighed, and analyzed for organic carbon contents.

Soil total organic carbon: Organic carbon total was assessed through wet oxidation with $K_2Cr_2O_7$ at 120°C for an hour in presence of sulphuric acid and the solution's color intensity was measured at 578 nm wavelength using UV visible spectrophotometer (Hitachi U-2000) (Schlichting *et al.*, 1995).

Carbon sequestration: The SOC pool is calculated from SOC concentration (g kg^{-1}) and soil bulk density (Mg m^{-3}) determined in the control treatment and after the completion of the experiment for soil profile from 0-30 cm depth in Mg ha^{-1} using the following equation:

$$\mathrm{C-Pool} = \frac{\mathrm{A\ x\ D\ x\ BD\ x\ OC}}{1000} \text{---------------------- (v)}$$

where A is the area of the hectare (ha = 10^4 m^2); D is the depth (m); BD is the bulk density (Mg m^{-3}); and SOC is the soil organic carbon concentration (g kg^{-1}) (Lal *et al.*, 1997). Then the net carbon pool and carbon sequestration were calculated using the following equations:

$$[\text{Net C} - \text{Pool} = \text{Carbon Pool in case of control treatment} - \text{Final C} - \text{Pool}] \text{------------(vi)}$$

$$\text{Carbon Sequestration} = \frac{\text{Net C}-\text{Pool}}{No.of\ years} \text{------- (vii)}$$

Carbon management index: Carbon management index (CMI) is an indicator of soil quality improvement through management practices that indicates the degree of alteration in soil carbon of treated soil system relative to stable reference soil (Diekow *et al.*, 2005). In the present study, CTRL soil was used as reference soil to calculate CMI:

C pool index (CPI)

$$CPI = \frac{Total\ OC\ of\ sample\ (g/kg)}{Total\ OC\ of\ reference\ (g/kg)} \text{---------(viii)}$$

Lability index (LI)

$$LI = \frac{Lability\ of\ carbon\ in\ sample}{Lability\ of\ carbon\ in\ reference\ soil} \text{------(ix)}$$

Carbon Lability (CL)

$$CL = \frac{Oxidizable\ Carbon\ by\ KMnO4}{SOC-Oxidizable\ Carbon\ by\ KMnO4} \text{--------(x)}$$

Carbon management index (CMI)

$$CMI = CPI \times LI \times 100 \text{----------------------(xi)}$$

Soil aggregate stability: Water stable aggregation of aggregates (0.25-2.00 mm) was measured from crushed and sieved (<2 mm) soil samples using an artificial rain simulator (Moebius *et al.*, 2007). The stable aggregate fraction was calculated using equation:

$$WSA = \frac{Wstable}{Wtotal} \text{-------------------------(xii)}$$

$$Wstable = Wtotal - Wslaked \text{----------(xiii)}$$

where, W_{stable}, $W_{total,}$ and W_{slaked} are dry weights of stable aggregates, total tested aggregates, and soil aggregates slaked through the sieve, respectively.

Soil aggregates were fractionated by wet sieving soil through 1000, 500, 250, and 106 µm sieves (Six *et al.*, 1998). Fractionation was performed using Soil Aggregate Analyzer (Model SAA 8052). 60 g 2mm sieved soil samples were soaked in de-ionized water for overnight at room temperature (20±2°C). The soaked sample was then placed on top 1000 µm sieve and then series of sieves were moved up and down 3 cm automatically at a rate of 30 oscillations per minute for an hour. Five size classes of aggregates were collected, oven-dried at 60°C, and weighed. Oven-dried samples were subjected to subsequent organic carbon fractionation.

Soil bulk density and total porosity: Undisturbed soil samples were collected in steel cores and soil bulk density and total porosity were estimated using the core method (Blake & Hartge, 1986)

$$\rho b = \frac{Ws}{V} \text{------------------- (xiv)}$$

(where W_s is oven-dried soil weight and V is soil bulk volume)

$$\phi = 1 - \frac{\rho b}{\rho p} \text{----------------- (xv)}$$

(where ϕ is total porosity, ρ_b is bulk density and ρ_p is particle density)

Infiltration rate: Infiltration rate was measured with a double ring infiltrometer. The inner and outer rings were driven 10 cm into the soil utilizing a driving plate and impact-absorbing hammer. The inner and outer rings were filled with water. The water flows vertically through the inner ring into the soil was noted until the constant rate was obtained (Klute, 1986).

Field saturated hydraulic conductivity (K_{fs}): A uniform debris-free well hole was made with the help of auger and sizing auger. The Guelph Permeameter (Model 2800 KI) was assembled and installed in the well hole. Three steady-state readings were taken from two depths (5.0 cm and 10.0 cm at constant head). The field saturated hydraulic conductivity (K_{fs}) was calculated from the following formula:

$$Kfs\ = 0.0041\ \times)\ R2 - 0.0054 \times R1 \text{-------- (xvi)}$$

where R_1 = the steady-state rate of fall of water in the reservoir when the first head H_1 of water is established, in mm h^{-1}.

H_1 = the first head of water established in the well hole, in cm.
H_2 = the second head of water established in the well hole, in cm.
R_2 = the steady-state rate of fall of water in the reservoir when the second head of water is established, in cm/s.
X = Reservoir constant corresponds to the cross-sectional area of the combined reservoir expressed in cm^2.

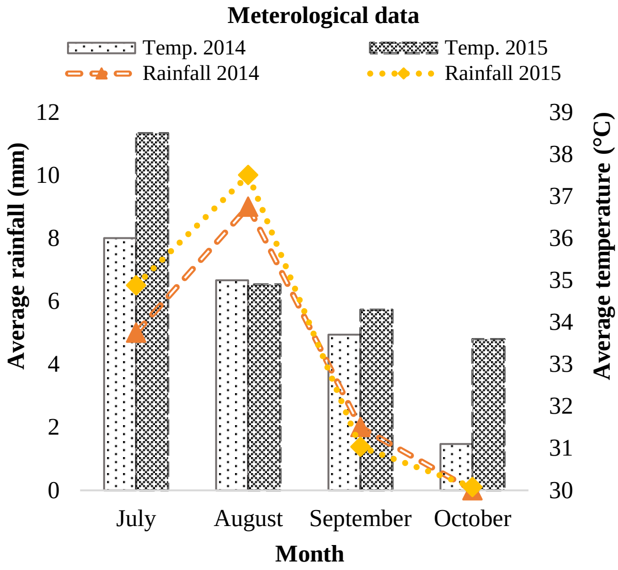

Fig. 1. Meteorological data of field area during study.

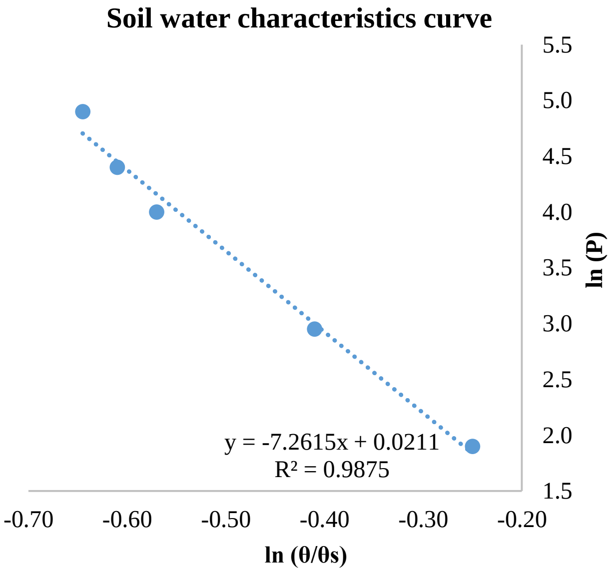

Fig. 2. Soil water characteristics curve.

Table 1. Water Retention properties of soil used for pot study.

Water retention properties	Θ_S	Θ_{FC}	Θ_{PWP}	Θ_{AWC}
Units	(%)			
	45.8 ± 0.93	23.68 ± 0.63	11.21 ± 1.02	12.47 ± 0.79

Data is average of three replicates with standard error

Table 2. Physicochemical characteristics of organic amendments used for the study.

Property unit	pH	EC dS m^{-1}	WHC %	C %	N %	P %	K %
FM	6.9 ± 0.07	2.6 ± 0.03	43.1 ± 2.1	34.02 ± 2.45	0.67 ± 0.07	2 ± 0.14	0.12 ± 0.01
PM	6.3 ± 0.10	3.5 ± 0.01	45.3 ± 1.23	25.67 ± 2.12	1.12 ± 0.13	1.73 ± 0.09	0.29 ± 0.01
MO	6.1 ± 0.09	1.1 ± 0.02	39.87 ± 1.24	28.1 ± 2.06	0.51 ± 0.07	2.67 ± 0.18	0.49 ± 0.01

WHC (Water holding capacity), C (Carbon), N (Nitrogen), P (Phosphorus), K (Potassium), FM (Farm manure), PM (Poultry manure) and MO (Molasses)

Statistical analysis

The average of all the treatment replicates was calculated and all treatments were tested for significance at (p>0.05) using analysis of variance technique. The significance of individual treatments was tested using Tuckey's Honestly Significant Difference (HSD) test (Montgomery, 2013).

Results

Crop parameters

Plant height: Results (Table 3) about plant height exhibited that different organic wastes positively influence the plant height as compared to control. Maximum plant height (248.30 cm) was achieved from plants grown on poultry added soils that were statistically similar to FM (233.03 cm) and MO (227.84 cm). Treatment combinations namely FM, PM, and MO cause 14.30, 21.79, and 11.75% increase in plant height respectively, as compared to standard treatment.

The divergent response of different treatments was empirical during 2nd study. It showed that MO treated soils produced heighted plants (241.87 cm) than other treatment combinations. Plants treated with PM produced less plant height (237.07 cm) than MO, however, it was statistically similar to MO treated plants. The minimum plant height (201.83 cm) was achieved from control. The increase in plant height with FM, PM, and MO was 13.98, 17.46, and 19.84%, respectively, as compared to the non-treated control.

Total biomass: Table 3 showed that all treatment combinations caused an increase in total biomass than T_0. However, among the treatment combinations, there was a statistical difference regarding total biomass. A respective increase of 26.98, 43.02, and 35.73% in FM, PM, and MO treatments was found as compared to CTRL. During 2nd study, statistically greater biological weight was provided by PM and MO which produced 43.70 and 43.76% more biomass as compared to CTRL. FM produced less biomass than PM and MO, however, it was (34.07%) greater than CTRL.

Table 3. Effect of different organic substrates at 75% soil moisture on plant height, plant total biomass, grain yield, and harvest index of maize.

Plant parameters	Organic substrates	Treatments	1st Year (Trial)	2nd Year (Trial)
Plant height (cm)	CTRL	T_0	203.88 ± 7.06 b	201.83 ± 10.00 b
	FM	T_1	233.03 ± 9.51 ab	230.05 ± 4.51 ab
	PM	T_2	248.30 ± 3.55 a	237.07 ± 4.57 a
	MO	T_3	227.84 ± 10.16 ab	241.87 ± 3.33 a
Plant biomass (Mg ha^{-1})	CTRL	T_0	33.70 ± 1.19 b	31.41 ± 1.36 b
	FM	T_1	42.79 ± 1.77 a	42.12 ± 0.52 a
	PM	T_2	48.20 ± 1.05 a	45.14 ± 0.92 a
	MO	T_3	45.74 ± 1.36 a	45.16 ± 2.19 a
Grain yield (Mg ha^{-1})	CTRL	T_0	6.85 ± 0.23 c	6.65 ± 0.27 c
	FM	T_1	9.47 ± 0.20 a	9.21 ± 0.42 a
	PM	T_2	8.61 ± 0.26 b	8.40 ± 0.68 ab
	MO	T_3	8.16 ± 0.17 b	8.09 ± 0.23 b
Water use efficiency (kg ha^{-1} mm^{-1})	CTRL	T_0	8.06 ± 0.27 c	7.83 ± 0.32 c
	FM	T_1	11.15 ± 0.23 a	10.83 ± 0.49 a
	PM	T_2	10.13 ± 0.31 b	9.88 ± 0.80 ab
	MO	T_3	9.60 ± 0.20 b	9.52 ± 0.28 b
Harvest Index (%)	CTRL	T_0	20.44 ± 1.41 ab	21.19 ± 0.15 a
	FM	T_1	22.23 ± 1.17 a	21.83 ± 0.73 a
	PM	T_2	17.86 ± 0.17 b	18.57 ± 1.17 b
	MO	T_3	17.87 ± 0.25 b	18.06 ± 1.44 b

*HSD values for plant height (32.55 and 31.22), Plant biomass (7.24 and 7.53), Grain yield (1.12 and 1.27), WUE (0.94 and 1.07) and HI (3.15 and 2.58)

Grain yield: Table 3, verified the significant increase in grain yield due to treatment combinations as compared to T_0. It revealed that the maximum grain yield produced by T_1 that was 38.24% more than T_0. Other organic applications namely T_2 and T_3 produced 25.69 and 19.12% more grain yield, respectively, as compared to T_0. However, there was no significant difference between the treatment combinations regarding grain yield. T_1, T_2, and T_3 enhanced 38.5, 26.3, and 21.65% grain yield respectively as compared to T_0 during 2nd year of study.

Water use efficiency: It is attributed to the table (3) that crop water use efficacy got enhanced with the incorporation of organic manures into the soil at 75% soil moisture. 11.15 kg ha^{-1} mm^{-1} water utilization efficacy was found in T_1 treated plots that were bluntly greater than T_2 (10.13 kg ha^{-1} mm^{-1}) and T_3 (9.60 kg ha^{-1} mm^{-1}). All the plants in treated plots had significantly more water uptake efficiency than non-treated control (8.06 kg ha^{-1} mm^{-1}). During the second trial, a little decline in effective water uptake was observed in each treated plot. T_1 and T_2 (10.83 and 9.88 kg ha^{-1} mm^{-1}) were at par statistically but T_1 plants had expressive water use efficiencies than T_3 (9.52 kg ha^{-1} mm^{-1}). T_2 and T_3 shared the lettered values but each organic waste treated plot had expressively greater water use efficacies than control.

Harvest index: Table 3 particularizes the impact of mixing of organic substrates in the soil while maintaining soil moisture @ 75% of AWC on harvest index of maize crop. The highest index (22.23 and 21.83%) was found in farm manure treated plants that were in context with control but proposedly greater than molasses and poultry treated plants.

Chlorophyll content: Treatment combinations increased the chlorophyll contents, however, statistically non-significant increase of (21.27 and 21.35), (13.08 and 13.33), and (12.58 and 12.97) % chlorophyll contents were observed in T_1, T_2, and T_3, respectively, as compared to T_0.

Transpiration rate: Table (4) validates the positive effect of all organic substrate blending on the transpiration rate. A noteworthy increase of 46.98, 30.22, and 30.38% in the transpiration rate was observed in T_1, T_2, and T_3 plants than T_0. There was a small increase in transpiration during 2nd study in case of all the treatments except T_2.

Photosynthetic rate: Organic substrates undeniably influenced photosynthesis, as T_1 yielded a maximum (27.07 µ mol m^{-1} s^{-1}) photosynthetic rate that was eloquently higher than other treatment combinations. Table 4 also elaborates 12.58, 14.98, and 8.64% more photosynthesis in treated plots as compared to control. A similar trend but suggestively more photosynthetic rate of 31.9, 15.16, and 16.81% than T_0 was there for T_1 to T_3 treatments.

Sub-stomatal conductance: Table 4, showed the influence of treatment combination on stomatal conductance. It exhibited that the treatment combination caused a significant increase in stomatal conductance. The effect of T_1 and T_3 was statistically similar regarding stomatal conductance however it was statistically higher than control. T_2 less increase in stomatal conductance than other treatment combinations but higher than control. Different treatment combinations including T_1, T_2, and T_3 caused 32.23, 24.01, and 28.40% increase in stomatal conductance.

Table (4) revealed that in study 2 different treatment combinations caused an almost similar effect regarding stomatal conductance. All treatment caused a significant increase of 32.17, 23.57, and 27.69% in stomatal conductance as compared to control.

Table 4. Effect of different organic substrates at 75% AWC on plant chlorophyll and gas exchange parameters.

Physiological Parameters	Organic substrates	Treatments	1st Year (Trial)	2nd Year (Trial)
Chlorophyll content (SPAD)	CTRL	T_0	38.36 ± 2.66 b	37.00 ± 2.16 b
	FM	T_1	46.52 ± 2.49 a	44.90 ± 1.82 a
	PM	T_2	43.38 ± 1.18 ab	41.93 ± 1.48 ab
	MO	T_3	43.19 ± 1.64 ab	41.80 ± 2.36 ab
Photosynthetic rate (µmol m^{-2} s^{-1})	CTRL	T_0	20.56 ± 1.22 b	19.85 ± 1.01 b
	FM	T_1	27.07 ± 0.74 a	26.18 ± 1.06 a
	PM	T_2	23.63 ± 1.20 ab	22.86 ± 1.34 ab
	MO	T_3	22.30 ± 0.70 b	23.19 ± 0.64 ab
Transpiration rate (µmol m^{-2} s^{-1})	CTRL	T_0	6.14 ± 0.33 b	5.95 ± 0.42 c
	FM	T_1	9.03 ± 0.24 a	8.81 ± 0.27 a
	PM	T_2	8.00 ± 0.29 a	7.61 ± 0.20 b
	MO	T_3	8.01 ± 0.22 a	8.09 ± 0.28 ab
Substomatal conductance (µmol m^{-2} s^{-1})	CTRL	T_0	204.40 ± 6.10 b	202.10 ± 13.20 b
	FM	T_1	270.01 ± 3.79 a	268.33 ± 7.17 a
	PM	T_2	253.49 ± 5.80 a	249.74 ± 4.05 a
	MO	T_3	262.45 ± 12.78 a	258.07 ± 3.81 a
CO_2 Intake rate (µmol m^{-2} s^{-1})	CTRL	T_0	255.67 ± 7.22 a	250.67 ± 11.39 a
	FM	T_1	250.00 ± 14.29 a	262.00 ± 28.01 a
	PM	T_2	268.67 ± 11.55 a	262.67 ± 8.74 a
	MO	T_3	273.67 ± 14.81 a	268.00 ± 12.77 a

*HSD values for chlorophyll content (6.29 and 5.97), Photosynthetic rate (3.57 and 3.64), Transpiration rate (1.07 and 0.79), Sub-stomatal conductance (29.24 and 24.79) and CO_2 Intake rate (41.38 and 45.56).

CO_2 intake rate: Intake of carbon dioxide is not being regulated by the application of manures to soil as no significant difference was observed among the treatments as well as their difference from control as being elaborated in Table 4.

Soil physical characteristics

Total organic carbon: It was experiential from data (Fig. 3) of total soil organic carbon (SOC) that soil unified with organic manures pointedly enhanced SOC contents. Farm manure returned 12.64 g kg^{-1} total SOC that was 16.2, 22.36, and 69.66 % extra than T_2, T_3, and intact control, respectively. T_1 added an eloquently greater amount of organic carbon in the soil than T_2 and T_3, respectively. However, manure addition yielded an irrational increase in soil organic carbon and each treated soil had a significantly greater amount of carbon than un-added control.

A weighty deterioration in the soil organic carbon was detected in T_1 treated soil yielding 12.09 g kg^{-1} soil organic carbon that did not diverge significantly from other treatment, T_2 (11.12% more) but was pointedly 16.92 percent greater than T_3. All the treatments yielded vigilantly greater carbon fillings in soil than control.

Water stable aggregates: Figure 4 elaborates the variation in the aggregation of soil basic particles with amalgamated of manures and soil in maize maintaining water at 75% of AWC. The figure substantiates macro aggregation under the application of organic substrates.

Treatment T_1 yielded 40.68% water stable aggregates that were 5.3 and 13.9% greater in proportion than T_2 and T_3 treatments, respectively. This amount was 2.7 times greater than untouched control. Aggregate proportion decreased in the preceding experiment yielding 39.91% stable aggregates that were 7.5, 16.08, and 171.9% greater in amount than T_2, T_3, and T_0, respectively.

Infiltration rate and saturated hydraulic conductivity: Table 5 overt the bulky variation in the surface entry of water with the application of organics. Farm manure had made the soil surface crumb and the water infiltration bounced to 26.07 mm hr^{-1} that was statistically at par with T_2 (24.13) but was confrontationally greater than T_3 (22.70) and CTRL (7.57). Latter water infiltration got enhanced in each treatment evident from the table (5.4) showing 25.38 mm hr^{-1} in treatment combination T_1 that was not at a far distance from T_2 but it had an audacious difference was observed from T_3 and CTRL.

Water conduction within the soil profile is exhibited in table 5, presenting a clear variation among the manure application. Farm manure formulated continuous channels to allow the water movement @ 27.85 mm hr^{-1} that was 14.85, 15.03% greater than T_2, and T_3 combinations. Comparison with control showed that water conduction was 3.5 times greater in T_1. During 2nd study, maximum saturated hydraulic conduction was found in T_1 (27.04 mm hr^{-1}) that was not statistically far from poultry manure. Hydraulic conduction in farm manure added soil was vigilantly (3.49 mm hr^{-1}) and (18.2 mm hr^{-1}) greater than T_3 and T_0.

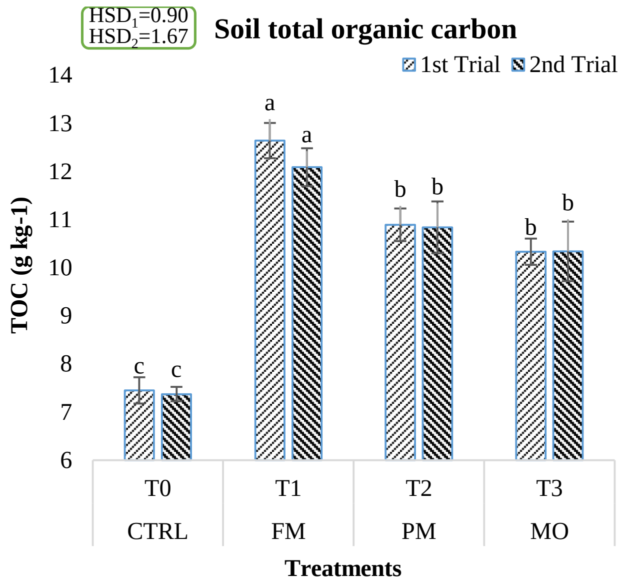

Fig. 3. Effect of different organic substrates on soil total organic carbon.

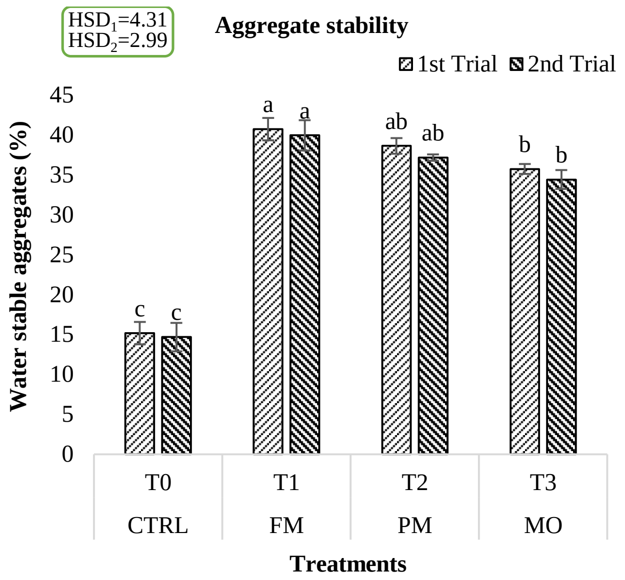

Fig. 4. Effect of different organic substrates on soil aggregate stability at 75% AWC.

Bulk density and total porosity: Measure of compactness is elucidated in (Fig. 5A), which shows 1.34 Mg m^{-3} bulk density in T_1 that is significantly lesser than 1.42 (T_3). Except T_2 other treatment combinations yielded significantly less compact stature than control in either of the studies. Total porosity is reciprocated to bulk density yielding 0.49 m^3 m^{-3} porosity in T_1 that is pointedly higher than T_3 and T_0 treatment combinations (Fig. 5B). No significant variation in pore space occurred in the latter study. All the treatment combinations had significantly greater pore spaces than control at the end of each study.

Soil water retention characteristics: A clear absurdity in soil hygroscopic water content (PWP) upon blended application of organic substrates at optimum irrigation is presented in (Fig. 6B). 11.96% water is tightly bound to soil particles in T_1 that was statistically similar to T_2 and T_3 but is significantly lower than CTRL. While total water retained at 0.33 bars (FC) (Fig. 6A) was found maximum (26.15%) in T_1 that was 6.78 and 13% higher in amount than T_2, T_3, and CTRL, respectively. The field capacity of the soil was found highest in T_1 that was statistically greater than other treated soils and control.

Data regarding plant available water is presented in figure 6C. Soil of treatment combination T_1 had a maximum capacity of 14.19% water retention in the plant-available form that is significantly greater than other treatment 12.51% (T_2), 12.42% (T_3) combinations and control (10.99%). Other treatment combinations had also precisely greater plant available water capacity. A minute decline in T_1 soil was observed during 2nd study, in the meanwhile minute increase was observed in other treated soils but there was not a significant change, so the course of variation remained the same as of 1st-year study.

Discussion

This study was conducted to evaluate the effect of organic substrate addition on soil physical quality indices and maize yield, while the water content was maintained at 75% of available water. Soil physical quality is the capacity of the soil to function physically (Doran & Parkin, 1994). Physical indicators assessed were effective to address the specific soil processes that are important to sustain agricultural production. Overall physical quality of Pakistani soil is poor due to intensive cropping, use of straw as fuel and fodder, burning f crop residues, use of manure as a domestic fuel, non-inclusion of green manure crops into existing cropping patterns, farmer's illiteracy about modern challenges, scenarios, and modern technique adaptability. Organic substrate addition resulted in striking improvement in available water capacity, water stable aggregation, bulk density, and total porosity. A significant decrease in bulk density with manure addition increased soil organic carbon, soil water retention capacity, plant available water, field saturated hydraulic conductivity, and infiltration rate. Transmission and storage pores were far more abundant in manured soils (Chakraborty *et al*., 2010). Betterment of soil physical health with organic substrate addition has been reported earlier (Celik *et al*., 2004; Madari *et al*., 2005), as it decreased bulk density (Miller *et al*., 2002), with improved soil structural (Pagliai *et al*., 2004) and hydraulic behavior (Celik *et al*., 2004). Chakraborty *et al*., (2010) found better soil physical health with improved soil aggregation status in manured plots that might be because of enhanced root and microbial action which significantly improves soil structure. Organics application had a critical decline in bulk density because of which plant available water holding capacity of the soil was boosted by 86% and 56% of compost and manure treated soils (Celik *et al*., 2004). Organic substrate application improves soil physical characteristics by an increase in pore size distribution and total porosity (Aggelides & Londra, 2000).

Extensive tillage disrupts aggregates and reduces stable aggregate formation, leading to exposure of existing aggregates to environmental stresses and microbial degradation, therefore resulted in reduced soil organic carbon accumulation (Six *et al*., 2000). Manure addition along with balanced mineral nutrition improves and sustains soil organic carbon even under intensive cultivation (Chakraborty *et al.*, 2010). During the present study, a provocatively greater amount of soil organic carbon was found in manured soils compared to one without organic substrate addition. An increase in soil organic carbon content with organic management is widely reported (Stockdale *et al.*, 2000). Organics application enhanced total soil organic carbon, organic fractionation, aggregation, K_s, IR, soil matrix and structural porosities, and water-retaining capabilities (Fig. 7a, 7b).

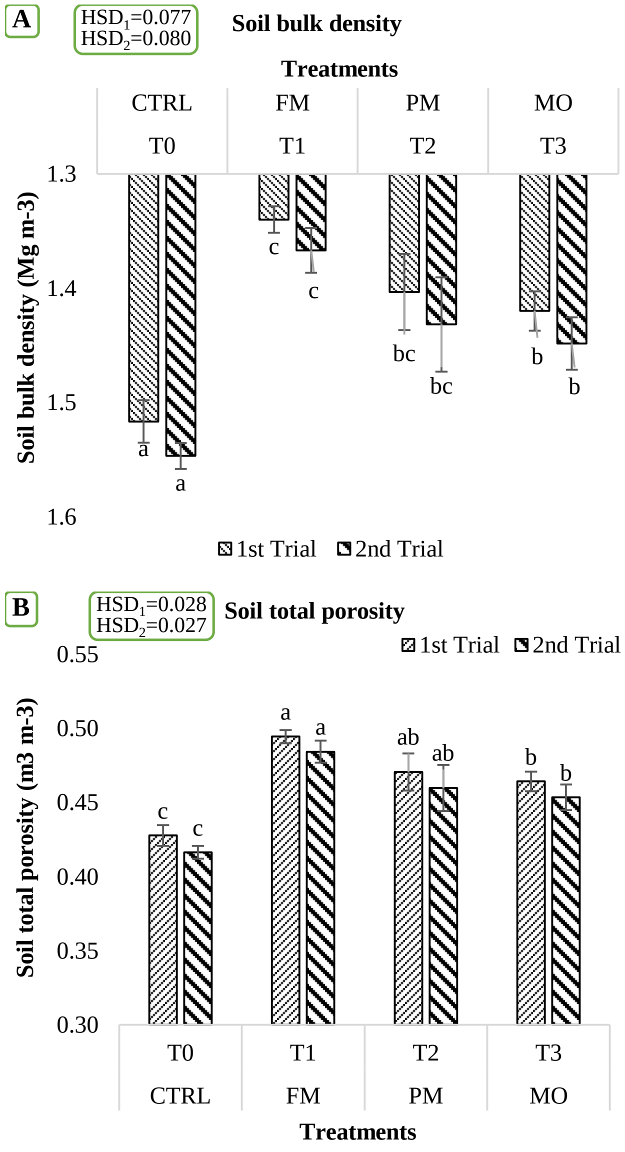

Fig. 5. Effect of different organic substrates on soil bulk density (A) and soil total porosity (B).

Soil organic matter is a nutrient rich source that upon mineralization releases nutrients into soil fulfilling plant's mineral requirements. N is a major part of proteins and ammonification release NH_4^+ into the soil that is plant available form and nucleic acid degradation make the phosphorus plant available. Most of the phosphorus in our soils (Calcareousness and high pH) is tightly bound to calcium formulating Ca_3PO_4 that is not available to plants. Soil microbes degrade organic substrates releasing organic acids that lower pH near root vicinity in microsites that increase phosphorus lability. Organic matter is porous like a sponge that holds more water-reducing leaching and evaporative losses. This stored water is plant available and is efficiently up-taken by plants. Dissolved nutrients are also extracted by roots in the presence of water yielding more plant growth and grains. The EPS producing microflora use organic substrates as food and release organic substrates as gluing materials that are the source of primary particles aggregation yielding crumb structure that also have more water retention capacities. Therefore, more water is plant available in a better structure that also yields more grains along with better water uptake efficacies (Fig. 8a, 8b).

An increase in soil organic carbon with the application of manures was observed at the end of the study in surface (0-30 cm) soil. These observations could be attributed to the artificial addition of organics that got accumulated and resulted in higher carbon content (Qin *et al.*, 2010; Ibrahim *et al.*, 2008). Increase in particulate organic carbon, soil carbon pool, and total soil organic content has been reported with minor changes in soil management practices i.e. tillage and inputs (organic, inorganic, bioagents and combined), etc. (Lewis *et al.*, 2011; Lopez-Garrido *et al.*, 2011). It was observed at the end of the study that soil organic carbon in various sized fractions has proportioned variously with the amalgamation of organic substrates with soil. These results are in close context with (Yu *et al.*, 2012; Huang *et al.*, 2010), who reported increased carbon contents in various sized soil aggregates and various sized carbon fractions that also resulted in better aggregation with the application of manures in presence and absence of other amendments.

Figure (9A) shows a statistically non-significant variation in fine light organic carbon (fLOC) at the end of each crop harvest. After 1st crop harvest, treatment T_3 had a maximum 1.19 g kg^{-1} fLOC that was 0.85, 3.48, and 8.18% greater in content than T_2, T_1, and T_0, respectively. While after 2nd trial the fLOC, the content was highest in T_3 (1.32 g kg^{-1}), that was 2.32, 12.82, and 10% greater in amount than T_2, T_1, and T_0, respectively.

Quantity of organic carbon in coarser soil fragments (cPOC) fluctuated meaningfully among treatments as presented in Figure (9B). T_1 had a maximum (1.89 g kg^{-1}) amount of organic carbon that was 29.45, 29.45, and 53.65% greater in content than T_2, T_3, and T_0, respectively. In the successive experiment cPOC lessened 16.4% in T_1 while enchanted 13, 4.1% in T_0 and T_4 treatments. Soil treated with poultry manure had retained the same amount of organic substrate as in the 1st study.

Carbon retained in fine particles (fPOC) varied pointedly upon various treatments as signposted in the figure (9C). Unification of farm manure with soil had stored only 0.86 g kg^{-1} fPOC that was significant, 19.77, 51.16, and 55.81% lesser in content than T_3, T_0, and T_2, respectively. In the later trial fPOC amplified to 0.92 g kg^{-1} in T_1 that was 20.65, 51.09, and 55.43% less than T_3, T_0, and T_2, respectively.

Variation in the organic portion of carbon that is allied with minerals (mSOC) is depicted in figure (9D). Figure (9D) indicates the maximum amount of mineral attached organics in T_1 (6.71 g kg^{-1}) with non-significant follow path T_2 and T_3, respectively. This amount is 2 folds greater in (mSOC) content than the untouched control. In succeeding study 5.6, 7.3, 5.33, and 15.86% decline in mSOC content was obvious in T_1, T_2, T_3, and T_0, respectively.

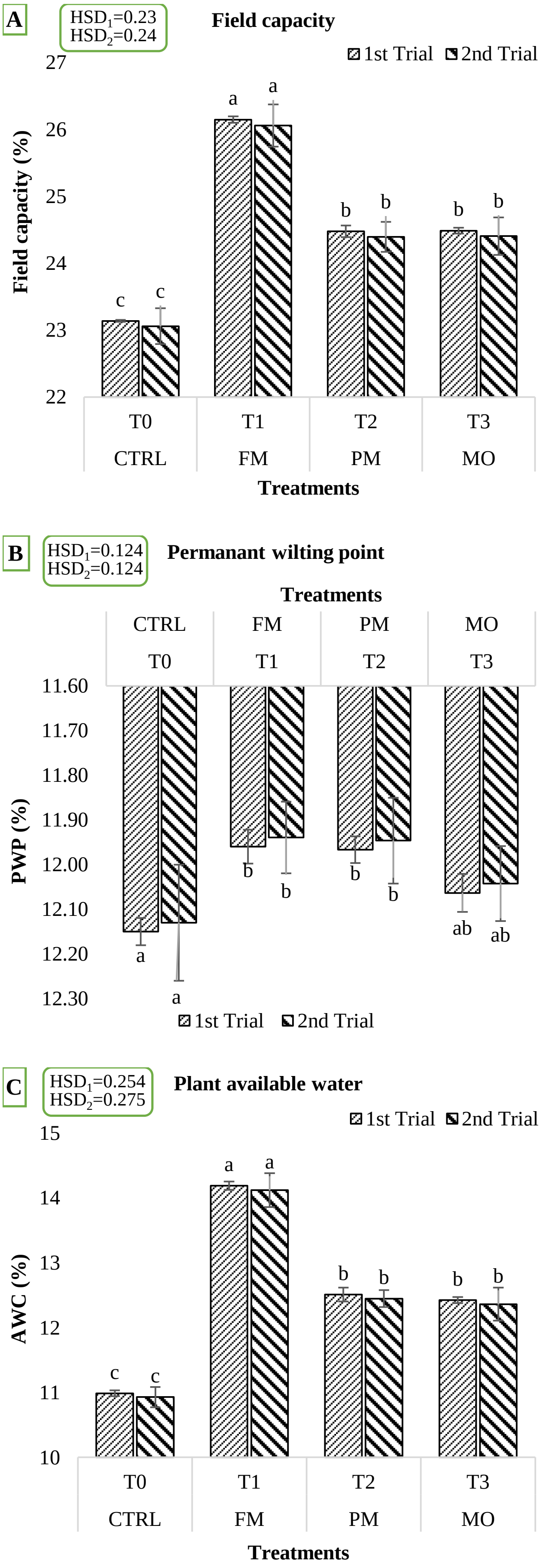

Fig. 6. Effect of different organic substrates on field capacity (A), permanent wilting point (B), and plant available water (C).

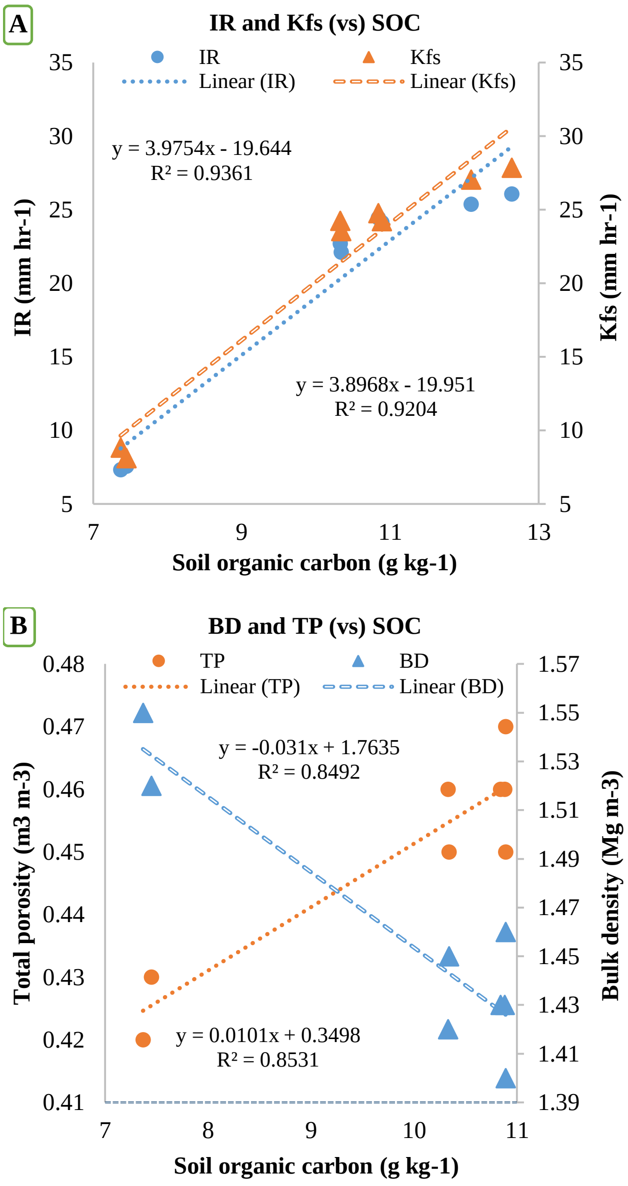

Fig. 7. The trend of infiltration rate (A), saturated hydraulic conductivity (K_{fs}) (A), Bulk Density (B), and Total Porosity (B) with an increase in soil organic carbon.

The part of organic carbon present in solution form (DOC) had been varied significantly among treatments. Organic dissolution pattern is shown in figure (9E) that indicates minimum quantity (0.29 g kg^{-1}) in control that is 2.86, 4.58, and 2.86 times lesser in amount than T_1, T_2, and T_3, respectively. This dissolved proportion increased to 0.30 g kg^{-1} in control but declined in treated soils showing, 2.63, 4.5- and 2.63-folds' difference of T1, T_2, and T_3 with control.

Our results had shown that dissolved and mineral associated carbon contents were relatively greater than other fractions that are consistent with previous findings of various researchers (Bartoli *et al.*, 1992; Barral *et al.*, 1998). Increase in carbon contents with an increase in aggregate size (Saroa & Lal, 2003; Huang *et al.*, 2010) was in line with our findings but Holeplass *et al.*, (2004) contradict this reporting decline in organic carbon content with increase in aggregate size, as carbon in larger sized aggregates is more prone to microbial attack that degrades them rapidly (Tisdall & Oades, 1982).

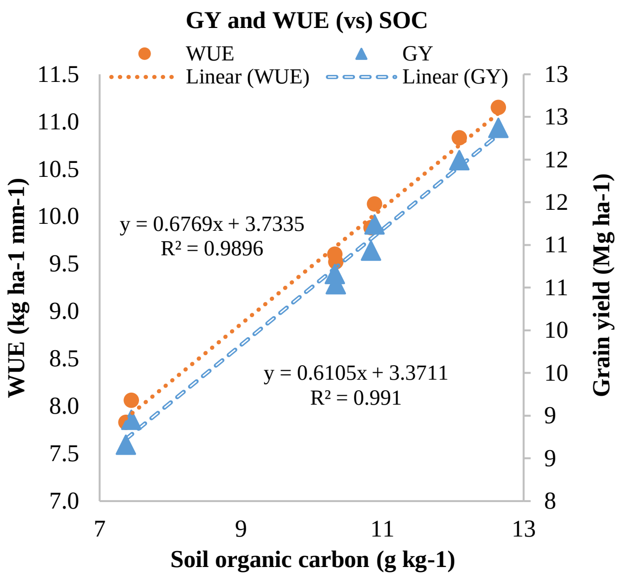

Fig. 8. Trend of grain yield and water use efficiency with increase in soil organic carbon.

The total amount of carbon sequestered during the time and because of treatment application has been presented in figure (10). Results indicate 8.12 Mg ha^{-1} amount of carbon sequestered in farm manure blended soil that was 2.11 and 2.90 Mg ha^{-1} more in amount than T_2 and T_3, respectively. Huang *et al*., (2010) and Saroa & Lal (2003) presented an increase in the total amount of carbon stored in soil with the application of manures.

Blair *et al*., (1995) suggested carbon management index (CMI), a valuable parameter to weigh the status and rate of change in soil organic carbon (SOC) pools in cultivable systems. CMI is based on alterations in easily oxidizable and total SOC resulted from different agricultural practices. CMI values are sizable indicators of carbon dynamics in agricultural systems (Yang *et al*., 2012). Regardless of the minor importance of CMI's absolute values, variances among CMI values echo the effects of various management strategies on different systems (Blair *et al*., 1995). The present study (Table 6) enunciates substantial upsurge in particulate organic carbon content as a labile fraction, upon organic addition, further surging of CMI values as compared to the un-amended control treatment. Hence, shifts in carbon dynamics were triggered by the addition of organic substrates relative to chemically fertilized control.

In the present study proportion of various sized aggregates speckled in different treatment combinations and time (Table 7). Large macroaggregate (>1 mm) proportion was 17.63% in T_1, that was 2.4 times more than standard but was at par with T_2 and T_3 during 1st study, while that increased to 18.4% in T_1 during 2nd study that differed significantly and was 23.66 and 24% greater in amount than T_2 and T_3, respectively, while control yielded 2.7 times lesser quantity than T_1. Macroaggregates (0.5-1 mm) was 19.67% in T_1 that was statistically non-significant with other treatments but 2 folds larger in proportion than untreated soil. During the 2nd experiment, little increase in proportion was observed in treated soils along with a little decline in control soil. T_1 yielded 27.14 and 27.21% small macroaggregates (0.25-0.5 mm) that were at par with (25.73, 26.6) % proportion of T_2 but suggestively greater than T_3 and control. A decrement in micro aggregates (0.106-0.25 mm) was seen in treated soils showing an 18.68% amount in T_1 that was statistically at par with T_2 (17.77) and T_3 (20.29) but was almost half of the control (33.18%). The proportion of micro aggregates had an insignificant decline in T_1 and a negligible increase in T_0, T_2, and T_3, respectively. The proportion of dispersed particles was 26.86% and 28.44% in control that was suggestively greater than the unification of organics and soil.

Larger aggregates improve soil structure and reduce soil bulk density resulting in enhanced water retention capacity (Ciric *et al*., 2012). Organic amendments supply water-soluble, hydrolyzable substrates and carbon, which promotes microbial activities in soil, leading to the production of exopolymers i.e. aliphatic and aromatic polymers, that increase aggregate cohesion, accounting for increased aggregate stability to mechanical breakdown (Bandyopadhyay *et al*., 2010). Organic carbon act as particle cementer and bind little particles to formulate bigger aggregates of worth size. Organic manures work as substrates to supplement microbes for growth and exopolysaccharides secretion that can play an important role to increase the proportion of water stable aggregates >0.25 mm in surface soil (Liu, 2007). Soil organic carbon is a major particle cementer to formulate larger sized aggregates, so compost application indirectly increases aggregate stability that is also responsible for water retention, nutrient stability, plant growth, grain production especially the soil sustainability (Aoyama *et al*., 1999). The addition of stalks, straw, and other crop residues subsequently formulate organic cementers (e.g. lignin and cellulose) by microbial action promotes aggregate formation (Huo *et al*., 2008; Tisdall & Oades, 1982).

This study virtually showed increased aggregate stability with an increase in organic carbon in the soil as presented in figure (11). The particles are majorly bound together as divalent cations force them to bind together but organic matter is natural cementer as microbes (Fungi and Bacteria) use organic carbon source for energy production and release jelly materials out of their cells that cover the particle surfaces and flocculate them together to give larger sized aggregates (Huo *et al*., 2008). The substances released for the gluing of these particles are also organic. That's the reason there is a very narrow gap for the decline in organic matter as that one is a little bit compensated with release and most of it is entrapped between the particles that are safe from the attack of degrading microbes. While the supplementation of organic substrates as microbial food which secrete these polymeric substance yields greater aggregate stabilities as being shown during this study.

Stable aggregation elaborates improved structure and in turn soil physical properties i.e. bulk density, total air and water-filled pores, water retention capacity, soil surface water entry (IR) and water conduction within soil profile (K_{fs}) or indirectly providing a supportive soil environment for the crop to establish roots that will result in more water retention as well for more time for better nutrients uptake resulting into better water uptake efficacy and higher yields. The application of organic substrates increased the proportion of larger sized aggregates that in return had a positive impact on various soil and plant characteristics as shown in figure 12.

Table 5. Effect of different organic substrates @ 75% AWC on infiltration rate and field saturated hydraulic conductivity of the soil.

Organic substrate	Treatments	Infiltration rate (mm hr^{-1})		Field saturated hydraulic conductivity (mm hr^{-1})	
		1st Year (Trial)	2nd Year (Trial)	1st Year (Trial)	2nd Year (Trial)
CTRL	T_0	7.57 ± 0.47 c	7.34 ± 0.26 c	8.11 ± 0.64 c	8.84 ± 0.70 c
FM	T_1	26.07 ± 0.78 a	25.38 ± 1.11 a	27.85 ± 0.19 a	27.04 ± 0.64 a
PM	T_2	24.13 ± 0.27 ab	24.43 ± 0.84 ab	24.22 ± 0.45 b	24.77 ± 1.74 ab
MO	T_3	22.70 ± 0.76 b	22.12 ± 1.16 b	24.25 ± 0.26 b	23.55 ± 0.52 b
HSD		2.03	2.53	1.66	2.36

Table 6. Effect of different organic substrates on carbon dynamics.

Organic substrate	Treatments	Lability index (LI)		Carbon pool index (CPI)		Carbon management index (CMI)	
		1st Year (Trial)	2nd Year (Trial)	1st Year (Trial)	2nd Year (Trial)	1st Year (Trial)	2nd Year (Trial)
CTRL	T_0	1.00	1.00	1.00	1.00	100.00	100.00
FM	T_1	1.46	1.53	1.70	1.64	247.04	251.26
PM	T_2	1.42	1.54	1.46	1.47	207.96	226.27
MO	T_3	2.01	1.97	1.39	1.40	279.37	276.71

Table 7. Effect of different organic substrates on different sized water stable aggregates of soil.

Aggregate size (mm)	Organic substrates	Treatments	Water stable aggregates (%) (1st Trial)	Water stable aggregates (%) (2nd Trial)
>1	CTRL	T_0	7.36 ± 0.34 c	6.84 ± 0.27 c
	FM	T_1	17.63 ± 0.57 a	18.40 ± 0.46 a
	PM	T_2	15.14 ± 0.14 b	14.88 ± 0.27 b
	MO	T_3	15.26 ± 0.21 b	14.79 ± 0.57 b
0.5-1	CTRL	T_0	9.64 ± 0.27 b	8.89 ± 0.62 b
	FM	T_1	19.67 ± 0.10 a	19.83 ± 0.16 a
	PM	T_2	19.25 ± 0.13 a	20.25 ± 0.93 a
	MO	T_3	19.05 ± 0.25 a	19.89 ± 0.19 a
0.25-0.5	CTRL	T_0	22.96 ± 0.33 c	21.41 ± 0.47 b
	FM	T_1	27.14 ± 0.25 a	27.21 ± 1.43 a
	PM	T_2	25.73 ± 0.55 ab	26.60 ± 1.60 a
	MO	T_3	23.61 ± 0.74 bc	26.42 ± 0.83 ab
0.106-0.25	CTRL	T_0	33.18 ± 0.32 a	34.47 ± 0.41 a
	FM	T_1	18.68 ± 0.35 b	16.17 ± 1.42 c
	PM	T_2	17.77 ± 0.75 b	18.60 ± 0.36 bc
	MO	T_3	20.29 ± 0.66 b	20.73 ± 0.99 b
<0.106	CTRL	T_0	26.86 ± 1.57 a	28.44 ± 1.87 a
	FM	T_1	16.81 ± 1.02 d	18.02 ± 1.56 b
	PM	T_2	22.23 ± 1.21 b	19.62 ± 1.65 b
	MO	T_3	21.78 ± 0.89 bc	18.08 ± 0.66 b

*HSD values for >1 mm (1.6 and 2.19), 0.5-1 mm (1.17 and 3.03), 0.25-0.5 mm (2.26 and 5.07), 0.106-0.25 mm (2.53 and 4.32) and <0.106 mm (4.5 and 7.3)

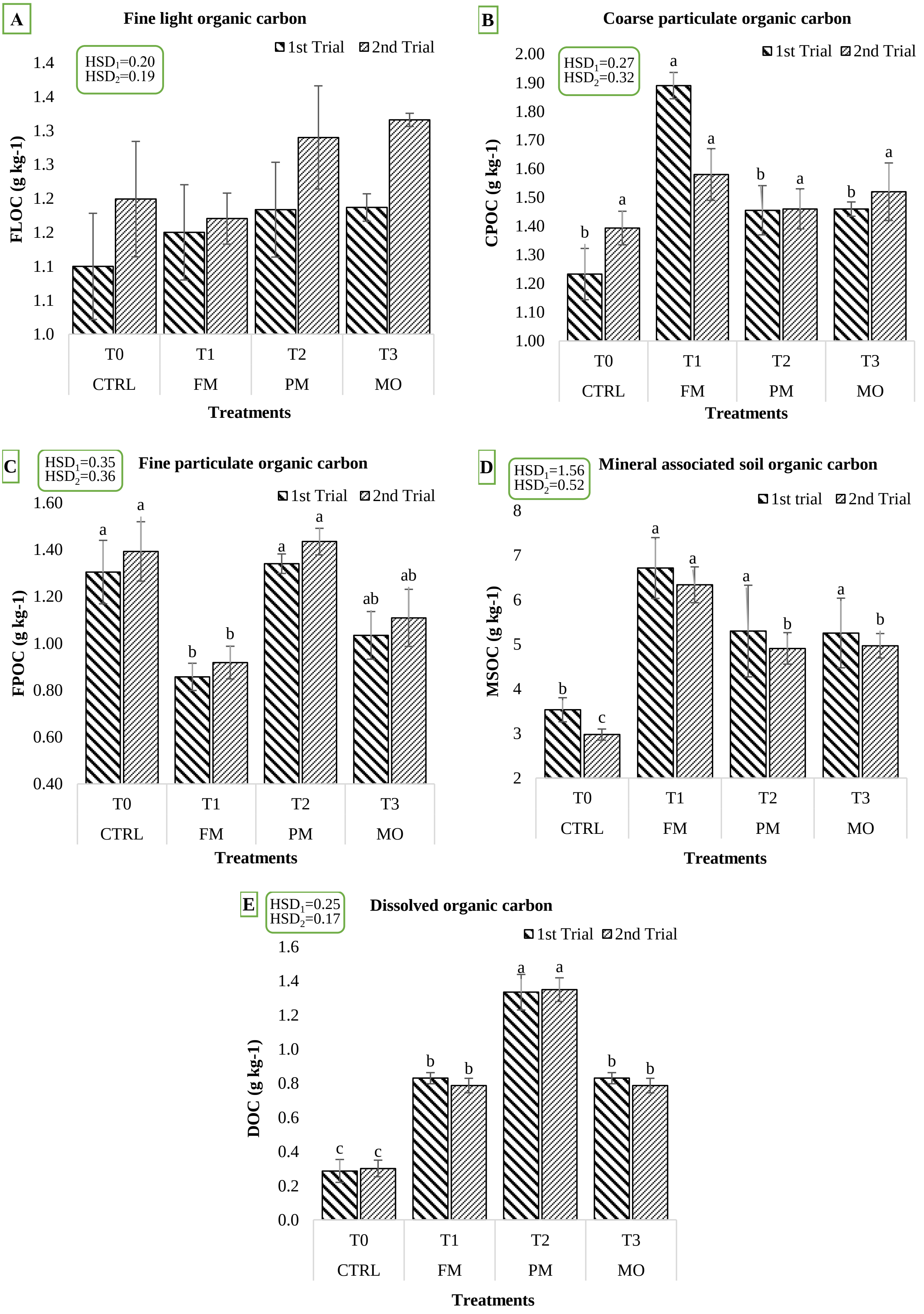

Fig. 10. Effect of different organic substrates on FLOC (A), CPOC (B), FPOC (C), MSOC (D) and DOC (E).

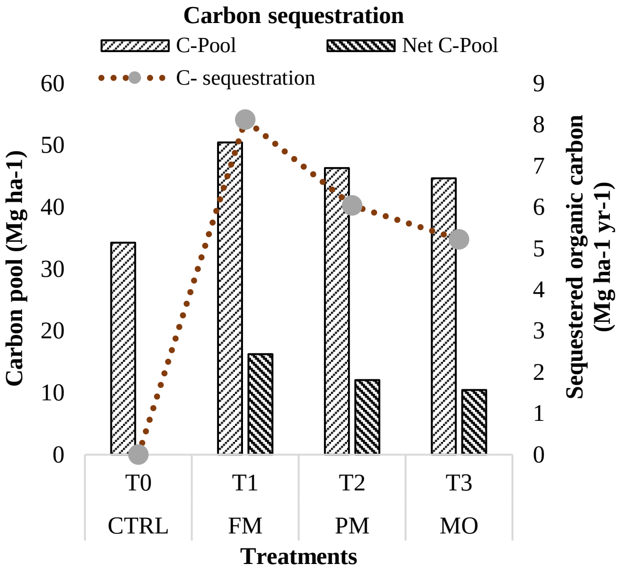

Fig. 10. Effect of different organic substrates on carbon sequestration.

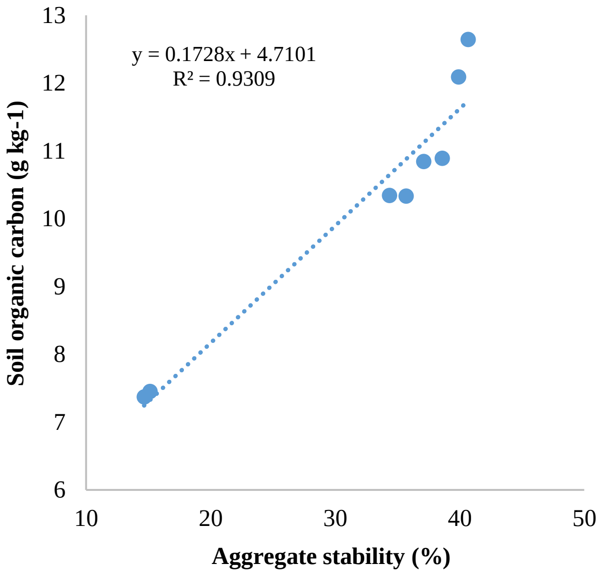

Fig. 11. Variation in soil aggregate stability with variation in soil organic carbon.

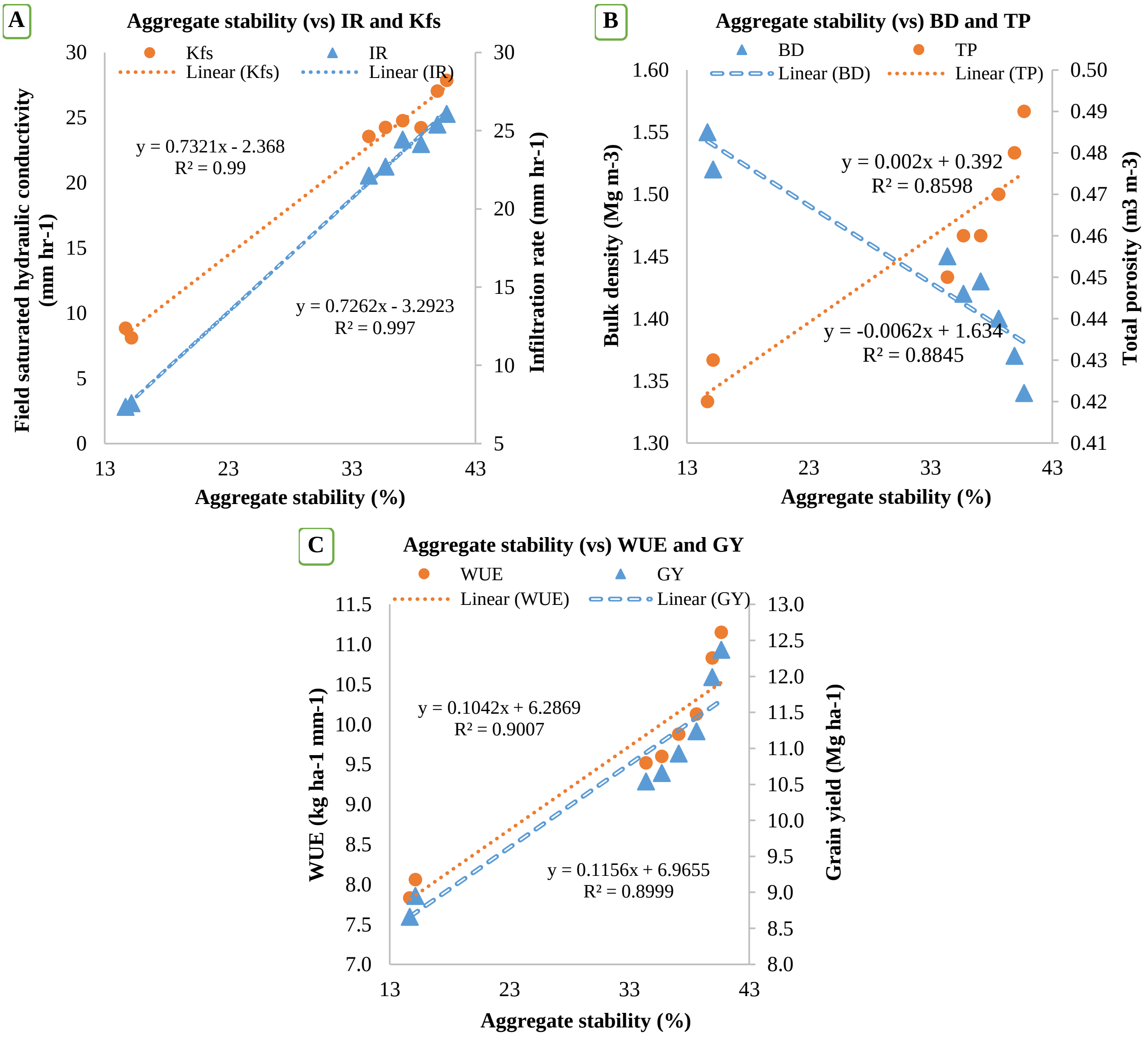

Fig. 12. The trend of infiltration rate (A), saturated hydraulic conductivity (K_{fs}) (A), Bulk Density (B), Total porosity (B), WUE (C), and Grain yield (C) with an increase in aggregate stability.

Conclusion

All the treatments improved the soil structure and soil organic carbon contents that in turn improved soil physical health (bulk density, total pore spaces, infiltration capacity, and hydraulic conduction) as compared to mineral treated control. T_1 (farm manure) application resulted in more betterment of structure than all other treatments. It is, therefore, concluded that the application of farm manure not only adds carbon to the soil but also improves soil physical and nutritional health.

References

Aggelides, S.M. and P.A. Londra, 2000. Effect of compost produced from town wastes and sewage sludge on the physical properties. *Biores. Technol.*, 71: 253-259.

Ali, H., N. Iqbal, A.N. Shahzad, S. Ahmad, Z.M. Khan and N. Sarwar. 2014. Agro-management practices for sustainable wheat production under scarce water condition of arid climate. *Turk. J. Field Crops*, 19(1): 70-78.

Annabi, M., S. Houot, F. Francou, M. Poitrenaud and L.Y. Bissonais. 2007. Soil aggregate stability improvement with urban compost of different maturities. *Soil Sci. Soc. Amer. J.*, 71: 413-423.

Anonymous. 2014-2015. Food and Agriculture Organization. FAO STAT.

Aoyama, M., D.A. Angers, A.N. Dayegamiye and N. Bissonnette. 1999. Protected organic matter in water-stable aggregates as affected by mineral fertilizer and manure applications. *Can. J. Soil Sci.*, 79: 419-425.

Azevedo Neto A.D., J.T. Prisco, J. Enéas-Filho, C.F. Lacerda, J.V. Silva, P.H. Costa and E. Gomes-Filho. 2004. Effects of salt stress on plant growth, stomatal response and solute accumulation of different maize genotypes. *Braz. J. Plant Physiol.*, 16(1): 31-8.

Bandyopadhyay, K.K., A.K. Misra, P.K. Ghosh and K.M. Hati. 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soil Till. Res.*, 110: 115-125.

Barral, M.T., M. Arias and J. Guerif. 1998. Effects of iron and organic matter on the porosity and structural stability of soil aggregates. *Soil Till. Res.*, 46: 261-272.

Bartoli, F., G. Burtin and J. Guerif. 1992. Influence of organic matter on aggregation in Oxisols rich in gibbsite or in goethite. II. Clay dispersion, aggregate strength and water-stability. *Geoderma*, 54: 259-274.

Behera, U.K., A.R. Sharma and H.N. Pandey. 2007. Sustaining productivity of wheat–soybean cropping system through integrated nutrient management practices on the Vertisols of central India. *Plant Soil*, 297: 185-199.

Blair G.J., R.D.B. Lefory and L. Lisle. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural system. *Aust. J. Agri. Res.*, 46: 1459-1466.

Blake, G.R. and K.H. Hartage. 1986. Bulk density. p. 363-375. In: Klute, A. (ed.), Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. Agronomy Monograph No. 9, 2nd Ed., Madison, WI, USA.

Bremner, J.M. and C.S. Mulvaney. 1982. Nitrogen - total. In: Methods of Soil Analysis. (Eds.): Page, A.L., R.H. Miller and D.R. Keeney. Part II. Chemical and Microbiological Properties, 2nd Ed. Am. Soc. Agron, Madison, WI, USA.

Celik, I., I. Ortas and S. Kilic. 2004. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. *Soil Till. Res.*, 78: 59-67.

Chakraborty, D., R.N. Garg, R.K. Tomar, B.S. Dwivedi, P. Aggarwal, R. Singh, U.K. Behera, A. Thangasamy and D. Singh. 2010. Soil physical quality as influenced by long-term application of fertilizers and manure under maize-wheat system. *Soil Sci.*, 175: 128-136.

Chivenge, P., B. Vanlauwe, R. Gentile and J. Six. 2011. Comparison of organic versus mineral resource effects on short-term aggregate carbon and nitrogen dynamics in a sandy soil versus a fine textured soil. *Agri. Ecosyst. Environ.*, 140: 361-371.

Ciric, V., M. Manojlovic, Lj. Nesic and M. Belic. 2012. Soildry aggregate size distribution: Effects of soil type and land use. *J. Soil Sci. Plant Nutr.*, 12: 689-703.

Dane, J.H. and J.W. Hopmans. 2002. Laboratory determination of water retention. p. 671-720. In: Methods of Soil Analysis. Part 4, Physical Methods. (Eds.): Dane, J.H. and G.C. Topp. Soil Sci. Soc. Am. Inc., Madison, WI, USA.

Diekow, J., J. Mielniczuk, H. Knicker, C. Bayer, D.P. Dick and I. Kogel Knaber. 2005. Carbon and nitrogen stocks in physical fractions of a subtropical Acrisol as influenced by long-term no-till cropping systems and N fertilization. *Plant Soil*, 268: 319-328.

Doran, J.W. and T.B. Parkin. 1994. Defining and assessing soil quality. In: Defining Soil Quality for a Sustainable Environment. P: 3-21. (Eds.): Doran, J.W., D.C. Coleman, D.F. Bezdicek and B.A. Stewart. SSSA Spec. Pub. No. 35, Soil Sci. Soc. Amer., Amer. Soc. Argon., Madison, Wisconsin, USA.

Fallah, S., A. Ghalavand and F. Raiesi. 2013. Soil chemical properties and growth and nutrient uptake of maize grown with different combinations of broiler litter and chemical fertilizer in a calcareous Soil. *Commun. Soil Sci., Plant Anal.,* 44: 3120-3136.

Fang, Q., L. Ma, Q. Yu, L.R. Ahuja, R.W. Malone and G. Hoogenboom. 2010. Irrigation strategies to improve the water use efficiency of wheat–maize double cropping systems in North China Plain. *Agri. Water Manag.*, 97: 1165-1174.

Fonte, S.J., E. Yeboah, P. Ofori, G.W. Quansah, B. Vanlauwe and J. Six. 2009. Fertilizer and residue quality effects on organic matter stabilization in soil aggregates. *Soil Sci. Soc. Amer. J.*, 73: 961-966.

Gentine, P., D. Entekhabi, A. Chehbouni, G. Boulet and B. Duchemin. 2007. Analysis of evaporative fraction diurnal behavior. *Agric. Forest Meteorol.*, 143: 13-29.

Holeplass, H., B.R. Singh and R. Lal. 2004. Carbon sequestration in soil aggregates under different crop rotations and nitrogen fertilization in an inceptisol in southeastern Norway. *Nutr. Cycl. Agroecosys.*, 70: 167-177.

Huang, S., X.X. Peng, Q.R. Huang and W.J. Zhang. 2010. Soil aggregation and organic carbon fractions affected by long-term fertilization in a red soil of subtropical China. *Geoderma.*, 154: 364-369.

Huo, L., T.Y. Wu, H.M. Lin, S.Y. Cao and W.X. Tang. 2008. Effect of long-term fertilization on water-stable aggregates in calcic kastanozem of Loess Plateau. *Chin. J. Appl. Ecol.*, 19: 545-550.

Ibrahim, M., A. Hassan, M. Iqbal and E.E. Valeem. 2008. Response of wheat growth and yield to various levels of compost and organic manure. *Pak. J. Bot.*, 40(5): 2135-2141.

Imran, M., A.U. Hassan, M. Iqbal, E. Ullah and J. Šimunek. 2015. Assessment of actual evapotranspiration and yield of wheat under different irrigation regimes with potassium application. *Soil Eviron.*, 34(2): 156-165.

Karam, F., R. Lahoud, R. Masaad, R. Kabalan, J. Breidi, C. Chalita and Y. Rouphael. 2007. Evapotranspiration, seed yield and water use efficiency of drip irrigated sunflower under full and deficit irrigation conditions. *Agric. Water Manag.*, 90(3): 213-223.

Khan, S. and A. Abbas. 2007. Upscaling water savings from farm to irrigation system level using GIS-based agro-hydrological modeling. *Irri. Drain.*, 56: 29-42.

Klute, A. 1986. Method of soil analysis. Part1 Physical and Mineralogical Analysis. Agronomy Monograph No.9. Madison, WI, USA.

Kuo, S. 1996. Phosphorus. In: (Ed.): Bigham, J.M. *Methods of Soil Analysis*. Part 3: Chemical Methods. Soil Sci. Soc. Am./Am. Soc. Agron., Madison, WI, USA.

Lal, R., J. Kimble and R. Follet. 1997. Land use and soil C pools in terrestrial ecosystems, In: (Eds.): Lal, R., J. Kimble, R.F. Follett and B.A. Stewart. Management of carbon sequestration in soil, Advances in Soil Science, CRC Lewis Publishers, Boca Raton, FL, USA. p. 1-10.

Lewis, D.B., J.P. Kaye, R. Jabbour and M.E. Barbercheck. 2011. Labile carbon and other soil quality indicators in two tillage systems during transition to organic agriculture. *Renew. Agr. Food Syst.*, 26: 342-353.

Liu, E.K. 2007. Microbiological features of soil under different fertilization systems and their related soil fertility [Ph.D. thesis]. *Chinese Academy of Agricultural Sciences, Beijing, China*.

Liu, W.Z. and X.C. Zhang. 2007. Optimizing water and fertilizer input using an elasticity index: A case study with maize in the loess plateau of china. *Field Crops Res.*, 100: 302-310.

Lopez-Garrido, R., E. Madejon, J.M. Murillo and F. Moreno. 2011. Soil quality alteration by mouldboard ploughing in a commercial farm devoted to no-tillage under Mediterranean conditions. *Agr. Ecosyst. Environ.*, 140: 182-190.

Madari, B., P.L.O.A. Machado, E. Torres, A.G. de Andrade and L.I.O. Valencia. 2005. No tillage and crop rotation effects on soil aggregation and organic carbon in a Rhodic Ferralsol from southern Brazil. *Soil Till. Res.*, 80: 185-200.

Miller, J.J., N.J. Sweetland and C. Chang. 2002. Hydrological properties of a clay loam soil after long-term cattle manure application. *J. Environ. Qual.*, 31: 989-996.

Moebius, B.N., H.M. Van Es, R.R. Schindelbeck, O.J. Idowu, J.E. Thiesand and D.J. Clune. 2007. Evaluation of laboratory-measured soil properties as indicators of soil physical quality. *Soil Sci.*, 172: 895-912.

Montgomery, D.C. 2013. Design and analysis of experiments. 8th Ed. John Wiley and Sons Inc, New York (USA). pp. 98-100.

Odlare, M., M. Pell and K. Svensson. 2008. Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. *Waste Manag.*, 28(7): 1246-1253.

Pagliai, M., N. Vignozzi and S. Pellegrini. 2004. Soil structure and the effect of management practices. *Soil Till. Res.*, 79: 131-143.

Parasuraman, K., A. Elshorbagy and S.K. Carey. 2007. Modelling the dynamics of the evapotranspiration process using genetic programming. *Hydrol. Sci. J.*, 52: 563-578.

Parras-Alcántara, L., B. Lozano-García, S. Keesstra, A. Cerdà and E.C. Brevik. 2016. Long-term effects of soil management on ecosystem services and soil loss estimation in olive grove top soils. *Sci. Tot. Environ.,* 571: 498-506.

Qin, S.P., C.S. Hu, X.H. He, W.X. Dong, J.F. Cui and Y. Wang. 2010. Soil organic carbon, nutrients and relevant enzyme activities in particle-size fractions under conservational versus traditional agricultural management. *Appl. Soil Ecol.*, 45: 152-159.

Saroa, G.S. and R. Lal. 2003. Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian soil in central Ohio. *Land Degrad. Dev.*, 14: 481-493.

Schlichting, E., H.P. Blume and K. Stahr. 1995. Bodenkundliches Praktikum. Paul Parey. Hamburgo. Germany: 209 p.

Scialabba, N.E.H. and M. Müller-Lindenlauf. 2010. Organic agriculture and climate change. *Renew. Agric. Food Sys.*, 25(2): 158-169.

Shahzad, H., M. Iqbal, S. Bashir and M. Farooq. 2019. Relative efficacy of organic substrates on maize root proliferation under water stress. *Biosci. J.*, 35(1): 101-114.

Six, J., E.T. Elliott and K. Paustian. 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biol. Biochem.*, 32: 2099-2103.

Six, J., E.T. Elliott, K. Paustian and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Sci. Amer. J.*, 62(5): 1367-1377.

Stockdale, E.A., N. Lampkin, M. Hovi, R. Keatinge, E.K.M. Lennartsson, D.W. McDonald, S. Padel, F. Tatersall, M.S. Wolfe and C.A. Watson. 2000. Agronomic and environmental implications of organic farming systems. *Adv. Agron.*, 70: 261-32.

Tisdall, J.M. and J.M. Oades. 1982. Organic matter and water-stable aggregates in soils. *J. Soil Sci.*, 33: 141-163.

Vassilev, N., A. Medina, R. Azcón and M. Vassileva. 2007. Microbial solubilization of rock phosphate on media containing agro-industrial wastes and effect of the resulting products on plant growth and P uptake. *Plant Soil*, 287: 77-84.

Wesseling, J.G., C.R. Stoof, C.J. Ritsema, K. Oostindie and L.W. Dekker. 2009. The effect of soil texture and organic amendment on the hydrological behaviour of coarse-textured soils. *Soil Use Manag.*, 25(3): 274-283.

Williams, J., R.E. Prebble, W.T. Williams and C.T. Hignett. 1983. The influence of texture, structure and clay mineralogy on the soil moisture characteristic. *Aust. J. Soil Res.*, 20: 15-32.

Yang X. Y., W.D. Ren, B.H. Sun and S.L. Zhang. 2012. Effects of contrasting soil management regimes on total and labile soil organic carbon fractions in a loess soil in China. *Geoderma*, 177-178: 49-56.

Yazdanpanah, N., M. Mahmoodabadi and A. Cerdà. 2016. The impact of organic amendments on soil hydrology, structure and microbial respiration in semiarid lands. *Geoderma,* 266: 58-65.

Yu, H.Y., W.X. Ding, J.F. Luo, R.L. Geng, and Z.C. Cai. 2012. Long-term application of organic manure and mineral fertilizers on aggregation and aggregate-associated carbon in a sandy loam soil. *Soil Till. Res.*, 124: 170-177.

(Received for publication 2 December 2018)