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Effect of Reversal of Conservation Tillage on Soil Nutrient Availability and Crop Nutrient Uptake in Soybean in the Vertisols of Central India

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Abstract: Effect of conservation tillage on crop performance and soil properties has been studied extensively under different agro-climatic situations. However, the impact of reversal from conservation tillage to conventional tillage on crop growth and soil nutrient release is rarely addressed. Thus, this study was conducted by converting half of the eight years old conservation tillage experiment to the conventional one with a similar level of residue return to compare the effect on soil nutrient availability and nutrient uptake in soybean crops in the Vertisols of Central India. The conservation tillage treatments included no-tillage (NT) and reduced tillage (RT) with 100% NPK (T1), 100% NPK + farmyard manure (FYM) at 1.0 Mg-carbon (C)/ha (T2), and 100% NPK + FYM at 2.0 Mg-C/ha (T3). After eight years of the experiment, the RT and NT treatments were subjected to conventional tillage, and thus the tillage treatments were RT-CT, RT, NT, and NT-CT. After tillage reversal for three growing seasons, soybean yield and nutrient uptake (N, P, K) got significantly influenced by the tillage and nutrient management. Averaged across nutrient treatments, NT showed highest soil organic carbon (SOC) content (8.4 g/kg) in the surface 0–5 cm layer. However, at 5–15 cm depth, the SOC was greater in the RT-CT treatment by 14% over RT and by 5% in the NT-CT treatment over NT. The soil nutrient availability (N and P) was not significantly ($p > 0.05$) affected by the interaction effect of tillage and nutrient on the surface soil layer (0–5 cm). Interaction effect of tillage and nutrient was significant on available P content at 5–15 cm soil depth. In contrast to N, soil available P relatively increased with reversal of tillage in both NT and RT. Tillage reversal (NT-CT, RT-CT) and RT had significantly higher available potassium than NT in 0–5 and 5–15 cm soil layers. Among the treatments, NT-CT-T3 showed significantly higher seed N (85.49 kg/ha), P (10.05 kg/ha), and K (24.51 kg/ha) uptake in soybean. The study indicates conventional tillage with residue returns and integrated nutrient management could be a feasible alternative to overcome the limitations of no-till farming in the deep black Vertisols of Central India.

Keywords: tillage reversal; nutrient uptake; crop yield; soil properties; nutrient management; soybean; no tillage; reduced tillage; conventional tillage; residue return

1. Introduction

Conservation tillage as a part of the solution to greenhouse gas mitigation and sustainable agriculture started its history to reduce soil erosion, improve soil organic carbon (SOC), and water storage [1–4]. Conservation tillage including no-tillage (NT) and reduced tillage (RT) has a substantial effect on soil properties and processes compared to conventional tillage [5–10]; these changes are beneficial for the delivery of ecosystem services and regulation of climate through carbon sequestration, greenhouse gas fluxes, and energy security [1,4]. Approximately 20% of the total cultivated area covering a few developed countries like the USA, Brazil, Argentina, Australia, and Canada are presently under conservation agriculture [11]. However, acceptability and spread are limited in developing countries like India [11]. Conservation agriculture, especially no-tillage faces a major challenge of adoption by farmers because of higher weed infestation in the rainy season, lower crop yield in the initial years, increasing soil surface hardness, lack of farm machinery for sowing in heavy residue fields, use of residues for fuel and livestock feed, and lack of skilled manpower [11–13]. Thus, it is difficult to convince farmers of its potential benefits in developing countries like India [14,15]. Although farmers take up no-tillage and reduced tillage with the help of the state agriculture department and national research institutes, they revert to conventional tillage once the efforts of government agencies are withdrawn.

Conservation tillage, especially no-tillage, results in accumulation of crop residues on the soil surface and reduces nutrient distribution in the soil profile [16]. Long-term no-tillage is reported to result in pronounced vertical stratification of soil nutrients, SOC, and other related soil properties [1,3,5,17–20], which is otherwise distributed among soil layers in tilled soils [21]. No-tillage and reduced tillage upon conversion to conventional tillage will have a huge impact on SOC storage, nutrient uptake, and nutrient availability [10]. Further, the stored SOC might be a source of additional CO₂ emissions to the atmosphere. The imposition of intensive tillage practices in previously untilled soils may lead to a rapid breakdown of organic matter connected with deterioration in the physical quality of the soils.

Considering the above constraints related to the adoption of no-tillage, a feasible and more convenient option could be conventional tillage with residue retention. Previous research has clearly shown the significance of residue retention for no-tillage to show a better performance than other tillage practices [22,23]. On the other hand, if conventional tillage which is being practiced by the farmers is integrated with residue retention, it might help in enhanced decomposition and mineralization of residues in soil, the release of plant-available nutrients in the soil system, and preventing stratification of SOC and nutrient availability in soil layers. Further, this may help in unlocking the locked nutrients in soil organic matter and may be beneficial in improving soil nutrient availability and crop uptake [24–26]. Tillage operations reduce soil compaction, improve aeration, and create a better environment for soil microorganisms [27,28].

Keeping the above in view, we propose conventional tillage with residue retention as an alternative approach to no-tillage. It was hypothesized that the SOC storage, soil nutrient availability, and crop growth would be better under conventional tillage with residue retention than no-tillage per se. However, there is little information available globally comparing no-tillage with conventional tillage under uniform residue retention in terms of soil properties, crop yield, and nutrient uptake, and more so when no-tillage plots are converted to conventional tillage. Thus, this study was conducted by converting half of the eight years old conservation tillage experiment to the conventional one with a similar level of residue return to compare the effect on SOC storage, soil nutrient availability, and nutrient uptake in soybean crops in the Vertisols of Central India.

The major objectives of the investigation were to assess the changes in (1) soil available nutrients and SOC storage in different soil layers and (2) crop yield upon reversal to conventional tillage from NT and RT practices with uniform residue levels.

2. Materials and Methods

2.1. Experimental Site

The study was conducted in an on-going eight-year-old field experiment on conservation tillage established in June 2008 at the research farm of ICAR-Central Institute of Agricultural Engineering, Bhopal, India. The study site is located at 23°15'N latitude and 77°25'E longitude, at 427 m above mean sea level, and is characterized by a humid subtropical climate with mild, dry winters and hot summers followed by a humid monsoon season. For other experimental details and initial soil properties of the site, reference is made to Singh et al. [3]. The soil on site was deep Vertisol (Isohyperthermic Typic Haplustert) [29] with clay texture (52% clay), bulk density of 1.34 Mg/m³ at 0.27 g/g soil water content, and medium in SOC. The soil was neutral to alkaline in reaction (pH-7.85) with electrical conductivity of 0.3 ds/m and Ca²⁺ as the dominant exchangeable cation in the Ap horizon.

2.2. Experimental Details

The on-going conservation tillage experiment included no-tillage (NT) and reduced tillage (RT) with 100% NPK (T1), 100% NPK + farmyard manure (FYM) at 1.0 Mg-carbon (C)/ha (T2), and 100% NPK + FYM at 2.0 Mg-C/ha (T3) in a soybean-wheat cropping system. The manure was applied a fortnight before soybean sowing every year. In NT plots there was direct sowing by a no-till-seed cum fertilizer drill and RT plots, one pass rotavator, and sowing by a seed cum fertilizer drill. All the treatments received recommended dose of nutrients for soybean (30:60:30) and wheat (100:60:30) N-P₂O₅-K₂O kg/ha. In the rainy (kharif) season, soybean was sown during the last week of June or first week of July, depending upon the onset of monsoon at a row spacing of 35 cm. Soybean was harvested mostly in the last week of September to the first week of October. In the winter (*rabi*) season, wheat was sown during the last fortnight of November to the first week of December, depending on the optimum temperature for wheat sowing. Uniformly in all treatments, soybean residues, generated mainly from the leaf fall and above-ground dried stem (30%) after harvest, were retained on the soil surface. All the recommended crop management practices essential to maintain the crop growth was followed from time to time during the crop growth period. For weed control, glyphosate was applied at least a week before the sowing of soybean and wheat followed by pendimethalin as a pre-emergence spray at 2 days after sowing and use of a suitable post-emergence herbicide for soybean (pursuit/imazethapyr) and wheat (2, 4-D) at 20–24 days after sowing. Subsequently, one-hand weeding was done for escaped weeds a week after the post-emergence herbicide spray to keep the fields weed-free. Soybean was grown as a rainfed crop, while wheat was irrigated at critical growth stages. Wheat was sown after the application of pre-sowing irrigation of 6 cm in depth and three to four post-sowing irrigations depending on the availability of water. The wheat was harvested using a combine harvester, and 30% above-ground wheat residues were retained in all of the treatments.

To study the effect of tillage reversal at the same level of residue retention on soil properties and crop yield, the RT and NT plots were converted to conventional tillage in the year 2016 after eight years of NT or RT. The RT and NT main plots were divided into two parts each resulting in 4 tillage treatments, viz. (1) RT, (2) RT-CT (reduced tillage converted to conventional tillage), (3) NT, and (4) NT-CT (no-tillage converted to conventional tillage). The residue retention was uniform (30% above-ground wheat residue) in all treatments. The RT-CT and NT-CT main plots were ploughed with a cultivator (one pass) at least a week before sowing, rotavator (one pass) followed by sowing with a seed cum fertilizer drill. Therefore, the experimental design was split-plot with three replications. The main plot treatments were tillage at four levels (RT, RT-CT, NT, and NT-CT), and sub-plot treatments were three nutrient levels (100% NPK (T1), 100% NPK + FYM at 1.0 Mg C/ha (T2), and 100% NPK + FYM at 2.0 Mg-C/ha (T3)).

2.3. Soil and Crop Yield Sampling and Analysis

Soil samples (0–5 and 5–15 cm) were randomly collected and homogenized from different treatment plots after the harvest of soybean in the year of 2017. Visible litter and roots were removed before analyzing the soil samples. Part of the soil samples was air-dried at room temperature and gently passed through a 2 mm sieve and stored in an airtight container for further analysis of soil properties. Standard analytical procedures were followed to analyze the soil samples. The pH of the soil was determined by using a pH meter with a glass electrode (model, 420 A) using 1:2.5 soil-water suspensions [30]. The soil organic carbon was estimated by the dichromate wet oxidation method of Walkley–Black [31]. In this method, organic matter in the soil was oxidized with a mixture of potassium dichromate ($K_2Cr_2O_7$) and concentrated H_2SO_4 utilizing the heat of dilution of H_2SO_4 . Unused $K_2Cr_2O_7$ was back-titrated with ferrous ammonium sulphate. Available nitrogen was estimated by an alkaline $KMnO_4$ method where the organic matter in the soil was oxidized with hot alkaline $KMnO_4$ solution. The ammonia (NH_3) evolved during oxidation was distilled and trapped in boric acid and mixed indicator solution. The amount of NH_3 trapped was estimated by titrating with standard acid [32]. The available phosphorus content of the soil was extracted with 0.5 M $NaHCO_3$ (pH 8.5) [33]. The content of phosphorus in the extract was determined using an ammonium molybdate and ascorbic acid reduction method by developing blue color, and the intensity of the blue color was measured using a spectrophotometer (model-CE2031) at 660 nm wavelength. Available potassium content in soil was extracted with neutral normal ammonium acetate and the content of potassium in the extract was estimated by a flame photometer (model, CL 378) [30].

Soybean plant samples were collected from an area representing $100 \times 100 \text{ cm}^2$ from each treatment after harvestable maturity. In the laboratory, the plant samples were first air-dried, separated into straw and seed, followed by oven drying at 70°C until constant weight. The dry weight of seed and straw was recorded after oven drying for 48 h. The dried seed and straw samples were ground in an electric grinder to 0.250 mm in size. These samples were used for the analysis of N, P, and K concentration. Plant N content was determined in Flash 2000 NC elemental analyzer (based on a dry combustion method). Total P and K in the tissue were extracted after acid digestion with concentrated nitric acid and perchloric acid (9:4). The total P concentration in the digested samples was determined by the development of yellow color (ammonium molybdate vanadate mixture) and color intensity was measured in a spectrophotometer (model CE 2031) at 470 nm after setting the instrument to zero with blank as described by Jackson [30]. The potassium content in the extract was estimated by a flame photometer (ELICO-model CL 378) [34]. The crop nutrient uptake was computed using the following equation:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)} \times \text{Yield (kg ha}^{-1}\text{)}}{100}$$

2.4. Statistical Analysis

Data sets were first analyzed for normal distribution and homogeneity of variance using the Shapiro–Wilk and the modified Levene test and then subjected to ANOVA followed by the Tukey's test ($\alpha = 0.05$). All the collected data were analyzed using two-way analysis of variance (ANOVA) using statistical software SPSS 11.5. For a significant f -value, the means were separated with least significant difference (LSD) with $p < 0.05$.

3. Results

3.1. Soybean Yield and Nutrient Uptake

The interaction effect of tillage and nutrient was statistically significant ($p < 0.05$) on soybean seed and biomass yield (Figure 1). Among treatments, the effect of the NT-CT-T3 treatment was the highest on seed and biomass yield. The mean soybean seed yield ranged from 845 to 1546 kg/ha. In general,

fertilization with NPK+FYM (T2, T3) increased the yield to the extent of 19–35% over NPK fertilization (T1). The seed yield response to fertilizer followed the order $T3 > T2 > T1$. The soybean total biomass ranged from 2240 to 3405 kg/ha across treatments. The tillage and nutrient interaction were significant on N, P, and K uptake by seed, but no consistent pattern was observed on N uptake (Tables 1–3). For example, the highest N uptake in straw was observed in the NT-CT-T3 treatment and RT-T3 in the seed. The mean N uptake (average of all tillage and fertilizer treatments) was 68.5 kg/ha in the seed and 25.7 kg/ha in the stem of soybean at maturity. Similarly, the mean K uptake followed the order: seed (18.6 kg/ha) > straw (12.3 kg/ha). Averaged over treatment the P uptake ranged from 7.5 kg/ha in seed to 1.5 kg/ha in straw. However, the interaction effect was not significant on P and K uptake in straw. The main effect of tillage was not significant on N, P, and K uptake in the seed and straw, except for N uptake in the soybean seed. In general, the reversal of NT to CT relatively increased the nutrient uptake in the seed and straw by approximately 6%–10%. Across tillage, the addition of organic manure with NPK fertilizers in the T2 and T3 treatments significantly increased the N uptake by 34% and 20% in the seed and straw, respectively, 44% and 34% P uptake in the seed and straw, and 28% and 24% K uptake in the seed and straw, respectively. The differences in nutrient uptake in the seed and straw were mainly due to differences in biomass and seed yield.

Figure 1. Effect of tillage, nutrient, and interaction of tillage and nutrient on the seed and biomass yield (kg/ha) at maturity in soybean in the year of 2017. LSD ($p < 0.05$) to compare the means of treatment for seed: $T = ns$; $N = ns$; $T \times N = 308$; and straw: $T = ns$; $N = ns$; $T \times N = 586$. RT: reduced tillage; NT: no-tillage; RT-CT: reduced tillage converted to conventional tillage; NT-CT: no-tillage converted to conventional tillage. (a) seed yield; (b) biomass yield.

3.2. Soil Properties and Nutrient Availability

3.2.1. Soil Organic Carbon

Significant interaction effect of tillage and nutrient ($T \times N$) was observed on SOC concentration at 0–5 and 5–15 cm soil depth (Table 4). Across tillage and nutrient, the SOC concentration decreased with soil depth from 6.4–9.3 g/kg at 0–5 cm depth to 5.6–8.3 g/kg at 5–15 cm soil depth. Among treatments, SOC was the highest in the NT-T3 treatment at 0–5 cm and RT-CT-T3 at 5–15 cm soil depth. Compared to T1, the NPK + FYM treatments (T2 and T3) increased the SOC concentration by 25%–30% at 0–5 cm soil depth and by 11%–21% at 5–15 cm soil depth. In general, tillage reversal increased SOC concentration at 5–15 cm soil depth. Both RT-CT and NT-CT treatments had relatively higher SOC concentration than the corresponding RT and NT treatments. The increase in SOC was greater in the RT-CT treatment by 14% over RT and NT-CT treatment by 5% over NT. Averaged across fertilizer in general, the order of SOC in the 0–5 cm layer was $NT > NT-CT \approx RT \approx RT-CT$.

Table 1. Effect of tillage, nutrient, and interaction of tillage and nutrient on N uptake (kg/ha) in soybean at maturity in the year of 2107 with statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
	Seed			
RT-CT	63.15	68.85	79.44	70.48
RT	60.15	72.63	90.11	74.29
NT-CT	49.72	66.24	85.49	67.15
NT	49.78	62.25	74.28	62.10
MEAN	55.70	67.49	82.33	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	5.84	10.08	6.41	
<i>p</i> Value	0.041	0.019	0.041	
	Straw			
RT-CT	26.91	25.08	28.49	26.83
RT	24.95	28.35	24.34	25.88
NT-CT	18.61	26.10	32.84	25.85
NT	20.61	23.52	29.07	24.40
MEAN	22.77	25.76	28.68	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	NS	7.64	
<i>p</i> Value	0.737	0.245	0.042	

T1: 100% NPK; T2: 100% NPK + farmyard manure (FYM) at 1.0 Mg-C/ha; T3: 100% NPK + FYM at 2.0 Mg-C/ha (T3).

Table 2. Effect of tillage, nutrient, and the interaction of tillage and nutrient on P uptake (kg/ha) in soybean at maturity in the year of 2017 with statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
	Seed			
RT-CT	6.08	7.41	8.86	7.45
RT	6.04	8.23	9.58	7.95
NT-CT	5.28	7.64	10.05	7.65
NT	5.77	6.40	8.65	6.94
MEAN	5.79	7.42	9.29	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	1.52	2.01	
<i>p</i> Value	0.703	0.609	0.0147	
	Straw			
RT-CT	2.84	3.25	3.68	3.26
RT	3.02	3.14	4.42	3.53
NT-CT	1.85	2.17	3.40	2.47
NT	1.93	2.97	2.88	2.59
MEAN	2.41	2.88	3.59	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	NS	NS	
<i>p</i> Value	0.235	0.218	0.358	

T1: 100% NPK; T2: 100% NPK + farmyard manure (FYM) at 1.0 Mg-C/ha; T3: 100% NPK + FYM at 2.0 Mg-C/ha (T3).

Table 3. Effect of tillage, nutrient, and the interaction of tillage and nutrient on K uptake (kg/ha) in soybean at maturity in the year of 2017 with statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
	Seed			
RT-CT	16.74	17.52	21.15	18.47
RT	17.64	21.15	22.79	20.53
NT-CT	13.53	18.92	24.51	18.99
NT	14.71	14.64	19.54	16.30
MEAN	15.66	18.06	22.00	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	2.91	5.16	
<i>p</i> Value	0.659	0.032	0.045	
	Straw			
RT-CT	12.3	12.7	14.0	13.01
RT	12.1	11.9	16.8	13.60
NT-CT	8.4	10.2	15.2	11.25
NT	9.6	12.5	11.8	11.32
MEAN	10.60	11.84	14.45	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	NS	NS	
<i>p</i> Value	0.348	0.549	0.199	

T1: 100% NPK; T2: 100% NPK + farmyard manure (FYM) at 1.0 Mg-C/ha; T3: 100% NPK + FYM at 2.0 Mg-C/ha (T3).

Table 4. Effect of tillage, nutrient, and the interaction of tillage and nutrient on SOC (g/kg) after the harvest of soybean in the year of 2017 with statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
	0–5 cm			
RT-CT	6.6	8.0	8.5	7.7
RT	6.4	8.4	8.7	7.8
NT-CT	6.6	8.3	8.7	7.9
NT	7.2	8.7	9.3	8.4
MEAN	6.7	8.4	8.8	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	1.5	1.7	
<i>p</i> Value	0.061	0.001	0.038	
	5–15 cm			
RT-CT	6.9	7.5	8.3	7.5
RT	5.6	6.6	7.5	6.6
NT-CT	6.4	7.0	8.0	7.1
NT	6.4	6.8	7.2	6.8
MEAN	6.3	7.0	7.8	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	1.01	1.1	
<i>p</i> Value	0.09	0.001	0.041	

T1: 100% NPK; T2: 100% NPK + farmyard manure (FYM) at 1.0 Mg-C/ha; T3: 100% NPK + FYM at 2.0 Mg-C/ha (T3).

3.2.2. Soil Nutrient Availability

In general, the main effects of tillage and fertilizer were significant on available N, P, and K. However, the interaction effect was not significant on available N and K in 0–5 and 5–15 cm soil layers (Tables 5–7). Similarly, no significant effect of tillage was observed on available N and P at the 0–5 cm soil layer and K at 5–15 cm. The soil available N was relatively higher under NT and RT compared to the NT-CT and RT-CT treatments in both soil layers. Averaged over treatments the mean soil available N ranged from 341 kg/ha in 0–5 cm to 293 kg/ha in 5–15 cm soil depth. The interaction effect of

tillage and fertilizer was significant on soil available P at the 5–15 cm soil layer only. The reversal in tillage (RT-CT and NT-CT) along with the application of 100% NPK + FYM (T3) resulted in higher soil available P than the NT and RT treatment with 100% NPK (T1). Averaged across tillage and nutrient, the mean soil available P ranged from 30 kg/ha in 0–5 cm to 12 kg/ha in 5–15 cm soil depth. Unlike N and P, tillage reversal NT-CT had a significant effect on soil available K compared to NT in the 0–5 cm soil layer (Table 7). Although tillage reversal (NT-CT and RT-CT) tended to have higher soil available K in the 5–15 cm soil layer, the effect was not significant. Averaged across tillage and nutrient, the mean soil available K ranged from 679 kg/ha in 0–5 cm to 525 kg/ha in 5–15 cm soil depth.

Table 5. Effect of tillage, nutrient, and the interaction of tillage and nutrient on soil available N (kg/ha) after the harvest of soybean in the year of 2017 with statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
		0–5 cm		
RT-CT	326	320	350	332
RT	314	318	354	329
NT-CT	332	341	344	339
NT	333	368	392	364
MEAN	326	337	360	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	26	NS	
<i>p</i> Value	0.091	0.039	0.806	
		5–15 cm		
RT-CT	259	292	298	283
RT	269	274	301	281
NT-CT	266	299	327	297
NT	305	308	323	312
MEAN	275	293	312	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	21	18	NS	
<i>p</i> Value	0.017	0.001	0.605	

T1: 100% NPK; T2: 100% NPK + farmyard manure (FYM) at 1.0 Mg-C/ha; T3: 100% NPK + FYM at 2.0 Mg-C/ha (T3).

Table 6. Effect of tillage, nutrient, and the interaction of tillage and nutrient on soil available P (kg/ha) after the harvest of soybean in the year of 2017. Statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
		0–5 cm		
RT-CT	23	28	43	31
RT	22	30	36	29
NT-CT	27	28	36	30
NT	25	27	35	29
MEAN	24	28	38	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	3	NS	
<i>p</i> Value	0.355	0.001	0.118	
		5–15 cm		
RT-CT	7	13	17	12
RT	8	9	15	11
NT-CT	10	12	17	13
NT	11	12	12	12
MEAN	9	11	15	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	2	4	
<i>p</i> Value	0.476	0.002	0.041	

Table 7. Effect of tillage, nutrient, and the interaction of tillage and nutrient on soil available K (kg/ha) after the harvest of soybean in the year of 2017. Statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
		0–5 cm		
RT-CT	622	720	724	689
RT	635	678	706	673
NT-CT	645	710	750	701
NT	609	654	695	653
MEAN	628	690	719	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	30	37	NS	
<i>p</i> Value	0.023	0.001	0.960	
		5–15 cm		
RT-CT	466	580	645	564
RT	487	489	573	516
NT-CT	488	522	574	528
NT	482	493	501	492
MEAN	481	521	573	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	35	NS	
<i>p</i> Value	0.171	0.001	0.063	

T1: 100% NPK; T2: 100% NPK + farmyard manure (FYM) at 1.0 Mg-C/ha; T3: 100% NPK + FYM at 2.0 Mg-C/ha (T3).

3.2.3. Soil Reaction

The effect of tillage and nutrient management was not significant on soil pH_(H2O). Soil pH_(H2O) under NT was 0.06–0.2 units lower than under RT at a depth of 0–5 cm but was not different between tillage regimes at 5–15 cm soil depth (Table 8). Addition of FYM at 2 Mg-C/ha with 100% NPK lowered the soil pH_(H2O) by 0.05 units compared to 100% NPK.

Table 8. Effect of tillage, nutrient, and the interaction of tillage and nutrient on soil pH_(H2O) after the harvest of soybean in the year of 2017. Statistical significance (*p* values) and LSD (*p* < 0.05) to compare the means of treatment.

	T1	T2	T3	MEAN
		0–5 cm		
RT-CT	7.94	7.95	7.79	7.89
RT	7.88	7.96	7.85	7.90
NT-CT	7.83	7.78	7.87	7.83
NT	7.75	7.69	7.67	7.70
MEAN	7.85	7.85	7.80	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	NS	NS	
<i>p</i> Value	0.396	0.317	0.062	
		5–15 cm		
RT-CT	7.89	7.87	7.84	7.87
RT	7.91	7.98	7.81	7.90
NT-CT	7.90	7.90	7.88	7.89
NT	7.91	7.94	7.86	7.91
MEAN	7.90	7.92	7.85	
	TILLAGE	NUTRIENT	INTERACTION (TxN)	
LSD (<i>p</i> < 0.05)	NS	NS	NS	
<i>p</i> Value	0.723	0.093	0.940	

4. Discussion

4.1. Soybean Yield and Nutrient Uptake

The likely significant ($p < 0.05$) interaction effect of tillage and fertilization on the soybean seed and biomass yield at maturity was probably due to the influence of tillage operations on soil properties, nutrient release, and availability from the soil and fertilizer [8,35,36]. Reversal of NT and RT to CT at the same level of residue showed a positive effect on the soybean yield. This could be because of the improvement of nutrient availability and uptake due to tillage [19,36]. Better growth and yield performance of the soybean observed under complementary use of NPK + FYM compared with the NPK fertilizer alone could be attributed to increased nutrient uptake and nutrient use efficiency, following the application of the organic manure [37–40]. Agbede [41] reported that nutrients from mineral fertilizers enhanced the establishment of crops, while those from the mineralization of organic manure promoted yield when both fertilizers were combined. The reversal of NT to CT with NPK + FYM had a significant effect on N uptake. This could be attributed to enhanced mineralization of crop residue accumulated at the soil surface in the NT treatment from tillage which in turn increased crop nutrient availability and uptake. Similar results were obtained by [10] who observed greater nutrient uptake (N, P) and crop yield after four years of reversal of NT to reduced tillage. Better utilization of nutrients by crops because of more root biomass and proliferation in the NT-CT treatment might have resulted in greater N, P, and K uptake. However, we did not observe higher N uptake in the RT-CT treatment than RT. Our results are in agreement with Ishaq [6] who observed no significant difference among conventional tillage, minimum tillage, and deep tillage on the nutrient uptake by wheat. Irrespective of tillage system, the addition of FYM with 100% NPK resulted in higher nutrient uptake because FYM has a lower C:N ratio than crop residue that acts as a better substrate for greater microbial activity and related soil enzymatic activity for enhanced soil organic matter mineralization. Secondly, the application of FYM with NPK fertilizer was effective in increasing SOC concentration and soil nutrient availability (Tables 5–7). Several studies reported a positive effect of organic manure application on crop yield, biomass, nutrient uptake, and soil health [39–42].

4.2. Soil Properties and Nutrient Availability

Higher SOC in the surface 0–5 cm soil layer observed in our study is in conformity with previous studies which showed surface-layer (0–5 cm) increments of SOC content in NT than RT [8,28,43,44]. The increase in SOC concentration with reversal of tillage was closely associated with enhanced decomposition of incorporated crop residues. The mixing of crop residue with tillage improves soil aeration and microbial activity that increases the mineralization of soil organic material [45–49]. Further, greater input of C and N through above- and below-ground biomass and FYM in the NT-CT-T3 and RT-CT-T3 treatment would have resulted in higher SOC concentration compared to other treatments. Lal [50] also reported the application of inorganic fertilizer in conjunction with organic manure increasing SOC and crop yield. The volume and density of root proliferation and biomass could be greater at the 5–15 cm soil layer than 0–5 cm which might have contributed to no significant effect of tillage on soil nutrient content (N and K) at the 0–5 cm layer [5]. After three growing periods, tillage reversal (NT-CT and RT-CT) significantly lowered soil available N in the 5–15 cm soil layer which could be attributed to higher crop biomass and N uptake by soybean. The amount of residue incorporation is greater as tillage intensity increases in the NT-CT and RT-CT treatments. Tillage enhances the decomposition and mineralization of incorporated crop residues by increasing soil aeration [51] and soil microbial activity [52]. Further, mineralization of residue is strongly related to soil nutrient availability and crop nutrient uptake. Greater soil available N in NT than NT-CT was ascribed to higher crop biomass and N uptake in the NT-CT treatment that could have lowered soil available N in NT-CT.

Interaction effect of tillage and nutrient was found significant on available P content at the 5–15 cm soil depth. In contrast to N, soil available P relatively increased with the reversal of tillage in NT

and RT. This could be attributed to the accumulation of inorganic P derived from the incorporation and mineralization of organic residues in reverse tillage treatments [53] and to the effect of organic manure (FYM) negative charges maintaining freely available phosphate [54]. Other researchers have observed similar effects of tillage and nutrient management on available P surface layer soil [55–57]. In comparing the tillage systems, tillage reversal (NT-CT, RT-CT) and RT had significantly higher available potassium than NT. Other studies have also reported similar effects of tillage and organic manure application on available K in soil [58,59]. This result was explained by the mineralization of this element resulting from mechanical incorporation and mineralization of crop residues, fertilizers, and FYM in the NT-CT, RT-CT, and RT treatments and agree with those reported by [60,61].

Addition of organic manure in the T2 and T3 treatments significantly increased the N, P, and K content by 3%–13%, 17%–67%, and 8%–19%, respectively, over T1 (100% NPK) across tillage and soil depth. Other previous studies suggested that integrated use of NPK + FYM can maintain a high level of crop production and soil nutrients throughout the period of the experiment [1,2,8] because FYM ensures the sustained activity of microorganisms and the regular dynamics of labile biomass carbon [62]. The higher availability of potassium in the NPK + FYM treatments may be attributed to the beneficial effect of organic manures on the reduction of potassium fixation and release of potassium due to interaction of organic with clay [63,64].

A similar effect of no-tillage was reported for the 0–5 cm soil layer due to enhancement of acidification [7,21,64]. However, among the tillage practices, the mean highest pH was found under RT-CT and RT (7.90) followed by NT-CT (7.83) and the lowest under NT (7.70) in the 0–5 cm soil layer. And the order for the 5–15 cm soil layer was RT≈NT>NT-CT>RT-CT. Tarkalson [63] reported a 9 per cent decrease in soil pH under NT as compared to CT due to enhancement of acidification. Across tillage, soil pH was found to relatively decrease with application of FYM at 2.0 Mg-C/ha (T3) at 0–5 and 5–15 cm.

5. Conclusions

In conclusion, the study indicated that under comparable residue retention, conventional tillage can perform better in terms of crop performance and SOC storage than no-tillage. The findings are particularly vital in the context of poor adoption of no-tillage due to several constraints, such as high weed infestation, difficulty in seeding, and others, under no-tillage conditions. Thus, the alternative approach of conventional tillage with similar residue retention as under no-tillage could be a better strategy in improving SOC storage, crop performance, and overall soil sustainability. The results further showing that integrated nutrient management increasing the seed yield of soybean indicate the role of organic manures in maintaining soil productivity across different types of tillage. Tillage reversal showed a beneficial effect on crop yield and nutrient uptake in the NT-CT treatment with the application of 100% NPK + FYM at 2.0 Mg-C/ha. The magnitude of nutrient uptake was not consistently influenced by tillage treatments, but the application of organic manure relatively increased the nutrient uptake. Tillage reversal from the RT-CT and NT-CT treatments under uniform residue retention had no negative effect on soil properties. However, the addition of organic manure with inorganic fertilizer significantly increased the SOC and the related nutrient availability in all tillage treatments. The finding suggests that returning crop residue and conventional tillage with integrated nutrient management could be a viable approach to resolve the issue of non-adoption of no-tillage in different cropping systems, particularly in developing countries. Conventional or minimum tillage with residue retention may increase the potential for soil productivity and offset the limitations of no-till farming in different cropping systems and soil types. This particular approach can be particularly useful for developing countries characterized by small landholding situations and farmers' hesitation in switching to no-tillage. Nevertheless, future research is required to understand the comparative performance of the proposed approach over no-tillage under different crop, soil, and climatic conditions.

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