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Effect of conservation tillage on yield of spring wheat (*Triticum aestivum* L.) and soil mineral nitrogen and carbon content**

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A b s t r a c t. Conservation farming practices using the least soil disturbance and straw-return benefits the crop agronomic attributes and soil nutrient accumulation. The four-year (2016-2019) research was conducted under randomized complete blocks design to explore the agronomic benefit of conservation tillage practices on wheat yield performance and on soil fertility parameters. The two straw treatments consisted of wheat straw-return to the no-tilled soil and straw incorporation into the conventionally tilled soil. The two tillage treatments were the no-tillage and conventional tillage control. These conservative tillage treatments were compared with the conventional tillage control. In comparison with conventional tillage, the conservation management practices of no-tilled soil, conventionally tilled soil, and no-tillage notably increased the yield by an average of 33, 26, and 18% respectively. Moreover, conservative tillage practices improved the soil nitrate-nitrogen, ammonium nitrogen and carbon contents in the 0-30 cm soil layer by 12, 9, and 15% respectively over conventional tillage, averaged across conventionally tilled soil, no-tilled soil, and no-tillage. The overall distribution of soil nitrate-nitrogen, ammonium nitrogen, and carbon in the 0-30 cm soil layer with regard to conventionally tilled, no-tilled soil, and no-tillage was greater than conventional tillage, based on Principal Component Analysis. We concluded that conservation tillage practices could replace conventionally tilled practice with respect to productivity, soil mineral nitrogen, and carbon accumulation benefits.

K e y w o r d s: agronomic traits, conservation agriculture, soil mineral nitrogen, no-till, C dynamics

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INTRODUCTION

Maintaining a sustainable environment with a global food demand from a population of nine billion will be one of the defining challenges for the next generation. Currently, farmers and agriculture scholars are under considerable pressure due to the enhancement of worldwide food demands (Shah and Wei, 2019). According to UN predictions (2015), the worldwide population is set to reach at 9.7 billion by 2050, which probably means larger demands for grain production in the future. Wheat (*Triticum aestivum* L.) is currently the most important cereal crop so it follows that it makes a vast contribution to universal food security. It is a chief constituent of the human diet which is responsible for meeting the majority of the calorie requirements of the human body.

However, fulfilling worldwide food requirements is becoming ever more challenging due to stagnant crop productivity as well as the limited availability of arable land. Accordingly, an intensive cropping system and the maximum permissible level of inorganic fertilization have been used to attain higher crop production. Unfortunately, these approaches lead to reduced soil quality and environmental pollution (Guo *et al*., 2010). Therefore, in order to achieve a sustainable level of agriculture in the future, it is vitally important to maintain and enhance the soil nutrient status of arable land. Any agricultural practice that aims to conserve soil and water, minimize soil erosion by leaving the surface soil covered by crop straw or cause the minimum possible disturbance to the subsoil is known as conservation tillage (Yang *et al*., 2018). In intensive cropping systems where field and weather conditions are critical, the results of conservation tillage implementation may conserve soil and water (Sayre and Govaerts, 2011; Yang *et al*., 2018).

Conservation tillage practices including least soil disturbance, maintenance of soil cover with stubble-return and straw incorporation into the soil have been implemented in many countries around the world (Xie *et al*., 2016). It has been established that conservation tillage practices improve soil nutrients, and crop yields (Han *et al*., 2020; Hirzel *et al*., 2020; Zhao *et al*., 2019; Omara *et al*., 2019). Economically sustainable production may be achieved by improving soil conservation practices (Zhao *et al*., 2019). As a result, the investigation of the effects of these new conservation tillage practices on crop agronomic traits, and nutrients accumulation would be desirable.

Many strategies have been tried in an attempt to enhance crop agronomic traits and soil nutrients. The most competent method is the adaptation of NT (Hirzel *et al*., 2020), residue-return to the soil (Han *et al*., 2020) and residue incorporation into the soil or the mulching of residue on the surface of the soil (Wang *et al*., 2017; Han *et al*., 2020). Straw return or crop residue incorporation is an effective measure, straw is easily obtained and contributes significant value in agriculture due to the nutrient-rich source, it should be regarded as an alternative approach to chemical fertilization and used as a form of organic fertilization (Zhao *et al*., 2019; Wang *et al*., 2017). As a consequence, straw return or incorporation seems to be capable of sustaining soil fertility and increased crop productivity. However, to date, residue-return remains an issue of discussion because experiments with different soil types and climatic conditions have led to inconclusive findings (Han *et al*., 2020).

China is the most important agricultural country, the practice of burning of crop residues after the harvest still continues which produces a negative effect on the agro-ecological system. Jinghua *et al*. (2019) declared that the residues of crops contain macronutrients of more than 118 million Mg which is equivalent to 83% of the world's fertilizer consumption per year. Both the application of residue incorporation into the soil and residue-return to the soil has led to positive effects on the level of soil nutrients, and this accordingly improves crop productivity (Han *et al*., 2020; Zhao *et al*., 2019). Residue incorporation into the soil indicates the restoration of losses of carbon to the environment of quantities up to 22 Tg C and straw-return restores carbon losses to amounts reaching 28 Tg C per year (Qi *et al*., 2019).

It has been well established that crop residue incorporation or residue-return techniques have a beneficial effect on soil N dynamics. Yang *et al*. (2018) conducted a field experiment and showed that straw incorporation treatments significantly improved the soil nitrate-nitrogen levels and crop production under the wheat-rice cropping system. However, Brennan *et al*. (2014) indicated that crop residues did not have any notable effect on agronomic attributing factors and also found that straw incorporation caused a reduction in crop yield. Rani *et al*. (2017) declared that residue incorporation notably increased soil NO_3^--N and NH_4^+-N content as compared with the implementation of CT.

It is well known that NT management practice has been documented as a constituent of environmentally smart farming practice which enhances crop yields and soil nutrient content (Huang *et al*., 2018; Devita *et al*., 2007). Moreover, residue-return to soil using the no-tillage method has positive effects on soil nutrient accumulation and crop yields. Using this method, straw residues are distributed over the surface of the soil during seeding; just the in-row soil is disturbed. When comparing NT with conventional tillage practice, NT demonstrates sustained crop yields and improves soil fertility (Wang *et al*., 2017; Yang *et al*., 2016; Omara *et al*., 2019). Returning straw to the soil supports sustainable crop yields and balances the nitrogen and carbon losses in arable land (Wang *et al*., 2017; Chen *et al*., 2014).

It is estimated that worldwide an area of approximately 155 million ha is managed under the NT farming system. In considering yield performance response to NT practice, it is worth noting that there is also modest agreement with results from the literature (Pittelkow *et al*., 2015). Farooq *et al*. (2011) noted that crop productivity in water-limited conditions improved due to the NT farming system whilst Ogle *et al*. (2012) showed that crop production decreased with NT practice due to soil compaction and nutrient deficiencies. These contradictory observations suggest that NT impacts may be sustained by several variables including the environment (*e.g*., soil properties and climate) and management practices (*e.g*., tillage duration, type of crop, fertilization) (Daryanto *et al*., 2017; Gwenzi *et al*., 2009). Therefore, these factors may be studied to explore the degree to which NT affects the soil nitrogen and carbon cycles.

Evidence from wheat-based system studies shows that soil nitrogen availability for plants depends on the carbon mineralization rate. Several researchers have demonstrated that no-till practice is connected with the least nitrogen availability due to a higher degree of immobilization by the residues of crops on the soil surface (Wang *et al*., 2008). In contrast, a clear nitrogen improvement was quantified under the no-tillage system as compared to conventional tillage systems (Jat *et al*., 2017). The application of crop residues facilitate nutrient cycling and mineralization intensity and that's why nitrogen availability is lower under the no-till system as compared to straw incorporation practice. The conventional tillage system enhanced the soil temperature which increased the decomposition of organic matter and hence improved mineralization (Rani *et al*., 2017).

The experiments cited above were designed to explore the consequences of residue incorporation on crop yields. Moreover, most of the studies considered mainly concentrated on the effects that the NT tillage system and deep ploughing practices had on crop yields and nitrogen changes. As a consequence, the exploration of these conservational management practices like straw incorporation, residue-return, and no-tillage is highly desirable with regard to wheat crop yield-attributing factors and the evaluation of soil fertility components.

This research aims to explore the effect of using straw-return, straw incorporation and NT strategies on the agronomic traits of wheat. Moreover, soil nutrient nitrate-nitrogen, ammonium-nitrogen, and carbon were also evaluated. We hypothesized that conservation management practices would improve spring wheat agronomic performance and soil nutrient concentration.

MATERIALS AND METHODS

The research was conducted under the supervision of the department of soil and water conservation at Dingxi, in Northern China (35°34' 53" N, 104° 38'30" E) on a sandy-loam texture. Before the research took place, the major physicochemical soil properties were determined (Table 1). In the 0-80 cm soil layer, the soil electrical conductivity, available phosphorous, soil temperature, nitrate nitrogen, ammonium nitrogen, soil organic carbon, pH, soil bulk density, soil porosity and soil water content were 0.34 dSm^{-1}, 0.39 $mg\,kg^{-1}$, 5.62°C, 25.94 $mg\,kg^{-1}$, 9.92 $mg\,kg^{-1}$, 6.10 $g\,kg^{-1}$, 8.27, 1.43 $g\,cm^{-3}$, 45.75%, 13.57%, respectively.

The research area has semi-arid climatic conditions, with an altitude of 2000 m above sea level, winter temperatures that can fall below -1°C, summer temperatures that can increase above 31°C, and rainfall irregularly scattered throughout the year, being concentrated mainly in the winter months. During the four years of the research period, the average annual precipitation was 401.25 mm, and the average evaporation was 1531 mm. The average annual temperature and rainfall in the Dingxi research station during the period of the study are presented in (Fig. 1).

This experiment was carried out in 2015 with different tillage practices (NT, CT, and CTS), which were modified to include straw-return to the no-tilled soil (NTS) in the subsequent years. The results of the four-year study from 2016 to 2019 are presented in this manuscript.

In the four years of the study, spring wheat was sown with a sowing date of the 15th of March and harvested at the end of July. The study was carried out in accordance with a randomized complete block experimental design (RCBD) with three replications giving a total of 12 individual plots with an area of 24 m^2. During this research,

Table 1. Soil physicochemical properties (means ± standard deviation) of research site

Property	Soil depth (cm) 0-10	10-20	20-30	30-40	40-50	50-60	Measurement Method
Soil texture			Sandy-loam				Hydrometer method
ECe (dSm^{-1})	0.32 ± 0.01	0.33 ± 0.03	0.35 ± 0.04	0.38 ± 0.02	0.32 ± 0.06	0.37 ± 0.08	By EC meter
Soil temp. (^{0}C)	3.84 ± 1.02	4.02 ± 1.12	5.34 ± 1.09	5.45 ± 0.87	5.89 ± 1.23	7.05 ± 2.38	By digital soil thermometer
Soil NO_3^--N (mg kg^{-1})	25.8 ± 1.37	26.5 ± 2.56	25.7 ± 3.88	26.1 ± 2.67	27.0 ± 5.20	23.9 ± 3.98	Colorimetric method
Soil NH_4^+-N (mg kg^{-1})	10.3 ± 2.95	9.75 ± 3.10	10.04 ± 4.2	10.5 ± 2.60	9.21 ± 2.85	9.45 ± 5.33	Colorimetric method
SOC (g kg^{-1})	6.50 ± 0.97	6.38 ± 1.12	6.26 ± 0.84	5.88 ± 1.24	6.14 ± 1.02	5.95 ± 1.05	Walkley-Black dichromate oxidation method
pH	8.32 ± 0.06	8.20 ± 0.34	8.15 ± 0.38	8.40 ± 0.17	8.36 ± 0.20	8.46 ± 0.14	By pH meter
Soil B.D (g cm^{-3})	1.34 ± 0.42	1.25 ± 0.10	1.46 ± 0.22	1.27 ± 0.08	1.52 ± 0.17	1.64 ± 0.05	Core sampler method
Soil porosity (%)	49.43 ± 9.79	52.83 ± 10.4	44.09 ± 7.58	52.07 ± 5.82	42.64 ± 6.42	38.12 ± 5.85	By (1-(B.D/P.D))x100 equation
Gravimetric soil water content (%)	15.6 ± 1.82	13.3 ± 0.57	12.5 ± 1.34	10.7 ± 0.92	12.9 ± 1.46	16.2 ± 2.38	Oven dry method
Available P (mg kg^{-1})	0.44 ± 0.02	0.42 ± 0.74	0.39 ± 0.45	0.37 ± 0.78	0.38 ± 0.09	0.40 ± 0.69	By 0.5 M $NaHCO_3$ extraction

P.D. – particle density = (2.65 g cm^{-3}).

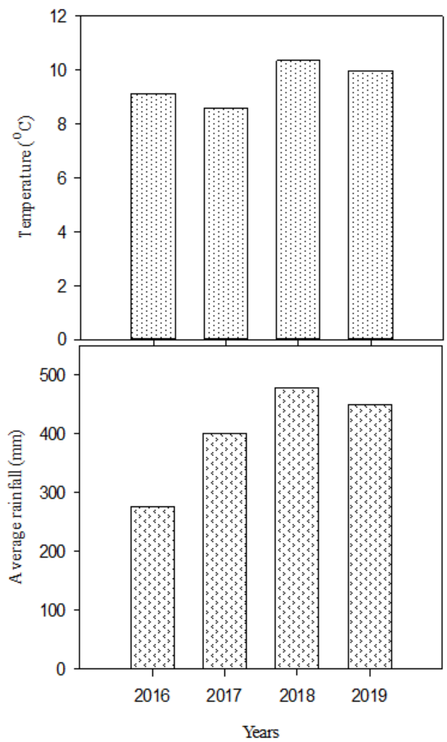

Fig. 1. Climatic conditions of the research field during 2016-2019.

four experimental treatments were implemented: (1) no-tillage (NT), (2) conventional tillage (CT), (3) straw-return to the no-tilled soil (NTS), and (4) straw incorporation into the conventionally tilled soil (CTS) as described in Table 2.

In order to manage the NTS treatment, after the harvest of the crop the wheat straw was returned to the NTS treated plot. For the CTS treatment, wheat straw materials were homogeneously incorporated into the CTS treated plots. For the NT treated plots the crop residues were removed after the wheat harvest. All of the CT treated plots were upturned manually before planting by using a shovel to a 20 cm depth. All of these conservation tillage practices (NT, NTS, and CTS) were compared with the control CT tillage practice.

A spring wheat variety (Dingxi 42) was used as a test crop, sowing involved maintaining a 25 cm row-to-row spacing. Planting was completed by adopting the seed drill method. All plots were fertilized in the same way (120 kg ha^{-1}) with nitrogen and phosphorous, based on a soil test which is recommended during the wheat-growing season. NP fertilizers (Di-ammonium phosphate and urea) were used as a basal dose before transplanting, this is consistent with standard local agronomic management practices.

Throughout the four-year period, one week prior to planting, manually weeding was implemented. The weeds were more numerous in the NT and NTS tillage systems compared to conventional tillage systems. The herbicide Glyphosate 30% was applied to control the growth of weeds in the crop growing seasons, weeding was also accomplished manually when necessary during the growing seasons. There did not seem to be any evidence of disease on the wheat. During the four-year research period, the spring wheat was sown in an identical way to the first year and on similar plots. Throughout the study period, all of the different agronomic management practices were kept constant.

At the harvesting stage, at the end of July each year (2016 to 2019) one-metre square of wheat crop samples were harvested randomly from all sub-plots. The agronomic traits of biomass yield, grain yield, seed m^2, and thousand grain weights were determined. At the soil surface, one-metre square samples for each plant were cut to determine biomass yield. Randomly taking a sample of the whole grains using a seed counter, they were dried at 70ºC

Table 2. Different experimental treatments with description used in this study

T_1 = NT	T_2 = CT	T_3 = NTS	T_4 = CTS

Treatment	Description
T_1 = NT	The above-ground portions of wheat straws were removed after harvesting the wheat crop. The wheat crop was sown in 20 cm deep by adopting no-tillage crop planter (Sazeh Kesht) without using any tillage implement.
T_2 = CT	After the harvest of wheat, the above-ground wheat straws portions were removed. Cultivation of land was done at 20 cm depth by using shovels. Crop planting was performed by using the seed drill method (Bazegar Hamedan seed drill).
T_3 = NTS	By adopting no-tillage crop planter (Sazeh Kesht) in the absence of any preceding tillage having straw-return to the no-tilled soil, wheat crop sowing was done in 20 cm depth, under standing previous wheat stocks.
T_4 = CTS	Land cultivation was performed by using shovels at 20 cm deep, concurrently and homogeneously 5-15 cm wheat straw was incorporated into the conventionally tilled soil. Earlier than planting uniform seed-bed was prepared with land leveller. Wheat crop planting was done by following the seed-drill method as conventional tillage soil practice (Bazegar Hamedan seed drill).

Nitrogen and phosphorous (120 kg ha^{-1}) as a basal dose were applied with all treatments.

for 48 h then the thousand grain weight was measured. By harvesting time, all of the plots for the different treatments including the one square metre grain yield were measured.

Post-harvest soil sampling was implemented at various soil depths (0-10, 10-20, and 20-30 cm) for the determination of ammonium-nitrogen (NH_4^+-N), nitrate-nitrogen (NO_3^--N) and soil organic carbon (SOC). After sampling from the field the soil samples were transported to the laboratory and then the NO_3^--N, NH_4^+-N, levels and SOC were determined.

Soil NO_3^--N and NH_4^+-N were determined by using the colorimetric method. In accordance with the colorimetric method, the colour intensity produced with the reagent is directly proportional to its concentration. For NO_3^--N and NH_4^+-N detection, a moist soil sample (10 g) was extracted with 100 mL of 2M KCl solution through continuous shaking for one hour. After that, by using the filter paper Whatman No. 42, the contents were filtered and collected in plastic bottles. Then by using an N Autoanalyser (M/S Medizin- und Labortechnik Engineering GmbH Dresden, Germany) the soil nitrate-nitrogen and ammonium-nitrogen contents in these soil extracts were determined.

The SOC was determined by adopting the Walkley-Black dichromate oxidation method. In this method, the air-dried soil sample (1 g) was treated with 8.0 ml of 0.4M of $K_2Cr_2O_7$ and 8.0 ml of concentrated sulphuric acid at 180°C for half an hour. Then the solution was allowed to cool. After that, 2-3 drops of o-phenanthroline were added to the solution. Then the solution was back-titrated by using a 0.4N ferrous ammonium sulphate solution (Nelson and Sommers, 1996).

The data were subjected to statistical analysis using SPSS computer software (IBM SPSS statistics 23) with a one-way interaction (ANOVA) at a 5% probability level, the significant difference among the different treatments and their interaction were checked with an LSD test. The correlation between the wheat crop yield, soil nitrogen, and carbon were obtained using Pearson correlation coefficients at $p < 0.05$ and $p < 0.01$. The data is displayed in terms of the mean values of three replications with a standard deviation. Moreover, the exploration of the multivariate variability introduced by the various treatments for NO_3^--N, NH_4^+-N, and SOC accumulation at different depths in the soil system principal component analysis (PCA) was implemented by using PAST-Palaeontological Statistics.

RESULTS

An analysis of variance (ANOVA) exhibits the significance of variable treatments (T), years (Y), and their interactions which are shown in Table 3. In the four-year research period between the different conservation tillage treatments, all variables exhibited significant differences. The two-way factor interactions (Treatment*Year) were not significant for all parameters.

Throughout the four-year period, the grain yield ranged from a high value of 0.114±0.01 kg m^{-2} in 2019 to a low value of 0.086±0.01 kg m^{-2} in 2017. The conservation practices NTS, CTS, and NT treatments notably increased grain yield by 33, 26, and 18% respectively compared to CT from 2016 to 2019. NTS produced a high value of (0.119±0.02 kg m^{-2}) grain yield which was followed by CTS. The lowest grain yield (0.081±0.01 kg m^{-2}) was associated

Table 3. Crop yield and yield-attributing characters under different conservation tillage practices

Year/ Treatment	Bio-yield (kg ha^{-1})	Seed yield (kg m^{-2})	Thousand seed-weight (g)	Seeds (n m^{-2})
		Year (Y)		
2016	3322 ± 180ab	0.108 ± 0.01ab	31.83 ± 1.51b	6824 ± 1055a
2017	3148 ± 237b	0.086 ± 0.01b	30.85 ± 1.53b	5368 ± 715b
2018	3230 ± 262b	0.091 ± 0.02b	31.70 ± 1.90b	5067 ± 625b
2019	3507 ± 290a	0.114 ± 0.01a	32.98 ± 1.26a	7268 ± 980a
		Treatment (T)		
NT	3245 ± 246b	0.096 ± 0.01b	30.14 ± 1.6b	5739 ± 913b
NTS	3485 ± 232a	0.119 ± 0.02a	32.97 ± 1.15a	6873 ± 1470a
CT	2963 ± 168c	0.081 ± 0.01b	31.62 ± 1.27b	5238 ± 847b
CTS	3442 ± 133a	0.102 ± 0.01ab	32.60 ± 1.32a	6678 ± 1050a
		Analysis of variance (ANOVA)		
Source of variation				
Years	*	*	*	*
Treatments	*	*	*	*
(Y×T)	n.s.	n.s.	n.s.	n.s.

Indicates significance at *$p < 0.05$, n.s. – non-significant. The values in each column followed by a different letter are significantly different according to the LSD test.

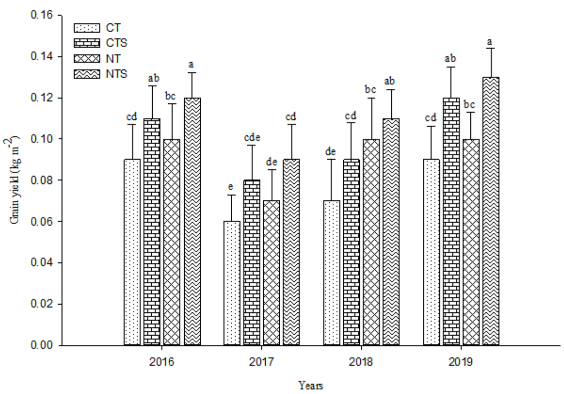

Fig. 2. Two-way factor interaction between treatments and years for seed yield (kg m^{-2}).

with CT. The grain-productivity followed the trend of (NTS>CTS>NT>CT). Interaction between certain factors (treatment and year) for the grain yield is shown in Fig. 2. It was recorded that the wheat grain yield was lowest in 2017 and 2018 compared with 2016 and 2019.

The maximum bio-yield (3507±290 kg ha^{-1}), which was observed in 2019, is presented in Table 3. In 2017 and 2018, the minimum biomass production values were noted. Biological productivity followed the trend (2019>2016>2018>2017). On average, the NTS and CTS treatments exhibit the highest levels of wheat bio-production compared to CT. The lowest bio-productivity was noted under CT. Compared with CT and NTS, CTS, and NT increased the biological yield by 17, 15, and 9% from 2016 to 2019.

On average, over the four-year research period, the maximum thousand-grain weight (32.97±1.15 g) was recorded under NTS treatment whereas the lowest weight of a thousand grains (30.14±1.6 g) was noted under NT. The thousand seed weight followed the trend of (NT<CT<CTS<NTS). Moreover, the maximum thousand seed weight (32.98±1.26 g) was observed in 2019 whilst the minimum thousand seed weight was recorded in 2017. The NTS treatment in 2019 increased the thousand seed weight by 6% compared with CT in 2017, which is presented in Table 3.

Averaged over a four-year period, the number of seeds m^{-2} recorded a minimum value of (5067±625 m^{-2}) in 2018 to a maximum value of (7268±980 m^{-2}) in 2019. NTS produced the highest value of (6873±1470 m^{-2}) whilst the lowest seeds number (5238±847 m^{-2}) was associated with CT. The NTS, CTS, and NT increased the number of seeds m^{-2} by 31, 27, and 10% compared with CT from 2016-2019. As expected, a positive correlation was noted between seed yield and other yield-attributing traits (Rharrabtia *et al.*, 2003) as shown in Table 4.

The means of soil NO_3^--N at different depths during the post-harvest stage of each year under different conservation tillage practices are shown in Fig. 3. The two-way factor interactions (Treatment*Year) for all depths show no statistical difference between them for the presented data. A statistical difference was recorded between different treatments.

On average, over the four-year research period, in the 0-10 cm soil layer, NTS produced a maximum of (27.61 ± 2.12 mg kg^{-1}) surface soil NO_3^--N value, which was statistically on par with CTS. A minimum value of (26.14 ± 1.58 mg kg^{-1}) surface soil nitrate-nitrogen value was associated with CT. NTS, CTS, and NT considerably increased surface soil NO_3^--N by 6, 5.7, and 5.2%, respectively in comparison with CT. The surface soil nitrate-nitrogen followed the trend of (CT<NT<CTS<NTS). Moreover, the highest surface soil nitrate-nitrogen value (27.68±1.70 mg kg^{-1}) was obtained in 2019 whilst the lowest soil nitrate-nitrogen value (26.00±1.93 mg kg^{-1}) was noted in 2017 as presented in Fig. 3.

In the 10-20 cm soil layer, the sub-surface soil nitrate-nitrogen value ranged from a maximum value of (28.44±1.32 mg kg^{-1}) in 2019 to the lowest value of (26.65±2.05 mg kg^{-1}) in 2016. Moreover, the highest sub-surface soil NO_3^--N value of (28.26±2.05 mg kg^{-1}) was recorded under CTS treatment whereas the minimum sub-surface soil NO_3^--N value (26.60±2.85 mg kg^{-1}) was associated with CT. CTS, NTS, and NT treatments notably increased the sub-surface soil NO_3^--N by 6.5, 6, and 5.7% respectively as compared to CT from 2016 to 2019. The sub-surface soil NO_3^--N followed the trend of (CT<NT<NTS<CTS).

Table 4. Correlation between wheat yield and yield-attributing traits

	Bio-yield (kg ha^{-1})	Seed yield (kg m^{-2})	Thousand seed-weight (g)	Seeds (n m^{-2})
Bio-yield (kg ha^{-1})		0.775* 0.000	0.507* 0.000*	0.750* 0.000
Seed yield (kg m^{-2})			0.454* 0.001	0.697* 0.000
Thousand seed-weight (g)				0.571* 0.000
Seeds (n m^{-2})				

Indicates significance at *$p < 0.001$.

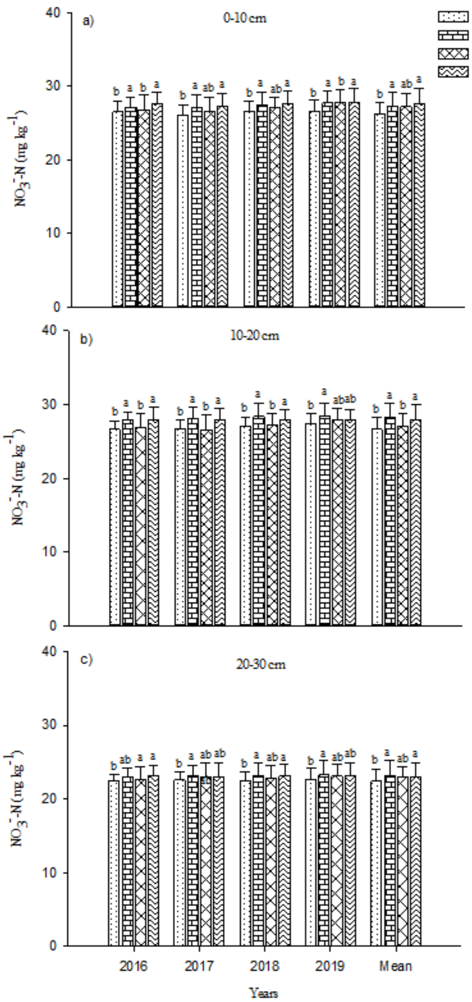

Fig. 3. Soil NO_3^--N with regards to conservation tillage practices. Bars with different lower-case letters show significant differences at $p<0.05$.

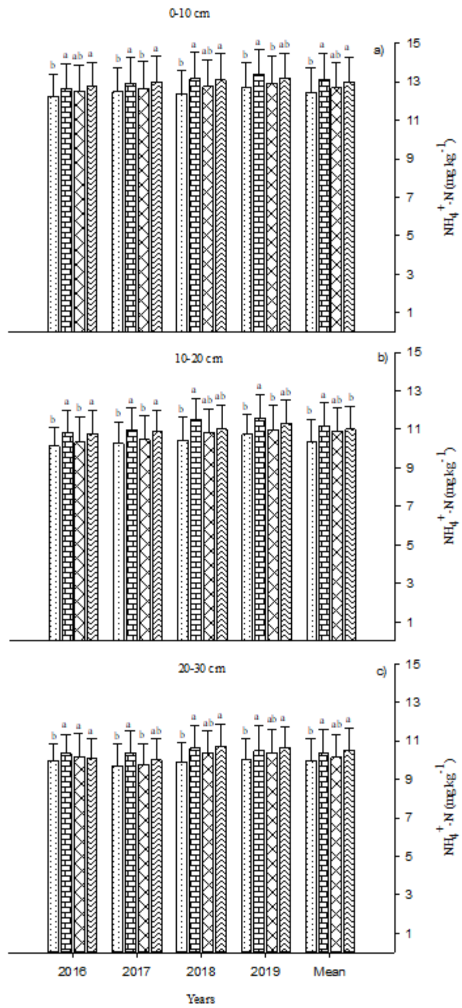

Fig. 4. Effect of treatments on NH_4^+-N. Bars with different lower-case letters show significant differences at $p<0.05$.

At a 20-30 cm soil depth, the highest sub-surface soil NO_3^--N value (23.20±1.45 mg kg^{-1}) was recorded in 2019 whilst the minimum sub-surface soil NO_3^--N value (22.46±2.00 mg kg^{-1}) was noted in 2016. Non-significant differences were recorded in the sub-surface soil NO_3^--N from 2016 to 2019. In addition, the maximum sub-surface soil NO_3^--N value (23.12±2.16 mg kg^{-1}) was observed under CTS. The lowest sub-surface soil NO_3^--N value (22.57±1.62 mg kg^{-1}) was recorded with CT. The conservation tillage practices CTS, NTS, and NT notably increased the sub-surface soil nitrate-nitrogen by 3, 2.8, and 2.4% respectively in comparison with CT from 2016 to 2019. The sub-surface soil NO_3^--N followed the trend of (CT<NT<NTS<CTS) shown in Fig. 3.

On average, over a four year period, in the 0-10 cm soil layer, the surface soil NH_4^+-N ranged from a maximum value of (13.39±1.32 mg kg^{-1}) in 2019 to the lowest value (12.21±1.67 mg kg^{-1}) in 2016.

In addition, with regards to different treatments, the highest value of the surface soil NH_4^+-N (13.10±1.47 mg kg^{-1}) was noted under CTS. The lowest surface soil NH_4^+-N value (12.44±2.08 mg kg^{-1}) was associated with CT. The surface soil NH_4^+-N in the 0-10 cm soil layer was significantly influenced by different treatments. In addition, we found non-significant differences in the surface soil NH_4^+-N between CTS and NTS. The CTS, NTS, and NT increased the value of this parameter notably by 5.5, 5.2, and 4.6% respectively compared with CT. The surface soil NH_4^+-N followed the trend of (CTS>NTS>NT>CT) presented in (Fig. 4).

According to the available data, in the 10-20 cm soil depth, the maximum sub-surface soil NH_4^+-N (11.20±2.68 mg kg^{-1}) was observed under CTS practice. The lowest sub-surface soil NH_4^+-N value (10.35±1.83 mg kg^{-1}) was noted in CT soil practice. The CTS, NTS, and NT amendments notably increased the sub-surface soil NH_4^+-N value by 8.3, 8, and 7.6% respectively as compared to CT from

2016-2019. The sub-surface soil NH_4^+-N followed the trend of (CT<NT<NTS<CTS). Furthermore, the highest value of sub-surface soil NH_4^+-N (11.60±2.46 mg kg^{-1}) was recorded in 2019 whilst the minimum sub-surface soil NH_4^+-N value (10.12±1.94 mg kg^{-1}) was noted in 2016.

In the 20-30 cm soil depth, the maximum sub-surface soil NH_4^+-N value (10.62±2.23 mg kg^{-1}) was recorded in 2019 whereas the lowest sub-surface soil NH_4^+-N value (9.70±1.14 mg kg^{-1}) was recorded in 2017. Additionally, the highest sub-surface soil NH_4^+-N value (10.49±1.86 mg kg^{-1}) was noted under NTS. The minimum sub-surface soil NH_4^+-N value (9.96±2.00 mg kg^{-1}) was recorded with CT. The soil management practices of NTS, CTS, and NT notably increased the sub-surface soil NH_4^+-N value by 5.5, 5.1, and 3.8% respectively as compared to CT from 2016 to 2019. The sub-surface soil NH_4^+-N value followed the trend of (CT<NT<CTS<NTS) shown in Fig. 4.

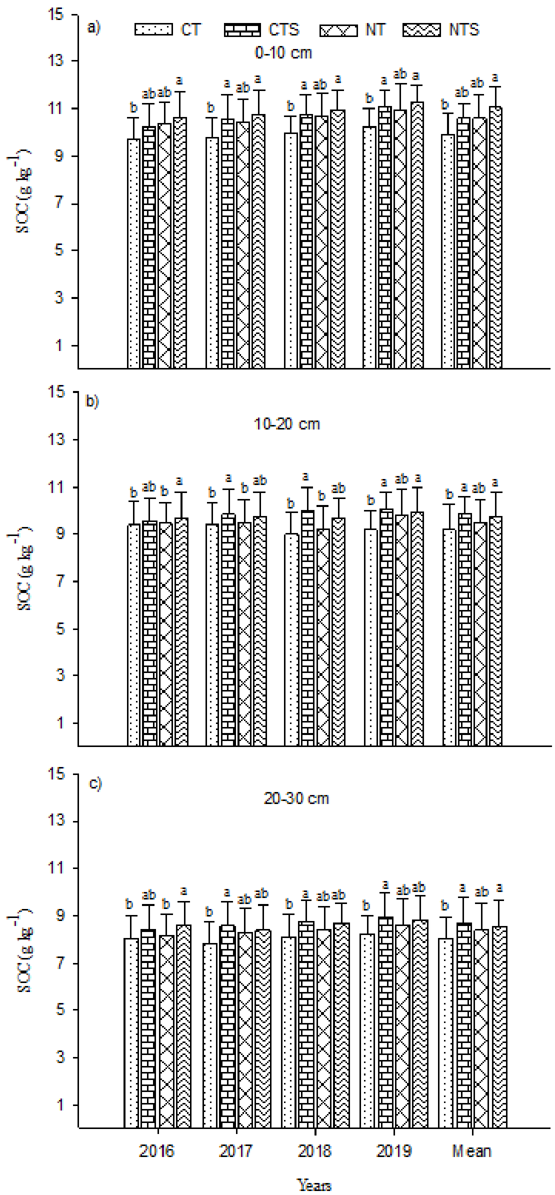

Fig. 5. Effect of treatments on SOC. Bars with different lowercase letters show significant differences at $p<0.05$.

Soil organic carbon at different depths was notably affected under different soil management strategies shown in Fig. 5. There was no significant difference noted between the various years and treatments.

On average, over the four-year research period, in the 0-10 cm soil depth, the surface SOC ranged from the highest value of (11.05±1.02 g kg^{-1}) with NTS to the minimum value of (9.90±0.92 g kg^{-1}) with CT. In the 0-10 cm soil layer, the SOC was significantly affected by different treatments. A non-significant difference was noted between CTS and NT. NTS, NT, and CTS notably increased the surface SOC concentrations by 11, 7.3, and 7%, respectively for the period of 2016-2019 compared with CT. The surface SOC followed the trend of (NTS>NT>CTS>CT). In addition, maximum surface SOC was noted in 2019 whilst the minimum surface SOC was observed in 2016.

In the 10-20 cm soil layer, the minimum sub-surface SOC (8.97±0.84 g kg^{-1}) was recorded under CT. The maximum sub-surface SOC (10.07±0.57 g kg^{-1}) was noted in the plots where CTS was practiced. Compared with CT, the CTS, NTS, and NT considerably increased the sub-surface SOC by 12, 9, and 7.7%, respectively from 2016-2019. The sub-surface SOC followed the trend of (CTS>NTS>NT>CT). With regard to the four year research period, the maximum sub-surface SOC was observed in 2019 whereas the lowest sub-surface SOC was noted in 2017.

In the 20-30 cm soil depth, the lowest sub-surface SOC value (8.03±1.03 g kg^{-1}) was observed in plots where CT was practiced. The maximum sub-surface SOC (8.66±0.8 g kg^{-1}) was recorded under CTS. CTS, NTS, and NT notably increased sub-surface SOC by 7.8, 7.2, and 6.4% respectively from 2016-2019 as compared to CT. The sub-surface SOC followed the trend of CTS>NTS>NT>CT. Considering the effect of the conditions of the year on SOC, the highest value (9.05±1.24 g kg^{-1}) of sub-surface SOC was associated with 2019 whilst the lowest value of sub-surface SOC (7.87±0.69 g kg^{-1}) was associated with 2017. The SOC followed the trend of 2017<2016<2018<2019.

According to Jolliffe (1986), the cut-off value of 47.01 which showed that the PCA analysis allows for the isolation of five principal components. The average variance is equal to 90% of the total variance. The maximum loadings of PC1 comprise 40% of the total variance and in PC2 the higher loadings of 28% of the total variance were observed and included both surface and sub-surface NO_3^--N, NH_4^+-N, and SOC whilst minimum loadings of 22% of the total variance in PC3 was noted.

The observations plot points drawn by the interaction between PC1/PC2 and PC1/PC3 are shown in Fig. 6. PC4 and PC5 do not permit the addition of supplementary information, that's why they are not included. The graph indicates

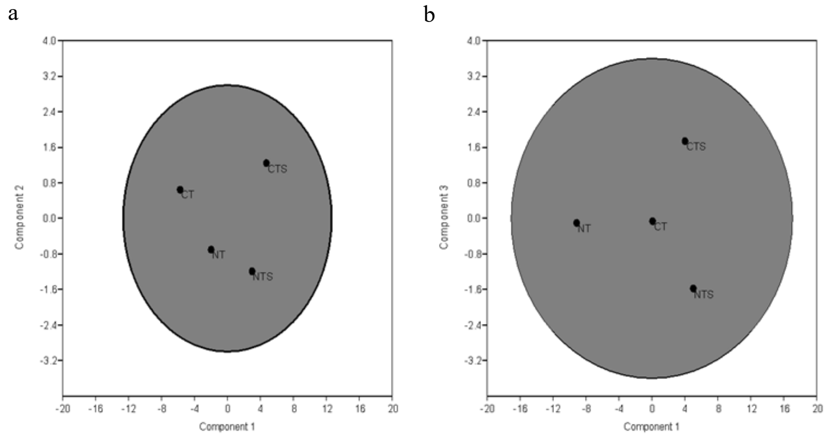

Fig. 6. Scatter plot of the principal components PC1/PC2(a) and PC1/PC3(b).

that for PC1/PC2, CTS and NT occupied a more extreme position as compared to CT treatment. Furthermore, the observation points of NTS were closer together compared to CTS and NT treatments. The PC1/PC3 values show that CTS, NTS, and NT occupied a more defined position in the soil system than CT. Moreover, the PC1/PC3 value indicates that NT was closer to the central point of the PCA components compared with CTS and NTS.

DISCUSSION

Residue incorporation, straw-return, and the reduction or even elimination of soil inversion are the most valuable approaches to the sustainability of agriculture. Straw has the potential to increase nutrient availability and facilitate the agronomic traits of crops (Han *et al*., 2020; Qi *et al*., 2019; Zhao *et al*., 2019). NT has different advantages including the improved physical properties of soil, reduced soil runoff, and increased crop production (Omara *et al*., 2019). Regardless of these benefits, nonstop no-till practice resulted in surface crop-residue accumulation which in turn led to soil organic matter build-up and nutrient accumulation compared to deep ploughing or conventional tillage (Wang *et al*., 2008; Omara *et al*., 2019).

Moreover, long-term soil management practices influence nutrient cycling and their availability to crops (Obour and Holman, 2017). Therefore, it is vital to explore the consequences of straw-return, residue incorporation, and no-tillage on wheat yield attributes and soil nutrient dynamics under the semi-arid climate conditions of Dingxi China.

The extent of the positive impact of straw-return to the field or residue incorporation into the field and no-till soil practice remains a subject of discussion because experiments conducted in different types of soil and climatic conditions have led to unconvincing findings (Han *et al*., 2020; Pittelkow *et al*., 2015; Ogle *et al*., 2012). The present findings indicate that in comparison with CT, the different conservation tillage practices of NTS, CTS and NT considerably improved the agronomic traits of wheat, as confirmed by other researchers (Bartaula *et al*., 2020; Hirzel *et al*., 2020; Han *et al*., 2020; Yang *et al*., 2016; Farooq *et al*., 2011; Devita *et al*., 2007).

There were multiple factors responsible for the improved wheat agronomic performance. Firstly, soil nutrient accumulation and the availability of nutrients to plants may increase through straw-return or straw incorporation because straw return is essential for plant nutrient return to the soil, this contributes to improved crop production (Bartaula *et al*., 2020; Zhao *et al*., 2019). Secondly, wheat-straw includes a considerable amount of organic matter which contributes to the quality of the soil leading to improved crop yield attributes (Yang *et al*., 2016). Thirdly, the positive impact of CTS on wheat yield and yield components was due to better hydrological and physical soil conditions (Mazzoncini *et al*., 2011; Han *et al*., 2020).

Our results are in agreement with the observations of (Jat *et al*., 2017; Devita *et al*., 2007) as they observed that no-tilled soil improved crop production compared with CT. In addition, the results of the present study are also in line with the observations of (Han *et al*., 2020; Zhao *et al*., 2019; Khorami *et al*., 2018) who reported that straw return improved wheat crop production. Conversely, the results are in contrast with the findings of Brennan *et al*., in 2014 they noted that straw retention did not positively improve the agronomic traits of wheat.

Moreover, our results also contradict the observations of Khorami *et al*. (2018) they took the view that NT practice did not notably improve the agronomic attributes of wheat. It has been documented that NT practice could benefit from a long-term continuous NT study (Wang *et al*., 2008). Additionally, it is also well known that straw-return may result in a significant immobilization of nitrogen thereby leading to reduced crop yields (Morris *et al*., 2010). The positive impact of straw-return and NT practices were observed in this research as compared to CT.

Furthermore, the results of four years of research indicate that the spring wheat crop agronomic attributes indicated greater changes due to variability in climatic conditions. In particular, the mean temperature in 2018 was higher than in 2016, 2017 and 2019. Compared with 2016, the wheat yield in 2017 and 2018 was notably lower because of crop straw accumulation, this led to a notable reduction in seed yield. Most rainfall occurs during the winter and fall seasons in Dingxi, which is unfavourable for the decomposition of straw (Keshavarz *et al*., 2015). Consequently, undecomposed crop straw remained in the soil in 2017 and 2018, and it appeared that the straw nutrient contents were not transformed into an available form. The lowest annual average rainfall was associated with 2016 and 2017 compared with 2018 and 2019 (Fig. 1). Spring wheat productivity and yield were also affected by environmental conditions. The reduction in spring wheat yield in 2017 and 2018 may have been due to an increase in temperatures at the end of the crop cycle (Debiase *et al*., 2016). The improved wheat crop agronomic performance in 2019 could have been due to the fact that incorporated residue decomposition requires time. Moreover, the yield was lower in 2017 and 2018 as shown in Fig. 2, which may have been due to soil nitrogen immobilization (Morris *et al*., 2010).

Moreover, a significant positive correlation was observed between wheat yield and yield-attributing components (Table 5) because of certain genetic and environmental factors (Rharrabtia *et al*., 2003; Debiase *et al*., 2016). In addition, a significant positive correlation was observed between yield and surface soil NO_3^--N and NH_4^+-N whilst a negative correlation was noted between wheat productivity and sub-surface soil NO_3^--N and NH_4^+-N (Table 5), which suggests the maximum translocation of these nutrients from the soil system to the plant (Koutroubas *et al*., 2016).

Conservation tillage practices play a vital role in the sustainability of agriculture, facilitate soil nutrient accumulation, and finally, improve crop production (Pagnani *et al*., 2019). On the other hand, intensive soil manipulation and imbalanced inorganic fertilization have been used to achieve maximum crop yields. However, these practices lead to a decline in the fertility of the soil which threatens crop yields.

Table 5. Correlation between yield, soil mineral nitrogen and carbon at different soil depths

Parameter ($mg\ kg^{-1}$)/ Soil depth (cm)	NO_3^--N ($mg\ kg^{-1}$)			NH_4^+-N ($mg\ kg^{-1}$)			SOC (%)			Seed-yield ($kg\ m^{-2}$)
	Soil depth (cm)									
	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30	
NO_3^--N										
0-10										
10-20	0.603**									
20-30	-0.261 0.073	-0.088 0.551								
NH_4^+-N										
0-10	0.439** 0.002	0.549**	-0.070 0.634							
10-20	0.582**	0.709**	-0.075 0.611	0.533**						
20-30	0.594**	0.503**	0.081 0.584	0.382** 0.007	0.410**					
SOC (%)										
0-10	0.430** 0.002	0.295* 0.042	-0.279 0.055	0.317* 0.028	0.505**	0.464** 0.001				
10-20	0.400** 0.005	0.519**	-0.339* 0.018	0.351** 0.014	0.524**	0.219 0.135	0.509** 0.000			
20-30	0.387**	0.548**	-0.361* 0.012	0.371** 0.010	0.493**	-0.208 0.156	0.453** 0.001	0.863**		
Seed-yield ($kg\ m^{-2}$)	0.632**	0.513**	-0.224 0.126	0.306* 0.034	0.479** 0.001	-0.564 0.134	0.626** 0.000	0.477** 0.001	0.405** 0.001	

Indicates significance at: *p < 00.05, **p < 00.010.

Our findings demonstrated that different conservation tillage management practices significantly increased soil NO_3^--N, NH_4^+-N, and SOC at a 0-30 cm soil depth from 2016 to 2019 compared with CT soil practice as shown in Fig. 4, 5 and 6 which is consistent with the results of other researchers (Han *et al*., 2020; Rani *et al*., 2017; Jat *et al*., 2017; Lafond *et al*., 2011). There was a multi-factor explanation for improvements in soil NO_3^--N, NH_4^+-N, and SOC under CTS, NTS, and NT treatment. Firstly, straw can reduce nitrogen leaching and volatilization losses by minimizing the soil temperature and finally improving soil NO_3^--N and NH_4^+-N (Rani *et al*., 2017). In the case of SOC, the maximum SOC was due to climatic conditions which increased the crop residue decomposition (Wang *et al*., 2017). Crop straw usually contains essential plant growth nutrients.

However, the minimum SOC under CT treatment was due to ploughing with shovels and without straw or crop residue which led to the deterioration of the soil structure, and may have produced a greater mineralization rate of carbon and decomposition rate of soil organic matter which promoted a loss of carbon (Jat *et al*., 2017). Secondly, the higher soil NO_3^--N and NH_4^+-N with straw incorporated treatments may be related to a greater level of biological activity. The nitrification process enhanced the transformation of the soil organic matter to soil nitrogen (Morris *et al*., 2010). In general, under NTS and CTS treatment the maximum soil NO_3^--N and NH_4^+-N levels were due to higher soil compaction which restricted water-movement and led to a decrease in leaching losses.

With regard to SOC, NT treatment minimized the disintegration of macro-aggregates which impounded carbon and contributed to an increase in soil organic carbon (Khorami *et al*., 2018; Lafond *et al*., 2011). Moreover, the maximum level of SOC achieved under NT management practice may be due to the consequences of biomass production (Dolan *et al*., 2006; Zhao *et al*., 2019). This is consistent with the result achieved by Jat *et al*. (2017), Omara *et al*. (2019). Our observations suggest that conservation tillage practices improved soil NO_3^--N, NH_4^+-N, and SOC. In addition, the level of soil NO_3^--N was higher than soil NH_4^+-N. These findings are in accordance with the results of (Rani *et al*., 2017) who reported that straw incorporation significantly improved the level of NO_3^--N and NH_4^+-N.

There is a positive correlation between surface soil NO_3^--N with the surface as well as sub-surface soil NH_4^+-N and SOC whilst a negative correlation was observed between surface NO_3^--N with sub-surface soil NO_3^--N shown in Table 5. Furthermore, a negative correlation was recorded between sub-surface soil NH_4^+-N and SOC with sub-surface soil NO_3^--N. In addition, a positive correlation was found between surface soil NH_4^+-N and surface SOC whereas a negative correlation was observed between sub-surface soil NH_4^+-N and sub-surface SOC, and this coincides with the findings observed by (Rani *et al*., 2017; Lafond *et al*., 2011).

According to PCA analysis, the observation point made by a combination of PC1/PC2 and PC1/PC3 shows the overall variance explained by the five major components. In the 0-30 cm soil layer, the highest loading was observed in the PC1component whilst the lowest loading was recorded in the PC3 component included NO_3^--N, NH_4^+-N, and SOC. Moreover, PC4 and PC5 are not plotted because they don't allow for any additional information. As expected, the principal component analysis indicates that the CT treatment was least affected by the surface as well as sub-surface soil NO_3^--N, NH_4^+-N, and SOC accumulation in the soil system as compared to the conservation tillage practices (Fig. 6). In fact, the found points of CT practice were closer in comparison with other conservation tillage practices, and closer to the central point of the PCA components (Fig. 6a and b). In the PC1/PC2 combination, CT was less affected as compared to CTS, NT and NTS. In addition, the NTS was the least affected in comparison with CTS and NT by the NO_3^--N, NH_4^+-N and SOC accumulation in 0-30 cm soil layer. The observation points of NTS were closer to the central point of the PCA components. With regard to the PC1/PC3 combination, the observation points of NT were nearer to the central point of the PCA components over NTS and CTS. NT was more affected than CT soil treatment included NO_3^--N, NH_4^+-N, and SOC in 0-30 cm soil layer. In fact, the found points of NT were far from the central point of the PCA components. The results showed that, after short-term NT application, the soil system did not change in comparison with CTS and NTS as suggested by other researchers such as Fuentes *et al*. (2003), Dolan *et al*. (2006), Wang *et al*. (2008). Moreover, PCA analysis also revealed that overall, in comparison with CTS, the observation points of NTS and NT are closer to PCA components. As a consequence, NTS and NT did not increase nutrient accumulation compared with CTS treatment. Consequently, the long-term application of NTS and NT may improve nutrient concentration in the soil system as suggested by Chen *et al*. (2014), Omara *et al*. (2019).

CONCLUSIONS

1. Conservation tillage treatments (wheat straw-return to the no-tilled soil, straw incorporation into the conventionally tilled soil and no-tillage) improved wheat crop productivity in comparison with conventional tillage practice.

2. The soil under conservation tillage practices demonstrates a higher yield attributes compared to conventional tillage practice.

3. Conservation tillage practices improved soil mineral nitrogen (NO_3^--N and NH_4^+-N) contents as compared to conventional tillage.

4. The plots under conservation tillage treatments showed higher soil organic carbon contents as compared to conventional tillage.

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