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Depth-wise soil physical property alterations from 38 years of continuous fertilizer and manure application in a rice-wheat cropping system

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Abstract
Long-term experiments are regarded as important tools. Long-term fertiliser experiments could monitor the trends in crop yield resulting from changes in soil fertility. It is essential to monitor the long-term changes in soil nutrient status, and nutrient supplying capacity to ensure and improve crop productivity. These considerations have prompted to undertake the present investigation, which was carried out in an on-going field experiment started in *Rabi* 1988-89 under AICRP on STCR project at the Research Farm of Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India. The experimental site experienced a sub-tropical climate with an average annual precipitation of 1345 mm, the summer was hot and humid, and too cold winter, and the experimental soil belonged to order entisols. The experiment was conducted in different land use management systems with random block design and split-plot design with four levels of fertilizers viz. no NPK (F_o), 50% of the recommended dose of NPK (F_1), 100% of the recommended dose of NPK (F_2) and 150% of the recommended dose of NPK (F_3) were applied as treatments in main plots. The main plots were divided into sub-plots in which treatments viz. no manures (M_0), compost @ 10 t ha^{-1} (M_1), crop residue (M_2), and compost + crop residue (M_3) were superimposed over NPK levels, making a total of 16 treatment combinations with 3 replications. The study intended to assess the effect of the organic and inorganic treatments on soil health, and nutrient fractions in rice-wheat cropping system. Interaction effects of organics and inorganic fertilizers were non-significant for MWD at all the soil depths. Overall, there was 40-60% improvement of soil parameters in the Conjoint application of 150% NPK + compost and crop residue over control.

Keywords: Crop residue organic and inorganic fertilizers, STCR, long term

Introduction
The rice-wheat cropping system (RWCS) is a long-established grain production system in India. The wheat yield following rice was only 0.7 to 1.0 tonnes ha^{-1} until the 1940s, and it increased progressively after the 1950s as a result of improved varieties, better agronomic management, and pest control (Sanyal *et al*., 2014). Occupying about 14 Mha are in the Indo-Gangetic plain (IGP), RWCS is considered as the principal cropping system of South Asian countries. This cropping system has covered nearly 30% and 40% of the total rice and wheat cultivated area respectively of the four major rice and wheat producing countries, i.e. India, Pakistan, Bangladesh and Nepal (Chauhan *et al*., 2012; Srivastava *et al*., 2015). In India, RWCS is dominant in Punjab, Haryana, Bihar, Uttar Pradesh and Madhya Pradesh, contributing about three-fourths of the total food grain production of the nation (Srivastava *et al*., 2015). Taking into account the dependency of the Indian population on RWCS, this cropping system has been considered as the cornerstone of India's food self-sustenance. But contradictorily considering intensive cultivation of cereal crops to meet the hunger demand of the overcrowded countries has created 1 havoc to the soil health as cereal crops are exhaustive crops, and practices involved in their production are hampering the physical properties of soil and aggravating deterioration of overall soil health (Brar *et al*., 2015). Barzegar (2002) [2], Rachman (2003) [20], decreasing micropore volume while increasing macro-pores Hati (2006) [9], improving soil water-holding capacity and wilting point Hati (2007) [10].

Applications of compost and organic manure resulted in a greater SOC content than an equivalent amount of inorganic fertilizer (Gregorich, 2001) [8]. However, the decomposition process controls the pace at which SOM builds up after applying organic manures. When compared to the non-treated control and NPK treatment alone, the SOM content in winter wheat and summer maize rotation after 13 years of manure application combined with NPK treatment was considerably higher from depth 0-20 cm. Applying FYM + inorganic N to irrigated settings has been shown in several studies to imrove microbial communities, soil structure, bulk density, SOC and hydraulic conductivity, Bhattacharya (2007) [5]. To achieve significant breakthroughs in food grain production, it is critical to develop approaches that improve fertilizer efficiency.

Long-term fertilizer trials compare crop yields and soil parameters under continuous cropping and extensive fertilization. J.B. Lawes and J. H Gilbert established the world's oldest long-term experiment at Rothamsted (United Kingdom) in 1843 (Johnston and Powlson, 1994) [13]. As a result, long term research has been done to determine the ideal ratios of organic and inorganic fertilizer. It would be very promising to continuously check soil parameters by integrating organic manures and fertlizers with a cropping system. Therefore, the present study was conducted to determine how long-term manure & fertilizer application affects the physical properties of different depth in rice-wheat crop on Indo-Gangatic plain.

Materials and Method

Site description

A major objective of the study (since 1988-1989) was to examine the long-term effects of crop residue management (since 1988-1989) on soil fertility and fertilizer economy. RPACU Pusa in Bihar, India, is conducting the All-India Coordinated Research Project on Soil Test Crop Response Correlation (AICRP-STCR). The experimental site, located in Samastipur district at 25°58'51.92N latitude and 85°40'5.64E longitude, is 52.18 m above mean sea level and has a subtropical humid environment. Initial properties of the soil are detailed in Table 1.

Table 1: Initial soil characteristics experimental soil (1988)

S. No.	Soil Characteristics	Values
1	pH (1:2.5 Soil-water suspension)	8.5
2	EC (dSm^{-1} at 25 °C)	0.3
3	Organic carbon ($g\ kg^{-1}$)	0.51
4	Bulk Density ($Mg\ m^{-3}$)	1.48
5	Water holding capacity (% w/w)	30.12

Experimental details

Split-plot design was used for the experiment with four different levels of fertilizer application. A main plot was treated with no nitrogen, potassium, and salt (Fo), 50% of the recommended amount of nitrogen, potassium, and salt (F1), 100% of the recommended amount of nitrogen, potassium, and salt (F2), and 150% of the recommended amount of nitrogen, potassium, and salt (F3). Four subplots were used for the main plots, containing treatments such as. A total of 16 treatments with three replications were superimposed over NPK levels: no manure (M0), compost at 10 t ha-1 (C), crop residue (CR), and compost + crop residue (C + CR).

Collection and processing of soil samples

During rice harvest in December 2021, soil samples were taken intriplicate from each plot at two depth layers (0-15 and 15-30 cm). Soil samples were processed through a 2 mm (i.e. 10 mesh) sieve, stored at room temperature and used for soil physical evaluation.

Soil physo-chemical analysis

Wet oxidation (Walkley and Black, 1934) [27] was employed to measure soil organic carbon (Jackson, 1973) [12], pH and electrical conductivity (EC). The water holding capacity [W/W%] was determined using the keen's Raczkowski box method (Piper, 2005). The bulk density [g/cc] of soil was measured using the core method with a metalcore in the middle of each soil layer (Blake and Hartage, 1986) [6].

Statistical analysis

We analysed all soil properties using Analysis of Variance (ANOVA) for a split-plot design. Krus wallis test were conducted for similarity test.

Results and Discussion

Aggregate Stability

Macro and micro aggrigate

Percent of macro and micro aggregates at the surface and sub-surface samples were significantly influenced by the application of organics and inorganic fertilizers; however, the interaction of organics and fertilizer was non-significant. As inorganic fertilizers, 150% NPK recorded the highest value of macroaggregates i.e., 60.1 and 51.8 followed by (100% NPK) 56.6 and 49.8, (50% NPK) 54.2 and 45.7, and control being the least i.e., 53 and 43 at both depths (Table 2). 100 and 150% NPK treatments, being statistically at par were significantly superior to no fertilizer treatment. In contrast, the increasing levels of NPK significantly recorded a lower percentage of microaggregates. There was a 13% rise and 27% fall in macro aggregates and micro aggregates at surface soil, and lower depth of macro aggregates and micro aggregates was 23%, 1% rise, respectively, with 150% NPK application over the control. Improved macroaggregates might be the result of organic carbon and microbial secretions due to the decomposition of the root biomass (Zong and Lu, 2020). With organics, the highest value for macro aggregates percentage i.e., 62.1 and 56.6 was recorded with both depth of Compost + crop residue followed by compost (56.2), (48.6), and crop residue (54.6), (48.3) control being the least i.e., 51.0, 35.8. All the organic treatments significantly improved macroaggregates as compared to no organics treatment. There was a 22% and 59% rise in macro aggregates and 14% and 22% fall in micro aggregates in both depths with Compost + crop residue application over the control. Increased macro aggregates percent followed the trend Compost + crop residue > Compost = Crop residue > No organics due to application of organics. While the decline in micro aggregate percent followed the reverse trend. Long-term application of compost and crop residue had a pronounced effect on increasing soil organic carbon content and soil microbial function, which directly contribute towards the formation of macroaggregates (Zhang *et al.*, 2016). Annabia *et al.* (2011) found similar results in the improvement of macroaggregates due to the application of compost at different stages of stability in ~~a~~ silty clay loam soil

Table 2: Effect of long-term application of organic and inorganic fertilizers on percentage of Macro aggregates (> 0.25 mm) and Micro aggregates (< 0.25 mm) in calcareous soil under RWCS

STCR	Percentage of Macro aggregates (>2mm-250 µm), Micro aggregates (250-53µm) depth 0-15cm										
	Macro aggregates (>2mm-250 µm)					Micro aggregates (250-53µm)					
Treatments	**M_0**	**C**	**CR**	**C+CR**	**Mean**	**Treatments**	**M_0**	**C**	**CR**	**C+CR**	**Mean**
F_0	46.2	54.3	52.7	58.9	53.0	F_0	39.9	38.7	38.1	34.9	37.9
F_1	49.9	54.8	52.7	59.6	54.2	F_1	37.8	35.4	31.3	31.1	33.9
F_2	51.9	57.9	55.3	61.1	56.6	F_2	33.2	32.3	29.8	29.9	31.3
F_3	55.9	58.0	57.6	68.9	60.1	F_3	30.8	27.3	27.8	25.1	27.8
Mean	51.0	56.2	54.6	62.1		Mean	35.4	33.4	31.7	30.3	
	F	M	F × M				F	M	F × M		
SEm (±)	1.2	1.2	2.3	CV (a)	7.3	SEm (±)	0.7	0.9	1.8	CV (a)	7.1
CD (p=0.05)	4.1	3.4	NS	CV (b)	7.1	CD (p=0.05)	2.3	2.8	NS	CV (b)	10.1
	15-30 cm					15-30 cm					
Treatments	***M_0**	**C**	**CR**	**C+CR**	**Mean**	**Treatments**	**M_0**	**C**	**CR**	**C+CR**	**Mean**
F_0	25.4	45.9	44.8	52.0	42.0	F_0	45.1	37.7	34.6	34.7	38.0
F_1	31.9	47.0	50.1	53.8	45.7	F_1	42.8	40.6	38.2	35.5	39.3
F_2	40.9	49.1	49.9	59.2	49.8	F_2	42.2	42.2	33.5	34.1	38.0
F_3	45.0	51.0	49.7	61.4	51.8	F_3	44.2	38.9	38.3	31.3	38.2
Mean	35.8	48.6	48.3	56.6		Mean	43.6	39.9	36.2	33.9	
	F	M	F × M				F	M	F × M		
SEm (±)	1.2	1.0	2.1	CV (a)	8.7	SEm (±)	0.7	0.8	1.5	CV (a)	6.4
CD (p=0.05)	4.1	2.9	6.2	CV (b)	7.4	CD (p=0.05)	NS	2.3	NS	CV (b)	7.0

Mean weight diameter

Soil EC (dSm^{-1}) indicated an increment in units though nonsignificant. The maximum and minimum EC was recorded with the ranged of between 0.21 to 0.30 dSm^{-1} and 0.18 to 0.25 dSm^{-1} at the both surface and sub-surface depths in table no 3 and Similar result was reported by Benbi and Brar (2009) [3].

Table 3: Effect of long-term application of organics and inorganic fertilizers on mean weight diameter (MWD) (mm) in calcareous soil under RWCS

STCR	MWD of water stable aggregates										
	0-15 cm					15-30 cm					
Treatments	**M_0**	**C**	**CR**	**C+CR**	**Mean**	**Treatments**	**M_0**	**C**	**CR**	**C+CR**	**Mean**
F_0	1.28	1.40	1.49	1.69	1.47	F_0	0.79	1.33	1.40	1.51	1.26
F_1	1.28	1.49	1.65	1.81	1.56	F_1	0.96	1.46	1.53	1.59	1.39
F_2	1.41	1.54	1.71	1.90	1.64	F_2	1.13	1.47	1.64	1.69	1.48
F_3	1.42	1.64	1.74	2.09	1.72	F_3	1.27	1.50	1.66	1.85	1.57
Mean	1.35	1.52	1.65	1.87		Mean	1.04	1.44	1.56	1.66	
	F	M	F × M				F	M	F × M		
SEm (±)	0.04	0.03	0.07	CV (a)	9.20	SEm (±)	0.0	0.0	0.1	CV (a)	9.0
CD (p=0.05)	0.15	0.09	NS	CV (b)	6.88	CD (p=0.05)	0.1	0.1	NS	CV (b)	10.3

Organic carbon

Organic carbon concentrations ranged from 0.44 to 0.78 percent at 0-15 cm depth and 0.34 to 0.65 percent at 15-30 cm depth, with a significant difference (Table 4). As soil depth climbed from 0-15 cm to 15-30 cm, soil organic carbon reduced. The highest value of organic carbon was obtained with 150% NPK + compost + CR (0.78%), followed by 150% NPK + compost (0.74%). The lowest organic carbon content was reported in (0.44%), which was under control. The subsurface soil layer (15-30 cm) revealed the highest value of organic carbon in 150% NPK + compost + CR (0.65%), followed by 150% NPK + compost (0.61%). During the evaluation, organic carbon (0.34%) was found to be below control at the lowest level. When manures and fertilizers are combined, they may result in more organic residues in soil, which may increase the amount of organic carbon after decomposition due to enhanced root growth. These results are in agreement with those reported by Kumpawat and Jat (2005) [14], Balyan *et al*. (2006) [1], and Brar *et al*. (1998) [7]. Similarly, Parmar and Sharma (2000) [17] observed a decrease in soil organic carbon as depth was increased from 0-30 cm in the rice-wheat sequence of the North Western Himalayas. Surface soil retains more carbon in active or passive pools than subsurface soil because organic manure is supplied and extensively mixed with inorganic fertilizer each year. The buildup of C that was observed in the subsurface soil depth might be due to climatic and crop management factors that have occurred over the years under rice-wheat cropping. In a long-term lantana amended soil in rice-wheat systems, Raina and Bharati (2013) [21] reported a similar result regarding carbon sequestration and nutrient dynamics.

Table 4: Fertilizer application over a long period of time, organic and inorganic on SOC (%) in calcareous soil under RWCS

STCR	SOC (%)									
	0-15 cm					15-30 cm				
Treatments	**M_0**	**C**	**CR**	**C + CR**	**Mean**	**Treatments**	**M_0**	**C**	**CR**	**C + CR**	**Mean**
F_0	0.44	0.62	0.67	0.71	0.65	F_0	0.34	0.52	0.42	0.60	0.47
F_1	0.60	0.68	0.61	0.65	0.66	F_1	0.34	0.51	0.40	0.57	0.46
F_2	0.54	0.65	0.62	0.70	0.63	F_2	0.42	0.58	0.57	0.57	0.54
F_3	0.52	0.74	0.55	0.78	0.58	F_3	0.47	0.61	0.51	0.65	0.55
Mean	0.53	0.69	0.61	0.69		Mean	0.39	0.54	0.48	0.61	
	F	M	F × M				F	M	F × M		
SEm (±)	0.0	0.0	0.0	CV (a)	7.4	SEm (±)	0.0	0.0	0.0	CV (a)	8.1
CD (p=0.05)	0.0	0.0	0.1	CV (b)	7.0	CD (p=0.05)	0.0	0.1	0.2	CV (b)	12.6

Water holding capacity

The treatment receiving 150% NPK recorded the highest value for percent water holding capacity of 37%, followed by 100% NPK (35%) and 50% NPK (33%). All these treatments were significantly superior to control, the least (32%) among inorganic fertilizer treatments (Table 5). There was a percentage increment of 16, 9, and 3 of water holding capacity with 150% NPK, 100% NPK, and 50% NPK respectively over the control. The enhanced water holding capacity of the treated plots might be due to the increase in root biomass as compared to the control plots (Rasool *et al*., 2008) [23]. Increased organic carbon due to increased application of inorganics has been reported to contribute towards better water holding capacity of the fertilized plots (Pant *et al*., 2018) [16]. Compost + Crop residue had the maximum water retention capacity (38%), followed by compost (36%) and crop residue (34%) and these values were considerably higher than the control (29%). The water holding capacity of treatment Compost + crop residue was 31% superior to the control. The highest soil organic carbon because of the combination of application of compost and crop residue may result in an increased water retention capacity when compared to control (Bhatt *et al*., 2017) [4]. Soil organic carbon has a direct effect on soil aggregate stability and soil porosity or water holding capacity (Ojeda *et al*., 2015) [15]. Soil aggregate stabilization due to the continuous application of organics increased its total porosity by improving the pore structure. On the other hand, increases the moisture retention capacity of the soil in comparison to the control (Kumar *et al*., 2010) [19].

Table 5: Effect of long-term application of organic and inorganic fertilizers on bulk density (Mg m^{-3}) and water Holding Capacity (W/W%) in STCR field

STCR	Bulk Density (Mg m^{-3})					Water Holding Capacity (w/w%)					
	0-15 cm					0-15 cm					
Treatments	**M_0**	**C**	**CR**	**C + CR**	**Mean**	**Treatments**	**M_0**	**C**	**CR**	**C + CR**	**Mean**
F_0	1.58	1.43	1.51	1.43	1.49	F_0	26.91	34.01	31.84	36.94	32
F_1	1.53	1.38	1.36	1.29	1.39	F_1	29.55	34.66	32.90	37.72	33
F_2	1.39	1.28	1.35	1.14	1.29	F_2	31.07	37.70	35.34	38.76	35
F_3	1.32	1.25	1.26	1.10	1.23	F_3	32.27	39.73	35.98	42.16	37
Mean	1.45	1.34	1.37	1.24		Mean	29	36	34	38	
	F	M	F × M				F	M	F × M		
SEm (±)	0.03	0.03	0.06	CV (a)	6.93	SEm (±)	0.92	0.79	1.65	CV (a)	9.19
CD (p=0.05)	0.09	0.09	NS	CV (b)	7.66	CD (p=0.05)	3.20	2.31	NS	CV (b)	7.86

Conclusion

When the continuous rice-wheat cropping system causes nutrient fixation and mining, enhancing inorganic fertilizers and organics were shown to be effective in overcoming these issues. The most effective and cost-effective NPK doses combined with compost and crop residue were found to improve soil health and crop performance at a rate of 150% recommended. The study intended to assess the effect of the organic and inorganic treatments on soil health, and nutrient fractions in rice-wheat cropping system. Interaction effects of organics and inorganic fertilizers were non-significant for MWD at all the soil depths. Overall, there was 40-60% improvement of soil parameters in the Conjoint application of 150% NPK + compost and crop residue over control.

References

1. Balyan JK, Singh P, Kumpawat BS, Jain LK. Effect of integrated nutrient management on maize growth and its nutrient uptake. Curr Agric. 2006;30:79-82.
2. Barzegar AR, Yousefi A, Daryashenas A. The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. Plant Soil. 2002;247:295-301. doi:10.1023/A:1021561628045
3. Benbi DK, Brar JS. A 25-year record of carbon sequestration and soil properties in intensive agriculture. Agron Sustain Dev. 2009;29:257-265. doi:10.1051/agro/2008070
4. Bhatt MK, Labanya R, Joshi HC, Pareek N, Chandra R, Raverkar KP. Long-term effects of inorganic fertilizers and FYM on soil chemical properties and yield of wheat under rice-wheat cropping system. Envis Bull Himalayan Ecol. 2017;25:28-35.
5. Bhattacharyya R, Chandra S, Singh R, Kundu S, Srivastva A, Gupta H. Long-term farmyard manure application effects on properties of a silty clay loam soil under irrigated wheat-soybean rotation. Soil Tillage Res. 2007;94:386-396. doi:10.1016/j.still.2006.08.014
6. Blake GR, Hartge KH. Bulk density. In: Klute A, editor. Methods of Soil Analysis: Part 1—Physical and

Mineralogical Methods. SSSA Book Ser. 5.1. Madison (WI): ASA and SSSA; 1986. p. 363-375. doi:10.2136/sssabookser5.1.2ed.c13
7. Brar BS, Pasricha MS. Long-term soil fertility management through integrated plant nutrient supply system. Bhopal (India): Indian Institute of Soil Science; 1998. p. 154.
8. Gregorich EG, Drury CF, Baldock JA. Changes in soil carbon under long-term maize in monoculture and legume-based rotation. Can J Soil Sci. 2001;81:21-31. doi:10.4141/S00-041
9. Hati KM, Swarup A, Singh D, Misra AK, Ghosh PK. Long-term continuous cropping, fertilisation, and manuring effects on physical properties and organic carbon content of a sandy loam soil. Soil Res. 2006;44:487-495. doi:10.1071/SR05156
10. Hati KM, Swarup A, Dwivedi AK, Misra AK, Bandyopadhyay KK. Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. Agric Ecosyst Environ. 2007;119:127-134. doi:10.1016/j.agee.2006.06.017
11. Haynes RJ, Naidu R. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr Cycl Agroecosyst. 1998;51:123-137. doi:10.1023/A:1009738307837
12. Jackson ML. *Soil chemical analysis*. New Delhi: Prentice Hall of India; 1967. p. 83-192.
13. Johnston AE, Powlson DS. Long-term field experiments: their importance in understanding sustainable land use. In: Greenland DJ, Szaboes I, editors. Soil resilience and sustainable land use. Wallingford (UK): CAB International; 1994. p. 367-393.
14. Kumpawat BS, Jat ML. Profitable and energy efficient integrated nutrient management practices for maize-mustard cropping system in Southern Rajasthan. Curr Agric. 2005;29:97-102.
15. Ojeda G, Mattana S, Àvila A, Alcañiz JM, Volkmann M, Bachmann J. Are soil-water functions affected by biochar application. Geoderma. 2015;249-250:1-11. doi:10.1016/j.geoderma.2015.02.014
16. Pant PK, Ram S. Long-term manuring and fertilization effects on soil physical properties after forty-two cycles under rice-wheat system in north Indian mollisols. Int J Curr Microbiol Appl Sci. 2018;7:232-240. doi:10.20546/ijcmas.2018.707.028
17. Parmar DK, Sharma V. Studies on long-term application of fertilizers and manure on yield of maize-wheat rotation and soil properties under rainfed conditions in Western Himalayas. J Indian Soc Soil Sci. 2000;50:311-312.
18. Piper CS. Soil and plant analysis. New Delhi: Sristi Book Distribution; 2005.
19. Prasad J, Karmakar S, Kumar R, Mishra B. Influence of integrated nutrient management on yield and soil properties in maize-wheat cropping system in an Alfisol of Jharkhand. J Indian Soc Soil Sci. 2010;58:200-204.
20. Rachman A, Anderson SH, Gantzer CJ, Thompson AL. Influence of long-term cropping systems on soil physical properties related to soil erodibility. Soil Sci Soc Am J. 2003;67:637-644. doi:10.2136/sssaj2003.6370
21. Raina D, Bharati A. Carbon sequestration and nutrient dynamics in a long-term lantana amended soil in rice-wheat system [MSc (Agri) thesis]. Palampur (India): CSK Himachal Pradesh Krishi Vishvavidyalaya; 2013.
22. Rasool R, Kukal SS, Hira GS. Soil physical fertility and crop performance as affected by long-term application of FYM and inorganic fertilizers in rice-wheat system. Soil Tillage Res. 2007;96:64-72. doi:10.1016/j.still.2007.02.011
23. Rasool R, Kukal SS, Hira GS. Soil organic carbon and physical properties as affected by long-term application of FYM and inorganic fertilizers in maize-wheat system. Soil Tillage Res. 2008;101:31-36. doi:10.1016/j.still.2008.05.015
24. Shukla MK, Lal R, Owens LB, Unkefer P. Land use and management impacts on structure and infiltration characteristics of soils in the North Appalachian region of Ohio. Soil Sci. 2003;168:167-177. doi:10.1097/01.ss.0000058889.60072.aa
25. Six J, Elliott ET, Paustian K, Doran JW. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci Soc Am J. 1998;62:1367-1377. doi:10.2136/sssaj1998.03615995006200050032x
26. Tisdall JM, Oades JM. Organic matter and water-stable aggregates in soils. J Soil Sci. 1982;33:141-163. doi:10.1111/j.1365-2389.1982.tb01755.x
27. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37:29-38. doi:10.1097/00010694-193401000-00003
28. Zhang MK, Fang LP. Effect of tillage, fertilizer and green manure cropping on soil quality at an abandoned brick making site. Soil Tillage Res. 2007;93:87-93. doi:10.1016/j.still.2006.03.016
29. Zhang S, Yang X, Wiss M, Grip H, Lövdahl L. Changes in physical properties of a loess soil in China following two long-term fertilization regimes. Geoderma. 2006;136:579-587. doi:10.1016/j.geoderma.2006.04.015
30. Grewal SS, Bajaj JC, Narang RS. Long-term effects of fertilizers on soil properties under intensive cropping. Bulletin of the Indian Society of Soil Science. 1981;14:122-126.
31. Singh B. Long-term effects of fertilizers and manure on soil properties under intensive cropping. Journal of the Indian Society of Soil Science. 1997;45(4):700-705.
32. Tyagi RK. Genesis and classification of soils under different physiographic units in part of Uttar Pradesh. Journal of the Indian Society of Soil Science. 1989;37(4):700-706.
33. Goyal SK, Singh NT. Genesis and classification of some soils of Indo-Gangetic alluvial plains. Journal of the Indian Society of Soil Science. 1987;35(2):367-373.