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Effects of long-term nutrient management practices on physicochemical properties of soils: A review

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Abstract
Long-term experiments have been conducted to quantify changes in physicochemical properties of the soils. Long-term experiments having different management practices can provide critical observations regarding the changes in soil quality and can help in prediction of future soil productivity and soil-environment interactions. With organic matter addition soil aggregation, total porosity and bulk density were improved. Cumulative infiltration and its rate were greater with crop residue incorporation than burning or removal. Significant variability in water-stable aggregates and mean weighted diameter with SOC indicated better soil stability. The increase in OC significantly increased the infiltration rate (IR), hydraulic conductivity (HC), soil water retention at all suctions, water stable aggregates (WSA) and mean weight diameter of the soil aggregates, while decreased the bulk density (BD) and penetration resistance (PR) both at surface and subsurface soil layers. The MWD, total porosity and WHC improved with balanced application of fertilizers. Organic manures substituted plots registered lower pH than sole chemically fertilized. Electrical conductivity was slightly lower in organic treated plots as compared to chemically fertilized plots. Integrated application of inorganic fertilizers and organic manure resulted in greater SOC accumulation and higher potentially mineralizable C in the soil. Long-term application of fertilizer has a positive effect on soil total nitrogen and total organic carbon compared to control treatment. Long-term studies in high Olsen-P soils showed increased P build-up with recommended fertilizer P application rates.

Keywords: Long-term, organic carbon, fertilizers, soil quality, soil productivity

1. Introduction

India has achieved food grain production of 305.44 million tons in 2020-21 (3rd Advance Estimates, DES, DoACFW, MoAFW). Applications of chemical fertilizers have contributed significantly to the increase in the food grain production world over. However, the cultivation of high yielding crops, use of high analysis fertilizers and decreased use of organics and crop residues have resulted in wide spread deficiencies of nutrients and low crop yields. As population is increasing at an alarming rate, there is an urgent need to consider the novel ways of increasing food production that are in consonance with sustainability and the retention of environmental quality. The adoption of improved technology for crop production has increased requirement of nutrients many folds. With the increased cost of inorganic fertilizers, application of the recommended dose of fertilizers has become difficult for small and marginal farmers to afford. Hence for supplementing and complementing chemical fertilizers, renewable and low-cost sources of plant nutrients must be substituted which should be affordable to the majority of the farming community. Integrated application of organic manures and chemical fertilizers is a useful practice to increase crop yields and maintain soil fertility (Mahapatra and Sharma, 1989) [31]. Cropping systems and their nutrient and crop management practices that ensure greater amounts of crop residue returned to the soil are expected to cause a net build-up of the soil organic carbon (SOC) stock. Identifying such cropping systems and practices is a prime area of importance for sustaining crop productivity.

Long-term field experiments using different nutrient management practices can provide critical observations regarding the changes in soil quality and fertility and can help in prediction of future soil productivity and soil-environment interactions (Li *et al.*, 2010 and Shen *et al.*, 2010) [30, 40]. Long-term monitoring helps in both the identification of current changes in the soil as well as prediction of future changes. The problem of soil fertility management can be monitored by long-term field experiments as it takes time for the crops, fertilizers and manures to have a measurable effect on soil quality. In order to maintain soil productivity, to prevent further land degradation, nutrients removed by the crop must be replenished back in soils.

In a number of field trials conducted in India, it has been observed that long-term application of organic manures helps, improve and maintain soil fertility, soil productivity and soil physical conditions.

Since many issues of sustainability are related to soil quality, assessment of soil quality and predicting the direction of change with time is a primary indicator of whether agriculture is sustainable (Karlen *et al*., 1997) [27]. The response of soils to the nutrient management also depends on soil quality. Hence it becomes important to identify the soil characteristics responsible for changes in soil quality, which might be eventually considered as soil quality indicators for assessing agricultural sustainability. Many of the earlier studies dealing with nutrient management impacts on soil quality and sustainability in sub-tropical soils were confined to measurement of a limited range of soil quality attributes.

Keeping in view the importance and very meagre information available about changes in the quality of intensively cropped sub-tropical soils, the above-proposed review will be focused on the impact of long-term nutrient management practices on Physical, Chemical and Biological properties of the soil.

2. Impact of long-term nutrient management practices on Physical properties of the soil

2.1 Bulk density

After 6 years of experimentation with pearl millet-wheat as a cropping system, the lowest bulk density (1.51 Mg m^{-3}) was found for the soils in which only FYM @ 20 t ha^{-1} was applied to both the crops and the highest in control i.e. where no fertilizer or manure was added. This will be due to the improvement in soil structure and porosity where FYM was applied. Reduction in bulk density was observed for surface and sub-surface by 7.7-8.59 and 7.35-8.15%, respectively, when fertilizer along with FYM was applied (Bhatt *et al*., 2017) [13]. Shirani *et al*., (2002) [41] reported significantly increased soil organic matter and decreased soil bulk density just after harvesting a maize field supplied with FYM. Bayu *et al*., (2006) [11] also concluded that FYM application increased soil organic carbon content upto 67% over control. The decrease in bulk density has been ascribed to better organic carbon content and improved soil aggregation. Tiwari *et al*., 2000) [47] recorded the lowest bulk density (1.20 Mg/m3) of Typic Haplusterts and was lower than in plots getting 100% NPK + FYM and 1.49 mg/m3 in plots receiving N alone or no fertilizer

2.2 Hydraulic conductivity

Flow of water through soil when pore spaces are completely filled with water has been defined as saturated hydraulic conductivity. A decrease in organic matter would cause an increase in bulk density and a decrease in porosity, thereby reducing soil infiltration, and water and air storage capacities (Celik, 2010) [15]. As a result of that, soil water holding capacity and hydraulic conductivity decreased. With 29 years of experiment, increase in hydraulic conductivity by 88.28 and 42.22%, respectively in surface and sub-surface soil layers have been reported with application of FYM along with RDF (Bhatt *et al*., 2017) [13]. However, Bassouny and Chen (2016) [10] observed the effect of organic and mineral fertilizer on physical properties of the clay soils and found that the saturated and unsaturated hydraulic conductivity decreased by 62.9% with application of organic manure as compared to control.

2.3 Soil moisture content

Soil moisture retention curve depicts the relationship between soil-water potential and corresponding moisture content in the soil. Results of the 14 years of fertilization showed that application of organic matter significantly increased soil water retention capacity at all tensions (0-1500 KPa) and depths under study but having larger increment in low tension at depths of 0-10cm and 10-20 cm ($p<0.05$) in comparison with control. On the contrary, NPK and NPK + straw led to a decrease in soil water retention capacity. Both in wet and dry periods, soil water content was significantly higher in OM plot than in NPK + straw and NPK only ($p<0.05$) since soil hydraulic conductivity (saturated and unsaturated) are lower in OM plot than in other treatments ($p<0.05$) reported by Bassouny and Chen (2016) [10]. Gudadhe *et al*., (2015) [22] reported that at field capacity soil moisture retention varied from 39.5 to 30.87% under various treatments but did not vary significantly where sole inorganic fertilizers were applied. Under various treatments permanent wilting point of soil varied significantly from 15 to 26.62%. In control highest permanent wilting point was recorded (26.07%) which was at par with application of 75% RDF + 25% RDN through VC.

2.4 Infiltration rate

Singh and Modugal (1976) [43] observed that adding FYM increased the infiltration rate and decreased resistance to the penetrometer while rates of the organic materials significantly influenced infiltration rate (Barzegar *et al*., 2002) [9]. Organic matter due to its low bulk density and ability to enhance soil aggregate stability results in lower soil bulk density and soil compactibility (Dexter, 1988) [17], higher soil porosity and infiltration rate (El-Shakweer *et al*., 1998) [19] as FYM makes the soil fluffy. The infiltration rate in treatment FYM control after rice was 0.85 and after wheat, it was 4.29 cm/45 minutes. In treatment with FYM to rice, the values were 1.14 after rice and 4.45 cm/45 minutes after wheat harvest. The values were 0.85 after rice and 4.33 cm/45 minutes after wheat when FYM was added in wheat. For FYM to both the crops, the infiltration was observed as 1.15 and 4.77 cm/45 minutes after rice and after wheat harvests, respectively.

2.5 Maximum water holding capacity

A decrease in organic matter would cause an increase in bulk density and a decrease in porosity, thereby reducing soil infiltration and thus water and air storage capacities (Franzluebbers, 2002) [20]. As a result of this, soil water holding capacity and hydraulic conductivity may decrease. All the retention properties (CHC, SWC) and infiltration characteristic (*Ks*) over all the soil layers and soil impedance properties (CI, BD) in 0-10 cm were affected significantly by FYM application. Additions of organic manures into soil resulted in increased water holding capacity, porosity, infiltration capacity, hydraulic conductivity and water stable aggregation and decreased bulk density and surface crusting. Aggelides and Londra (2000) [2] reported that porosity and water retention capacity of loam and clay soils increased with application of compost. Use of organic amendments, like FYM, vermicompost, microbial consortia and organic mulching are effective means for enhancing soil fertility, microbial diversity and population, microbial activity, improving the soil physical properties particularly moisture holding capacity of soils and increasing crop yields (Adak *et al*., 2013) [1]. Organic matters not only increase the water holding capacity of the soil but also the portion of water available for plant growth and improve the soil physical properties (Sial *et al*., 2007) [42]. The reduction in bulk density of the soil might be due to the increase in humic substances which further resulted in increased porosity and water holding capacity of soil. Incorporation of FYM @ 10 t ha^{-1} resulted in an improvement in soil porosity, saturated hydraulic conductivity in surface and sub-surface layers which ultimately increased moisture retention in soil the profile, while bulk density decreased. The higher percolation rate with lapse of time under FYM treated plots might be due to an increase in root biomass, better soil aggregation and improvement in mechanical composition of the soil as well as greater proliferation (Bhattacharya *et al*., 2004) [14].

2.6 Soil aggregate analysis

Aggregate analysis determines size distribution of water stable aggregates, which in turn influences the pore size distribution and consequently hydraulic properties of the soil. Studies have indicated the beneficial effect of organic matter in improving soil structural stability (Dexter, 1988; Tisdall and Oades, 1982) [17, 46]. An increase in water stability of aggregates by FYM was also reported for black clay soils (Kiba and Basu, 1952) [28]. The decrease in bulk density has been ascribed to better organic carbon content and improved soil aggregation. Tiwari *et al*., (2000) [47] recorded the lowest bulk density (1.20 Mg/m3) in Typic Haplusterts which was lower than in 100% NPK + FYM and 1.49 mg/m3 in plots receiving N alone or no fertilizers. Celik *et al*. (2010) [15] mean weight diameter of soil aggregates increased under the manure treatment while total porosity and saturated hydraulic conductivity decreases. Soil organic matter affects infiltration through its positive effect on the development of stable soil aggregates, or crumbs. Highly aggregated soil has increased pore space and infiltration. Soils high in organic matter also provide good habitat for soil biota, such as earthworms, that through their burrowing activities, increase pore space and create continuous pores linking surface to subsurface soil layers (Anonymous. 2008) [4]. Organic matter affects crops growth and yield either directly by supplying nutrients or indirectly by modifying soil physical properties such as stability of aggregates, porosity and available water capacity that can improve the root environment and stimulate plant growth (Rasoulzadeh and Yaghoubi, 2010) [37]. Aggregates of 0.75-0.125mm were positively correlated with application of organic carbon content of the soils (Aziz and Karim 2016) [6]. Mazumdar *et al*., (2015) [32] reported that addition of FYM, wheat straw and green manure increased macroaggregate fractions of the soil, with consequent decrease in microaggregate fractions. Among the macroaggregates, 14-23% of total aggregates were found in the range of 0.25-0.50mm size which constituted the largest proportion. The MWD was found to be significantly higher in plots receiving 50% NPK + 50% N through FYM in rice, 100% NPK in wheat or 50% NPK + 50% N through crop residue in rice, 100% NPK in wheat or 50% NPK + 50% N through green manure in rice, 100% NPK in wheat as compared to control.

2.7 Penetration resistance

Penetration resistance describes the degree of compactness of the soil. Soil penetration resistance value under dry and wet periods in top (0-7.5cm) soil layer were found below 2 Mpa for relatively unimpeded root growth but below 20 cm soil depth values of soil penetration resistance were found more than 2 Mpa except on treated plots (Bassouny and Chen 2016) [10]. Similarly, Celik *et al*., (2010) [15] observed the decrease in soil penetration resistance with application of fertilizer. Chouhan *et al*., (2018) [16] reported a decrease in penetration resistance of soils from 0.42 MPa to 0.36 MPa and 0.44 MPa to 0.38 MPa in surface and subsurface soils, respectively with FYM application.

3. Impact of long-term nutrient management practices on chemical properties of the soil.

3.1 Soil pH and EC

The soil reaction has direct correlation with nutrient availability for plant growth and development various studies (Jaja *et al*., 2013; Bahadur *et al*., 2013; Onwu *et al*., 2014) [26, 8, 36]. Soil organic matter plays an important role in soil chemical (pH, base saturation, salinity and CEC changes) and physical (bulk density, stabilization of soil structure and aggregate formation) properties. A pot experiment was conducted to study the effect of FYM application on some physical and chemical properties of a Lithic Rhodoxeralf soil. Treatments included four rates (0, 10, 20 and 40 t ha^{-1}) of FYM on a dry weight basis. After seven months of incubation, soil organic matter (SOM) content, total nitrogen (N), soil pH, electrical conductivity (EC), cation exchange capacity (CEC), base saturation (BS), and bulk density (BD) were determined. The use of FYM led to an apparent increase, especially in intermediate and high dose, in SOM, total N, pH, EC and CEC but in a slightly decrease in BD (Yilmaz *et al*., (2010) [50]. Integrated use of organic and inorganic sources in rice-wheat system for 20 years, have beneficial impact on soil pH and EC (Sharma and Subehia 2014) [39]. Babar and Dongale (2013) [7] found that addition of organic manure alone i.e., FYM increased significantly the soil pH after harvest of mustard and cowpea. A significant decrease in soil pH over control in the treatment receiving conjunctive application of FYM and sewage sludge was studied by Meena *et al*., (2013) [33]. Srikanth *et al*., (2000) [44] investigated the direct and residual effect of enriched compost, FYM and vermi-compost and fertilizers on soil properties and found a very slight variation in EC of soil due to the application of different compost. Application of NPK fertilizers along with farm yard manure and farm yard manure alone recorded higher electrical conductivity, NPK alone recorded lower electrical conductivity.

3.2 Available primary Macronutrients (N, P, K)

Soil organic nitrogen (SON) accounts for more than 95% of total soil nitrogen, which plays an important role in N retention and transformation (Schulten and Schnitzer 1998; Stevenson 1982) [38, 45]. The availability of N to the growing plant is closely associated with SON through depolymerization of the N-containing constituents and the subsequent mineralization (Nannipieri and Eldor 2009) [35]. However, because of diverse origins and composition of soil organic matter, SON is not immediately available to crop plants (Stevenson 1982) [45]. The addition of fertilizers led to mineralization of organic N; resulted in higher amounts of available N in comparison to control. Moreover, GM crop fixed atmospheric nitrogen through nodulation formed by the indigenous rhizobia and eventually resulted in higher available N in soil. Similarly, incorporation of organic manures along with chemical fertilizers significantly (p<.05) increased available N as compared to control over the years which may be attributed to the build-up of organic matter thereby augmenting mineralization of N in organically treated plots. This may be partially because of the slow release of N from manures (Guo *et al*., 2016) [23]. Hassan *et al*., (2018) [24] studied that maximum mineral nutrients in soil (available N and P) were found in treatment receiving 100% nitrogen from FYM followed by treatment receiving 75% nitrogen from FYM and 25% from urea. Nitrogen mineralization was found to be increased with application of manures (Indriyati, 2014) [25]. There was a significant increase in available P contents from October to November followed by a slight decrease in December and then maximum value in January. From January to April decrease in available P was observed and then slight change up to May (Akmal *et al*., 2012) [3]. Available S content in soil was more in the plots receiving N fertilizer as compared to FYM amended plots, however, lowest content was under control (Yasmin 2011) [49]. Long term application of FYM @ 20 t ha^{-1} alone in each crop significantly increased the availability of N (46.7%) and availability of K (56.3%) over the control while application of STCR based application of fertilizer with FYM significantly increased the availability of nutrients N and K by 20.57 and 13.4 per cent, respectively except available P compared to STCR based fertilizer recommendations but availability of nutrient N and K was slightly low over organic alone.

3.3 Available secondary Macronutrients (Ca, Mg, S)
Ganapathy *et al*., (2008) [21] reported that application of FYM alone increased the soil exchangeable Ca and Mg status significantly over the soils applied with only chemical fertilizer under finger millet crop production. Bharath Patil (2015) [51] reported that organic farming farms recorded higher in exchangeable Ca, Mg and available S as compared to inorganic farming farms and also indicated that a exchangeable calcium was significant positive correlation with soil pH.

3.4 DTPA extractable micronutrients (Zn, Fe, Mn and Cu)
Moharana *et al*., (2017) [34] observed significant effect of organic matter on availability of Zn, Mn and Fe under six years long study. They found an increase of 55.6, 39.9, 28.42, and 43.1 of Zn, Fe, Mn and Cu with INM treated plot in comparison to control. Significant increase in DTPA extractable Zn, Mn, Fe and Cu with the application of organic manure over no manured was observed by (Antil *et al*., 2007) [5]. They also did not find any significant difference in DTPA extractable micronutrients between integrated nutrient management treatments and organic manures alone. Incorporation of different manures like FYM, poultry manure and green manure in soil before rice transplantation resulted in significantly higher content of total and DTPA Zn in the soil (Dhaliwal *et al*., 2013) [18]. Kumar and Qureshi (2012) [29] found that use of organic manures i.e. FYM (10 t ha^{-1}), sulphitized pressmud (10 t ha^{-1}), in-situ green manuring with *Sesbania aculeate* and wheat residue (2.5 t ha^{-1}) decreased soil pH and their use in combination with fertilizers was significantly reflected in the build-up of available NPK, organic carbon and DTPA-extractable micronutrients in soil. Behera and Shukla (2013) [12] also observed that organic carbon content in surface soil was positively correlated with DTPA-Zn and DTPA-Cu which elaborates that the complexing agents produced by organic matter promote the availability of these nutrients in soil. Vidyavathi *et al*., (2012) [48] reported 18.5 and 30.0 percent increase in DTPA extractable Zn and Cu respectively due to integrated nutrient management practice over their initial values. Higher availability of these micronutrient cations in soil due to application of organic manures was ascribed to the formation of chelates with organic ligands which have lowered susceptibility to adsorption, fixation and precipitation in the soil and also to mineralization of organic manures and consequent release of micronutrients.

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