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Anand Kumar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Santosh Kumar Singh
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Bishnuprasad Dash
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Mani Mesha Nand
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Md. Mahtab Alam
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Deepak Kumar Prabhakar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Corresponding Author:
Anand Kumar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Effect of long–term crop-residue management on soil properties in rice-wheat cropping system in calcareous soil of North India

Anand Kumar, Santosh Kumar Singh, Bishnuprasad Dash, Mani Mesha Nand, Md. Mahtab Alam and Deepak Kumar Prabhakar

Abstract
A study was conducted in an ongoing field experiment in a calcareous soil in north-west alluvial plains of Bihar at Research Farm of Dr. Rajendra Prasad Central Agricultural University, Pusa. The experimental design was split-plot with four crop-residue (0, 25, 50 & 100%) levels in main plots and four levels of Zn application (0, 2.5, 5.0 & 10 kg ha^{-1}) in sub-plots. Post-harvest surface soil samples after 23rd wheat crop were analyzed for physical and chemical properties, *viz*., bulk density, water holding capacity, volumetric water content, pH, EC and $CaCo_3$ content. Recycling of increasing levels of crop-residue enhanced significantly the properties of soil like water holding capacity, volumetric water content whereas suppressing effect of crop-residue on pH and bulk density of soil was observed. Crop residue management improves all above soil properties of soil and increases the nutrient availability in soil.

Keywords: Bulk density, water holding capacity, crop residues, calcareous soil, calcium carbonate content

Introduction

Rice-wheat, an important cropping system, covers an area of 13.5 million hectares in South Asia and is vital for food security in the region. The system is prevalent in fertile soils occurring in hot semi-arid to hot sub-humid regions of the Indus and Gangetic alluvial plains of Bangladesh, India, Nepal and Pakistan. This is the most dominant system of the north-Indian states, such as Punjab, Haryana, Bihar, Uttar Pradesh and Madhya Pradesh, and contributes approximately three-fourth of total national food-grain production. A decline in land productivity under rice-wheat system has been observed over past few years despite application of optimum levels of inputs. The recycling of crop residues has the advantage of converting the surplus farm waste into useful product for meeting nutrient requirement of crop. It also maintains the soil physical and chemical condition and improves the overall ecological balance of the crop production system. Globally, about four billion tons of crop residues are produced (Chen *et al*., 2013) [8]. Removal of crop residues has a negative effect on organic carbon status of soil, but Blanco-Canqui (2013) [5] estimated that 25–50% of crop residues could be harvested without threatening soil functions.

Soil physical properties play a key role in soil sustainability and crop production (Amezketa, 1999) [1]. Soil moisture can positively impact leaf area index and crop yield while it can negatively affect crop emergence (Odjugo, 2008) [14]. Soil texture has a large influence on water holding capacity (Bouma *et al*., 2003) [6], water conducting ability, soil structure (Tueche *et al*., 2007) [22], chemical soil properties and the relative stabilization of soil organic matter (Six *et al*., 2002) [20]. Moreover, the proportions of sand, silt and clay can correlate diversely with crop yield (Tueche *et al*., 2013) [23]. The addition of organics reduces the bulk density of soil (Bhatia and Shukla, 1982; Sharma *et al*., 2000) [3, 18]. Mulumba and Lal (2008) [13] also reported that the addition of crop residues to cultivated soils had positive effects on the soil porosity, available water content, soil aggregation, and bulk density. Li *et al*. (2006) and Tan *et al*. (2007) [29] found that straw incorporation can promote a favorable soil environment for production, while also maintaining the physico-chemical condition of the soil and improving the overall ecological balance of the crop production system. Bhagat and Verma (1991) [27] showed that the incorporation of crop straws for 5 years significantly increased the crop yield and improved the soil properties.

Thus, long-term straw incorporation has positive effects on the soil quality. However, the application of straw incorporation in hot humid subtropical region of India has not been reported previously. Thus, we investigated the effects of 23-year crop residue incorporation combined with initial application of zinc on the soil bulk density, porosity, volumetric water content, maximum water holding capacity, pH, electrical conductivity (EC) and calcium carbonate content in Entisol of northern region of India.

Materials and Methods

A study was conducted in an ongoing field experiment under AICRP on Micro- and Secondary Nutrients and pollutant Elements in Soils and Plants, initiated in *Kharif*, 1994 in light textured highly calcareous soil at Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India, having 25^0 94' N latitude, 85^0 67' E longitude and an altitude of 52.00 meter above mean sea level. The climate is sub-tropical having average annual rainfall 1135 mm. The experimental design was split-plot with four crop-residue (0, 25, 50 & 100%) levels in main plots and four levels of Zn application (0, 2.5, 5.0 & 10 kg ha^{-1}) in sub-plots. Subplot treatments were applied only once in the year 1994. The soil of experimental area having texture sandy loam, pH 8.4, organic carbon 5.07 g kg^{-1} and $CaCO_3$ content 366 g kg^{-1}. Rice and wheat crops are being grown continuously with necessary tillage under rice-wheat system during *kharif* and *rabi* seasons. The chopped straw of the previous crops treated as crop residues, was incorporated as per treatment. The source of N, P and K was urea, di-ammonium phosphate (DAP), muriate of potash (MOP), respectively. Dose of fertilizer was 120, 60, 40 (N, P_2O_5, K_2O).

Physical Analysis

A. Bulk density

The core sampler was pressed into the soil in such a way that soil is collected by core from the centre of surface soil depth (0-15 cm). Soil samples were dried in oven at 105^0C for 24 hrs. Bulk density (Mg m^{-3}) was calculated by dividing the weight of dried soil by the volume of core used (Blake, 1986) using the following formula.

$$\text{Bulk density (Mg m}^{-3}\text{)} = \frac{\text{The weight of oven dry soil (Mg)}}{\text{The volume of soil (m}^3\text{)}}$$

The volume of the soil was taken as the inner volume of the core sample, which was, in turn, calculated by $\Pi r^2 h$, where r-radius, h-height of the core.

B. Soil porosity

The soil porosity was calculated using the bulk density (BD) and particle density (PD, 2.65 Mg m^{-3}) according to the following equation:

Porosity (%) = (1-BD/PD)

C. Volumetric Water Content

Volumetric Moisture Content was estimated by multiplying bulk density with corresponding soil moisture content.

D. Water Holding Capacity

Water holding capacity was determined by Keen box method (Piper, 1966) [15].

Chemical Analysis

A. Soil pH:

The pH of the suspension of soil in water with a soil water ratio of 1:2 was determined with the help of glass electrode pH meter (Jackson, 1973) [10].

B. Electrical Conductivity

The electrical conductivity in the clear extract of soil with water in soil: water ratio of 1:2 was determined with the help of Electrical Conductivity Bridge (Bower and Wilcox, 1965) [7].

C. Free Calcium Carbonate content:

It was determined by the rapid titration method (Piper, 1966) [15].

Results and Discussion

Bulk density (BD) is an important soil property because it affects soil porosity, which in turn affects water infiltration. In the present study, bulk density of surface soil decreased from 1.47 Mg m^{-3} to 1.36 Mg m^{-3} (presented in table 1) with increasing crop residue levels (0 to 100%). The BD significantly reduced to 1.36 Mg m^{-3} with 100% crop residue incorporation in comparison with 50, 25% and no crop residue treated plots. This might be due to crop residue is lighter than mineral matter and residue decomposition products should promote more aggregation and thus reduce bulk density. No significant decrease in BD was observed with increase in the residue rate from 50% to 100%. Bhatia and Shukla (1982) [3] recorded that addition of organics reduced the bulk density of soil. A similar result was also found by Sharma *et al*. (2000) [18] and Shukla and Tyagi (2009) [19]. No significant decrement or increment pattern in BD was found in treatment receiving different residual zinc levels. In this study, we found that the residues incorporation significantly increased the total porosity. After 23 years, it increased 9.5% in treatment receiving 100% crop residue compared to that received no crop residue. This improvement was attributed to the incorporation of crop straw, which caused the soil particles to stick together and form aggregates. Thus, the bulk density was reduced and the total porosity increased (Wei *et al*., 2006) [30]. The change in total porosity by different levels of zinc application was not significant.

Volumetric water content (VWC) is the product of moisture content, bulk density and depth of soil. In the present study volumetric water content varied from 3.42 to 4.01 cm for 15 cm soil depth (table 1). It increased significantly with subsequent increase in crop residue levels. After 23 years of crop residue incorporation VWC increased by 4.68, 10.23, 17.25% in treatments receiving 25%, 50%, 100% crop residue compared to no crop residue treatment. Similar result has been reported by Karami *et al*. (2012) [11]. They found that incorporation of crop residues into the soil significantly improved the soil physical and chemical properties and increased soil water storage. No significant increment in volumetric water content was found with increased residual zinc level.

Maximum water holding capacity (WHC) of the surface soil increased from 34.92 to 43.55% (table 1) with increasing levels crop residue. WHC varied due to increasing levels of Zn from 38.87 to 39.66%. The maximum water holding capacity (44.84%) was recorded in the plot receiving 5 kg zinc per hectare and 100% of crop residue, whereas the minimum (34.27%) in the plot receiving 5 kg Zn ha^{-1} and no crop residue. Similar results were obtained by Saha *et al*.

(2010) [17], who also reported that the continuous application of balanced nutrition, FYM, microbial inoculants and crop residue induced substantial buildup of SOC, associated with improvement in soil aggregate size (48.82%) and stability (39.57%), water retention and porosity (32.41%) of the soil over fertilizer NPK. Water holding capacity was not affected by residual zinc levels.

The pH of soil under different main-plot treatments ranged between 7.96 and 8.20 (presented in table 2). Incorporation of the crop residue with inorganic fertilizers significantly reduced the soil pH as compared to application of inorganic fertilizers alone. The pH was significantly reduced to 7.96 with 100% crop-residue incorporation as compared to 25% and no crop residue treated plots. No significant decrease in pH was observed with increase in residue rates from 50% to 100% and 0% to 25%. Decrease in soil pH can have positive impact on availability of nutrients, such as phosphorus, zinc, iron and manganese (Benbi *et al*., 2009) [2]. Decrease in soil pH with the incorporation of crop residue might be due to production of organic acid and release of CO_2 during the decomposition of organic matter. Similar findings were reported by Yang *et al.* (2015) [26] and Harikesh *et al.* (2017) [9]. The pH of soil under different sub-plot treatments ranged from 8.06 to 8.09. However, there are also some opposite observations regarding the effect of crop residues on soil pH, which may result from differences in composition and type of plant residues, characteristics of soils, and experimental conditions of studies (Xu *et al*., 2006) [25]. Residual zinc levels did not influence soil pH significantly.

Table 1: Effect of Long- term Crop-Residue Incorporation on Bulk Density, Volumetric Water Content, Maximum Water Holding Capacity and Porosity of Soil

Crop residue level (% of straw produced)	Bulk Density (Mgm^{-3})	Volumetric Water Content (cm)	Maximum Water Holding capacity (%)	Porosity (%)	Zn levels (kg ha^{-1})	Bulk Density (Mgm^{-3})	Volumetric Water Content (cm)	Maximum Water Holding capacity (%)	Porosity (%)
0	1.47	3.42	34.92	44.55	0	1.42	3.74	39.25	46.42
25	1.43	3.58	37.77	45.93	2.5	1.42	3.69	38.87	46.47
50	1.39	3.77	40.88	47.43	5	1.40	3.66	39.66	47.09
100	1.36	4.01	43.55	48.79	10	1.41	3.69	39.34	46.72
SEm±	0.008	0.036	0.654	0.321	SEm±	0.006	0.060	0.494	0.228
CD (P=0.05)	0.03	0.13	2.30	1.13	CD (P=0.05)	NS	NS	NS	NS

The EC values in all the treatments were less than 0.6 dS m^{-1}(table 2), which is considered safe for growth of all crops. The electrical conductivity of soil was not significantly influenced by different levels of crop residue incorporation and residual zinc level. Electrical conductivity was maximum in the treatment receiving 25% crop residue followed by that in no crop residue. Treatments receiving five kg of residual zinc and no zinc had more electrical conductivity than others. Stalin *et al*. (2006) [21] also found that electrical conductivity of soil was not influenced by long-term continuous application of manure.

Crop residue incorporation reduced the calcium carbonate content of soil from 34.72 to 33.83 (presented in table 2). It reduced non-significantly after twenty three years of crop residue incorporation, too, reduction in $CaCO_3$ content was much less probably because high amount of free calcium carbonate (34.66%) present in soil. However, the reduction might be due to organic acid released during the decomposition of organic materials reacting with and solubilized $CaCO_3$ (Prasad, 1994) [16]. There was no reduction or increment found in the treatments receiving different residual zinc levels. Similar result was reported by Keram *et al*. (2012) [12]. They found that effect of 100 % NPK in combination with different levels of Zn did not affect the $CaCO_3$ content of soil significantly.

Table 2: Effect of Long- term Crop-Residue Incorporation on Soil pH, Electrical Conductivity and Calcium Carbonate

Crop residue level (% of straw produced)	pH	Electric Conductivity (dS m^{-1})	$CaCo_3$ Content (%)	Zn levels (kg ha^{-1})	pH	Electric Conductivity (d Sm^{-1})	$CaCo_3$ Content (%)
0	8.20	0.47	34.72	0	8.06	0.49	34.23
25	8.11	0.52	34.29	2.5	8.09	0.48	34.19
50	8.01	0.46	34.11	5	8.06	0.49	34.25
100	7.96	0.45	33.83	10	8.08	0.45	34.28
SEm±	0.027	0.029	0.264	SEm±	0.029	0.025	0.303
CD (P=0.05)	0.095	NS	NS	CD (P=0.05)	NS	NS	NS

Conclusion

Long –term application of crop residues reduces the pH, calcium carbonate, bulk density and increases water holding capacity and porosity of calcareous soil, which increases the availability of water and nutrients in soil leads to better plant growth.

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