Vol. 49, No. 3, pp 195-200, 2021

Indian Journal of Soil Conservation

Effects of long-term (6 years) nutrient management on soil loss and carbon management index principal component analysis approach

Vijay Singh Meena[1,*], Birendra Nath Ghosh[2], Raman Jeet Singh[3], Ranjan Bhattacharyya[4], N.K. Sharma[3], N.M. Alam[5], K.S. Dadhwal[3] and P.K. Mishra[3]

[1]ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand; [2]ICAR-National Bureau of Soil Survey and Land Use Planning, Kolkata, West Bengal; [3]ICAR-Indian Institute of Soil and Water Conservation, Kaulagarh Road, Dehradun, Uttarakhand; [4]ICAR-Indian Agricultural Research Institute, Pusa, New Delhi; [5]ICAR-Central Research Institute for Jute and Allied Fibres, Kolkata, West Bengal.

**Corresponding author:*

E-mail: vijay.meena@icar.gov.in (*Vijay Singh Meena*)

ARTICLE INFO

DOI : 10.59797/ijsc.v49.i3.188

Article history:

Received : June, 2021
Revised : December, 2021
Accepted : December, 2021

Key words:

Carbon management
PCA
Sloping crop lands
Soil loss

ABSTRACT

A long-term (6 years) field experiment was carried out for testing different nutrient management combination in a maize-wheat cropping system to compare the long-term effects on soil loss, crop yield, and system productivity through principal component analysis (PCA) approach. Six treatments {nutrient management practices: T_1 - control; T_2 - recommended dose of fertilizer (RDF - nitrogen, phosphorus, potassium); T_3 - farmyard manure (FYM); T_4 - 50% NPK + 50% FYM; T_5 - 50% NPK + 50% vermicompost (VC); T_6 - 50% NPK + 50% poultry manure (PM), T_7 - 50% NPK + 50% green manure (GM) were tested. Results revealed that the soil loss varies from 9.54 to 19.62 t ha^{-1} with different nutrient management plots. Overall, cluster I- possessed nutrient management practice of 50% NPK + 50% PM and 50% NPK + 50% GM, which are best discernible by their highest mean values of positive influence on soil and CMI parameters, and lowest mean values for negative influencing soil and CMI parameters. Relationships revealed that the single value CMI can be used for the assessment of soil degradation in the sloppy crop lands of Himalaya.

1. INTRODUCTION

There are both conventional (organic) and modern (mineral fertilizer based) farms in Indian Himalayas and agricultural production to focus the seasonality is an important force that drives the quality characteristics of the soil. The long-term fertilizer experiments play an important role in understanding the complex interaction involving crop management and their effects on productivity and sustainability (Ghosh *et al.,* 2016; Singh *et al.,* 2017; Priyadarshini *et al.,* 2019). It also provides opportunities to investigate the crop and soil quality to evaluate the factors which are responsible for the agriculture sustainability (Singh *et al.,* 2019). Erosion causes the breakdown of macro-aggregates into micro-aggregates and possibly completes soil dispersion, exposing hitherto encapsulated different pools of carbon (Ghosh *et al.* 2019). The soil system is one of the largest stores of soil organic carbon (SOC), C pools, and it is not static. Soils are inherently dynamic; furthermore, climate change and management can alter the amount of C that the soil can store (Nave *et al.,* 2019).

Soil, an important medium of global C cycle has twice the capacity to store C compared to the atmosphere (Kundu *et al.,* 2007; Culman *et al.,* 2011). Dynamics of organic C storage in agricultural soils affects global climatic change and crop productivity (Li *et al.,* 2018). Carbon sequestration potential is influenced by many factors such as climate and soil conditions, cropping systems, managements including tillage and fertilization (Andrews *et al.,* 2004: Bhattacharyya *et al.,* 2012; Lal, 2015). Carbon pools such as dissolved organic carbon, microbial biomass carbon and permanganate-oxidizable carbon, have recently received attention due to their sensitivity to agricultural management practices (Lucas and Weil, 2012). Permanganate oxidizable organic carbon (LOC), total organic carbon (TOC) and carbon concentration of water-stable macroaggregates, microaggregates within macroaggregates and the silt + clay - sized fraction suggested to be a more sensitive indicator than bulk SOC to tillage induced changes (Plaza-Bonilla *et al.,* 2014).

Soil system, an important medium of global carbon cycle has twice the capacity to store carbon compared to the atmosphere (Ghosh *et al.* 2016; Yaduvanshi and Sharma, 2016). The carbon management is considered a key indicator of the changes in crop productivity *vis-a-vis* land degradation in a long-term field experiment. To test this assumption, we examined the carbon management in relations to soil loss and productivity of long-term maize-wheat cropping system on 2% land slope in Indian sub-Himalayan region from 2009 to 2014 with different nutrient management practices.

The basic objective was to develop a carbon management index (CMI) to quantify soil degradation status of these management practices over control and undisturbed forest soils (native soils). Principal component analysis (PCA) to reveal the interrelationships between the different variables and to find the optimum number of extracted principal components.

2. MATERIALS AND METHODS

Study Area

The long-term field experiment was established in June 2009 in Research Farm, Selakui (fine mixed hyperthermic Typic Udorthent) of the ICAR-IISWC, Dehradun, India (30° 20'40'N, latitudes, 77°52'12'E, longitudes) at 516.5 above mean sea level (MSL) on a 2% slope (Ghosh *et al.,* 2019). The climate of the region is sub-temperate, average annual rainfall for the last 55 years is 1625 mm. The average daily maximum and minimum air temperatures ranged from 31.7°C and 20.6°C in June and 17.8°C and 1.1°C in January. Before imposing the treatments, initial soil samples from 0 to 15 cm depth (n = 6 for each plot) were collected from all the plots. The soil moisture content at maximum water-holding capacity, field capacity and permanent wilting point was 35.5, 24.8 and 11.2%, respectively. A short summary of initial physico-chemical properties and fertility status of the experimental plots are mentioned in Table 1. The details of the seven treatments are described in Table 2. The cropping system of this experiment was maize (cultivar *Kanchan*)-wheat (cultivar UP 2572). The growing period of maize was from June to the September (rainy season) and that for wheat from mid-November to first week of April (winter season or *rabi*).

Treatment and Experimental Details

The long-term field experiment established for different organic and inorganic manure practices under maize-wheat cropping system. Experimental plot size: 25 × 25 m^2, de-

Table: 1
Initial (before imposition of treatments) properties of the surface (0-15 cm) soils

Soil properties	Mean ± SD
pH (1:2.5 soil : water)	6.06 ± 0.17
Soil organic carbon (g kg^{-1})	6.6 ± 0.7
Available N (kg ha^{-1})	224.0 ± 4.6
Available P (kg ha^{-1})	16.0 ± 1.9
Available K (kg ha^{-1})	170.0 ±13.4
Sand (%)	42.0 ± 0.46
Silt (%)	35.5 ± 0.75
Clay (%)	22.5 ± 0.12
Bulk density (Mg m^{-3})	1.33 ± 0.02
Infiltration rate of the soil profile (cm h^{-1})	0.92 ± 0.03
Water holding capacity (%)	32.3 ± 1.69
Saturated hydraulic conductivity (cm h^{-1})	1.13 ± 0.04

Table: 2
Treatment details using during long-term application of different organic and inorganic manure practices under maize-wheat cropping system (FYM, VC, PM and GM were applied on a wet-weight basis, Experimental plot size: 25 × 25 m^2, de-silted soil deposited @ 60-80 t ha^{-1} with approximately 30 cm depth in the year, 2008)

Treatment details	Notations used	Nutrient source	Amount of organic manure (t ha^{-1})	Nutrient added (kg ha^{-1}yr^{-1}) to the maize crop	Nutrient added (kg ha^{-1}yr^{-1}) to the wheat crop
Control	T_1	0-0-0	0-0-0	0-0-0	0-0-0
RDF of NPK	T_2	Mineral fertilizer to both crop	0-0-0	120-27-35 (NPK) through mineral fertilizer	100-16-27 (NPK) through mineral fertilizer
FYM	T_3	FYM to both crop	15	75-30-60 (NPK) through FYM	75-30-60 (NPK) through FYM
50% NPK + 50% FYM	T_4	Mineral fertilizer + FYM to both crop	7.5	60-14-18 (NPK) through mineral fertilizer and 38-15-30 (NPK) through FYM	50-08-14 (NPK) through mineral fertilizer and 38-15-30 (NPK) through FYM
50% NPK + 50% VC	T_5	Mineral fertilizer + VC to both crop	2.5	60-14-18 (NPK) through mineral fertilizer and 33-30-20 (NPK) through VC	50-08-14 (NPK) through mineral fertilizer and 33-30-20 (NPK) through VC
50% NPK + 50% PM	T_6	Mineral fertilizer + PM to both crop	1.6	60-14-18 (NPK) through mineral fertilizer and 37-26-20 (NPK) through PM	50-08-14 (NPK) through mineral fertilizer and 37-26-20 (NPK) through PM
50% NPK + 50% GM	T_7	Mineral fertilizer + GM to both crop	1.8	60-14-18 (NPK) through mineral fertilizer and 58-07-18 (NPK) through GM	50-08-14 (NPK) through mineral fertilizer and 58-07-18 (NPK) through GM

silted soil deposited @ 60-80 t ha^{-1} with approximately 30 cm depth in the year, 2008. Six treatments {nutrient management practices: T$_1$ - control; T$_2$ - recommended dose of fertilizer (RDF) - nitrogen, phosphorus, potassium); T$_3$ - farmyard manure (FYM); T$_4$ - 50% NPK + 50% FYM; T$_5$ - 50% NPK + 50% vermicompost (VC); T$_6$ - 50% NPK + 50% poultry manure (PM), T$_7$ - 50% NPK + 50% green manure (GM) were tested (Table 2).

Soil Sampling and Processing

After the harvest of wheat crop in the month of May, 2014, two sets of triplicate undisturbed soil cores were collected in the 0- to 5 and 5- to 15- cm soil layers with a core sampler (7.5 cm diam). Bulk density was determined from oven-dried core mass divided by the core volume using one sample set. Samples from individual plots (the second set) were thoroughly mixed, air-dried, and passed through a 4.75 mm sieve. Air-dried samples were placed in plastic bags and stored at ambient temperature. A soil subsample was taken from both depths and analyzed for soil aggregation, total SOC as well as labile and non- labile (recalcitrant) SOC pools as detailed below:-

Soil aggregate separation and carbon fractionation

Briefly, 100-g air-dried (4.75-mm sieved) soil sample was placed on the top of a 2-mm sieve and submerged for 5 min in deionized water at room temperature to allow slaking (Kemper and Rosenau, 1986). Sieving was mechanically done by modified Yodar apparatus moving the sieve up and down 3 cm, 50 times in 2 minutes to achieve aggregate separation (Elliott, 1986). A series of three sieves (2000, 250, and 53 μm) was used to obtain four aggregate fractions: > 2000 μm, 250 to 2000 μm, 53 to 250 μm, and< 53 μm (silt and clay particles). Small and large macroaggregates together constitute the macroaggregates. Mean weight diameter, MWD = $\sum$ (percentage of sample weight on sieve × the mean diameter of the size classes), was calculated as an index that characterizes the structure of the bulk soil (Van Bavel, 1950).

The total SOC in each fraction of aggregates was determined using a CHN analyzer (Nelson and Sommers, 1982), labile organic carbon (Blair *et al.,* 1995) and bulk SOC was determined following the procedure of Walkley and Black (1934) using $K_2Cr_2O_7 + H_2SO_4$ as oxidizing agents.

Carbon management index (CMI)

CMI was calculated using the procedure given by Blair *et al.* (1995) where undisturbed forest soils is consider as reference sample.

$$\text{Lability of C (L)} = \frac{\text{C in fraction oxidized by } KMnO_4}{\text{C remaining unoxidized by } KMnO_4} = \frac{C_L}{C_{NL}}$$

$$\text{Lability Index (LI)} = \frac{\text{Lability of C in sample soil}}{\text{Lability of C in reference soil}}$$

$$\text{Carbon Pool Index (CPI)} = \frac{\text{Sample total C}}{\text{Reference total C}} = \frac{C_T\text{Sample}}{C_T\text{Reference}}$$

$$\text{Carbon Management Index (CMI)} = CPI \times LI \times 100$$

Measurement of runoff and soil loss

Runoff and soil loss were measured using multi-slot divisors from seven runoff plots using the methodologies described in Ghosh *et al.* (2019).

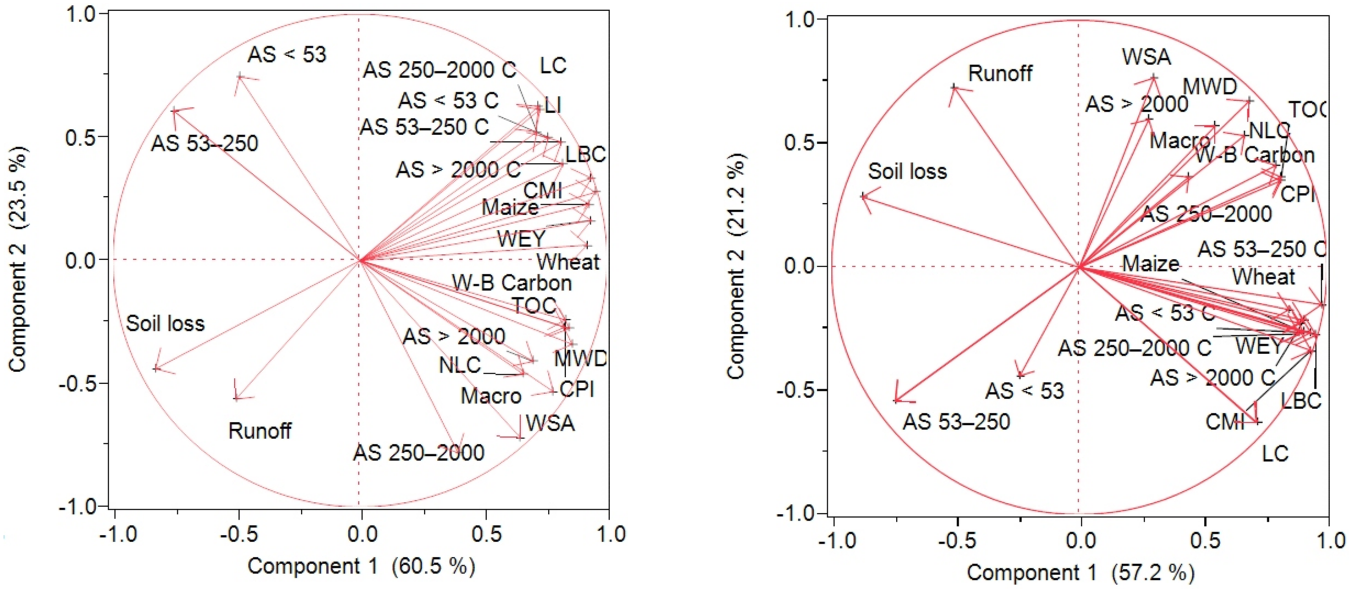
Data analyses

Data obtained during the experiment were subjected to analysis of variance (ANOVA) by using SPSS version 10.0. SAS 9.2 software was used for PCA. All the parameters except runoff and soil loss were analysed following R&D with three replications. Agglomerative hierarchical clustering (AHC) was used to display correlations between parameters and their relations with different nutrient management practices.

3. RESULTS AND DISCUSSIONS

The PCA is a worthwhile statistical technique which had found application in reduction of the original variables into a smaller number of most contributing variables (principal component); to reveal the interrelationships among the different variables and to find the optimum number of extracted principal components. The different soil properties and yield of maize, wheat and wheat equivalent yield were depicted in Fig. 1. The PCA for 0-5 and 5-15 cm soil layers with eigen value more than one accounted for 84% and 78.4% of variance, respectively (Table 3). The longer the line in PCA, the higher is the variance; the variance among the variables in the biplot was almost similar for both 0-5 and 5-15 cm soil layer (Fig. 1a and b).

The biplot in Fig. 1 showed a strong positive relationship between the maize, wheat and WEY, all aggregate associated carbon, W-B carbon, macro and microaggregate, MWD and different parameters of CMI for both soil layers. Hence, strongly negatively correlated with soil loss, runoff, and AS <53 and 53-250 μm. The cut point of a perpendicular from a treatment point to a variable line approximates the value of that observation on the variable that the line represents. If the cut point falls on the origin, the value of the observation is approximately the average of the respective variable (Kohler and Luniak, 2005). Superimposition of different treatment and yield alongwith soil properties showed that 50% NPK + 50% PM and 50% NPK + 50% GM showed significantly higher correlation with these parameters. However, aggregate associated carbon followed by CMI, W-B carbon and MWD were the most important yield contributing soil properties. Soil aggregation fractions (250-2000 μm) were least important property for contributing productivity and influencing other soil property (Culman *et al.* 2011). The PCA of nutrient management practices compris-



(a) 0-5 cm (b) 5-15 cm

Note: AS = Aggregate size; WSA = Water stable aggregate; TOC = Total organic carbon; LOC = Labile organic carbon; NLC = Non labile carbon; Carbon pool index; LI = Lability index; CMI = Carbon management index; MWD = Mean weight diameter; Macro = Macroaggregate; Micro = Microaggregate; C = Carbon; WEY = Wheat equivalent yield

Fig. 1. Loading plot of multivariate factorial comparison of soil properties (a) 0-5 cm, and (b) 5-15 cm soil layer, CMI and yields using principal component analysis

Table: 3
Composition of clusters of nutrient management practices based on PCA value

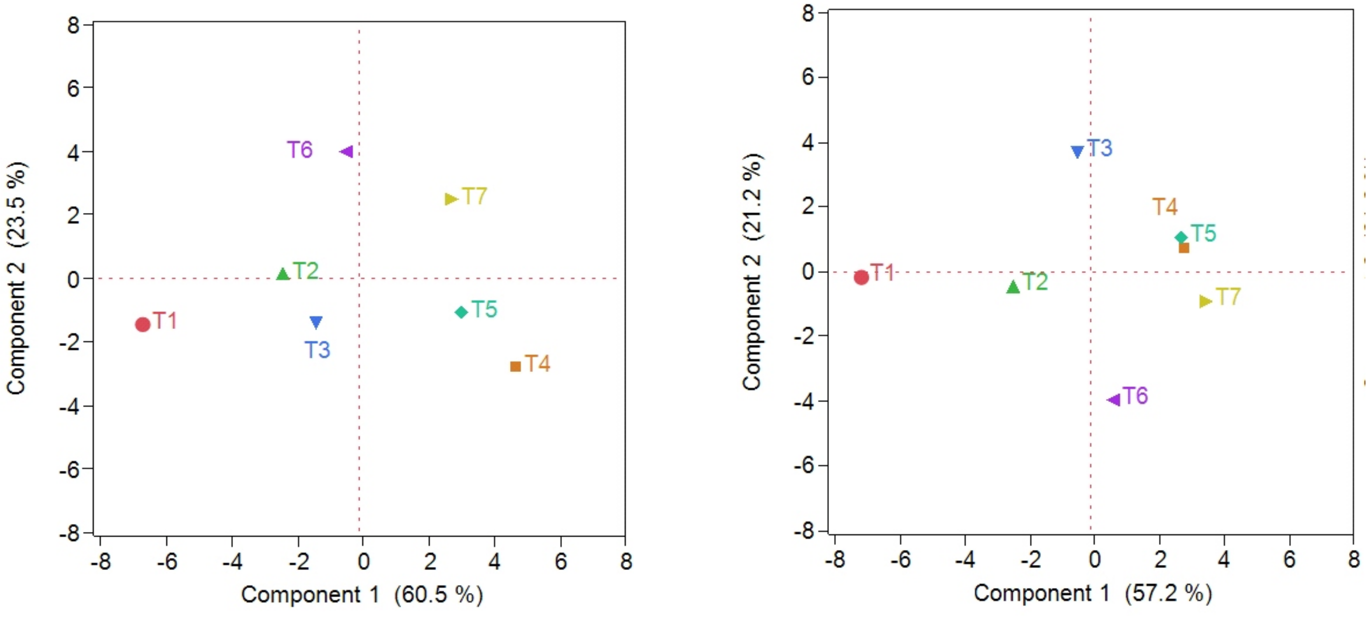
Cluster no.	No. of nutrient management practices	Nutrient management practices
I	2	50% NPK + 50% PM 50% NPK + 50% GM
II	2	50% NPK + 50% FYM 50% NPK + 50% VC
III	3	Control RDF of NPK FYM

ing two principal components (C1 60.5%; C2 23.5% for 0-5 cm soil layer and C1 57.2%; C2 21.25% for 5-15 cm soil layer) accounted for 84 and 78.4% of variance for 0-5 and 5-15 cm soil layers. The C1 and C2 had a cluster of nutrient management practices (T4, T5, T6, and T7) with large positive loading for the first component (Table 3). The second component also positive for 0-5 cm soil layer, except slight negative for T3, however, T1 was strongly negative for both 0-5 and 5-15 cm soil layers. Nutrient management practices T1 and T2 had negative loading for first and second component for both layers. The position of 25 parameters in relation to their influence by different treatment combination accounted for 84 and 78.4% variance for 0-5 and 5-15 cm soil layers, respectively. For both soil layers except soil loss, AS <53 and 53-2000 µm, all parameters occupied right side of the biplot (Fig. 2a and b).

Superimposition of both PCA of respective soil layers showed that T4, T5, T6 and T7 and all soil as well as CMI parameters except soil loss and runoff occupied similar positions. It was observed that the runoff and soil loss occupied opposite to similar positions of T4, T5, T6 and T7 (Table 3). This meant that these four nutrient management practices had direct involvement in enhancing soil property, CMI and crops productivity (Culman *et al.* 2011). As results of cluster analysis, three clusters were obtained. The cluster I possessed nutrient management practice of T6 and T7 (Table 3), which are best discernible by their highest mean values of positive influencing soil and CMI parameters, and lowest mean values for negative influencing soil and CMI parameters. The next best cluster was II, which retained T4 and T5 treatments, followed by cluster III (T1, T2 and T3). The grouping pattern of nutrient management practices observed in cluster as derived from CI and C2 of soil and CMI parameters and crops productivity.

4. CONCLUSIONS

The PCA showed a strong positive relationship between the maize, wheat and WEY, all aggregate associated carbon, W-B carbon, macro and micro-aggregate, MWD and different parameters of CMI and strongly negatively correlated with soil loss, runoff, and AS <53 and 53-250 µm. Superimposition of different treatment and yield along with soil properties showed that 50% NPK + 50% PM and 50% NPK + 50% GM showed significantly higher correlation with these parameters. The cluster I possessed nutrient management practice



(a) 0-5 cm (b) 5-15 cm

Fig. 2. Score plot grouping of nutrient management practices based on principal component scores (a) 0-5 cm, and (b) 5-15 cm soil layer (see for treatment details Table 2)

of T6 and T7, which was the best discernible by their highest mean values of positive influencing soil and CMI parameters. However, the lowest mean values for negative influencing soil and CMI parameters. Overall, among all practices, 50% NPK + 50% FYM, 50% NPK + 50% VC, 50% NPK + 50% PM and 50% NPK + 50% GM based nutrient management plots not only had highest system productivity, but also could have less soil losses under maize-wheat cropping system and hence should be recommended.

ACKNOWLEDGMENTS

Author(s) express sincere thanks to Director, ICAR-Indian Institute of Soil and Water Conservation, Dehradun and ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora for kind guidance and encouragement in initiating this study. We are also thankful to all field and laboratory staff for their help in recording observations.

REFERENCES

Andrews, S.S., Karlen, D.L. and Cambardella, C.A. 2004. The soil anagement assessment framework. *Soil Sci. Soc. Am. J.,* 68: 1945-1962.

Bhattacharyya, R., Tuti, M.D., Bisht, J.K., Bhatt, J.C. and Gupta, H.S. 2012. Conservation tillage and fertilization impact on soil aggregation and carbon pools in the Indian Himalayas under an irrigated rice-wheat rotation. *Soil Sci.,* 177: 218-228.

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

Culman, S.W., Snapp, S.S., Freeman, M.A., Beniston, J., Lal, R., Drinkwater, L.E., Franzluebbers, A.J., Glover, J.D., Grandy, A.S., Lee, J., Six, J., Maul, J.E., Mirsky, S.B., Spargo, J.T. and Wander, M.M. 2011. Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. *Soil Sci. Soc. Am. J.,* 76: 494-504.

Elliott, E.T. 1986. Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. *Soil Sci. Soc. Am. J.,* 50: 627-633.

Ghosh, A., Bhattacharyya, R., Dwivedi, B.S., Meena, M.C., Agarwal, B.K., Mahapatra, P., Shahi, D.K., Salwani, R. and Agnihorti, R. 2016. Temperature sensitivity of soil organic carbon decomposition as affected by long-term fertilization under a soybean-based cropping system in a sub-tropical Alfisol. *Agric., Ecosyst. Environ.,* 233: 202-213.

Ghosh, B.N., Meena, V.S., Singh, R.J., Alam, N.M., Patra, S., Bhattacharyya, R., Sharma, N.K., Dadhwal, K.S. and Mishra, P.K. 2019. Effects of fertilization on soil aggregation, carbon distribution and carbon management index of maize-wheat rotation in the north-western Indian Himalayas. *Ecolog. Indic.,* 105: 415-424.

Kemper, W.D. and Rosenau, R.C. 1986. *Aggregate stability and size distribution.* In: Klute, A. (ed.). Methods of soil analysis. Part I. (2nd ed.). Agron. Monogr. 9. ASA and SSSA, Madison, WI, pp 425-442.

Kohler, U. and Luniak, M. 2005. Data inspection using biplots. *Stata J.,* 5: 208-223.

Kundu, S. Bhattacharyya, R., Ved Prakash, Ghosh, B.N. and Gupta, H.S. 2007. Carbon sequestration and relationship between carbon addition and storage under rainfed soybean-wheat rotation in a sandy loam soil of the Indian Himalayas. *Soil Till. Res.,* 92: 87-95.

Lal, R. 2015. Sequestering carbon and increasing productivity by conservation agriculture. *J. Soil Water Cons.,* 70: 55-62.

Li, X., McCarty, G.W., Karlen, D.L. and Cambardell, C.A. 2018. Topographic metric predictions of soil redistribution and organic carbon in Iowa cropland fields. *Catena,* 160: 222-232.

Lucas, S.T. and Weil R.R. 2012. Can a labile carbon test be used to predict crop responses to improve soil organic matter management? *Agron. J.,* 104:1160-1170.

Nave, L., Marín-Spiotta, E., Ontl, T., Peters, M. and Swanston, C. 2019. *Soil carbon management, Developments in Soil Science,* doi.org/10.1016/B978-0-444-63998-1.00011-2.

Nelson, D.W. and Sommers, L.E. 1982. *Total carbon, organic carbon, and organic matter.* In: Page, A.L. (ed.). Methods of Soil Analysis, (2nd ed.). ASA Monograph, 9(2): 539-579.

Plaza-Bonilla, D., Álvaro-Fuentes, J., Arrúe, J.L. and Cantero-Martínez, C. 2014. Tillage and nitrogen fertilization effects on nitrous oxide yield-scaled emissions in a rainfed Mediterranean area. *Agric. Ecosyst. Environ.,* 189: 43-52.

Priyadarshini, P., Tripathi, R., Puree, C., Dhal, B., Shahid, M., Lal, B., Gautam, P., Mohanty, S., Kumar, U., Munda, S., Kumar, A., Panda, B.B., Bhattacharyya, P., Shukla, A.K. and Nayak, A.K. 2019. Distribution of N-mineralizing enzymes in soil aggregate fractions over 46 years application of inorganic and organic fertilizers in a tropical rice-rice system. *J. Indian Soc. Soil Sci.*, 67(3): 341-350.

Singh, A.K., Rahman, B. and Thakur, R. 2019. Assessment of land suitability and irrigation potential for improving cropping intensity and ensuring food security in northeast India. *J. Indian Soc. Soil Sci.,* 67(3): 281-290.

Singh, R.J., Ghosh, B.N., Sharma, N.K., Patra, S., Dadhwal, K.S., Meena, V.S., Deshwal, J.S. and Mishra, P.K. 2017. Effect of seven years of nutrient supplementation through organic and inorganic sources on productivity soil and water conservation, and soil fertility changes of maize-wheat rotation in north-western Indian Himalayas. *Agric., Ecosyst. Environ.,* 249: 177-186.

Van Bavel, C.H.M. 1950. Mean weight-diameter of soil aggregates as a statistical index of aggregation. *Soil Sci. Soc. Am. J.,* 14: 20-23.

Walkley, A. and Black, I.A. 1934. An examination of the Degtareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.,* 37: 29-38.

Yaduvanshi, N.P.S. and Sharma, D.R. 2016. Utilization of organics, amendment and fertilizers with sodic water irrigation: long-term effect on soil properties and rice-wheat productivity. *J. Indian Soc. Soil Sci.,* 64(3): 255-260.