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Research Article

Tillage Effects on Soil Biochemical Properties and Maize Grown in Latosolic Red Soil of Southern China

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Based on the hypothesis that soil biochemical and maize yield components should be affected by different tillage methods, a field experiment was conducted to study the effects of subsoiling (SS), two passes of rotary tillage (2RT), two passes of rotary tillage + subsoiling (2RTSS), and zero tillage (ZT) on distribution of organic C, available NPK and soil enzyme, and its effects on maize yield in latosolic red soil of southern China in 2016 and 2017. ZT treatment had significantly higher organic C and available NPK than the other treatments, whereas the SS treatment had higher concentration of soil urease, catalase, and acid phosphatase. Also, maximum grain yield, dry matter, harvest index, and 1000-grain weight were recorded under SS treatment. Overall, although ZT facilitated more organic C and available NPK, soil with ZT had lower soil enzyme and maize yield components compared to SS treatment, and therefore SS treatment could be exploited as a strategy for soil health and productivity resulting in a sustainable agricultural system.

1. Introduction

Increase in world population has led to intensive farming systems resulting in an increase in high level of food security [1–4]. However, intensive farming is characterized by environmental degradations like freshwater pollution through nitrate leaching, fade of biodiversity, and increase of soil erosion [3, 5, 6]. The proper use of the plant nutrients for agricultural production is of importance to reduce the negative impacts on the environment caused by unsustainable farming systems [3, 7]. Tillage practices in cropping systems have been part of most agricultural systems throughout history [8]. Different studies found that tillage has a negative impact on soil microbial biomass, community structure, and enzymatic activities [9–11]. Álvaro-Fuentes et al. [9] observed significant differences for tillage and depth in microbial biomass carbon and soil enzyme activities, finding a reduction in the surface layer with tillage but an increase in the 10–25 cm layer and no difference below the 25 cm soil depth. In comparison with conventional tillage, conservation tillage and no-tillage were found to increase soil bulk density and penetration resistance across the tillage layer [12–14] to increase soil water content [13–15], to reduce erosion [15], to improve soil structure [16, 17], and to increase microbial component and cation exchange capacity [18].

Several researchers observed an increase of soil organic matter (SOM) and carbon (SOC) with conservation tillage practices in the top soil layer [19–23]. In the lower soil layers, no difference or a decrease in SOC with conservation tillage were found, suggesting a balanced budget across the soil profile [9, 10]. The tillage impact on nutrient redistribution and availability on plant nutrient uptake is much less covered in the literature compared to the impact on soil physical properties. In general, tillage improves the decomposition of crop residues by facilitating contact between plant tissue and soil aggregate surfaces, the primary biome of soil microorganisms [24, 25]. In addition, tillage distributes organic matter in the soil and thus improves the availability of nutrients for plant growth through the formation of clay-humus complexes and the increase of charged surfaces for nutrient binding. Accumulation of considerable amounts of total nitrogen, phosphorus (P), and potassium with conservation tillage was observed [26, 27]. However, Calegari et al. [26] found in the same soil profile higher availability of phosphorous (P) and potassium (K) below the 10 cm layer. The presence of higher amount of nutrients in the very top soil (0–5 cm) under conservation tillage is also supported by different long-term experiments [28, 29, 30]. On the contrary, Roldán et al. [10] observed no tillage impact on available P.

Consequently, the understanding of nutrient availability and crop nutrient uptake for agricultural production requires in-depth knowledge of different and complex interacting processes among soil, plant, and environment. Thus, this study was to investigate the effects of tillage on soil biochemical properties and maize grown in latosolic red soil of Southern China.

2. Materials and Methods

2.1. Study Site. The field experiment was conducted during the 2016 maize growing seasons. The site is located at the farm of Wufengtai Agricultural Investment Co. Ltd., Lianping County, Heyuan City, Guangdong Province, China, at latitude 24° 9′ 25″ N, longitude 114° 23′ 43″ E, and at the altitude of 121 m. The area belongs to the central subtropical monsoon climate, with abundant sunshine and rainfall. The annual average temperature is 18.0°C–20.7°C, the annual average total sunshine hours are 1659.8 hours, and the annual average rainfall is 1779.7 mm. May and June are the most concentrated period of rainfall, and the intensity has always been great. However, lowest are recorded in August. The basic characteristics of the soil are shown in Table 1. The annual average humidity is 79%, and the average frost day of each year is 65 days.

Before the establishment of this tillage experiment, the field had undergone a middle-term (7 years) consistence tillage practice for continuing maize cultivation.

2.2. Experimental Design. The experiments were laid out in a randomized complete block design (RCBD) with three repeats each. The field experiment involved two passes of rotary tillage (2RT at 20 cm), subsoiling (SS at 40 cm), two passes of rotary + subsoiling (2RTSS at 20 and 40 cm respectively), and zero tillage (ZT). Each treatment plot was measured in $1.5 \times 100\ m^2$ area. In both seasons, the hybrid Yue Tian 26 (*super sweet corn single-cross variety*) was sown at a density of 44,400 plant ha^{-1} during the two growing seasons with seed moisture and germination percentage of 15 and 90%, respectively. Seeds were sown at 0.3 m within rows and 0.5 m between rows with the help of a 2-rows corn planter (2BMQE-2A Corn Planter), respectively. Organic fertilizer (pig manure) of $15000\ kg{\cdot}ha^{-1}$ applied in 7 cm depth was incorporated into the soil with a compound fertilizer of $220\ kg{\cdot}N{\cdot}ha^{-1}$, $80\ kg{\cdot}P_2O_5{\cdot}ha^{-1}$, and $150\ kg{\cdot}K_2O{\cdot}ha^{-1}$ as the basal fertilizer. Disease, pest, and weed control were performed according to the general local practices and recommendation. All other necessary operations except those under study were kept normal and uniform for all treatments.

2.3. Soil Sampling and Analyses. To determine the physical, chemical, and biological properties of the experimental site, composite soil samples was collected from 0 to 40 cm (i.e. 0–10, 10–20, 20–30, and 30–40 cm) depth before the start and after harvest of the maize crop. The soil of the experimental site is latosolic red soil (Orthic Acrisol, FAO-UNESCO system) derived from quaternary red earth with a sandy-loam texture (58% sand, 19% silt, and 23% clay). The soil sample was analyzed in the laboratory for dry bulk density, soil porosity, organic C, and available NPK. The mean bulk density and porosity of the 0–40 cm top soil zone were $1.38\ g{\cdot}cm^{-3}$ and 46.15%, respectively. The basic mean of the chemical and biological properties of the soil in 0–40 cm is presented in Table 1. pH was determined using the combined glass-electrode method [31, 32]. Urease activity was determined by the colorimetric method [33, 34]; acid phosphatase was measured by the phenyl diphenyl phosphate colorimetric method [35, 36]; catalase activity determined by Yan [37]; organic C and available N by Bao [38]; available P was determined by Bray No. 1 extract method [39]; and available K was determined by the colorimetric method [40].

2.4. Statistical Analysis. The analysis of variance for various soil chemical and biological characteristics was performed statistically using randomized complete block design (RCBD) as described in [41]. Duncan's multiple range test (DMRT) at 5% probability was performed to compare the means of different treatments by using the computer software IBM SPSS Statistics 23.0.

3. Results

3.1. Soil Physical Properties. The bulk density and porosity were significantly higher under ZT and SS treatments, respectively, in both years. The bulk density was greater at all tillage treatments in the growing seasons. The greatest bulk density (1.47 and $1.50\ g{\cdot}cm^{-3}$) and the greatest increase of 6.52 and 8.70% were observed under ZT treatment in the layer of 0–40 cm, respectively, in both years, whilst the lowest values 1.4 and $1.42\ g{\cdot}cm^{-3}$ were observed under SS treatment in 0–40 cm soil depth in the lowest increase of 1.45 and 2.90% in both years, respectively (Table 2). Average increase of 4.34 and 4.83% was observed under 2RTSS and 2RT treatment in 0–40 cm soil depth in the growing season.

Soil porosity significantly differed among the treatments, the highest 47.76 and 47.02% with the highest increase of 3.49 and 1.89% were observed under SS treatment in the depth of 0–40 cm for both years, respectively, followed by 46.83 and 46.27% in the increase of 1.47 and 0.26% in

Table 1: Basic chemical and biological characteristics of the soil.

pH	SOC (g kg^{-1})	Available (g·kg^{-1}) N	Available (g·kg^{-1}) P	Available (g·kg^{-1}) K	Urease [NH_4^+-N] (mg kg^{-1})	Catalase [0.1 NKMnO$_4$] (mL g^{-1})	Acid Phosphatase [P_2O_5] (mg kg^{-1})
4.73	12.28	105.75	68.05	185.26	241.15	1.28	281.42

Table 2: Effects of tillage practices on soil physical properties in two years.

Depth (cm)	Treatment	Bulk density (g·cm^{-3})		Porosity (%)	
		2016	2017	2016	2017
0–10	2RT	1.25 b	1.27 b	53.36 b	52.61 b
	2RTSS	1.24 b	1.26 b	53.73 b	52.99 b
	SS	1.21 c	1.24 c	**54.85 a**	**53.73 a**
	ZT	**1.28 a**	**1.31 a**	52.24 c	51.12 c
10–20	2RT	1.38 b	1.40 b	48.51 b	47.76 c
	2RTSS	1.36 c	1.38 c	49.25 b	48.51 b
	SS	1.33 d	1.35 d	**50.37 a**	**49.63 a**
	ZT	**1.48 a**	**1.51 a**	44.78 c	43.66 d
20–30	2RT	1.56 a	1.57 a	41.79 b	41.42 b
	2RTSS	1.55 a	1.56 a	42.16 b	41.79 b
	SS	1.53 b	1.54 b	**42.91 a**	**42.54 a**
	ZT	**1.56 a**	**1.58 a**	41.79 b	41.04 b
30–40	2RT	1.56 b	1.57 b	41.79 b	41.42 b
	2RTSS	1.55 b	1.56 bc	42.16 b	41.79 ab
	SS	1.53 c	1.55 c	**42.91 a**	**42.16 a**
	ZT	**1.57 a**	**1.59 a**	41.42 c	40.67 c

Values within a column in the same year followed by the same letters are not significantly different ($P < 0.05$). 2RT: two passes of rotary tillage; 2RTSS: two passes of rotary tillage + subsoiling; SS: subsoiling; ZT: zero tillage.

0–40 cm for both years, respectively, whilst the lowest 45.06 and 44.12% was observed under ZT treatment in the lowest decrease of 4.74 and 4.60% in 0–40 cm, respectively (Table 2).

3.2. Soil Chemical Properties. According to the one-way ANOVA, pH and available N, P, and K were influenced by different tillage methods. Soil pH varied considerably ($P \leq 0.05$) among tillage practices. This, at the end of the study, pH was increased due to tillage methods. The highest pH of 4.77 was recorded among 2RT, 2RTSS, and SS treatments in 0–40 cm in 2016 compared with 4.80, 4.75, and 4.77 under 2RT, 2RTSS, and SS treatment in 0–40 cm, respectively, in 2017, whilst the lowest pH 4.74 in 2016 and 4.73 in 2017 under ZT treatment (Figure 1).

Soil organic C was significantly different in all depths in 2017 compared to in 2016; however, the highest values (12.77 and 12.82 g·kg^{-1}) statistically with a highest increase of 3.99 and 4.40% in 0–40 cm in soil depth were recorded under ZT treatment, respectively, in 2016 and 2017 followed by 11.71 and 11.79 g·kg^{-1} under SS treatment in 0–40 cm, whilst the lowest 10.47 and 10.44 g·kg^{-1} in the lowest decrease of 17.29 and 17.62% was recoded under 2RTSS in 0–40 cm soil depth in both years, respectively (Figure 2(a)).

ZT treatment resulted in the highest activity of available N (117.90 and 117.98 mg·kg^{-1}) which markedly increased by 11.49 and 11.57%, respectively, followed by 108.48 and 108.16 mg·kg^{-1} under 2RT treatment (2.58 and 2.28%), and the lowest 103.14 and 101.95 mg·kg^{-1} observed under 2RTSS treatment in the decrease of 2.53 and 3.73% in 0–40 cm in soil depth in both years, respectively (Figure 2(b)).

Available P content was significantly varied ($P \leq 0.05$) among the different tillage practices. The highest 76.70 mg·kg^{-1} in 2016 and 81.1 mg·kg^{-1} in 2017 available P were observed under ZT treatment, followed by 70.88 mg·kg^{-1} in 2016 and 72.18 mg·kg^{-1} in 2017 under SS treatment, and the lowest (55.48 and 55.39 mg·kg^{-1}, respectively, in both years) were recorded under 2RTSS compared to the initial value in 0–40 cm soil depth (Figure 2(c)). Consequently, there was a higher increase of 12.71% in 2016 and 19.18% in 2017 under ZT treatment followed by 4.16% in 2016 and 6.07% in 2017 under SS treatment, whilst 2RTSS treatment markedly recorded the highest reduction of 22.66 and 22.86% in 0–40 cm soil depth in both years, respectively.

The highest available K (208.87 and 209.38 mg·kg^{-1}) content was recorded under the ZT treatment followed by 188.20 and 189.36 mg·kg^{-1} under 2RT treatment in 0–40 cm in soil depth for 2016 and 2017, respectively. The lowest available K (174.26 and 174.62 mg·kg^{-1}) was noted in the 2RTSS treatment (Figure 2(d)). This therefore resulted in a higher increase of 12.74 and 13.04% under ZT treatment, followed by 1.59 and 2.21% under 2RT treatment with the lowest reduction (6.31 and 6.09%) recorded under 2RTSS in 0–40 cm soil depth for both years, respectively.

3.3. Soil Biological Properties. Tillage practice had a significant effect on enzyme activities ($P \leq 0.05$) during the

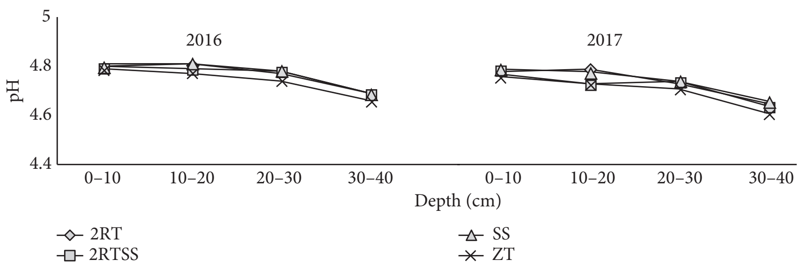


Figure 1: Effects of tillage methods on soil pH (2RT: two passes of rotary tillage; 2RTSS: two passes of rotary tillage + subsoiling; SS: subsoiling; ZT: zero tillage).

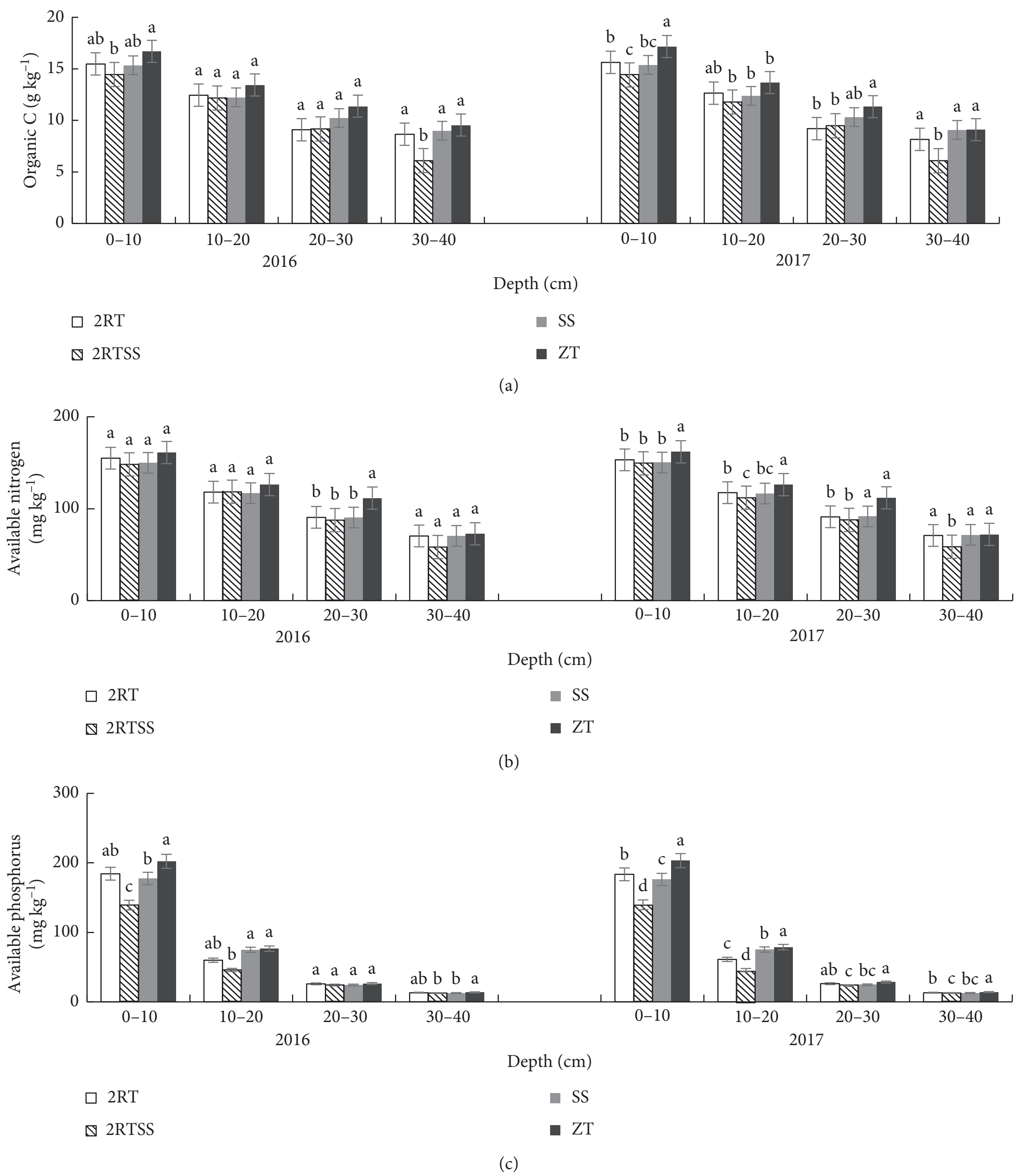
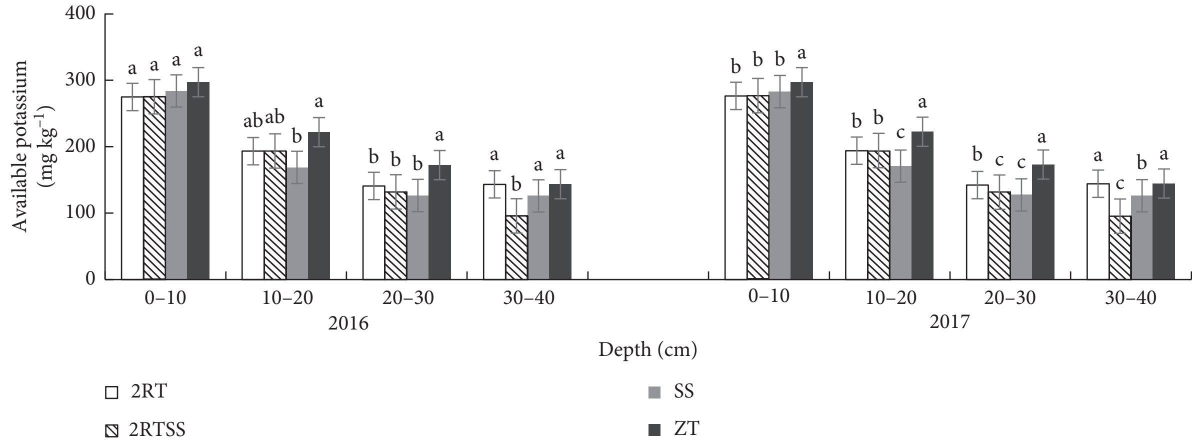


Figure 2: Continued.



(d)

Figure 2: Effects of tillage methods on organic carbon (a), available nitrogen (b), available phosphorus (c), available potassium (d) due to different tillage practices in 2016 and 2017 season (2RT: two passes of rotary tillage; 2RTSS: two passes of rotary tillage + subsoiling; SS: subsoiling; ZT: zero tillage. Means ± SE are shown in error bar ($P < 0.05$).

Table 3: Effects of tillage practices on enzymatic activities in the soil in two years.

Depth (cm)	Treatment	2016 Urease [NH_4^+-N] ($mg{\cdot}kg^{-1}$)	2016 Catalase [0.1 $NKMO_4$] ($mL{\cdot}kg^{-1}$)	2016 Acid Phosphatase [P_2O_5] ($mL{\cdot}kg^{-1}$)	2017 Urease [NH_4^+-N] ($mg{\cdot}kg^{-1}$)]	2017 Catalase [0.1 $NKMO_4$] ($mL{\cdot}kg^{-1}$)]	2017 Acid Phosphatase [P_2O_5] ($mg{\cdot}kg^{-1}$)]
0–10	2RT	406.46 a	1.95 a	412.22 a	408.63 b	2.05 a	423.17 c
	2RTSS	418.45 b	1.23 a	426.17 a	420.68 b	1.80 a	428.26 bc
	SS	**437.22 a**	**2.05 a**	**448.37 a**	**438.56 a**	**2.18 a**	**450.23 a**
	ZT	419.67 b	2.01 a	430.38 a	422.05 b	2.11 a	431.66 b
10–20	2RT	224.25 b	1.30 a	274.43 a	226.1 c	1.35 a	277.07 b
	2RTSS	233.70 b	1.23 a	313.69 a	235.25 b	1.31 a	314.36 ab
	SS	**278.49 a**	**1.44 a**	**348.82 a**	**283.92 a**	**1.66 a**	**345.83 a**
	ZT	236.11 b	1.44 a	334.5 a	239.15 b	1.51 a	335.48 a
20–30	2RT	165.27 b	0.86 ab	225.09 a	167.15 b	0.94 b	227.93 b
	2RTSS	125.93 c	0.78 b	216.90 a	127.93 c	0.81 c	217.58 b
	SS	**226.47 a**	**1.12 a**	**242.94 a**	**228.07 a**	**1.14 a**	**251.73 a**
	ZT	212.79 a	0.94 a	235.54 a	224.22 a	0.98 b	237.2 a
30–40	2RT	112.08 bc	0.82 b	126.46 b	114.70 bc	0.89 b	128.00 c
	2RTSS	111.07 c	0.80 b	122.63 b	113.32 c	0.86 b	124.29 d
	SS	**116.94 a**	**1.03 a**	**154.34 a**	**118.94 a**	**1.10 a**	**155.44 a**
	ZT	115.84 ab	0.96 a	150.48 a	117.07 ab	0.98 b	151.96 b

Values within a column in the same year followed by the same letters are not significantly different ($P < 0.05$). 2RT: two passes of rotary tillage; 2RTSS: two passes of rotary tillage + subsoiling; SS: subsoiling; ZT: zero tillage.

growing seasons (Table 3). Urease under SS treatment was higher than under ZT, 2RT, and 2RTSS treatments. SS treatment recorded 264.78 and 267.37 $mg{\cdot}kg^{-1}$ as the highest followed by 246.10 and 250.62 $mg{\cdot}kg^{-1}$ under ZT treatment and the lowest (227.02 and 229.15 $mg{\cdot}kg^{-1}$) being recorded under 2RT in 0–40 cm soil depth in both seasons, respectively. Consequently, higher increase of 9.80 and 10.87% was recorded under SS treatment followed by 2.05 and 3.93% under ZT treatment; however, reduction of 6.22 and 5.24% was recorded under 2RT in 0–40 cm soil in both years, respectively (Table 3).

Acid phosphatase was significantly different in all depths in 2017 compared to in 2016; however, the highest values statistically 298.62 $mg{\cdot}kg^{-1}$ in 2016 and 300.81 $mg{\cdot}kg^{-1}$ in 2017 were recorded under SS treatment followed by 287.73 $mg{\cdot}kg^{-1}$ in 2016 and 289.08 $mg{\cdot}kg^{-1}$ under ZT treatment with the lowest 259.55 $mg{\cdot}kg^{-1}$ in 2016 and 264.04 $mg{\cdot}kg^{-1}$ in 2017 under 2RT treatment in 0–40 cm soil depth for both years, respectively (Table 3).

There were some significant differences among the catalase activities in both seasons ($P \leq 0.05$); SS treatment recorded the highest catalase (1.41 and 1.52 $mL{\cdot}kg^{-1}$)

followed by ZT treatment (1.34 and 1.40 mL·kg^{-1}) and the lowest 1.19 and 1.20 mL·kg^{-1} recorded under 2RTSS in 0–40 cm soil depth in both years, respectively (Table 3).

3.4. Maize Yield Component Analyses. Different tillage methods significantly affected grain yield during both years of study. The highest grain yields of 7.34 and 7.40 ton·ha^{-1} were obtained in the case of SS treatment, and the minimum grain yields of 6.70 and 6.75 ton·ha^{-1} were obtained under ZT treatment in 2016 and 2017, respectively (Table 4). However, regarding SS treatment, grain yield was increased by 9.55 and 9.63% in both seasons, respectively.

After harvesting of maize, total dry matter was noted, and the highest (19.21 ton·ha^{-1}) was recorded under SS treatment in both years followed by (18.78 and 18.79 ton·ha^{-1}) under 2RT treatment, respectively, for both years. The lowest dry matter values 17.87 ton·ha^{-1} in 2016 and 17.85 ton·ha^{-1} in 2017 were recorded from the ZT treatment. SS treatment improved the total biomass up to 7.50 and 7.62% than the ZT treatment in both years, respectively (Table 4).

Highest harvest index (38.22 and 38.50%) was recorded from the SS treatment followed by 37.89 and 38.17% under 2RT treatment for both years, respectively. Lowest harvest index (37.48 and 37.80%) was recorded from the SS treatment in both years, respectively. As regards, SS treatment improved the harvest index 1.97 and 1.85% than ZT treatment (Table 3) in respective years. A similar trend was observed in the 1000-grain weight, as the highest (297.41 and 302.35 g) values were recorded under SS treatment followed by 283.70 and 288.41 g under 2RT treatment and the lowest 270.14 and 272.22 g under ZT treatment, respectively, for both years. The SS treatment improved the 1000-grain weight up to 10.09 and 11.07% than the ZT treatment in both years, respectively (Table 4).

3.5. Relationship among Variables and Hierarchical Analysis. Correlation analysis was conducted on the effects of the tillage methods on soil chemical and biological properties (Table 5). The results showed that that there was significant correlation between the chemical and biological properties; however, the highest significance at the 0.01 level was recorded between urease and available N, whilst the lowest was recorded between available P and pH.

In the hierarchical cluster analysis, the chemical and biological properties were grouped on the basis of their role in the transformation processes of their soil content. Generally, two clusters were obtained from the cluster analysis that was performed on the chemical and biological properties being studied (Figure 3). One included the pH, catalase, soil organic matter, available N, and P, and the second included acid phosphatase, urease, and available potassium which showed a linkage between the soil properties.

4. Discussion

The statistical results of the study indicated that tillage methods significantly ($P \leq 0.05$) affected bulk density and porosity. The bulk density was greater at all tillage treatments in the growing season. The greatest increase in bulk density of 6.52 and 8.70% was observed under ZT treatment in the layer of 0–40 cm in both years, respectively (Table 2); this might be due to the undisturbed soil. Similar results on the increase of soil bulk density were also reported by Kovac and Zak [42] and [43] confirms the upward trend of soil compaction and bulk density under the tillage practices. Rise in soil bulk density in the cultivated horizon on medium heavy soils has a negative effect on the growth and development of agricultural crops. The lowest average increase of bulk density 1.45 and 2.90% in both years, respectively (Table 2), was observed under SS treatment in 0–40 cm soil depth; this might be due to the loosening of the soil as a result of the lateral cut created by the implement which increases deposition of organic matter and water movement. Butorac et al. [44] observed the highest corn yield on Luvisol with the average bulk density of 1.40 Mg m^{-3}, while a much lower yield was obtained with the bulk density of 1.60 Mg·m^{-3}. Soils with high bulk density of the subcultivated horizon have also poor internal drainage and are characterized by reduced root growth, resulting in a substantial yield decrease [45].

Tillage generally alters soil porosity [46] but its effects are quite transitory, which was reflected in the worsening soil physical condition of the conventional tillage treatment, for example, predominance of microporosity. The consistent improvement in overall soil porosity under SS treatment (Table 2) was most probably related to increased aggregate stability, enhanced by minimum tillage, residue cover, and biological activity. This treatment also had a better distribution of the various pore size classes which is very important for the crop growth, since it influences plant available water, soil aeration, through increased connectivity, drainage, and channeling for enhanced root development [47].

Tillage practices showed that soil pH had no significant difference in average in 0–40 cm soil depth as indicated in Figure 1. This may be due to the fact that no limning material was applied as part of treatment. However, minimal increase difference was observed under ZT treatment in 0–40 cm soil depth compared to the initial pH of the soil in 2016. However, little difference in soil pH in zero-tillage practice was reported in the literature as compared with conventional practice [48, 49, 50].

The highest increase (3.99 and 4.40%) of organic C was observed under ZT treatment whilst the highest reduction of 17.29 and 17.62% in organic C was observed under 2RTSS treatment in 0–40 cm soil depth in both years, respectively (Figure 2(a)). This may be due to the fact that the land was not disturbed which increased the buildup of soil organic matter, resulting in high organic carbon which reflects a reduced rate of leaching in the soil profile in the soil studied. Tillage systems (zero tillage) that reduce soil disturbance and residue incorporation have generally been observed to increase organic C. ZT has been reported to have resulted in increased in organic C content which in turn enhances soil quality and resilience [51, 52].

Differences in available N (Figure 2(b)) among tillage systems are in agreement with those of other studies [50]. Available N was significantly higher in ZT treatment than in

Table 4: Effects of tillage practices on maize yield component in two years.

Year	Treatments	Dry matter (ton·ha^{-1})	1000-grain weight (g)	Grain yield (ton·ha^{-1})	Harvest index (%)
2016	2RT	18.78 b	283.70 b	7.11 b	37.89 a
	2RTSS	18.39 c	277.11 b	6.92 b	37.58 a
	SS	**19.21 a**	**297.41 a**	**7.34 a**	**38.22 a**
	ZT	17.87 d	270.14 c	6.70 c	37.48 a
2017	2RT	18.79 b	288.41 b	7.17 b	38.17 a
	2RTSS	18.53 c	281.54 c	7.02 b	37.87 a
	SS	**19.21 a**	**302.35 a**	**7.40 a**	**38.50 a**
	ZT	17.85 d	272.22 d	6.75 c	37.80 a

Values within a column in the same year followed by the same letters are not significantly different ($P < 0.05$). 2RT: two passes of rotary tillage; 2RTSS: two passes of rotary tillage + subsoiling; SS: subsoiling; ZT: zero tillage.

Table 5: Pearson's correlation coefficients among chemical and biological activities under tillage methods.

	pH	Organic C	Available N	Available P	Available K	Catalase	Acid phosphatase
SOC	0.728**						
AN	0.814**	0.934**					
AP	0.611**	0.891**	0.914**				
AK	0.658**	0.920**	0.941**	0.952**			
CT	0.697**	0.896**	0.955**	0.950**	0.960**		
AcP	0.636**	0.900**	0.916**	0.938**	0.938**	0.932**	
UR	0.808**	0.916**	0.967**	0.910**	0.937**	0.957**	0.921**

**correlation is significant at the 0.01 level; OC: organic carbon; AN: available nitrogen; AP: available phosphorus; AK: available potassium; CT: catalase; AcP: acid phosphatase; UR: urease.

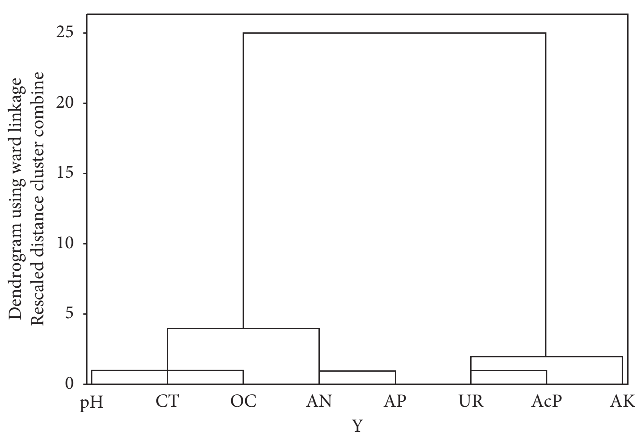


Figure 3: Dendrogram of the ward linkage from the hierarchical cluster analysis of soil properties; OC: soil organic carbon; AN available nitrogen; AP: available phosphorus; AK: available potassium; CT: catalase; AcP: acid phosphatase; UR: urease.

other treatments. Similarly, a study on Mollisols in Nebraska, available N was significantly greater under zero tillage than conventional tillage [53]. In another study, soil available N content was also significantly increased under zero or minimum tillage [50]. Higher available N in ZT treatment may be attributed to less loss through immobilization, volatilization, denitrification, and leaching [54], whereas alternate tillage practice and no disturbance of soil might lead to more loss of N through different mechanisms.

Available P and K (Figures 2(c) and (d)) were higher under ZT treatment probably due to higher soil organic C level and surface applied K and P fertilizers. Franzluebbers and Hons [49] and Zibilske et al. [55] reported that improvement of soil available P was due to redistribution or mining of P at lower soil depths. Also, work done in [56, 57] showed a high amount of P under ZT treatment compared to the conventional tillage and have attributed this to an increase in contact time between P and soil particles [58]. In the present findings, the K concentrations were higher in ZT treatment. Yin and Vyn [60] also observed more soil K in case of ZT treatment as compared to SS treatment (Figure 2(d)).

Enzyme activities were generally higher in SS treatment than in the other treatments, and it may be that SS treatment loosens the soil and adds the organic matter resulting in higher organic C into the soil, which increased the abundance of soil microorganism. The more the microorganisms, the higher the soil enzyme activities. Also, the higher urease, acid phosphatase, and catalase (Table 3) could perhaps be partially explained by a flush of microbial activity directly after the tillage practice as a result of an increase in substrate and oxygen availability [61]. Jin et al., [62] also reported that SS treatment consistently had higher enzyme activities compared with other tillage practices [62]. The consistent ranking of enzyme activities between soil management practices demonstrates that the activities of these enzymes could be a potential indicator for the effects of changes in tillage on soil functioning and soil quality [62]. Also, the consistent higher values in enzyme activities resulted in higher productivity in our study which is supported by [62]. With the increase of soil depth, urease, catalase, and acid phosphatase activities all decreased (Table 3). Kheyrodin et al., [63], Deng Tabatabai [64], and Jin et al. [62] reported a decrease in urease, acid phosphatase, and catalase activities, respectively, with increasing soil depth. They thought this decrease may be associated with the decrease in organic carbon content. Most enzyme activities in the surface soil were higher than that in deep soil. This may be because there were more soil microorganisms and plant residues in the surface soil, which were the main parts of soil enzymes. For urease in the soil, SS treatment was most effective in 0–10 cm. At this depth, urease activities of SS treatment increased by 81.31 and 81.86% higher than that of ZT treatment of 74.03 and 75.02%, respectively, in both years. Catalase was also effective at SS treatment with an increase of 60.16 and 70.31% compared to 57.03 and 64.84% under ZT treatment in 0–10 cm depth in both years, respectively. Similarly, SS treatment had the greatest effect on the activities of acid phosphatase in 0–10 cm, and 59.32 and 59.99% increase were observed compared to 52.93 and 53.39% under ZT treatment in both years, respectively.

Highest yield of maize (7.34 and 7.40 ton·ha^{-1}) was achieved under SS treatment in both 2016 and 2017, respectively (Table 4), and this might be due to lower bulk density for root penetration and build of soil nutrient. There was a lower yield under the ZT treatment (9.56 and 9.63% lower) for 2016 and 2017, respectively, hence, some greater significant differences (Table 4). Yields are often compared through different tillage systems, and authors often report that a higher yield can be achieved with a conventional tillage in comparison with others tillage systems (reduced, conservation, and no-till or zero-till). According to Sartori and Peruzzi [65], corn cultivated with minimum tillage methods produced around 20–25% less than with those based on ploughing, while the yield reduction is even more obvious with no-tillage. Among conventional tillage, minimum tillage, and no-tillage in corn production, the highest yield had been obtained with the conventional tillage reported Borin and Sartori [66]. In the experiment during 1995–1996 in Croatia conditions, Zimmer et al. [67] reported that no-tillage achieved 4% less yield of corn in comparison with the conventional tillage.

Maximum 1000-grain weight (297.41 and 302.35 g) was observed under the SS treatment for both years, and also highest dry matter (19.21 ton·ha^{-1}) was recorded under SS treatment (Table 4). Tillage practices significantly affected maize dry matter during both seasons (Table 4). During 2016, SS treatment was 7.50% higher compared with ZT treatment. In 2017, dry matter under SS treatment was about 2.24, 3.67, and 7.62% higher than with 2RT, 2RTSS, and ZT treatments, respectively. The highest dry matter may be attributed to higher plant height. This results strongly relate with Astier et al., Diaze-Zorita, Al-Kaisi and Licht, and Wasaya et al., [68–71], who reported that dry matter yield of maize improved due to good soil conditions provided to crop for better growth and development by loosening the soil with deep tillage or subsoiling (SS) implements.

There were no significant effects of different tillage treatments on maize harvest index (HI) in both years. However, SS treatment observed was 1.97 and 1.85% higher compared with ZT treatment in both years, respectively (Table 4). The results are closely associated with the findings of Patil and Sheelavantar [72] and Wasaya et al., [70], who observed the highest HI of maize grown in deeply tilled (subsoiling) plots, respectively.

The observed results pertaining to 1000-grain weight are illustrated in (Table 4). The results showed significant differences in 1000-grain weight between the different tillage treatments. SS treatment produced heavier grains compared to the other treatments. The maximum (297.41 and 302.35 g) 1000-grain weight was observed under SS treatment, followed by 283.70 and 288.41 g, and 277.11 and 281.54 g, 2RT and 2RTSS treatment, while the lowest (270.14 and 272.22 g) 1000-grain weight was observed under ZT treatment for both years, respectively. The results are in agreement with those by Ahmad et al. [73]. According to them, significantly higher grain yields were produced under conventional tillage treatment as compared to zero tillage.

5. Conclusion

In this paper, the ZT treatment showed significantly higher organic C and nutrient levels in their available form than the other treatments, whereas the SS treatment had higher concentration of soil urease, catalase, and acid phosphatase. Also, maximum grain yield, dry matter, harvest index, and 1000-grain yield were recorded under SS treatment. Overall, although ZT facilitated more organic C and available NPK, soil with ZT had lower soil enzyme and maize yield components compared to SS treatment, and therefore SS treatment could be exploited as a strategy for soil health and productivity resulting in a sustainable agricultural system.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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