Soil Physico-chemical Properties as affected by Long-term Application of Organics and Inorganic NPK Fertilisers under Rice-wheat Cropping System in Calcareous Soil of Bihar

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Authors' contributions

This work was carried out in collaboration of all authors. Authors RD, MK, SKS and SJ designed the study, performed statistical analyses, wrote the protocol and wrote the first draft of the article. Authors SKS and SJ managed the analyses of the study. Authors MK and SS managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

A balanced application of organics and inorganic fertilisers could be beneficial to both soil nutrient availability, soil health and crop growth. The experiment was conducted on light textured highly calcareous soil at Research Farm of Dr. Rajendra Prasad Central Agricultural University, Pusa. Four levels of inorganic fertiliser treatments were applied i.e. 50, 100 and 150% of NPK along with no NPK as control as main plot treatments while four levels of organic treatment (i.e. no organics, compost, crop residue and compost+ crop residue) were applied as sub plot treatments in a split plot design with a total sixteen (16) treatments with three replications to investigate the long term effect of application of various doses of recommended fertiliser along with organic amendments on

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various physico-chemical properties of calcareous soils after 32nd crop cycle . Data was collected on various physico-chemical properties i.e. Soil pH, electrical conductivity (dSm^{-1}), soil organic carbon (g kg^{-1}), free $CaCO_3$ (%), cation exchange capacity [cmol (p^+) kg^{-1}], bulk Density (Mg m^{-3}) and water holding capacity (w/w %). The result revealed that soil pH was reduced by 3.9% while electrical conductivity (EC) was reduced by 45% over initial (1988). Both soil pH and EC were reduced by 1.7% and 15.4% respectively in plots receiving combined application of compost and crop residue along with 150% NPK over control. Organic carbon was improves by 33% over initial (1988) which had direct effect on reduction in soil bulk density (32%) and improved water holding capacity (29%) over the control in plots receiving 150% NPK along with combined application of compost and crop residue. Soil cation exchange capacity and free $CaCO_3$ also showed an alternate trend former being enhanced and later being reduced after 32nd crop cycle in rice-wheat cropping system. Application of different levels of NPK along with different organics improved the overall soil physico-chemical properties which further have direct relation with enhanced crop growth and productivity.

1. INTRODUCTION

South Asia comprises of low- to middle-income countries, where shrinkage of land and water resources, climate change and population increase are currently the most important issues and concerns for sustainable development. To sustainably feed the ever-increasing population of South Asia by using the limited resources has now been the greatest challenge faced by farmers, scientists and policy-makers [1,2]. In the region, economic development is not happening at the pace of increasing population; the population pressure, changing dietary habits and use of non-renewable inputs (e.g., water, fertilizers, and pesticides) to obtain high yields require high use of natural resources. The present land-use practices in South Asia more particularly in the rice–wheat (R–W) cropping system are energy, capital, water and labor intensive; these are upsetting the ecological balance and exhausting the groundwater resources and soil organic carbon (SOC) along with adverse effects on soil physicochemical properties[1,2].The perception and understanding of existing intensive land use, particularly in the R–W cropping system, therefore necessitate urgent discussions on its adverse effects on the soil, water and overall ecosystems. There is a need to change the tillage and crop establishment practices in the conventional R–W systems by replacing intensive tillage in wheat and puddling and flooding in rice for achieving the overall sustainability of this important cropping system in the region [3,4].

Rice wheat cropping system (RWCS) in the Indian subcontinent is quite new and started only in the late 1960s with the introduction of dwarf wheat from CIMMYT, Mexico, which required a lower temperature (mean below 23C) for good germination than that required for traditional tall Indian wheat. Thus, wheat sowings were shifted from mid-October to mid-November. This set in the RWCS in the Indo-Gangetic plains (IGP) of the Indian subcontinent and the northwestern states of India [Punjab, Haryana, western Uttar Pradesh (UP)] and the Punjab and Sind province of Pakistan, which were traditionally wheat regions, were transformed into rice–wheat regions. The reverse of this happened in Bihar and West Bengal states of India and parts of Bangladesh, which changed from traditional rice regions to rice–wheat regions. RWCS covers about 32% of the total rice area and 42% of the total wheat area in four countries of south Asia (India, Pakistan, Bangladesh, and Nepal) and accounts for one-quarter to one-third of the total rice and wheat production [5].

Fertilization has been extensively used as a common management practice to maintain soil fertility and crop productivity. Chemical fertilizers are extremely attractive and commonly used for their high nutrient concentration, easy availability and convenient transportation and application [6]. In the pursuit of economic growth and food production, increasing amounts of chemical fertilizers have been applied in agroecosystems all over the world, which has resulted in serious degradation of soil physicochemical properties and productivity deterioration [7,8]. Alternatively, organic fertilizers are derived from animal and/or plant matter, which can modify soil physicochemical conditions because of abundant organic matter and balanced nutrients [9,10]. Unfortunately, the lower nutrient content and nutrient release rate of organic fertilizers make

them less likely to meet crop requirements, what's more, compared with chemical fertilizers, the higher amount and inconvenient usage of organic fertilizers resulted in a less prevalence. Nonetheless, combined using of organic and chemical fertilizers has been proven as an effective approach to improve soil fertility, crop yields and environmental quality compared with the single use of either of them.

Long term application of various combinations of organics and inorganic fertilisers have found to have direct or indirect effect on soil health and various soil properties. In preview of this, this research article has investigated the long-term effect of application of various doses of recommended NPK fertiliser along with organic amendments as compost and crop residue in sole form or in combination on various physico-chemical properties viz. pH, electrical conductivity, soil organic carbon, free $CaCO_3$, cation exchange capacity, bulk Density and water holding capacity after RWCS in calcareous soils of Bihar.

2. MATERIALS AND METHODS

2.1 Experimental Details

A field experiment was initiated during 1988-89 on light textured highly calcareous soil at Research Farm of Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar. The experimental soil (0-15 cm) had pH (1:2.5) 8.4, EC 0.37 dSm^{-1} and organic carbon 5.0 g kg^{-1}. Four levels of fertilizers viz. no NPK (F_o), 50% recommended NPK (F_1), 100% recommended NPK (F_2) and 150% recommended NPK (F_3) were applied as treatments in main plots. The main plots was divided into 4 sub-plots in which treatments viz. no manures (M_0), compost @ 10 tha-1 (M_1), crop residue (M_2) and compost + crop residue (M_3) were superimposed over NPK levels making a total of 16 treatments with 3 replications (Table 1). The recommended doses of NPK (120:60:40)* were applied to each crop of rice and wheat as Urea, Single superphosphate (SSP) and muriate of potash (MOP). Half of nitrogen and entire dose of P and K were applied at the time of transplanting of rice and sowing of wheat and remaining N fertilizer was applied in the equal splits at tillering and flower initiation stage. The experiment was laid out in a split plot design with three replications and plot size was 4.0m x2.5m. Rice and wheat crops were grown continuously under rice-wheat cropping system

with spacing 20 X 10 cm for rice and 20 cm row to row for wheat. Rice cv. Rajshree was 63rd test crop and wheat cv. HD 2733 as 64th test crop with seed rate of 35 kg ha^{-1} and 125 kg ha^{-1} of rice and wheat respectively during the reported period of 2019-20.

2.2 Collection of Soil Sample

Post-harvest composite surface (0-15 cm) soil samples were collected from five spots for each of the experimental plots after Rice –Wheat cropping system (2020). Processed soil samples were subjected to analysis of various physico-chemical characteristics viz. Soil reaction (pH), electrical conductivity (dSm^{-1}), soil organic carbon (g kg^{-1}), free $CaCO_3$ (%), cation exchange capacity [cmol (p^+) kg^{-1}], bulk Density (Mg m^{-3}) and water holding capacity (w/w %) according to referred procedures described below:-

2.3 Analysis of Soil Physico-chemical properties

Being a function of hydrogen ion (H^+) activity in soil system soil pH is considered as a governing property for many reactions in the soil. Soil reaction (Acidic, basic or neutral) is measured by measuring soil pH. Soil pH was measured by glass electrode from soil- water suspension (1:2.5) ratio [11]. Soil EC (dSm^{-1}) was measured from using soil- water suspension (1:2.5) ratio at 25°C by using conductivity meter [12]. Organic carbon content (g kg^{-1}) in the soil was determined by modified Walkely and Black method (1934) [11]. Free $CaCO_3$ (%) was determined from soil samples by rapid titration method [12]. CEC [cmol (p^+) kg^{-1}] was determined using neutral normal ammonium acetate (pH 7 1 N NH_4OAc) exchange method [13]. Soil BD (Mg m^{-3}) was determined from the ratio between oven dried soil (Mg) and volume of soil (m^3) collected by a core sampler [14]. Soil WHC (%) was determined from the ratio of water absorbed by soil (g) to weight of oven dried soil (g) using a Keen's Raczkowski box method [15].

2.4 Statistical Analysis

The data were analyzed analysis of variance (ANOVA) Split Plot Design using Microsoft office Excel 2013 as outlined by Gomez and Gomez, 1984 [16]. To compare treatment means, least significant difference (LSD) was worked out at 5% level of probability.

Table 1. Detailed description of treatments of the long-term manure and fertiliser experiment

No.	Treatments	Details
1	F_0M_0	Control
2	F_0M_1	FYM
3	F_0M_2	CR
4	F_0M_3	FYM + CR
5	F_1M_0	50% NPK
6	F_1M_1	50% NPK + FYM
7	F_1M_2	50% NPK + CR
8	F_1M_3	50% NPK + FYM + CR
9	F_2M_0	100% NPK
10	F_2M_1	100% NPK + FYM
11	F_2M_2	100% NPK + CR
12	F_2M_3	100% NPK + FYM + CR
13	F_3M_0	150% NPK
14	F_3M_1	150% NPK + FYM
15	F_3M_2	150% NPK + CR
16	F_3M_3	150% NPK + FYM + CR

*Recommended dose: N = 120 kg ha^{-1}, P$_2$O$_5$ = 60 kg ha^{-1} and K$_2$O = 40 kg ha^{-1}

3. RESULTS AND DISCUSSION

3.1 Effect of Long-term Application of Organics and Inorganic NPK Fertilisers on Soil pH, EC and Organic Carbon after RWCS

Application of inorganics significantly lowered soil pH value by 3.9% from initial (8.4) and 1.7% from control (8.21) with 150% NPK application although treatment effects were non-significant. The percent decrease in pH was noticed by 0.6, 1.1 and 1.7 over control (8.21) at 50, 100, 150% NPK levels (Table 2). Application of organic amendments as compost and crop residue also reduces soil pH between 2.9 to 3.4% from initial (8.4) and the percent decrease in pH was noticed by 0, 0.1 and 0.5 over control (8.15) by compost, CR and Compost applied with CR respectively (Table 2). Soil EC followed a similar trend of reduction over initial (45%) and control i.e. Percent reduction of 7.7, 15.4 and 23 over control at 50, 100, 150% NPK levels and percent reduction of 7.7, 15.4 due to application of various organics CR and compost + CR being at par. Soil organic carbon was found to be increased from 5.49 (g kg^{-1}) to 7.58 (g kg^{-1}) under the above mentioned treatment combinations. The maximum SOC (g kg^{-1}) was recorded with 150% NPK (7.33) and combined application of compost and CR (7.58) and lowest being recorded with plots with no organics (5.56) and inorganic (5.49) treatments (Table 2). The enhancement in SOC over control due to application of organics was 18, 12 and 36 percent respectively due to application of

compost, CR and combined application of both respectively.

Reduction in pH value might be a result of application of acid forming nitrogenous (urea) and phosphatic (sulfuric acid produced from 12% S present in SSP) fertilisers as source of RDF. Organic acids released during decomposition of organic material might be the reason behind the lowered pH range from initial and control [17,18]. Application of compost and crop residue along with different doses of NPK significantly lowered soil EC which is necessary for better plant growth and the interaction effect between manure and fertiliser was also found to be significant. Which might be due to the reason that organic acids produced due to decomposition of organic materials solubilized the salts which made them leach through the soil surface along with the irrigation water [18,19]. Addition of organics especially compost and crop residue enhanced growth of crop roots which further enhanced the overall crop growth therefore the amount of crop residue for further application [20].

3.2 Effect of Long-term Application of Organics and Inorganic NPK Fertilisers on Soil Free CaCO$_3$ and CEC after RWCS

An alternate trend was observed while recording free CaCO$_3$ (%) and CEC [cmol (p$^+$) kg^{-1}], while, free CaCO$_3$ (%) was found to be reduced in all other treatments as compared to control, CEC [cmol (p$^+$) kg^{-1}] was found to be increased significantly in various treatments over control

(Fig. 1). Among inorganic treatments lowest free $CaCO_3$ (%) (36.39%) was observed with 150% NPK and with combined application of compost and CR among organic ones (34.69%). Free $CaCO_3$ (%) was observed to be reduced by 6% maximum from the control (38.53 %) in case of different doses of RDF and 12% over respective control (39.57%) in case of various organic treatments the interaction between both being significant. Cation exchange capacity [cmol (p^+) kg^{-1}] showed an ascending trend while moving from control to superior treatments (150% NPK+ compost+ CR) i.e. by 34% over control.

Reduced levels of free $CaCO_3$ (%) being good indicator of soil health was established due to long-term application of organics and inorganics. Though interaction between both the inorganic and organic treatments was found to be significant the reduction in free $CaCO_3$ (%) was a result of combined application of organics and inorganics. Which might be due to the acidic nature of fertilisers applied (urea and SSP) in case of organic treatments and production of carbonic acid (HCO_3) due to decomposition of organic materials in organically treated plots [18]. In contrast, enhanced CEC is an important chemical phenomenon showing increased nutrient availability to crops [21]. The increased CEC was a result of increased application of inorganic fertilisers which consist of cations (K^+ and NH_4^+) in different doses of RDF and while comparing organic treatments increased organic matter contributed to better CEC of the corresponding soil [22].

3.3 Effect of long-term application of organics and inorganic NPK fertilisers on bulk density and water holding capacity after RWCS

A similar alternate trend was observed while comparing two physical properties i.e. BD (Mg m^{-3}) and WHC (w/w %) as presented in Fig. 2. While BD was reduced by 32% in plots receiving combined application compost and CR with 150% RDF over control (1.62 Mg m^{-3}); WHC was enhanced by 29% in the same plots as in case of BD over control (27.53%).

As, BD and WHC are the functions of soil porosity (%), both are influences by application of organic matter. Organic matter improves soil porosity (%) which further have positive effect on soil WHC and negative effect on BD [18,23]. Organic matter addition reduces soil BD by reducing the compactness of soil and increasing porosity thereby enhances the WHC (%) [18,24]. Both of the results are favourable for soil health, plant growth and yield.

Table 2. Effect of long term application of organics and inorganic fertilisers on soil pH, EC (dSm^{-1}) and Soil Organic Carbon (g kg^{-1}) after rice- wheat cropping system (2020)

| Treatments	Soil pH	Soil EC (dSm^{-1})	Soil Organic Carbon (g kg^{-1})
Fertilisers			
No NPK	8.21	0.26	5.49
50% NPK	8.16	0.24	6.41
100% NPK	8.12	0.22	6.74
150% NPK	8.07	0.20	7.33
SEm±	0.05	0.00	0.08
LSD (*p* =0.05)	0.17	0.01	0.28
Manures			
No Organics	8.15	0.26	5.56
Compost	8.15	0.24	6.57
Crop residue	8.14	0.21	6.22
Compost + Crop residue	8.11	0.22	7.58
SEm±	0.04	0.00	0.08
LSD (*p*=0.05)	NS	0.01	0.22
LSD (*p*=0.05) (Interaction)	NS	0.02	NS
SEm± (Interaction)	0.07	0.01	0.15
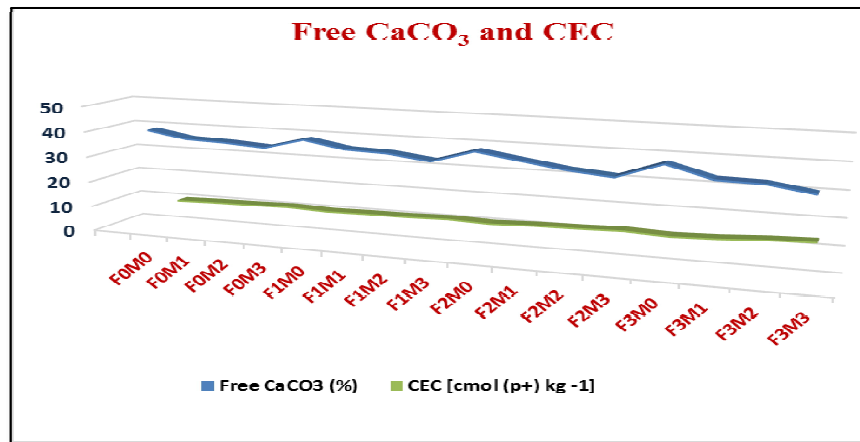
Fig. 1. Effect of long-term application of organics and inorganics on free CaCO₃ (%) and cation exchange capacity [cmol (p⁺) kg⁻¹] of calcareous soil after Rice- Wheat cropping system (2020)
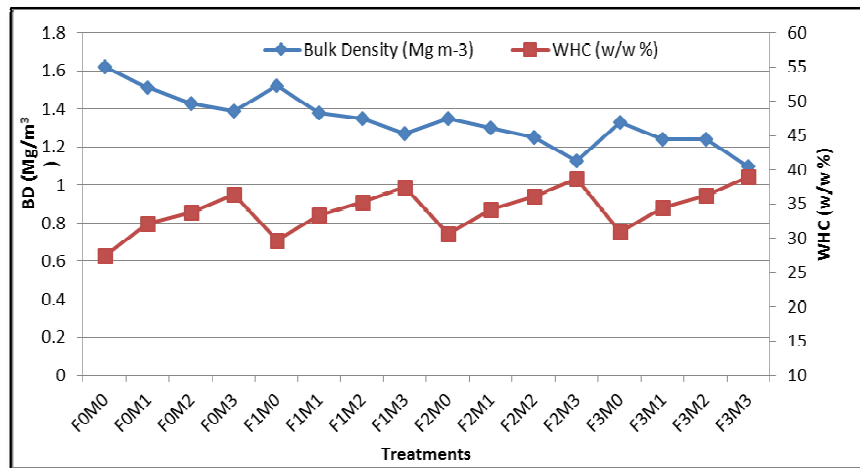

Fig. 2. Effect of long-term application of organics and inorganics on bulk Density (Mg m⁻³) and water holding capacity (w/w %) of calcareous soil after Rice- Wheat cropping system (2020)

4. CONCLUSION

All the physico-chemical properties were influenced by long-term application of organics and inorganic NPK fertilisers. Soil organic carbon in the fertilized plots was observed to be enhanced as compared to unfertilized plots. A reduction in soil pH and electrical conductivity was observed in plots receiving organic and inorganic treatments. Free calcium carbonate content was found to be reduced whereas cation exchange capacity was improved due to application of organics along with right doses of fertilisers. Same trend was seen in case of bulk density and water holding capacity of the experimental plots the former being reduced and the latter being improved due to combined application of organics and inorganic fertilisers. An improved organic matter content is the indication of better availability of nutrients to plants and better microbial activity in the soil. Whereas an improved cation exchange capacity indicates towards better absorption of nutrients by plants hence better crop growth. As the experimental soil is calcareous in nature a reduction in soil pH due to various treatments provides a suitable soil environment for various biochemical process in the soil. A reduced bulk density and improved water holding capacity are the suitable soil physical conditions for better soil aeration, root penetration, root growth and better water availability to plants during their growth period. Therefore, it can be concluded that balanced application of different levels of RDF

along with different organic treatments could improve overall soil health; thereby could contribute directly to better crop growth and even better crop yield and a sustainable soil health.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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