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Bidisha Borpatragohain
Department of Soil Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Vipin Kumar
Department of Soil Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Ranjan Laik
Department of Soil Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Shiv Nath Suman
Department of Soil Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Navneet Kumar
Department of Soil Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Corresponding Author:
Bidisha Borpatragohain
Department of Soil Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Soil chemical properties as influenced by crop establishment and residue retention in rice-wheat cropping system of indo-gangetic plains

Bidisha Borpatragohain, Vipin Kumar, Ranjan Laik, Shiv Nath Suman and Navneet Kumar

Abstract
Long-term field experiments are important for explaining tillage and residue effects on soil fertility and to develop sustainable nutrient management strategies. An investigation was conducted at Research Farm, Rajendra Agricultural University, Pusa during *kharif* 2019 and *rabi*, 2019-2020. The experiment was planned as randomized block design and was replicated thrice having eight treatment combinations. Soil from the experimental field (0-15 cm depth) was sampled and laboratory analysis following the standard procedures of various chemical properties was conducted to study the combined effects of crop establishment and residue retention. The results showed a reduction in pH and EC by 6.88% and 57.5% in the plots where crop residue was retained on permanent beds with zero tillage over control. The available B, Zn, Cu, Fe and Mn contents were significantly influenced by application of CA practices after harvest of wheat. Thus, we can observe that conservation tillage practice with residue retention have a positive effect on the soil chemical properties and can certainly increase crop growth and yield.

Keywords: Conservation tillage, Residue retention, pH, EC, soil available boron, soil available micronutrient cations

1. Introduction
The increasing world population demands more food leading to increase pressure on the already limited resources. One way to meet this challenge is to increase the productivity of poor soils. Rice–wheat cropping system (RWCS) being the world's largest agricultural production system occupies a significant area in the Indo-Gangetic plains (IGP), feeding about 1/5th of world population. In India, an estimated area of about 40 million hectares (mha) for rice and about 25 mha for wheat, together contribute more than 70% of total cereal production in India (Singh, 2000) [23].

According to Ladha *et al*. (2000) [12] in Asia, the rice-wheat system has been practiced for over 1000 years; it has since expanded and is now estimated at 23.5 million ha, including China with about 10 mha and South Asia with about 13.5 mha. With the use of various inputs and adoption of improved agronomic practices during green revolution, an impressive gain in production was witnessed but now the sustainability of the system is doubtful. Deteriorating soil health, stagnation of yield in rice-wheat cropping system (RWCS) in this belt and environmental pollution is posing a threat to food security. Tillage operation leads to the breakdown of organic matter and release of carbon dioxide to the atmosphere and hinders the sequestering of carbon in the soil. This could be further aggravated with deterioration of soil structure, declining underground water and lesser land and water productivity which ultimately are threat in front of sustainable and profitable RWCS in the region (Srinivasrao *et al.*, 2019) [26]. Hence, conventionally grown rice and wheat are labour-, water-, capital- and energy-intensive. To enhance soil productivity in rice-wheat system of the Indo-Gangetic Plains, conservation agriculture based management practices might be better option for sustainability in crop production.

Conservation agriculture (CA), typically represented by crop residue retention, and no-tillage (NT) or reduced tillage (RT), has been widely practiced to alleviate the negative effect of conventional soil management practices; such negative effects include loss of nutrients. Conservation tillage and residue management aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs.

It reverses soil degradation processes and builds up soil fertility through increase in water holding capacity, facilitating better infiltration of rainwater and enhancing ground water storage, enrichment in soil organic carbon (SOC), and enhanced microbial diversity in the rhizosphere. It eliminates power-intensive soil tillage, thus reducing the drudgery and labour required for crop production by more than 50% of the small scale farmers. It can be referred to as resource-efficient agriculture.

Likewise, crop residue management can provide a number of environmental benefits, including: reduced soil erosion, improved moisture content in soil; healthier, more nutrient-enriched soil; more earthworms and beneficial soil microbes; reduced consumption of fuel to operate equipment; the return of beneficial insects, birds and other wildlife in and around fields; less sediment and chemical runoff entering streams; reduced potential for flooding; and less carbon dioxide, dust and smoke to pollute the air.

Experiments conducted at various locations in the north-eastern IGP of India revealed that conservation agriculture (CA) based management practices can stabilize crop yield and reduce production costs (Parihar *et al.*, 2017) [20], increase the soil organic matter content and can improve the soil quality in long term (Parihar *et al.*,2016) [21]. Still, there is a rarity of information regarding the effect of crop establishment and conservation tillage practices on the various chemical properties of soil.

Materials and Methods

A. Experimental Site characteristics

The experimental field is located at Research Farm, Rajendra Agricultural University, Pusa, Samastipur, Bihar (25°30' N latitude, 85°-40' E longitude) and 52.00 meter above mean sea level, in sub-tropical humid climate. The long term experiment was initiated during *Kharif* 2006 on the sandy loam calcareous soil of Pusa. The site usually experiences hot and humid summers and cold winters with an annual rainfall of 1344mm, two-third of which is concentrated around July to September (Jat *et al.*, 2019) [10].

The soil of the experimental site belongs to order *Entisol*, suborder Fluvents, great group Ustifluvent and is taxonomically characterized as Calciorthents. The soil of the experimental field is sandy loam in texture with alkaline pH of 8.86, EC 1.06 dSm^{-1}, soil available Fe, soil available Mn, soil available Cu and soil available Zn is 13.85, 5.01, 3.95 and 0.70 mg kg^{-1}, respectively.

B. Treatments and Experimental Design

Eight combinations of tillage and crop establishment methods for a rice-wheat cropping system were established in large plots (each plot of 450 m^2). All the treatments were completely randomized and replicated thrice within a block. Treatment details were: Puddled transplanted rice followed by conventional tillage wheat [PTR-CTW]; Puddled transplanted rice followed by zero tillage wheat [PTR-ZTW]; Zero tillage rice followed by zero tillage wheat on permanent beds having 100% crop residues [ZTR-ZTW+RB+R]; Zero tillage rice followed by conventional tillage wheat (without residues) [ZTR-CTW-R]; Zero tillage rice followed by zero tillage wheat on permanent bed (without residues) [ZTR-ZTW +RB-R]; Zero tillage rice followed by zero tillage wheat having 100% crop residue retained on soil [ZTR-ZTW+R]; Direct seeded broadcasted rice followed by zero tillage wheat (only rice residue in wheat cycle) [DSBR-ZTW+RR]; Zero tillage rice with brown manuring followed by zero tillage wheat (without residues) [ZTRBM-ZTW].

C. Crop establishment

Kharif rice crop *cv.* Rajendra Mahsuri was grown with a seed rate of 30 kg ha^{-1} for puddled transplanted rice and direct seeded broadcasted rice; and 25 kg ha^{-1} under Zero tillage and bed planting transplanted. Wheat crop *cv.* HD-2967 with a seed rate 150 kg ha^{-1}, 70 kg ha^{-1} and 100 kg ha^{-1} for Conventional tillage wheat; Zero tillage with bed planting; and Zero tillage; respectively.

Scheduled supply of N, P_2O_5 and K_2O nutrients were made in the form of urea, di- ammonium phosphate (DAP) and muriate of potash (MOP), respectively in both rice and wheat crops. Both rice and wheat crops were fertilized @ 150, 60 and 60 kg of N, P_2O_5 and K_2O per hectare, respectively irrespective of the treatments. The total amount of P_2O_5 and K_2O and half dose of N were applied using di-ammonium phosphate and muriate of potash as basal dose at the time of seeding with seed-cum-fertilizer drill and N was applied in 2 equal splits using urea. In the treatment ZTRBM-ZTW, brown manuring was prepared where both rice and *Sesbania* crops were allowed to grow together and after 25-30 days of sowing, application of 2, 4-D (0.5 kg ha^{-1}) was made to kill the co-cultured *Sesbania*.

The surface mulch of dhaincha follows rapid decomposition to supply N. However application of 2, 4-D reduces weed population by nearly half without any adverse effect on rice yield. In permanent beds and zero till plots, weeds prior to seeding of rice and wheat were killed using pre-plant application of Glyphosate @ 1.25 L a.i. (active ingredient) per hectare but no herbicide was applied in conventionally tilled plots before seeding.

The weed in the experimental plots was controlled by using pre-emergence as well as post-emergence herbicides as and when required, but when applied, it was applied in all treatments. The herbicides used for weed control in rice were: Bispyribac sodium (25 g a.i. ha^{-1}) as post-emergence. In wheat, combinations of Carfentra zone (20 g a.i. ha^{-1}) and Clodinafop (60 g a.i. ha^{-1}) were used as post-emergence.

D. Sample collection and Analysis

Composite representative soil samples from each plot were collected as triplicates from 0-15cm depth after the completion of the cropping cycle in 2020. The collected samples were then shade dried and ground then sieved through a 2mm sieve.

Soil pH was estimated with a glass electrode pH meter from the soil: water suspension (1:2) as suggested by Jackson (1973) [9]. EC [dSm^{-1}] was measured using an electrical conductivity meter from the clear extract (1:2 soil: water ratio) (Jackson, 1973) [9]. Soil available B from hot water soluble B method (Berger and Troug, 1939) [2] and micronutrient cations from DTPA extractable method using AAS (Lindsay and Norvell, 1978) [14].

E. Statistical Analysis

The data were statistically analyzed online (http://14.139.232.166/opstat/ default.asp) using analysis of variance technique (ANOVA) in randomized block design (Sheoran *et al.*, 1998) [22]. The mean values were adjudged for testing significance using a critical difference value at $P \leq 0.05$.

Results and Discussion

A. Effect of residue retention and tillage practices on soil pH and EC after rice-wheat cropping system

The soil pH and EC values were also reduced by tillage practice. The conservation agriculture practices significantly altered the pH and EC recorded after wheat harvest as revealed by data enumerated in table 1. The data on pH and EC after harvest of wheat under different tillage practices were significantly reduced by zero tillage and residue management. After wheat harvest, the level of pH was decreased to some extent in all the treatment as compared to the initial pH value (8.86).

The lowest value of pH recorded in treatment ZTR-ZTW(B)+R (8.25) was statistically at par with ZTR-ZTW+R (8.30) and ZTR+BM-ZTW (8.30) and significantly lower as compared to conventional practices PTR-CTW (8.67). The decrease in pH value in treatments with conservation agricultural practices might be due to the dissolution of basic cations by the organic acid, produced during decomposition of crop residues Yang *et al.* (2015) [27] and Harikesh *et al.* (2017) [8]. Decrease in pH of calcareous soils may also be due to the release of sufficient amount of CO_2 during decomposition of organic matter. The increased concentration of CO_2 produces hydrogen ions (H^+) reacting with soil water and thereby decreases the soil pH (Das, 2016) [5].

Almost similar trend was followed by EC after wheat harvest as evident from data presented in Table 1. After wheat harvest, the level of EC was decreased as compared to EC recorded before the start of experiment (1.06 dS m^{-1}). The lowest value of EC recorded in treatment ZTR-ZTW(B)+R (0.45 dSm^{-1}). The net results showed that pH and EC decreased after completion of one cycle of rice wheat cropping. It has also been proposed that greater leaching under zero tillage was responsible for the higher removal of bases from upper layer to lower soil layer, which led to a lowering of surface soil pH (Blevins *et al.*, 1983) [3].

The lower soil pH was associated with lower EC. These findings are in line with those of Matowo *et al.* (1999) [15] and Lilienfein *et al.* (2000) [13] who also observed that conservation agriculture (CA) practices lowered the pH & EC. Decomposition of organic matter present in the surface layer can produce organic acids which can reduce the pH (Singh *et al.*, 2014, Li *et al.*, 2020, Noori *et al.*, 2021) [24, 25, 19]. Upon decomposition, organic acids synthesized can solubilize the salts which were then subjected to leaching with irrigation water hence, reducing the soil EC (Kumar *et al.*, 2014, Alijani *et al.*, 2021) [11, 1].

Table 1: Effect of tillage practices and residue management on pH and EC after wheat under rice wheat cropping system

Treatment	pH	EC
T_1: PTR-CTW	8.67	0.95
T_2: PTR-ZTW	8.64	0.80
T_3: ZTR-ZTW(B)+R	8.25	0.45
T_4: ZTR-CTW-R	8.58	0.56
T_5: ZTR-ZTW(B)-R	8.40	0.54
T_6: ZTR-ZTW+R	8.30	0.48
T_7: DSR-ZTW+R.R	8.32	0.51
T_8: ZTR+BM-ZTW	8.30	0.50
Mean	8.43	0.60
SEm±	0.01	0.02
CD (P=0.05)	0.03	0.05

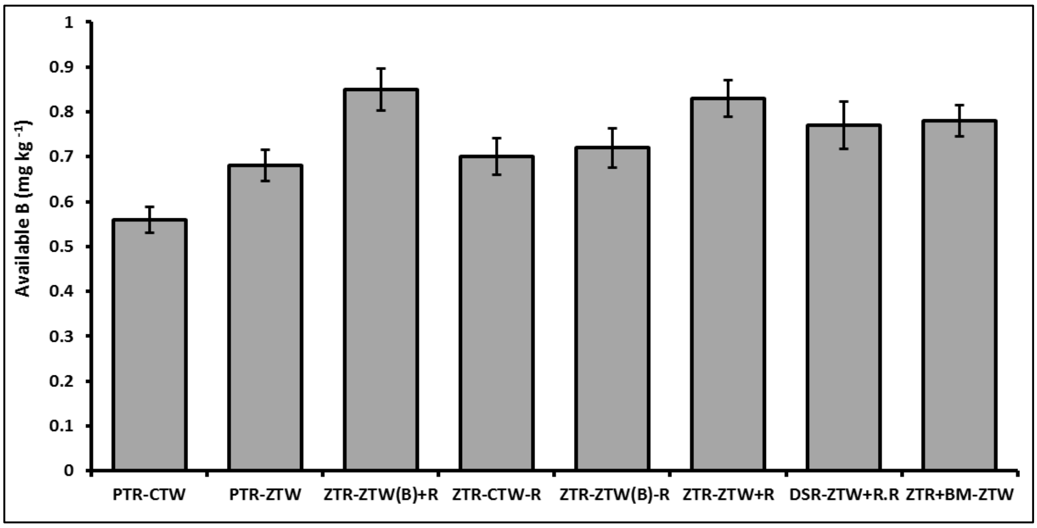

Fig 1: Impact of conservation agriculture on available B content (mg kg^{-1}) in post-harvest soil

B. Effect of residue retention and tillage practices on soil available B after rice-wheat cropping system

Data pertaining to the effect of residue retention and tillage practices on available B of soil after harvest of wheat has been presented in Fig. 1. The soil available B ranged from 0.56 to 0.85 mg kg^{-1} under different treatment details. Crop residue management and residue retention significantly increased the soil available B and the effectiveness followed the order: ZTR-ZTW (B) +R (0.85 mg kg^{-1})> ZTR-ZTW+R (0.83 mg kg^{-1})> ZTR+BM-ZTW (0.78 mg kg^{-1})> DSR-ZTW+R.R (0.77 mg kg^{-1})> ZTR-ZTW(B)-R (0.72 mg kg^{-1})> ZTR-CTW-R (0.70 mg kg^{-1}) > PTR-ZTW (0.68 mg kg^{-1})> PTR-CTW (0.56 mg kg^{-1}). This build-up of available B might be due to transformation of fixed form of B into available form by decomposed roots, stubbles and leaves left over in the soil by each crop (Chander *et al.*, 2007; Nadeem *et al.*, 2019) [4, 51].

C. Effect of residue retention and tillage practices on soil available Zn, soil available Fe, soil available Cu and soil available Mn after rice-wheat cropping system

The available Zn, Cu, Fe and Mn contents were significantly influenced by application of CA practices after harvest of wheat. The data on available Zn after harvest of wheat under different tillage practices were significantly increased by zero tillage and residues management. After wheat harvest, the level of available Zn was increased to some extent in all the treatment as compared to the initial available Zn value (0.70 mg ha^{-1}). The highest value of available Zn recorded in treatment ZTR-ZTW+R (0.92 mg ha^{-1}) was statistically at par with ZTR-ZTW(B)+R (0.89 mg ha^{-1}), ZTR+BM-ZTW (0.88 mg ha^{-1}) and DSR-ZTW+R.R (0.85 mg ha^{-1}) followed by ZTR-ZTW(B)-R (0.82 mg ha^{-1}), ZTR-CTW-R (0.78 mg ha^{-1}) and PTR-ZTW (0.76 mg ha^{-1}) and significantly superior as compared to conventional practices PTR-CTW (0.67 mg ha^{-1}). After harvest of wheat available Zn values were increased by 31% in treatment receiving zero tillage rice- zero tillage wheat with residue ZTR-ZTW+R as compared to initial value of Zn recorded before start of the experiment (2006).

With regard to available Cu status after wheat harvest, the data on available Cu after harvest of wheat under different tillage practices were significantly increased by zero tillage and residues management. After wheat harvest, the level of available Cu was increased to some extent in all the treatment as compared to the initial available Cu value (3.95 mg ha^{-1}). Treatment ZTR-ZTW(B)+R resulted in the highest content (6.85 mg kg^{-1}) which was statistically at par with ZTR-ZTW+R (6.72 mg kg^{-1}) and ZTR+BM-ZTW (6.47 mg kg^{-1}) followed by DSR-ZTW+R.R (6.15 mg ha^{-1}), ZTR-CTW-R (5.42 mg ha^{-1}), PTR-ZTW (4.90 mg ha^{-1}) and ZTR-ZTW(B)-R (3.92 mg ha^{-1}) and significantly superior as compared to conventional practices PTR-CTW (3.55 mg ha^{-1}). The data on available Cu after harvest of wheat under different tillage practices were significantly increased by zero tillage and residues management.

After wheat harvest, the level of available Fe was increased to some extent in all the treatment as compared to the initial available Fe value (13.85 mg ha^{-1}). The highest value of available Fe recorded in treatment ZTR-ZTW+R (18.00 mg ha^{-1}) was statistically at par with ZTR-ZTW(B)+R (17.8 mg ha^{-1}), ZTR+BM-ZTW (17.6 mg ha^{-1}), DSR-ZTW+R.R (17.00 mg ha^{-1}) and ZTR-CTW-R (16.2 mg ha^{-1}) followed by ZTR-ZTW(B)-R (16.1 mg ha^{-1}) and PTR-ZTW (15.7 mg ha^{-1}) and significantly superior as compared to conventional practices PTR-CTW (15.2 mg ha^{-1}). After harvest of wheat available Fe values were increased by 30% treatment receiving zero tillage rice-zero tillage wheat with residue ZTR-ZTW+R as compared to initial value of Fe recorded before start of the experiment (2006).

The available Mn after harvest of wheat under different tillage practices were significantly increased by zero tillage and residues management. After wheat harvest, the level of available Mn was increased to some extent in all the treatment as compared to the initial available Mn value (5.01 mg ha^{-1}). The highest value of available Mn recorded in treatment ZTR-ZTW+R (6.91 mg kg^{-1}) was statistically at par with ZTR-ZTW(B)+R (6.80 mg kg^{-1}) followed by ZTR+BM-ZTW (6.61 mg kg^{-1}), DSR-ZTW+R.R (6.15 mg kg^{-1}), ZTR-ZTW(B)-R (5.88 mg kg^{-1}), ZTR-CTW-R (5.60 mg kg^{-1}) and PTR-ZTW (5.53 mg kg^{-1}) and significantly superior as compared to conventional practices PTR-CTW (5.31 mg kg^{-1}). After harvest of wheat available Mn values were increased by 37.92% treatment receiving zero tillage rice-zero tillage wheat with residue ZTR-ZTW+R as compared to initial value of Mn recorded before start of the experiment (2006).

Addition of organic matter or humus will often chelate (form complexes with) the metals, which tends to increase or maintain their availability to plants, even at higher pH levels (McCauley, 2009) [16]. Numerous compounds including humic & fulvic acids and a variety of biochemical substances like, organic acids, polyphenols, amino acids and polysaccharides of different organic matters and crop residues form stable complexes with Fe, Mn, Cu and Zn (Prassad *et al.*, 1984) [7]. The results are in conformity of those reported by Franzluebbers and Hons (1996) [18] and Fando and Pardo (2009) [6].

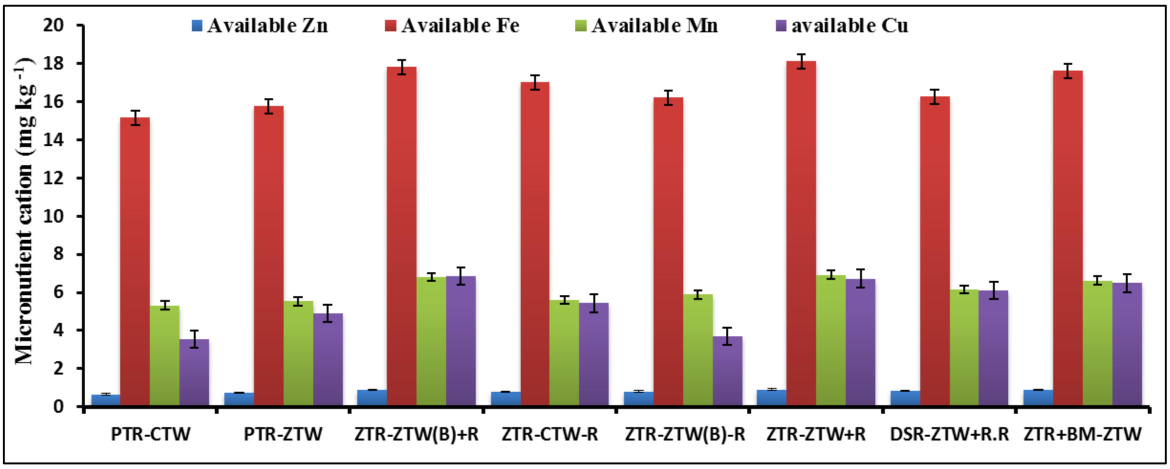

Fig 2: Impact of conservation agriculture on micro nutrient cation content (mg kg^{-1}) in post-harvest soil

Conclusion

On the basis of foregoing findings it may be concluded that conservation agriculture (CA) practices are an ecological approach to soil surface management. Proper use of crop residues with zero tillage favored the nutrient buildup and improved the soil environment. Distribution of nutrients in the soil profile (0-15 cm) was altered as a result of various CA practices being applied for a 7 years period. Nutrients accumulated at the soil surface under CA practices and improved soil physical, chemical and biological conditions. Zero tillage practices without residues retention also improved the nutrients but to a lesser extent as compared to zero tillage with residues retention. In addition, available nutrient status was better in 0-15 cm soil depth under CA practices as compared to conventional practices. CA based rice-wheat production system is one of the pathways for improving productivity, income and food security while sustaining the natural resources in Calcareous soils of Bihar. Thus, PBZTR- ZTW+RB (T3) and ZTR-ZTW+RB (T6) may be recommended to farmers in the best interest of conservation agriculture.

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