Short Communications

Effects of Long Term Rice-based Cropping Systems on Soil Quality Indicators in Central Plain of Chhattisgarh

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Introduction

The definition of soil quality encompasses physical, chemical and biological characteristics, and it is related to fertility and soil health. Many indicators are used to describe soil quality, but it is important to take into account sensitivity, required time, and related properties, than can be explained. Soil physical, chemical, and biological attributes (Karlen et al., 2001) have been used historically as proxies to soil quality (Andrews et al., 2002), which is a concept related to intrinsic characteristics of the soil, to its interactions with the ecosystem, and to the type of land use or management. This implies some degree of subjectivity as to individual perceptions of what can be deemed “good quality” (Blanco and Lal, 2008). More recently, the discussion has been centered on the concept of ‘soil health’, largely defined for soil biological properties (Doran and Jones, 1996). Both concepts are focused on assessing soil functions in the landscape, but there is no explicit reference state to be used in a soil quality or health framework. Soil quality indicators are normally chosen according to the research focus. The dataset of indicators may be constructed according to expert opinion (Sanchez-Navarro et al., 2015), based on how often the parameters appear in scientific papers or it may be guided solely on statistical criteria. Certainly, it can also consist of the combination of both strategies (Lima et al., 2013). However, comparing soil quality indicators is not an easy task, since there is neither a consensus as to the appropriate indicators to compose the SQI, nor as to the way that they should be selected to minimize personal subjectivity.

According to USDA, soil quality indicators are classified into four categories that include visual, physical, chemical, and biological indicators. Visual indicators can be obtained through field visits, perception of farmers, and local knowledge. These are identified through observation or photographic
interpretation, subsoil exposure, erosion, presence of weeds, color, type of coverage, and through comparison between systems operated with the unaudited interim anthropogenic, which gives a clear idea whether the soil quality has been affected positively or negatively. The physical indicators are related to the organization of the particles and pores, reflecting effects on root growth, speed of plant emergence and water infiltration; they include depth, bulk density, porosity, aggregate stability, texture and compaction. Chemical indicators include pH, salinity, organic matter content, phosphorus availability, cation exchange capacity, nutrient cycling, and the presence of contaminants such as heavy metals, organic compounds, radioactive substances, etc. These indicators determine the presence of soil-plant-related organisms, nutrient availability, water for plants and other organisms, and mobility of contaminants. Finally, biological indicators include measurements of micro- and macro-organisms, their activities or functions. Concentration or population of earthworms, nematodes, termites, ants, as well as microbial biomass, fungi, actinomycetes, or lichens can be used as indicators, because of their role in soil development and conservation; nutrient cycling and specific soil fertility. Due to the variety of soil properties that can act as quality indicators, researchers should identify and select the most suitable ones according to the research goals (Nortcliff, 2002). Keeping these points in mind the present study was conducted objective of this work was to study impact of different rice-based cropping system on soil quality indictors under hot humid eastern plateau of India for further evaluation of soil quality.

The study area (Balod district) is a part of Chhattisgarh state of India, lies between 20°24’ to 21°03’ N latitude and 80°47’ to 81°31’ E longitude, at an elevation of 324 m above the mean sea level, which occupies an area of 3527 sq. km. In Balod district survey was carried out and identified two important soil orders i.e. *Inceptisols* and *Vertisols*. The prominent cropping sequences identified for detailed study were; rice – wheat (RW), rice – chickpea (RC), rice – lathyrus (RL) and rice – fallow (RF). Rice crop was sown as an autumn–winter crop (July to November) and subsequent crops i.e. wheat, chickpea and lathyrus were grown as winter–spring crop (November to February). Stratified soil sampling was adopted and 10% of the total villages in the district were taken into consideration. In each village, based on the cropping system, soil samples were taken from *Inceptisols* and *Vertisols*, where the crop rotation was followed since 2000. After the harvest of cropping system for each soil sample, five points (0-15 cm) were taken into account before compositing. A total 40 samples were collected (20 samples for each cropping system), air dried and sieved under shade. The fine earth (< 2 mm) was analyzed for soil physical, chemical, and biological properties following standard laboratory procedures (Table 1).

**Soil physical properties**

The mean values of BD of soils were 1.40, 1.34, 1.36 and 1.37 Mg m\(^{-3}\) for RW, RC, RL, and RF cropping system, respectively (Table 2). The higher amount of added biomass from leguminous crops (chickpea and lathyrus) made soil loose, porous and less squeezed. Therefore, the lower BD was found under rice-legume cropping system (RC and RL) (Rahman *et al.*, 2007). The mean values of PD of soils were 2.65, 2.64, 2.63 and 2.63Mg m\(^{-3}\) for RW, RC, RL, and RF cropping system, respectively (Table 2). The PD of soil only affected by size of the particles, therefore, the PD of soils was found to be no difference among the cropping systems (Alam and Salahin, 2013). The mean values
of porosity of soils were 47.07, 49.16, 48.11 and 47.92 per cent for RW, RC, RL, and RF, respectively (Table 2). The greater extant of added biomass from leguminous crops made soil porous, increase macro pores, makes the soil more voluminous (Bandyopadhyay et al., 2011). Accordingly, the higher porosity was found under rice-legume cropping system. The mean values of FC of soils were 24.50, 32.45, 27.95, and 26.55 per cent for RW, RC, RL, and RF cropping system, respectively (Table 2). The mean values of WC of soils were 16.00, 21.45, 18.80, and 16.20 per cent for RW, RC, RL, and RF cropping system, respectively (Table 2). The mean values of WHC of soils were 33.95, 50.42, 36.68, and 35.74 per cent for RW, RC, RL, and RF cropping system, respectively (Table 2). Rice-legume cropping system store large extant of carbon in to the soil. By the decomposition of organic matter, polysaccharides, fulvic acid and humic acid are produced, which bind soil particles, increase mean weight diameter, improve water stable aggregates, and consequently increase in WHC of soil (Bama and Somasundaram 2017; Kumar et al., 2018). The mean values of HC of soils were 0.83, 0.85, 0.90, and 0.86 cm hr\(^{-1}\) for RW, RC, RL, and RF cropping systems, respectively (Table 2). Rice-legume cropping system notable for organic carbon build-up in soils, which improves soils aggregation (Cotching et al., 2002), reduces pH and ESP and enhance the hydraulic conductivity of the soils (Bhattacharyya et al., 2000). The mean values of MWD of soils were 0.70, 0.86, 0.79, and 0.71 mm for RW, RC, RL, and RF, respectively (Table 2). Rice-legume cropping system (RC and RL) having high root mass density, mean root diameter, root diameter diversity and the percentage of fine roots was all positively linked to the stability of soil aggregates by increasing SOC content. Higher root biomass of leguminous crops helped to accumulation of higher amount of SOC through roots and leaf-fall with increased macro-aggregate formation.

### Soil chemical properties

The mean values of soil pH were 7.2, 6.5, 6.7 and 6.8, for RW, RC, RL, and RF, respectively (Table 2). The soil pH of soils under RC cropping system was lower than that of soils under RL, RF and RW cropping system. This result has been accredited to the well-known soil acidification effects induced by leguminous crops (Burle et al., 1997). Legume plants reliant on \(\text{N}_2\) fixation take up more cations than anions, resulting in a net export of protons. The mean values of soil EC were 0.16, 0.14, 0.12, and 0.13 dS m\(^{-1}\) for RW, RC, RL, and RF cropping system, respectively (Table 2). The EC of soils was found to be no difference among the cropping systems (Table 2). The mean values of soil OC were 4.08, 5.8, 4.9, 4.5 g kg\(^{-1}\) for RW, RC, RL, and RF cropping system, respectively (Table 2). Higher SOC was observed in the rice-legume cropping system (RC and RL) may be attributed to these rotations was considered to have high root biomass, higher carbon sequestration capacity and less carbon release than that of soils under RW and RF cropping system (Mitsch et al., 2010). The mean values of soil CEC were 37.35, 46.76, 41.53 and 39.58 cmol (p\(^+\)) kg\(^{-1}\) for RW, RC, RL, and RF, respectively (Table 2). Rice-legume cropping system store large extant of carbon content in to soil and high carbon content might be responsible for higher CEC. The mean values of available N of soils were 220.32, 246.95,
Legume is a natural mini-nitrogen manufacturing factory in the field. Legumes playing a pivotal role especially in N supply to the cereals by symbiotic association between legume roots and rhizobium bacteria. As a result, rice-legume cropping system (RC and RL) stores more N rather than RW and RF (Kumar et al., 2018).

The mean values of available P of soils were 15.5, 19.20, 17.6, and 15.90 kg ha\(^{-1}\) for RW, RC, RL, and RF, respectively (Table 2). A greater P availability was observed under RC cropping system presumably due to the lower pH. Crop rotations, especially those with legumes, can increase root colonization by mycorrhizae. Mycorrhizal associations have the greatest impact on increasing P availability for crops by colonizing root (Newton et al., 2011). The mean values of available K of soils were 355.78, 439.90, 391.40, and 371.80 kg ha\(^{-1}\) for RW, RC, RL, and RF cropping system, respectively (Table 2). The available K of soils under RW cropping system was lower than that of soils under RC and RL. The mean values of available S of soils were 13.65, 17.00, 15.15, and 13.65 kg ha\(^{-1}\) for RW, RC, RL, and RF, respectively (Table 2). The available S of soils under RC cropping system was higher than that of soils under RL and RF.

**Soil biological properties**

The mean values of soil MBC were 201.98, 234.38, 193.21, and 217.14 ppm for RW, RC, RL, and RF, respectively (Table 2). The mean values of soil MBN were 771.53, 830.76, 787.08, 783.48 ppm for RW, RC, RL, and RF, respectively (Table 2). Soils under rice-legume crop rotations with a high input and diversity of organic materials are reported to contain higher concentrations of microbial biomass and enzymes as compared with RW and RF cropping systems (Moore et al., 2000; Kumar et al., 2018). The mean values of soil PMC were 406.29, 429.08, 405.85, and 410.82 ppm for RW, RC, RL, and RF, respectively (Table 2). The mean values of soil PMN were 158.11, 202.78, 164.40, 179.04 ppm for RW, RC, RL, and RF, respectively (Table 2). Retention of crop residue on or near the soil surface has been shown to reduce residue carbon loss and increase SOC over time (Lal 2004). High SOC content, biomass production, microbial activity and lower C: N ratio might be responsible for higher carbon and nitrogen mineralization under rice-legume cropping system (Justin et al., 2015). Carpenter-Boggs et al., (2000) reported that crop rotations differing in crop components could have large effects on PMN and N availability by altering the quantity and quality of residue input.

The mean values of acid phosphatase activity of soil were 78.37, 92.00, 90.75, and 83.37 µg p-nitrophenol g\(^{-1}\) 24 hr\(^{-1}\) for RW, RC, RL, and RF, respectively (Table 2). The mean values of alkali phosphatase activity of soil were 259.55, 308.60, 308.41, and 274.17 µg p-nitrophenol g\(^{-1}\) 24 hr\(^{-1}\) for RW, RC, RL, and RF, respectively (Table 2). Rice-legume cropping system responsible for high SOC content, biomass production, microbial population and activity, consequently enhance mycorrhizae association. The rhizosphere is directly influenced by root and mycorrhizae secretions of phosphatase enzyme, and sustains dense populations of root-associated and free-living microorganisms. Therefore, soil under rice-legume cropping system contains large quantities of intracellular and extracellular phosphatases. The mean values of urease activity of soil were 20.66, 31.41, 25.57, and 24.02 µg NH\(_4\)-N g\(^{-1}\) 24 hr\(^{-1}\) for RW, RC, RL, and RF, respectively (Table 2).
Table 1: Analytical method adopted for soil physical, chemical, and biological properties

| Parameters                                      | Reference to method of analysis                                                                 |
|-------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Soil texture                                    | International pipette method (Piper, 1950)                                                       |
| Bulk density (BD)                               | Method No. 39, USDA Hand book No. 60 (Richards, 1954)                                            |
| Particle density (PD)                           | Method No. 39, USDA Hand book No. 60 (Richards, 1954)                                            |
| Porosity                                        | Calculating BD and PD.                                                                           |
| Water holding capacity (WHC)                    | Keen raczkowski box method (Piper, 1950)                                                         |
| Soil moisture retention (SMR) at -33 kPa (FC) and -1500 kPa (WP) | Using pressure plate membrane apparatus as described by Kumar et al. (2018a)                      |
| Porosity                                        |                                                                                                  |
| Porosity                                        | Calculating BD and PD.                                                                           |
| Water holding capacity (WHC)                    | Keen raczkowski box method (Piper, 1950)                                                         |
| Soil moisture retention (SMR) at -33 kPa (FC) and -1500 kPa (WP) | Using pressure plate membrane apparatus as described by Kumar et al. (2018a)                      |
| Aggregate stability (Mean weight diameter)      | Yoder’s Modified weight sieving method (Yoder, 1936)                                            |
| pH                                              | pH Meter method No. 21(b), USDA Hand book No. 60 (Richards, 1954)                                |
| Electrical conductivity (EC)                    | EC Meter (in soil suspension) method No. 04 (b), USDA Hand book No. 60 (Richards, 1954)          |
| Soil organic carbon (SOC)                       | Walklay and Black’s wet digestion method (1934)                                                  |
| Cation exchange capacity (CEC)                  | Method No. 19, USDA Hand book No. 60 (Richards, 1954)                                            |
| Available N                                     | Alkaline KMnO₄ method (Subbiah and Asija, 1956)                                                  |
| Available P                                     | Olsen’s method as described by Kumar et al. (2018a)                                              |
| Available K                                     | Neutral normal ammonium acetate method with flame photometer (Jackson, 1950).                    |
| Available S                                     | Turbidimetric method as described by Kumar et al. (2018a)                                        |
| Microbial biomass C and N                       | Jenkinson and Powelson (1976)                                                                    |
| Potentially mineralized C and N                 | Anderson (1982)                                                                                  |
| Dehydrogenases activity                         | Klein et. al. (1971)                                                                             |
| Acid and alkaline phosphatase activity          | Tabatabi and Bremner (1969) using borate buffer pH 9.4                                         |
| Urease activity                                 | Pancholy and Rice (1973)                                                                         |
Table 2 Descriptive statistics of soil properties among different cropping system

| Soil Property | Rice – Wheat | Rice – Chickpea | Rice – Lathyrus | Rice – Fallow |
|---------------|--------------|-----------------|-----------------|--------------|
|               | Mean | Min. | Max. | Mean | Min. | Max. | Mean | Min. | Max. | Mean | Min. | Max. |
| BD (Mg m⁻³)  | 1.40 | 1.29 | 1.49 | 1.34 | 1.27 | 1.44 | 1.36 | 1.29 | 1.44 | 1.37 | 1.29 | 1.47 |
| PD (Mg m⁻³)  | 2.65 | 2.58 | 2.74 | 2.64 | 2.59 | 2.69 | 2.63 | 2.57 | 2.71 | 2.63 | 2.52 | 2.74 |
| Porosity (%)  | 47.07 | 42.86 | 50.57 | 49.16 | 46.21 | 51.71 | 48.11 | 45.17 | 52.22 | 47.92 | 44.44 | 51.29 |
| SMR % (-33 kpa)  | 24.50 | 16.50 | 32.50 | 32.45 | 26.70 | 38.20 | 27.95 | 21.10 | 34.80 | 26.55 | 21.50 | 31.60 |
| SMR % (-1500 kpa) | 16.00 | 10.40 | 21.60 | 21.45 | 15.10 | 27.80 | 18.80 | 12.50 | 25.10 | 16.20 | 10.80 | 21.60 |
| WHC (%)  | 33.95 | 18.48 | 43.43 | 50.42 | 42.52 | 58.33 | 36.68 | 20.42 | 52.95 | 35.74 | 14.65 | 56.84 |
| HC (cm hr⁻¹)  | 0.83 | 0.68 | 1.07 | 0.85 | 0.67 | 0.96 | 0.90 | 0.71 | 1.06 | 0.86 | 0.66 | 1.10 |
| MWD (mm)  | 0.70 | 0.58 | 0.82 | 0.86 | 0.76 | 0.98 | 0.79 | 0.64 | 0.99 | 0.71 | 0.60 | 0.85 |
| pH  | 7.2 | 6.8 | 7.6 | 6.5 | 5.2 | 7.5 | 6.7 | 5.2 | 7.9 | 6.8 | 5.40 | 8.2 |
| EC  | 0.16 | 0.04 | 0.32 | 0.14 | 0.08 | 0.23 | 0.12 | 0.03 | 0.26 | 0.13 | 0.02 | 0.28 |
| OC (g kg⁻¹)  | 4.08 | 2.60 | 6.1 | 5.8 | 4.7 | 6.7 | 4.90 | 3.4 | 6.4 | 4.5 | 2.6 | 6.4 |
| CEC [cmol (p⁺) kg⁻¹]  | 37.35 | 23.24 | 51.47 | 46.76 | 34.28 | 59.24 | 41.53 | 21.51 | 61.56 | 39.58 | 19.68 | 59.48 |
| Av. N (kg ha⁻¹)  | 220.32 | 177 | 251 | 246.95 | 199 | 275 | 232.72 | 164 | 261 | 225.38 | 186 | 258 |
| Av. P (kg ha⁻¹)  | 15.5 | 9.2 | 21.8 | 19.20 | 14.50 | 23.90 | 176 | 10.40 | 24.80 | 15.9 | 8.7 | 23.10 |
| Av. K (kg ha⁻¹)  | 355.78 | 187 | 459 | 439.90 | 387 | 501 | 391.40 | 318 | 475 | 371.80 | 267 | 138 |
| Av. S (kg ha⁻¹)  | 13.65 | 7.10 | 20.20 | 17.00 | 12.70 | 21.30 | 15.15 | 10.40 | 19.90 | 13.65 | 7.10 | 20.20 |
| MBC (ppm)  | 201.98 | 149.59 | 254.38 | 234.38 | 197.49 | 271.12 | 193.21 | 128.48 | 257.94 | 217.14 | 164.35 | 269.94 |
| MBN (ppm)  | 771.53 | 645.62 | 897.45 | 830.76 | 778.74 | 882.78 | 787.08 | 678.57 | 95.59 | 783.48 | 668.54 | 901.42 |
| PMC (ppm)  | 406.29 | 326.35 | 486.24 | 429.08 | 359.58 | 498.59 | 405.85 | 304.35 | 507.35 | 410.82 | 348.84 | 472.81 |
| PMN (ppm)  | 158.11 | 107.75 | 208.48 | 202.78 | 159.78 | 245.79 | 164.40 | 129.84 | 198.96 | 179.04 | 115.74 | 242.35 |
| Acid phosphatase activity (µg p-nitrophenol g⁻¹ 24 hr⁻¹)  | 78.37 | 62.35 | 94.39 | 92.00 | 85.35 | 98.65 | 90.75 | 62.96 | 118.54 | 83.37 | 62.35 | 104.39 |
| Alkali phosphatase activity (µg p-nitrophenol g⁻¹ 24 hr⁻¹)  | 259.55 | 208.24 | 310.86 | 308.60 | 259.86 | 357.34 | 308.41 | 248.24 | 368.59 | 274.17 | 202.35 | 345.61 |
| Urease activity (µg NH₃-N g⁻¹ 24 hr⁻¹)  | 20.66 | 10.57 | 30.75 | 31.41 | 24.25 | 38.58 | 25.57 | 11.68 | 39.47 | 24.02 | 11.48 | 36.57 |
| Dehydrogenase activity (µg TPF g⁻¹ 24 hr⁻¹)  | 29.51 | 15.53 | 43.49 | 40.12 | 31.67 | 48.57 | 35.79 | 21.84 | 49.79 | 32.84 | 16.35 | 49.34 |
Rice-legume cropping system stimulate microbial activity which build-up OC and microbial biomass in to the soil (Campbell et al., 2000). Higher microbial biomass carbon and nitrogen under rice-legume cropping system attributed to the greater urease activity. The mean values of DHA of soil were 29.51, 40.12, 35.79, 32.84 µg TPF g⁻¹ 24 hr⁻¹ for RW, RC, RL, and RF, respectively (Table 2). Rice-legume cropping systems were found significantly higher DHA might be due to higher microbial activity which was registered in the present study itself. Dehydrogenases are greatly associated with microbial biomass, which in turn mediates the decomposition of organic materials (Zhang et al., 2010).

From the results it is concluded that soil quality indicators were registered optimum for rice-legume cropping systems (RC and RL) than that of RW and RF cropping systems. Optimum in terms of lower BD, higher porosity, HC, MWD, FC, WHC, available macro- and micro-nutrient status, and high in soil microbial activities. Therefore, to perform soil functions and to sustain productivity rice-legume cropping system could be more effective.

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