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Full Length Article

Soil Health Indicators as Affected by Long-term Application of Farm Manure and Cropping Patterns under Semi-arid Climates

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Abstract

Intensive agriculture in South Asia has resulted in soil degradation and loss of crop production potential. Soil health is a key factor in crop production and the new emphasis on sustainable agriculture has generated interest in the optimization of all aspects of soil functioning - physical, chemical and biological. The objective of this study was to use a set of soil health indicators to measure the effects of farm manure (FM) application and cropping pattern on Pakistan soils. For this study five cropping systems, i.e. cotton-wheat (CW), maize-wheat (MW), rice-wheat (RW), sugarcane-wheat (SW) and vegetable-vegetable (V-V), both, manured and non-manured were selected from each cropping zones of Pakistan. Samples collected were analyzed for soil health indicators including soil bulk density, available water capacity (AWC), aggregate stability (WSA), macro porosity, organic matter (OM), soil active carbon (ActC), potentially mineralizable nitrogen (PMN), P, K, Zn, Ca, S, CEC and pH. Manured plots had significantly higher levels of OM (28%), ActC (43%), PMN (92%), AWC (24%), and macro porosity (19%) and significantly lower bulk density (5%) than non-manured plots. Among cropping systems highest values were found in SW, MW and SW compared to RW, with higher values in the former systems for WSA (243%), AWC (16%) and macro-porosity (39%). This clearly gave indication of the deteriorative effect of puddling in rice cultivation. Higher values were observed in MW, RW, CW with higher OM (36%), active carbon (ActC, 33.6%) and PMN (731%) compared to CW and VV. Only S and Mg were significantly higher in manured plots while pH, CEC, NO3-N, P, K, Zn and Ca were statistically not different in manured fields. Results of this study conclude that long-term manure applications improve soil quality, while puddling, especially in rice cultivation, exhibits maximum damage to soil physical quality indicators.

Keywords: Farm manure; Soil health; Aggregate stability; Available water capacity; Cropping pattern

Introduction

The integration of biological, physical and chemical soil processes into soil health management represents a major departure from the 20th century approach that focused almost exclusively on soil chemical testing and management (Wolfe, 2006). Soil health management in practice typically involves more attention to rhizosphere processes and building soil organic matter in relation to aggregate stability, water and nutrient holding capacity and drainage, and the capacity of soil to support beneficial soil organisms that improve nutrient availability and suppress diseases and other pests (Magdoff and van Es, 2009; Javeed and Zamir, 2013).

Soil degradation is the temporary or permanent loss of productive capacity of agricultural land. The prevalent management systems in Pakistani agriculture are not sustainable, as they cause severe problems of degradation and desertification. Symptoms of soil degradation in agricultural lands include water and wind erosion, salinization, waterlogging, soil fertility decline, depletion of soil organic matter, crusting, and compaction (Hassan and Lal, 2007). Soil organic matter (SOM) is critical for cycling plant nutrients and improving soil physical, chemical and biological properties. Manure application had beneficial effects on SOC stocks in the labile pool and to a greater extent in the recalcitrant pool, suggesting a pronounced change in SOM quality caused by long-term fertilization treatments (Ding *et al*., 2012). Long-term use of FM with NPK is a good management system in accumulating SOC (Bhattacharyya *et al*., 2007). Pakistani soils are very poor (less than 1%) in organic matter content due to less crop residue additions and arid climatic conditions (Khan, 1986). Use of organic manures along with fertilizers have been successfully used to enhance the soil heath and fertility (Magdoff and van Es, 2009; Magdoff and Amadon, 1980; Nawab *et al.*, 2011) resulting in higher crop yields and also improved soil physical and chemical properties (Negi and Gulshan, 2000; Zhao *et al*., 2009). Singh *et al*. (2007) found that manure application enhanced SOC, aggregate stability, infiltration and field saturated hydraulic conductivity and

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decreased bulk density and soil strength.

Inclusion of legumes in crop rotation increases the total N and PMN due to biological nitrogen fixation (Ussiri *et al.*, 2006; Shafi *et al.*, 2006). Legume based cropping pattern generally provides higher content of soil microbial activity, soil organic carbon and N.

In reality under existing circumstances and economic conditions of the farmers there is need of development of inexpensive integrated approach to address soil quality domains (Andrews and Carroll, 2001). The Cornell Soil Health Test (CSHT) includes such an integrative assessment framework and has been available for use by researchers and land managers, primarily in the United States (Idowu *et al*., 2008; Gugino *et al*., 2009). A better understanding of the impact of continuous cropping on physical, chemical, and biological soil properties is needed to optimize the soil conditions necessary to enhance the cropping system sustainability.

Keeping above facts in view the present study was planned with the objectives (i) to evaluate the impacts of manure application on soil health improvement under different cropping systems, (ii) apply soil quality assessment frame work to quantify the impact of farm manure application and assess detrimental effects of tillage under existing cropping systems under arid and semi-arid conditions.

Materials and Methods

Site Selection

Sampling sites were selected on the basis of cropping systems and farm manure application. Twenty fields of different farmers of each cropping systems were sampled across the Punjab, i.e. from District Faisalabad, Jhang, Toba Tek Singh, Pakpattan, Lahore, Sheikhupura, Sargodha, Sialkot, Gujranwala, Hafizabad, Gujrat, Kasur, Okara, Sahiwal, Multan, Bahawalpur, Rahimyar Khan, D.G. Khan, Mianwali, Bhakhar, Layyah, Chakwal and Attock. Cropping systems included in the study are cotton-wheat (CW), maize-wheat (MW), rice-wheat (RW), sugarcane-wheat (SW) and vegetable-vegetable (V-V). In each cropping system, fields with manure additions and without manure for the last 10 years were sampled.

Soil Sampling

Soil samples (six from each plot) were collected from selected sites during September-October 2009 at nearly field capacity water contents. A core sampler was used to collect undisturbed samples for bulk density and soil auger was used to sample from 0-0.15 m depth for other physical, biological and chemical tests. Samples were air-dried and shipped to the Cornell University, Ithaca, NY, USA.

Laboratory Tests

Soil cores were saturated ($\Psi = 0$) in their rings by raising the water table slowly. Macro porosity, i.e. the fraction of soil volume with pore diameter of > 1000 µm in m^3m^{-3}, was determined gravimetrically by allowing saturated core samples to drain freely on wet nylon gauze to reach an equilibrium at water potential of Ψ = -0.36 MPa (Karunatilake and van Es, 2002). Soil bulk density was determined by the core method (Blake and Hartge, 1986). Water stable aggregation of large (WSA_{lg}, 2-8 mm) and small aggregates (WSA_{sm}, 0.25-2 mm) was measured from disturbed samples using artificial rainfall simulator (Ogden et al., 1997; Moebius *et al.*, 2007). The fraction of the stable aggregates was calculated using the following formula:

$$WSA = w_{stable}/\, w_{total} \qquad (1).$$

$$W_{stable} = w_{total} - (w_{slaked} + w_{stones}) \qquad (2).$$

Where, w_{stable}, w_{total}, w_{slaked} and w_{stones} are the dry weights of stable soil aggregates, total aggregates tested, aggregates slaked through the sieve and stones remaining in the sieve, respectively.

Available water capacity (AWC) was determined using disturbed soil samples by pressure membrane apparatus. The water content at field capacity (-10 kPa) and at permanent wilting point (-1500 kPa) were estimated. The AWC is the soil water stored between Ψ = -10 and Ψ = -1500 kPa (Topp *et al.*, 1993).

Potentially mineralizable nitrogen (PMN) was determined by shaking the soil with 2.0 M KCl solution on a mechanical shaker for 60 min, centrifuged for 10 min and then supernatant was used for estimation of ammonium concentration. To the second tube distilled water was added, hand shaken and incubated for 7 days. Then 2.67 M KCl was added and shaken for 60 min and centrifuged for 10 min and the supernatant was used for determination of ammonium concentration.

Biologically active carbon (ActC) was estimated by reacting soil with 0.02 M potassium permanganate solution. The centrifuge tube was shaken for 2 min to oxidize the active carbon, and the supernatant was used to determine active carbon (Weil *et al*., 2003). This measurement is correlated with soil biological activity, aggregation and yield (Islam and Weil, 2000; Weil *et al.,* 2003).

For organic matter determination, the samples were ashed for two hours at 500^{o}C and then percent of weight loss was calculated. The percent loss on ignition (LOI) was converted to % organic matter using the following equation:

$$\% OM = (\% LOI * 0.7) - 0.23$$

The Melich-3 (Mehlich, 1984) extracts were analyzed for P, K, Ca, Mg, S and Zn contents by inductively coupled plasma optical emission spectrometry (ICP-OES, Varian 730-ES) and cation exchange capacity (CEC) was calculated as sum of exchangeable K, Mg and Ca contents. An analytical technique developed by the Kettler *et al.* (2001) was followed for soil textural analysis. The JMP (Version 8.0, SAS Institute, Inc., 2008) was used for statistical analysis.

Results

Physical Soil Health Indicators

Aggregate stability (WSA): Manure addition did not show any positive effect under conventional farming system. However, aggregate stability varied significantly under different cropping patterns (Table 1). The highest value of WSA (17.74%) was observed in sugarcane-wheat (SW) followed by cotton-wheat (14.85%), maize-wheat (9.73%), vegetable-vegetable (9.67%) and 5.17% in rice-wheat (RW) cropping system (Table 2). The WSA values were 243% and 187% higher in SW and CW compared to RW, which have lowest stability. Sugarcane-wheat system attained the good physical health due to longer crop stay on the field resulted in aggregate stability and poor health resulted in rice-wheat due to puddling of soil for rice seeding. Within cropping systems un-expected results were observed in SW where significantly higher aggregate stability was found in non-manured plots compared to manured although in all other systems manured plots achieved higher value (25%) and lowest was found in RW with the lowest value (5%) among all the systems (Fig. 1).

Available water capacity (AWC): Farm manure addition resulted in significant increase in AWC while effect of cropping pattern was non-significant (Table 2). Manure application increased AWC by 24% compared to non-manured fields. As regard cropping patterns, 20% more AWC was observed in MW compared to RW. Effect of manuring within cropping pattern was significant in CW and RW systems, where manured plots have higher AWC than non-manured plots. Thus manure addition caused improvement in soil physical quality indicators (Fig. 2).

Bulk density (ρb): Manure addition resulted in significant decrease in ρb that was almost 5% compared to non-manured plots. Effect of cropping pattern was non-significant on soil bulk density. Highest ρb (1.46) was found in MW followed by CW (1.42), SW (1.39 Mg m^{-3}), while lowest (1.36) in VV cropping sequence (Table 2). Maximum ρb reduction was observed in VV, which might be due to more addition of biomass in form of crop roots and fallen leaves (Fig. 3).

Macroporosity (m^3 m^{-3}): Manure addition and cropping systems have highly significant effect on macroporosity of soil (Table 1). Highest value of macroporosity (0.031) was observed in manured plots, which were 20% more than non manured plots (Table 2). If we compare cropping patterns highest value (0.033) was observed in SW, while lowest (0.023) in MW, which was statistically at par with RW (0.025). On comparison of farm manure within crop rotations highest value was found in CW in manured plots (Fig. 4), while lowest in MW in non-manured one.

Biological Soil Health Indicators

Active carbon (mg kg^{-1}): Manure addition effect was highly significant on soil active carbon (ActC) as 42% higher value was found in manured plots compared to non-manured (Table 3). Among the cropping patterns highest value of ActC (342.1) was observed in case of RW followed by VV (289.6), MW (270.4), SW (268.5) and lowest (256.1) in CW. On percentage basis, 34, 13, 6 and 5% more active carbon was found in RW, VV, MW and SW, respectively compared to CW. Statistically no difference

Table 1: ANOVAs table with *P* values of physical, chemical and biological soil quality indicators

Treatments	WSA	AWC	ρ_b	MP	pH	CEC	NO_3-N	P	K	S	Zn	Ca	Mg	Act C	OM	PMN
Cropping pattern (CP)	0.033	0.609	0.168	0.010	0.432	0.957	0.199	0.458	0.185	0.837	0.496	0.469	0.823	0.547	0.374	0.158
Farm manure (FM)	0.989	0.092	0.036	0.009	0.481	0.122	0.463	0.160	0.059	0.019	0.432	0.075	0.031	0.007	0.036	0.251
CP×FM	0.076	0.456	0.863	0.380	0.958	0.618	0.876	0.143	0.156	0.694	0.701	0.586	0.739	0.778	0.756	0.775

WSA: Wet aggregate stability, AWC: Available water capacity, ρ_b: Bulk density, CEC: Cation exchange capacity, ActC: Active carbon, OM: organic matter, PMN: Potentially mineralizable nitrogen, MP: Macroporosity

Table 2: Physical soil health indicators as affected by farm manure application and cropping pattern

Treatments		W A %	AWC g g^{-1}	Bulk density Mg m^{-3}	Macro-Porosity m^3 m^{-3}
Farm manure	M0†	11.41 A‡	0.148 B†	1.45 B	0.026 B
	M1	11.44 A	0.183 A†	1.39 A	0.031 A
	SE	1.721	0.016	0.020	0.0012
Cropping pattern	CW	14.85 A	0.157 A	1.42 A	0.031 A
	MW	09.73 A	0.180 A	1.46 A	0.023 AB
	RW	05.17 A	0.155 A	1.46 A	0.025 AB
	SW	17.74 A	0.177 A	1.39 A	0.033 AB
	VV	09.67 A	0.160 A	1.36 A	0.032 B
	SE	3.847	0.0275	0.0439	0.0027

Table 3: Biological soil health indicators as affected by farm manure application and cropping pattern

Treatments		Active carbon mg kg^{-1}	PMN µg g^{-1} wk^{-1}	Organic matter g kg^{-1}
Farm manure	M0†	234.9 B‡	1.40 A	0.725 B
	M1	335.7 A	2.69 A	0.933 A
	SE	24.17	0.77	0.066
Cropping pattern	CW	256.1 A	4.74 A	0.695 A
	MW	270.4 A	2.54 A	0.943 A
	RW	342.1 A	1.07 A	0.772 A
	SW	268.5 A	1.33 A	0.792 A
	VV	289.6 A	0.57 A	0.943 A
	SE	38.22	1.73	0.147

†M0: No manure; M1: Manured; CW: Cotton-wheat; MW: Maize-wheat; RW: Rice wheat; SW: Sugarcane-wheat; V-V: Vegetable-vegetable; SE: Standard Error. ‡Means for treatments within columns for each experiment followed by the same letter are not significantly different at α=0.05

FM0: no manure; FM1: manured; CW: cotton-wheat; MW: maize-wheat; RW: rice wheat; SW: sugarcane-wheat; VV: vegetable-vegetable

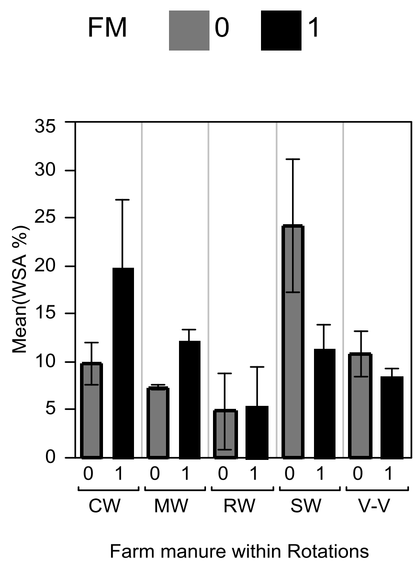

Fig. 1. Soil aggregate stability as influenced by interactive effect of farm manure within crop rotations.

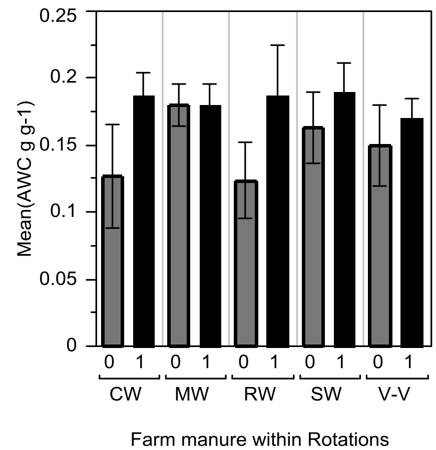

Fig. 2. Available water capacity as influenced by interactive effect of farm manure within crop rotations.

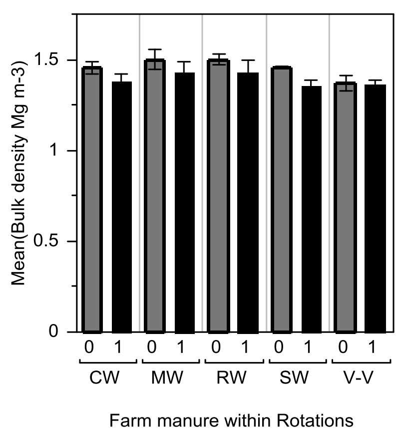

Fig. 3. Soil bulk density as influenced by interactive effect of farm manure within crop rotations.

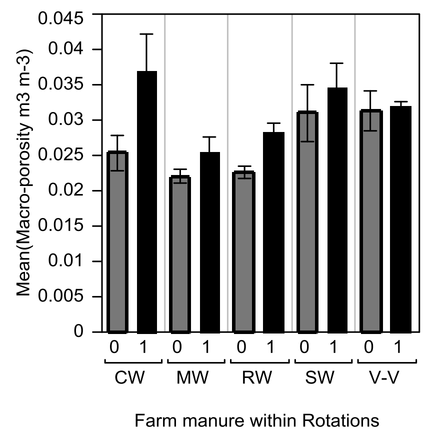

Fig. 4. Soil macroporosity as influenced by interactive effect of farm manure within crop rotations.

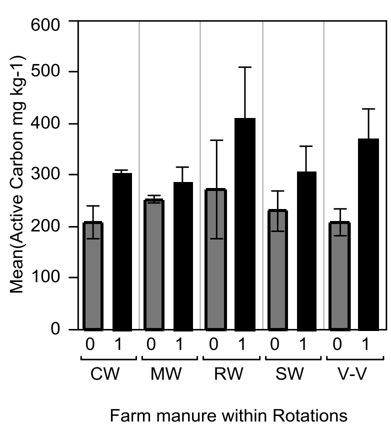

Fig. 5. Soil active carbon (Act C) as influenced by interactive effect of farm manure within crop rotations.

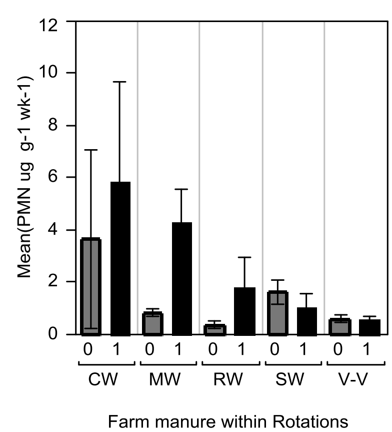

Fig. 6. Soil potentially mineralizable N as influenced by interactive effect of farm manure within crop rotations.

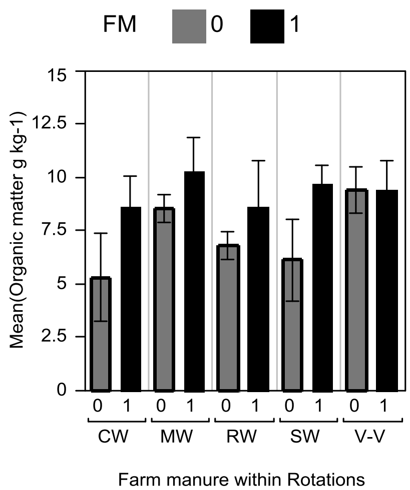

Fig. 7. Soil organic matter as influenced by interactive effect of farm manure within crop rotations.

FM0: no manure; FM1: manured; CW: cotton-wheat; MW: maize-wheat; RW: rice wheat; SW: sugarcane-wheat; VV: vegetable-vegetable

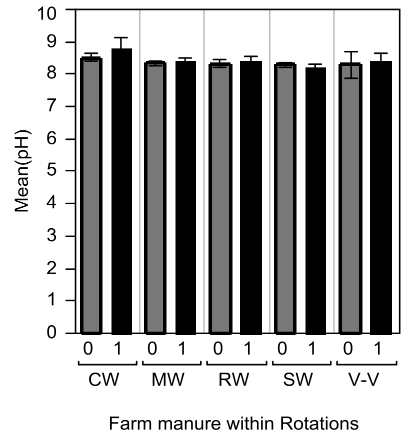

Fig. 8. Soil pH as influenced by interactive effect of farm manure within crop rotations.

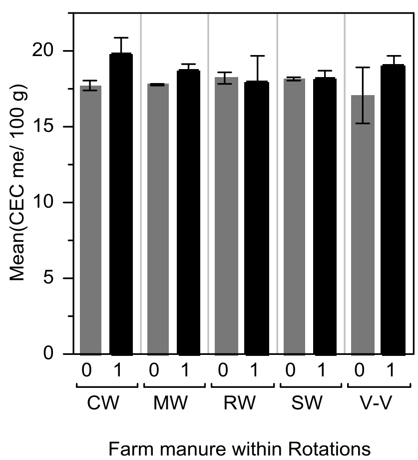

Fig. 9. Soil CEC as influenced by interactive effect of farm manure within crop rotations.

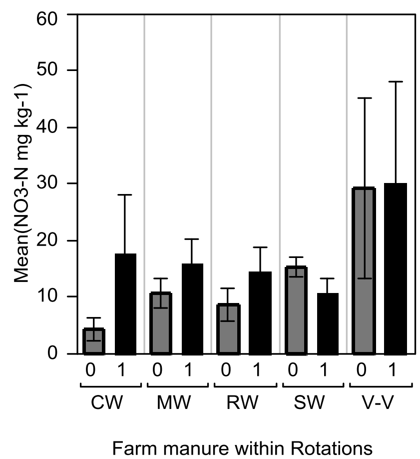

Fig. 10. Soil $NO^{3-}N$ as influenced by interactive effect of farm manure within crop rotations.

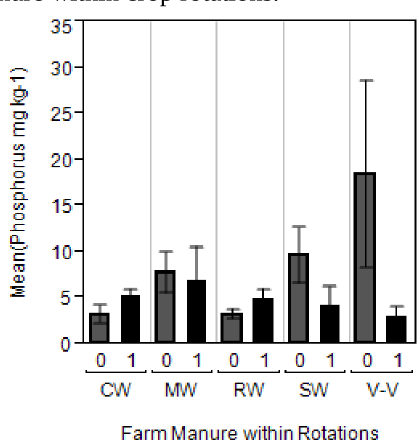

Fig. 11. Soil phosphorus (P) as influenced by interactive effect of farm manure within crop rotations.

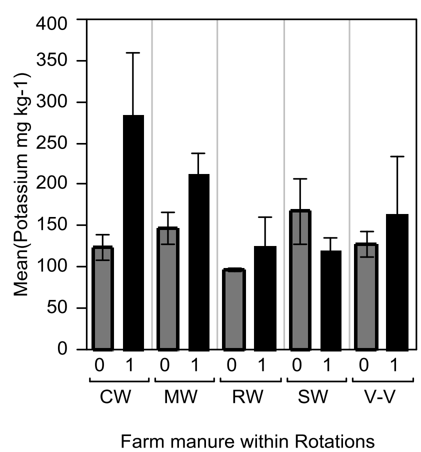

Fig. 12. Soil potassium (K) as influenced by interactive effect of farm manure within crop rotations

exists regarding cropping pattern effect on ActC (Fig. 5) if we compare manured plots with non-manured plots.

Potentially mineralizable nitrogen: Potentially mineralizable nitrogen (PMN) showed clear differences regarding manure addition as 92% more PMN was found in manured compared to non-manured plots (Table 3). Nitrogen availability to crops resulted in good crop growth and production and emphasis the importance of manure addition. Wide differences were also observed regarding PMN with respect to cropping patterns. Cotton-wheat (CW) got the first position having 4.74, which is three to four times more PMN compared to other cropping patterns. The cropping pattern follows the sequence CW (4.74) > MW (2.) > SW (1.33) > RW (1.07) > VV (0.57). The VV cropping sequence, showed least PMN (0.57) that might be due to more intensive cultivation and heavy fertilization. The interactive effect of farm manure within cropping pattern was not significant (Fig. 6). There was big difference between manured plots under VV and CW as many times higher values were found in CW compared to all other plots and very low values were found in RW compared to all other non-manured plots.

Organic matter: Soil organic matter (OM) was significantly affected by manure addition (Table 3). Higher values of OM in manured plots certify the positive effect of manure addition even under extreme climate and intensive cropping systems under semi-arid conditions. On percentage basis 28% higher OM contents were found in manured plots. Cropping pattern effect was non-significant on OM contents. The interactive effect of farm manure within cropping pattern was also non-significant (Fig. 7).

Table 4: Chemical soil health indicators as affected by farm manure application and cropping pattern

Treatments		pH	CEC me/100g	NO3-N mg kg^{-1}	P mg kg^{-1}
Farm manure	M0†	8.35 A‡	17.79 A	13.67 A	8.4 A†
	M1	8.44 A	18.73 A	17.77 A	4.5 B†
	SE	0.094	0.41	3.87	6.67
Cropping pattern	CW	8.65 A	18.71 A	11.03 A	4.2 A
	MW	8.37 A	18.22 A	13.35 A	7.4 A
	RW	8.37 A	18.10 A	11.57 A	4.1 A
	SW	8.25 A	18.18 A	12.96 A	5.7 A
	VV	8.35 A	18.08 A	19.71 A	10.6 A
	SE	0.209	0.92	8.657	3.73

Table 5: Chemical soil health indicators as affected by farm manure application and cropping pattern

Treatments		K mg kg^{-1}	S mg kg^{-1}	Zn mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}
Farm manure	M0†	132 B†	27.2 B	2.11 A	5186B†	317B
	M1	181 A†	43.6 A	2.48 A	6983A†	415A
	SE	17.29	4.55	0.329	676	29.73
Cropping pattern	CW	204 A	40.2 A	1.87 A	6096A	383A
	MW	180 A	32.1 A	2.64 A	6700A	332A
	RW	111 A	30.3 A	2.02 A	4441A	394A
	SW	144 A	39.0 A	1.96 A	7153A	338A
	VV	145 A	35.5 A	2.98 A	6035A	383A
	SE	27.34	7.19	0.736	1511	66.49

†M0: No manure; M1: Manured; CW: Cotton-wheat; MW: Maize-wheat; RW: Rice wheat; SW: Sugarcane-wheat; V-V: Vegetable-vegetable; SE: Standard Error; ‡Means for treatments within columns for each experiment followed by the same letter are not significantly different at α=0.05

FM 0 1

FM0: no manure; FM1: manured; CW: cotton-wheat; MW: maize-wheat; RW: rice wheat; SW: sugarcane-wheat; VV: vegetable-vegetable

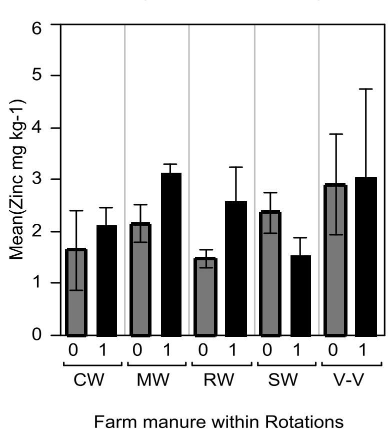

Fig. 13. Soil zinc (Zn) as influenced by interactive effect of farm manure within crop rotations

Chemical Soil Health Indicators

Soil pH: Manure addition and cropping pattern has no effect on soil pH (Table 4). Among the cropping patterns highest pH was observed in CW followed by MW, RW and VV and lowest in SW. The interactive effect of manure within crop rotations was also non-significant (Fig. 8).

Cation exchange capacity (CEC): Cation exchange capacity showed a positive response to manure addition as higher values were found in manured compared to non-manured plots (Table 4). On over all basis 5% higher CEC was noted in manured compared to non-manured plots. Cropping pattern showed no effect on CEC. Regarding the combined effect of farm manure with crop rotations highest value was observed in CW and lowest one in VV under non-manured plots (Fig. 9).

Nitrate nitrogen (NO_3^-N): Effect of manure addition was significant on NO_3-N as 30 % higher contents were found in manured plots (Table 4). The NO_3^-N differed also in various cropping patterns. Highest value of NO_3-N was found in VV, which was 170, 156, 129 and 122% higher than CW, RW, SW and MW, respectively. The pattern followed for NO_3^-N was quite different than physical and biological soil quality indicators. The interactive effects of manure with crop rotations on NO_3-N showed that CW rotation has lowest contents under non-manured plots, while three times higher contents under manured ones, whereas VV showed very high values under both manured and non manured areas (Fig. 10). In VV there was no increase in NO_3^-N due to manure addition. In SW system the result was contrary to all other cropping patterns as manured soil has lower values than non-manured plots.

Phosphorus concentration: Soil phosphorus (P) concentration was significantly affected by manure addition (Table 4) and resulted in two times increase in soil P compared to non-manured plots. This certifies the importance of farm manure as a source of soil P and it also increases its availability. Cropping patterns also differed widely regarding soil P and followed the same trend as was observed in NO_3^-N. Highest value of P was found in VV, which was 158, 152, 85 and 43% more than RW, CW, SW and MW, respectively. The interactive effect of manure with crop rotations showed many times higher values of P in non-manured compared to manured plots (Fig. 11).

Potassium concentration: Manure addition resulted in significant increase in soil potassium (K) concentration as 37% higher K was found in manured than non-manured fields (Table 5). This indicates positive contribution of manure along with improvement of soil physical health. Wide differences were observed among cropping patterns. Highest K contents were found in CW followed by MW, VV, and SW and lowest in RW. On overall basis trend is almost similar if we consider chemical soil constituents. Maize-wheat (MW) cropping pattern is having 84% higher K content than RW. Interactive effects of farm manure within cropping patterns are also giving very useful information's (Fig. 12). Among non-manured plots SW is showing significant differences over RW and SW, while among manured soils, CW is standing at the top while SW and RW are at the bottom line.

Sulphur, Zinc, Calcium and Magnesium contents: Manure addition significantly increased concentration of S, Ca and Mg, while effect on Zn concentration was non-significant (Table 5). Sulphur, Zn, Ca and Mg concentrations were increased by 60, 17, 23 and 31%, respectively in manured over non-manured plots. If we compare cropping patterns regarding S contents, highest concentration was found in CW, while lowest in RW rotations. Similarly, higher value of Zn was found in VV and lowest in CW. Zinc content is very low as it gets reduced and thus becomes unavailable to rice. Results showed that these are Zn deficient soils due to non-addition and intensive mining. Soil Ca contents are very high as these soils are developed from loess calcareous parent material.

Discussion

This study was conducted to evaluate the impact of cropping patterns on soil quality indicators in manured and non-manured soils to evaluate application of soil health test developed by Cornell Soil Health Team and soil quality indicators for Pakistan soils. Different soil properties including physical, chemical and biological were used as indicators of soil quality. The soil quality is said to be the capacity of the soil to function physically, chemically and biologically (Doran and Parkin, 1994). Indicators applied for assessment were selected from already developed by CSHT, which were effective to address specific soil processes that are important in sustaining agriculture production. Overall values of soil physical quality indicators for Pakistani soils were very low due to intensive cropping systems and use of straw as fuel and fodder and non-inclusion of green manure crops in existing cropping patterns. Manure addition resulted in significant improvement in AWC, WSA, bulk density and macro-porosity compared to non-manured plots. Manure addition reduced bulk density significantly and increased field capacity, plant available water and field saturated hydraulic conductivity. Transmission and storage pores were more abundant in manure-treated plots (Chakraborty *et al*., 2010).

FM0: no manure; FM1: manured; CW: cotton-wheat; MW: maize-wheat; RW: rice wheat; SW: sugarcane-wheat; VV: vegetable-vegetable

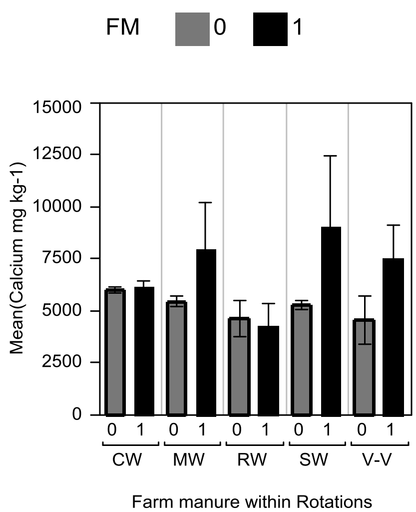

Fig. 14. Soil calcium (Ca) as influenced by interactive effect of farm manure within crop rotations

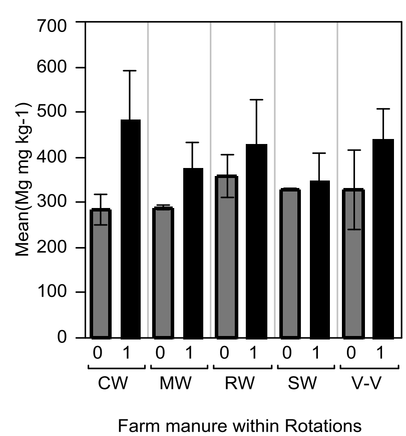

Fig. 15. Soil Magnesium (Mg) as influenced by interactive effect of farm manure within crop rotations

Improvement in soil physical properties with organic matter addition has been earlier reported (Celik *et al*., 2004; Madari *et al*., 2005). Long-term application of organic matter influenced bulk density (Miller *et al.*, 2002), soil structure (Pagliai *et al*., 2004) and soil hydraulic properties (Celik *et al*., 2004). Chakraborty *et al*. (2010) observed high soil physical health indices, better aggregation status under manured plots, which might be due to better root growth, enhanced microbial activities due to manure addition that improved soil structure significantly (Benbi *et al*., 1998).

Manure treated plots significantly decreased soil bulk density, while AWC was increased by 86% and 56% in compost and manure treated plots (Celik *et al*., 2004). Organic compost application improves the soil physical properties by increasing total porosity and pore size-distribution (Aggelides and Londra, 2000).

Cropping pattern behavior regarding physical properties revealed very important facts regarding our tillage systems and its impact on soil physical quality indicators. Lowest values (5.17%) of WSA were found in rice-wheat system due to puddling, which is being practiced since years for preparing fields for rice transplantation. This practice has destroyed the soil aggregation and may be the major reason for reduction in wheat production due to formation of dense soil and reduction in soil infiltration in rice growing areas. Sugarcane-wheat (SW) rotation shows highest value of WSA due to less soil disturbance and accumulation of more root biomass result in better soil aggregation. The structure stability in CW, MW and VV followed the SW system. This pattern depicts the real impact of tillage intensity and its deterioratic effect on soil physical health.

The data regarding biological soil health indicators clearly shows the impact of manure addition and cropping pattern. Active carbon (ActC) and organic matter were significantly affected by manure addition, whereas PMN was not affected. Among the cropping patterns highest PMN was found in CW and least in VV cropping pattern. This gave very useful information that least field operation resulted in higher PMN accumulation under CW, while more addition of chemical fertilizer in VV along with intensive tillage resulted in lower PMN. Maximum ActC was found in RW followed by VV, which clearly indicates that high tillage intensity along with more irrigation may result in releasing more ActC. If we compare the entire cropping patterns least ActC was indicated in CW receiving least irrigation and less soil disturbance. The disruption of aggregation due to tillage reduced stable micro-aggregate formation, leading to exposure of existing aggregates to microbial processes and therefore accelerated organic carbon turnover and reduced SOC accumulation (Six *et al*., 2000). Addition of manure along with balanced N, P and K could improve and sustain SOC even under intensive cultivation (Chakraborty *et al*. (2010). Significantly higher SOM was found in the manured plots compared to the one without addition of manure. Increases in SOM content for soils under organic management are widely reported (Stockdale *et al*., 2000). Residue incorporation significantly increased SOC and aggregate-associated C concentration, aggregation, K_s, soil matrix and structural porosities, and water retention capacity (Du *et al*., 2009).

The effect of manure and cropping pattern on soil chemical indicators (Table 3) in some cases is significant. There was statistically no difference in soil pH even in manured compared to the non-manured plots due to higher buffering capacity of soils. Manure addition also has no effect on soil cation exchange capacity and NO_3-N concentration. As regard cropping sequence highest CEC was found in CW, while lowest in VV pattern. This actually follows the same trend as was observed in soil biological indicators. In cotton-wheat this might be the result of lower tillage compared to other cropping patterns like rice-wheat etc. All cropping systems were statistically similar with reference to NO_3-N. Due to heavy fertilization in vegetables production maximum NO_3-N was found in vegetable-vegetable system. Phosphorus was also following the same pattern as in NO_3-N, while response of K was somewhat different. Maximum K was found in CW and least in RW. This trend might be due to the addition of K fertilizers in CW being a maximum returning cash crop and in RW there is less addition of K fertilizer. Regarding the micronutrients higher quantities were found in manured plots, while in cropping patterns affect was not statistically significant, although there is deficiency of Zn in rice growing areas due to conversion into ZnS.

In conclusion, physical, biological and chemical soil health indicators showed clear differences with respect to manure addition and cropping systems in different regions of the country. Clear differences were observed in different cropping patterns and their impact on soil quality. This will help to modify existing conventional sowing techniques in developing countries and their deteriorated effects on soil physical and biological health. Assessment regarding tillage, difference was not well established for physical health indicators but response was clear in case of chemical and biological indicators. We can conclude that soil management effects are significant for most of the soil quality indicators that are being used in CSHT. The overall composite analysis, however, proved to be best suited and provides excellent soil quality evaluation.

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