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SUNFLOWER AND SOIL RESPONSE TO SEVEN YEARS OF TILLAGE, RESIDUE MANAGEMENT AND NITROGEN FERTILIZER

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ABSTRACT

A 7-years (2006−2012) field study was carried out at the research station of Baikola, Neka, Iran; the experiment included treatments varying in: (1) wheat straw management: plus residue (+R) and minus residue (-R); (2) tillage system: zero tillage (ZT) and conventional tillage (CT); and (3) Nitrogen rates: 0 (control), 80, 160 and 240 kg N ha^{-1} (N1-N4). After 7 years of continuous practice, ZT+RN4 and ZTR+RN3 had the best soil quality and produced the highest sunflower yields of average 2010–2012 (5250 and 5150 kg ha^{-1}, respectively). Removing the residues, i.e. treatments ZT−RN1 (average 2010–2012: 2150 kg ha^{-1}), gave the lowest yields and less favorable soil physical and chemical characteristics compared to the other practices. Organic C, total N, moisture, aggregates stability, mechanical resistance, pH and EC were the factors that defined the difference in soil quality between conventional tillage and zero tillage. The principal component combining the variables organic C, total N, aggregate stability and moisture content showed the highest correlations with final seed yield (R = 0.87 for sunflower).The findings suggest that ZT+R together with nitrogen fertilization would improve some soil properties, crop production and may also be better for the sustainability of high crop production.

Keywords: ***Heliantus anuus*; Soil quality; Wheat residue; Yield; Zero tillage.**

INTRODUCTION

In today's world, the most prominent aim of human beings is to maximize the profit by increasing production. Higher inputs used in production in order to get maximum profit cause some economic losses since they pollute environment. Preventing environmental pollution and minimizing economic losses gain importance in sustainable agriculture. Sustainability would only be possible with the conservation of soil and plant (İdikut and Kara, 2011; Yolcu, 2011).

In the most parts of Iran, wheat **(***Triticum aestivum* L.**)** residues have been traditionally burned or removed; that is often criticized for soil organic and nutrient losses, reducing soil microbial activity and increasing CO_2 emission (Rahimizadeh et al., 2013). However, where residues have been soil incorporated, farmers often have concerns for reduced soil fertility from nutrient immobilization and problems for cultivation associated with slow rates of residues decomposition (Malhi et al., 2006). Effective mitigation of these effects depends on developing crop residue management strategies that enhance residues decomposition. Realizing the potential benefits of cereal residues incorporation depends on synchronizing the release of N with the crop demands, while minimizing the risks to nutrient losses (Malhi and lemke, 2007). Where residue have been incorporated before planting the next crop, grain yield was lower than where residues were removed or burned, resulting in N immobilization (Huang et al., 2013). There is not enough information on the effects of residue management and N rates on sunflower in northern part of Iran. This seven-years field experiment was aimed to 1) determine the effects of tillage management, residue and nitrogen fertilizer on physical and chemical soil qualitative traits following 7 years of continuous application of ZT as compared to CT, crop residue management (+R and -R) and select an optimum level of N, along with suitable strategies relative to tillage and crop residues for sustainable sunflower yield; 2) determine the relationship between the soil quality and the crop yields.

MATERIALS and METHODS

Site description

The experimental site at Baikola Agricultural Research Station of Mazandaran Agricultural Research Center (36°46'N, 53°13'E) is situated at 4 m above the mean sea level. The climate of Baikola is classified as sub-humid. The average maximum and minimum temperatures and rainfall during sunflower-growing season were, respectively, 25.46°C, 19.43°C, and 1.03 mm day^{-1}. Soil at the site was sandy-loam texture.

Treatments and field operations

The experimental site had been previously sown with winter dry land wheat to provide residue cover for the plot, and the experiment started in cropping year of 2005 and continued through 2012. The experiment was conducted as strip split plot with four replications. Horizontal plots consisted of crop residues, remove (-R) and keep (+R), vertical plots were two tillage systems, conventional tillage (CT) and zero tillage (ZT) and sub-plots were four N rates, 0 as a control, 80, 160 and 240 kg N ha^{-1} as urea (N1-N4). Urea N fertilizer was side-banded 2.5 cm away and 2.5 cm below seed rows at sowing. All plots received blanket annual applications of P (45 kg P ha^{-1}), K (42 kg K ha^{-1}) and S (17 kg S ha^{-1}) fertilizers broadcast prior to tillage and sowing. One-third of N was applied at planting time and rest of the nitrogen at vegetative stage, (4-5 leaf stage of sunflower) as top dressing. The irrigation was applied in the crop according to crop growth stages, before and after each irrigation. Soil samples were taken at 15 cm intervals up to 90 cm depth and soil moisture content was measured gravimetrically and then depth of irrigation water was determined.

Individual plots were 6m by 20 m and present a micro-relief with a slope of < 0.3%. Standard practices included the use of recommended crop cultivar, target density of 9 plants m^{-2} (0.20 m × 0.60 m). Planting of sunflower is usually done between June 5 and 15 and harvested on 27 October. Winter wheat was planted in fall of 2005-2011. Wheat plots received 150 kg ha^{-1} of granular urea (46–0–0). There is no significant different about of residue rates of winter wheat during experiment years (average 9.37 Mg ha^{-1}). The organic C and N contents of the wheat straw were 39.4% and 0.5%, respectively. After harvest, the residue was removed or kept in the field. Retained residues were incorporated, if tilled, or left on the surface with zero tillage.

Sunflower yield

To evaluate the yield, average yields for the last 2 years were used (2011–2012). Bradford and Peterson (2000), argue that the major benefits of conservation agriculture can be assessed only after it has been in place for five years or more. Relative yields give the possibility to compare treatments over the years so that the specific yield potential of each year had not to be considered (Govaerts et al., 2005).

Soil sampling and analyses

Soil was sampled after harvest of sunflower, i.e. end of the October, in 2012 (Because harvest was done on 27 October). Each plot was divided in two and 15 subsamples were taken from each sub-plot. The 15 sub-samples were pooled so that two composite soil samples were obtained from each plot for chemical characterization. Composite soil samples consisting were taken to soil depths of 0–5, 5-10 and 10–20 cm. Samples were air-dried and passed through a 2 mm sieve. Table 1 shows the analytical protocols selected.

Table 1. Protocol of measurements for each indicator.

Indicator	Protocol	Ref.
Total N	Kjeldahl[a]	Bremner (1960)
Total organic carbon	Wet digestion[a]	Walkley(1947)
pH	Soil paste[a]	Salinity Laboratory Staff (1954)
Electrical conductivity	Soil paste[a]	Salinity Laboratory Staff (1954)
Resistance to penetration		Bradford, 1986
Soil bulk density (ρ_b)		Hillel,1998

[a] Practical laboratory protocol as according to Handbook on reference methods for soil analysis. The Council on Soil Testing and Plant Analysis Athens, Georgia, 1992.

Soil samples for dry aggregates were collected from 0–5 cm depth at two inter-row locations in each plot using a rectangular trough (15 cm - 17.5 cm) with minimal disturbance. The soil was air-dried to about 5 g 100 g^{-1} water content. The samples were shaken, using an automatic rotary sieve shaker, at 12 cycle's min^{-1}, through a nest of sieves having rectangular holes with equivalent diameter of 38, 12.7, 6.4, 2.0, 0.83, and 0.42 mm, and a pan underneath. Aggregate fraction retained on each sieve and the pan was oven-dried (105 ºC), and expressed as a percentage of total dry soil mass. The results were expressed as percent aggregate size distribution as well as mean weight diameter (VanBavel, 1950).

Statistical analysis

Statistical analysis was done with SAS GLM, PRINCOMP (SAS Institute, 1994) procedures. Variables were grouped into chemical and physical properties. Four class factors were considered: nitrogen, tillage type, residue management and block. The first step (MANOVA) determined whether there was a significant effect of a class factor on at least one of the physical and chemical variables assessed. Wilk's lambda and derived *F* statistics were used to test the null hypothesis that no significant difference exist between treatments. The univariate ANOVAs was applied when this criteria was met (Wander and Bollero, 1999). Those variables, for which the class factor *F* statistics for tillage and residue, were not significant at P <0.05, were not retained for further analysis. All retained physical and chemical variables were then further explored under principal component analysis (PCA), through which, the number of independent variables could be reduced and problems of multicollinearity solved. Variables were auto-scaled prior to PCA (Sena et al., 2002). The number of components was determined by the Eigen value-one criterion (Kaiser, 1960). A VARIMAX rotation was performed to enhance interpretability of the uncorrelated components (Flury and Riedwyl, 1988). All meaningful loadings (i.e. loadings > 0.40) were included in the interpretation of principal components (PC), which were considered significant if > 5% of the total variance was explained. The rotated components were used to fit a multiple regression with sunflower and wheat yield, as dependent variables and the principal components as independent variables. Least significant difference (LSD 0.05) was used to determine significant differences between treatment means.

RESULTS and DISCUSSION

Crop yield

After 7 years, the highest yields for the last two years were obtained for sunflower in the ZT+RN4 treatment (Figure 1). Lowest yields were obtained with ZT-RN1: nearly 37% less than the same management with full residue retention (Figure 1). Retaining crop residues was important to both tillage systems, but was crucial in ZT. CT appears to ameliorate some of the adverse effects of residue removal. A good management practice has to lead to both high and stable yields. Year-to-year variation in sunflower yield was remarkably small, with only minor year-to-year yield interactions with treatments at the intermediate yield levels (Figure 2a and b). ZT systems with residue retention were the most stable, with the lowest year-to-year variation. The trend for this treatment is towards high and stable yields, even though it was low-yielding during the initial years. The effect of straw on crop growth and yield is communicated mainly through change in soil properties, which is a slow process; therefore, it took some time before the full benefits of ZT with residue retention appeared. When residues are removed, ZT results in very instable yields (Figure 2a and b).

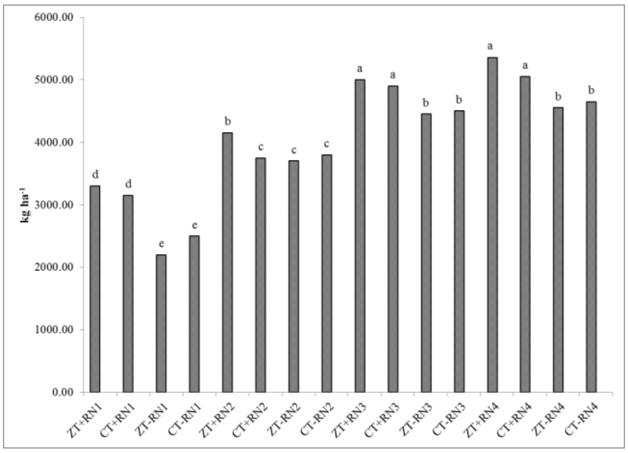

Figure 1. Average grain yields of sunflower (12% moisture) from 2010 to 2012, in soils subjected to zero tillage (ZT) and conventional tillage (CT), nitrogen fertilizer (0, 80, 160 and 240 kg N ha^{-1}; N1-N4), with residues (+R) and without residues (−R). Different letters indicate a significant difference between treatments at P < 0.05.

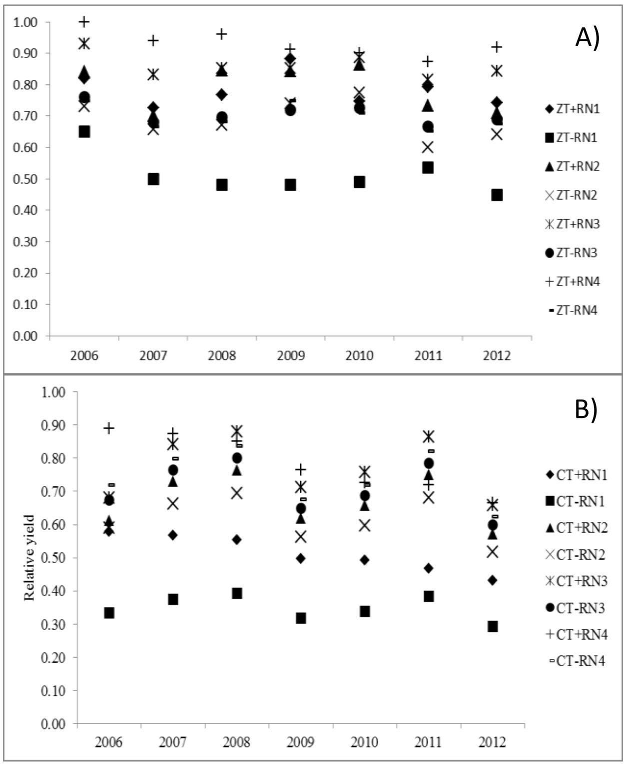

Figure 2. sunflower yields per treatment per year from 2006 to 2012, expressed relative to the highest yield of that year for zero tillage (ZT) treatments (A) and conventional tillage (CT) treatments (B).Nitrogen fertilizer (0, 80, 160 and 240 kg N ha^{-1}; N1-N4), with residues (+R) and without residues (−R).

Seed yield of sunflower responded strongly to applied N, with average increase of 25%, with the first 80 kg N ha^{-1} compared to no N (Figure 1). Compared to no N, seed yield increased significantly with application of 80 kg N ha^{-1} (i.e. N2) under ZT, but yield increase under CT was significant only with application of 160 kg N ha^{-1}. Although seed yield increased significantly with N3 under both +R and -R treatments, yield tended to increase with the N4 on +R but not on -R. N4 did not increase seed yield in CT-R treatment, and did so only modestly in CT+R. Response to N was much greater in ZT treatments with the highest yield increase occurring in the ZT+R combination. In the initial years of adopting ZT and where N fertilizer was broadcasted, retaining wheat straw on the soil has been found to reduce crop yield compared to removal, likely due to increased immobilization of Caused by the addition of straw with a very high C to N ratio (80:1) and also possible allelopathy effects (Huang et al., 2013; Rice, 1984).

Soil physical and chemical properties

Soil moisture content

The soil moisture content showed no effect of N rate (Table 2), but it was higher with +R than -R in the 0–15 cm depth in all years, and it was also higher under ZT than CT (Table 2). The ZT+R treatment had the highest soil moisture in many cases. Earlier studies have also shown that omitting tillage and retaining straw often improved the capacity of soil to store water (Malhi et al., 2006), also, the increase in total porosity, particularly micro-porosity, due to addition of organic matter probably led to enhancement of the moisture retention capacity and the presence of the residue on the surface of the soil had mulching effects on the soil surface (Malhi et al., 2006). However, differences between treatments were negligible from the farmer point of view. Our results agree with Verhulst et al. (2009) who showed that difference in soil moisture content between residue management practices was smaller in irrigated than in rainfed conditions due to the correcting effect of irrigation, allowing other factors such as nutrient availability to become more important than in rainfed conditions.

Soil aggregate size distribution

Dry aggregates < 0.83 mm in the present study were considered wind-erodible fraction (Malhi et al., 2006). At the end of 7 years, the proportion of wind-erodible aggregates was significantly greater in surface soil of CT compared to ZT treatment (Table 2). The ZT systems tended to have lower percentage of wind erodible aggregates and higher percentage of large aggregates than CT. Addition of straw decreased the proportion of wind erodible aggregates. Combination of ZT+R resulted in the lowest proportion of wind-erodible aggregates (34%) and greatest proportion of large aggregates (37%), whereas CT-R combination resulted in the greatest proportion of wind-erodible aggregates (50%) and lowest proportion of large aggregates (18%). The +R treatments tended to have lower percentage of wind erodible aggregates and higher percentage of large aggregates compared to -R treatments (Table 2). This indicates reduced potential for soil erosion when crop residues were retained.

The MWD generally tended to be larger for +R than -R under both tillage systems and it tended to be larger for ZT than CT under both straw management systems (Table 2).The MWD was greatest in the ZT+R treatment (15.1 mm) and the smallest in the CT-R treatment (7.3 mm).These observations are consistent with findings reported by Kihara et al. (2012) and Fuentesa et al. (2009), where minimum tillage resulted in higher aggregate MWD.

The proportion of large aggregates tended to increase and proportion of fine aggregates significantly decreased with increasing N rate from 0 to 240 kg N ha^{-1} (Table 2). This could be due to better root growth of corn could have helped to ameliorate soil physical properties (Agostini et al., 2012).The aggregation data indicated much greater impact of ZT on improvement of soil structure than straw management.

Table 2. The effect of tillage system, residue management and N rate on the dry soil aggregate distribution percentage for each size and mean weight diameter (MWD), after the first 7-year crop rotation cycle at Neka city.

Treatment		**Soil moisture content (g kg^{-1})**	**Bulk density (g cm^{-3})**	**Resistance to penetration (MPa)**	**MVD (mm)**	**Percentage for each soil aggregate size (mm)**						
						<0.42	**0.42–0.83**	**0.83–2.0**	**2.0–6.4**	**6.4–12.7**	**12.7–38.0**	**>38.0**
Tillage	ZT	239.43	1.21	2.22	13.4	25.8	11.2	5.8	16.2	8.2	20.6	12.2
	CT	218.95	1.09	1.72	7.79	35.8	12.8	6.1	17.4	8.7	15.1	4
LSD		ns	*	*	**	**	**	ns	*	ns	**	**
N rate (kg ha^{-1})	0	220.3	1.15	2.10	7.29	37.2	12.8	5.9	17	8.8	15.1	3.1
	80	237.8	1.17	1.98	8.29	34.5	12.9	6.3	17.7	8.6	15.1	5
	160	240.1	1.20	1.99	11.73	28	12.2	6.5	16.5	7.8	19.4	9.6
	240	239.5	1.21	1.98	15.07	23.7	10.1	5.2	15.9	8.5	21.8	14.7
LSD		ns	ns	ns	ns	ns	**	**	*	ns	ns	ns
Residue	+R	261.4	1.24	1.75	11.69	29.1	11.5	5.7	16.8	8.6	18.5	9.8
	-R	196.7	1.10	2.58	9.51	32.6	12.5	6.2	16.8	8.3	17.3	6.3
LSD		*	*	*	*	**	**	**	ns	ns	ns	*

• *, ** and ns refer to significant treatment effects in ANOVA at P ≤ 0.05, P ≤ 0.01 and not significant, respectively.
[a] CT and ZT refer to conventional tillage and no-tillage, respectively.
[b] -R and +R refer to no straw (straw removed) and straw (straw retained), respectively.

Soil bulk density

Soil bulk density was affected significantly by tillage and residue management (Table 2), but it showed no effect of N rate (Table 2). Differences in bulk density among treatments could probably due to the greater SOC content at the +R than -R which influenced the conversion of SOC from concentration to content. Our results agree with those reported by other authors (Agostini et al., 2012) who showed SBD increases due to ZT implementation.

Water infiltration

In the plots where residues were kept, both on the surface or incorporate, the resistance to penetration reduced regardless of the nitrogen rate (Table 2).

The ZT+R treatments had higher water content and a lower resistance to penetration than the ZT-R treatments (Table 2). In the ZT+R and CT+R treatments, soil moisture and resistance to penetration were more spatial homogeneous in the plot than in those without residues

(ZT-R and CT-R) (for example Figure 3a and b). The variation for resistance to penetration between treatments resulted from only residue management and not tillage or interaction between these.

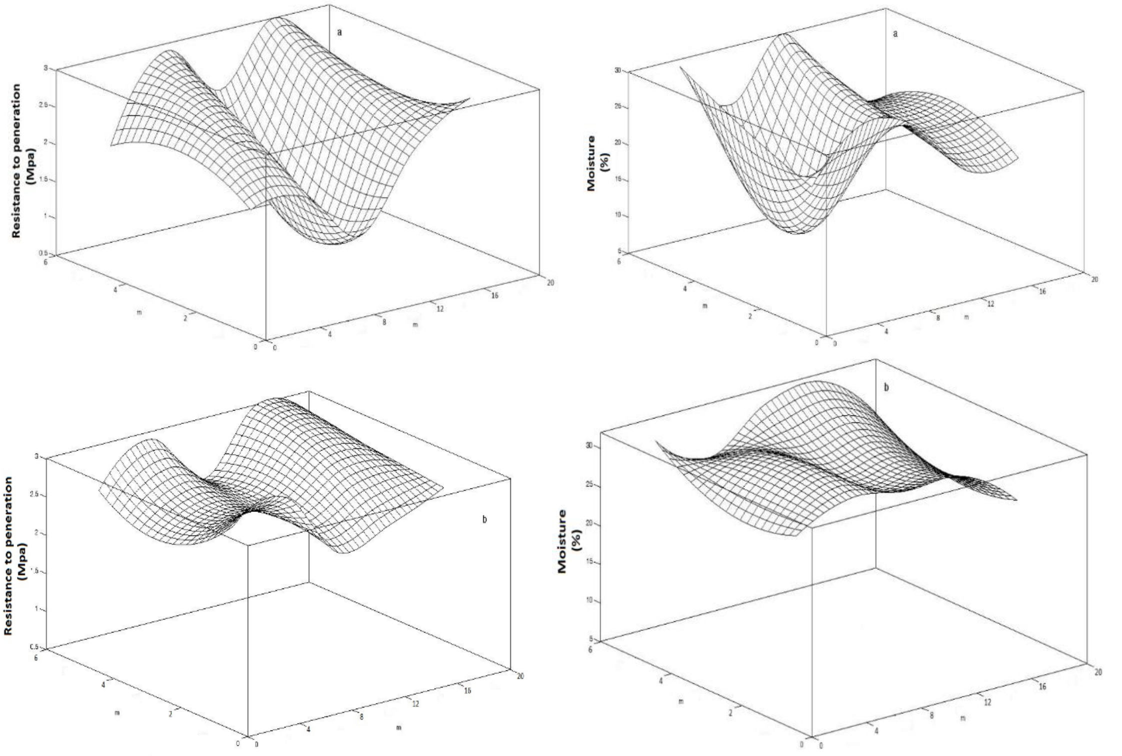

Figure 3. Example of resistance to penetration and volumetric moisture in (a) plot with zero tillage (ZT) and without residues and (b) a plot with zero tillage (ZT) and with residues.

Our results agree with Govaerts et al. (2007b), they reported that plots exhibited compaction (resistance to penetration under residue removal), hinders the water movement throughout the profile and causes a deficit of moisture, moisture retention is related to the increased aggregation, reduced evaporation, improved infiltration, etc. as found with zero tillage and residue retention.

In addition, the residues left on the top soil with zero tillage and crop retention act as a succession of barriers, reducing the runoff velocity and giving the water more time to infiltrate.

pH and EC

The pH was significantly affected by residue management, type of tillage and nitrogen rate. But only in the first 5cm layer (Table 3). The EC in the different layers of soil cultivated with sunflower was not affected by treatments (Table 3).

Application of urea can lead to soil acidification; on the other hand, can the retention of crop residue, depending on soil and climate, also result in a soil acidifying effect or the contrary by bringing back bases (Morari et al., 2008). Soil acidification caused by mineral fertilizations, ammoniac and ureic fertilizers, in particular, would have a marked effect on the pH, due to the absorption of the ammonia ion by plants or its nitrification. These processes produce hydrogen ions (Havlin et al., 1999). This phenomenon was clearly showed in the ZT-R soil with a pH 5.81as opposed to the initial valued when the experiment was started of pH 6.5 (Fischer et al., 2002). This strong acidification could reduce the availability of some nutrients (Ca, K, N, Mg, Mo, P, S) (Fischer et al., 2002). In contrast, the CT+R, CT-R and ZT+R treatments showed pH ranging from 6 to 6.5, which is optimal for nutrient availability (Havlin et al., 1999).The acidification of the soil with ZT-R was credited to the addition of nitrogen fertilizers, which remain in the first 5cm of the profile, as a result of the lack of moisture and the increased compaction in this treatment, hindering their mobility and availability by the crop (Bloom, 2000). This phenomenon does not occur in plots under ZT+R, CT+R and CT−R though the same rate of nitrogen fertilizer was applied, however productivity were higher in these treatments (ZT+R, CT+R and CT-R) compared to ZT-R (Figure1). This means there is a greater demand of nutrients in the former plot and the existing moisture conditions allow the availability of such fertilizers.

Soil organic C and organic N

At the end of seven growing seasons, mass of TOC (total organic carbon) and TN (total nitrogen) in the 0–15 cm soil depth were significantly greater under +R than under –R treatments (Table 3). Increase in organic C and N fractions due to straw retention was closely associated with greater input of C and N to soil through straw in the +R compared to -R treatments. Also TOC and TN were greater or tended to be greater under ZT than under CT. Ding et al. (2002) reported that CT changes and deteriorates the characteristics of SOM (soil organic matter), reducing organic C. In contrast, ZT+R optimizes the phenomena associated with moisture, the cycle of nutrients and the reduction of erosion, thus contributing to the preservation of the organic soil composition. The lower level of organic carbon for conventional tillage was probably a result of high organic matter and its decomposition which is usually enhanced by disruption of soil aggregates (Hassink, 1995). The N rate generally had no significant effect on TOC and TN, although mass of these parameters maximized at N4, the highest rate used in this study (Table 3). Franzluebbers et al. (1994) also observed that the SOC was 62% higher, in wheat cultivation, with fertilizer than without fertilizer, implying synergy in organic and inorganic resource inputs. Build-up of organic matter in soil is a slow process and it takes many years to accumulate significant amounts of organic matter in soil. That is why in the present 7-year study many effects, especially of tillage and N rate, and particularly on TOC and TN, were not significant. Malhi et al. (2007) reported that 8 years of ZT did not increase TOC or TN, but removal of straw in a crop rotation tended to reduce TOC and TN.

Table 3. The effect of tillage system, residue management and N rate on the pH, electrolytic conductivity (dSm^{-1}), mass of total organic C (TOC) and N (TN), after the first 7-year crop rotation cycle at Neka city.

Treatment		Mass of TOC ($Mg\ C\ ha^{-1}$)			Mass of TN ($Mg\ N\ ha^{-1}$)			pH in different soil layers			Electroltic conductivity in different soil layers ($dS\ m^{-1}$)		
		0-5 cm	5-10 cm	10-20 cm	0-5 cm	5-10 cm	10-20 cm	0-5 cm	5-10 cm	10-20 cm	0-5 cm	5-10 cm	10-20 cm
Tillage	ZT	24.85	23.33	11.39	1.842	1.788	1.668	5.82	6.28	6.6	0.09	0.09	0.08
	CT	23.14	23.04	11.2	1.8	1.7	0.94	6.14	6.25	6.62	0.08	0.08	0.07
LSD		ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns
N rate (kg ha $^{-1}$)	0	23.45	22.93	10.12	1.81	1.65	0.93	6.22	6.4	6.7	0.07	0.07	0.07
	80	24.91	23.12	10.78	1.83	1.69	0.90	6.11	6.4	6.7	0.09	0.08	0.07
	160	25.59	23.02	10.71	1.84	1.7	0.89	5.95	6.3	6.6	0.08	0.09	0.08
	240	26.01	23.65	11.61	1.84	1.77	1.04	5.64	6.11	6.5	0.1	0.09	0.08
LSD		ns	ns	ns	ns	ns	ns	*	*	*	ns	ns	ns
Residue	+R	24.31	23.59	13.12	1.85	1.75	1.07	6.17	6.3	6.64	0.09	0.09	0.07
	-R	20.02	18.01	9.5	0.99	1.72	0.81	5.8	6.23	6.56	0.07	0.08	0.07
LSD		*	*	*	*	ns	ns	*	ns	ns	ns	ns	ns

• *, ** and ns refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.
[a] CT and ZT refer to conventional tillage and no-tillage, respectively.
[b] -R and +R refer to no straw (straw removed) and straw (straw retained), respectively.

Principal component analysis of treatments

Loading parameters obtained after VARIMAX rotation are given in Table 4. PCA was performed using soil parameters that were significantly different between the treatments. Two PCs were retained with Eigen values >1 and that explain>10% of the total variance. A first PC (PC1) explained 59% of variation. PC1 had positive loading from organic C and total N in the 0–5cm and 5–10 cm layer, water content and aggregates. pH in the 0–5cm layer loaded positive and penetration resistance negative on the second PC (PC2), which explained another 23% of variation. The two PC's explained 82% of variation.

On the scatter plot, the soils fall into different groups, those are visually distinct (Figure 4). The ZT treatments with residue retention, independent of nitrogen rate, are rich in organic C in the 0–5 cm and 5–10 cm layer, water content and aggregates, i.e. a positive PC1. The ZT treatments with residue removal are located in the lower left quadrant, i.e. negative PC1. They are lower in organic C content, the aggregates are less stable and the water content is lower compared to the ZT+R treatments, but pH in the 0–5cm and 10–20 cm layer is lower and the penetration resistance is higher. The CT treatments can be found in the upper left quadrant, i.e. a negative PC1 and appositive PC2. The retention or removal of the residue separates the treatments, with the latter having lower organic C contents. Multivariate statistical approaches such as PCA may be an appropriate first step toward soil quality assessment within regions and cropping systems (Wander and Bollero, 1999) and it is a potential tool to identify the most sensitive soil attributes influencing crop yields (Jiang and Thelen, 2004). Andrews et al. (2002) compared soil quality index methods for plant production systems, in which they considered expert opinion and PCA as methods for MDS selection. They concluded that both methods resulted in minimum set of quantitative data (MDS), which were equally representative of variability in end-point measures of farmland environmental management goals for the vegetable production systems they considered.

Table 4. Rotated loadings on the principal components for treatments cultivated with sunflower.

Measurements	**Principal components**	
	PC1	**PC2**
Eigenvalues	5.84	2.26
Proportions [a]	0.59	0.23
Rotated loading on two retained components [b]		
Total C 0-5 cm	0.97[c]	0.16
Total N 0-5 cm	0.93[c]	0.10
pH 0–5cm	0.15	0.94[c]
Total C 5-10 cm	0.88[c]	0.36
Total N 5-10 cm	0.85[c]	0.24
pH 10–20cm	-0.12	0.57[c]
Mechanical resistance	-0.02	-0.91[c]
Soil water content	0.79[c]	0.45[c]
Aggregates in dry sieving	0.93[c]	-0.21

[a] Proportions of the total variation in the original database explained by the corresponding principal components.
[b] Only principal components with Eigen values >1 and that explain >10% of the total variance were retained.
[c] Parameters with significant loadings on the within column principal component.

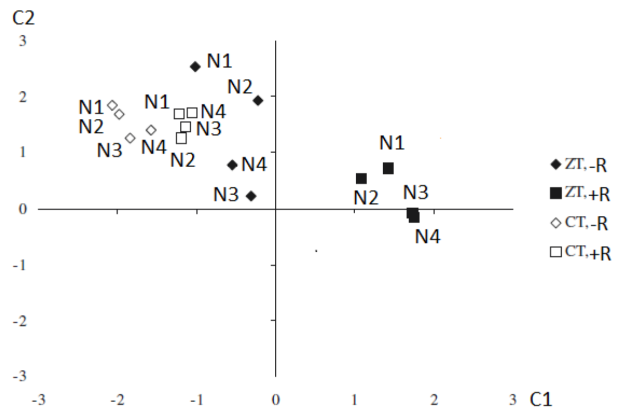

Figure 4. Biplot of the principal components representing chemical and physical soil quality; with zero tillage (ZT) and conventional tillage (CT); Nitrogen fertilizer (0, 80, 160 and 240 kg N ha^{-1}; N1-N4); with residues (+R) and without residues (−R).

However, the PCA method requires a large existing data set. The results presented confirm the PCA method is very suitable for MDS selection. PCA analysis grouped chemical and physical variables in different components. The organic C, total N content, pH and EC were chemical parameters with greater sensitivity to soil quality change, while physical parameters were aggregation, moisture and resistance to penetration. Shukla et al. (2006) conducted a study on soil quality and identified five factors after PCA including chemical and physical parameters related to one or more soil functions (e.g., water and nutrient retention and transport, soil structure, aeration, etc.). It has been shown that N cycling is linked directly with the C (Schlesinger, 1997). Karlen et al. (2006) concluded that total organic C was the most sensitive indicator for soil quality. As in our study soil organic C was also reported as the most powerful soil attribute by Brejda et al. (2000) for central and southern high plains and for northern Mississippi loess hills and Palouse prairie in the USA. In Northern California, a study compared methods to determine soil quality change and total N and total organic C were the most sensitive chemical soil quality indicators (Andrews et al., 2002). Malhi and Lemke (2007) found for a comparative study between ZT and CT in Canada that the difference in soil quality based on total C and total N was highly linked to the sustainability of crop production. The same authors also indicated aggregate distribution and stability as important indicators. Many studies in various soil and climatic conditions have demonstrated a positive correlation between organic carbon and SOM in the soil and the structural stability of both macro and micro aggregates (Shukla et al., 2006). The variables mentioned in these reports coincide with the variables sensitive to soil quality changes as found in this investigation. In the soil cultivated with sunflower PC1 (organic C, N, aggregates and moisture) and PC2 (compaction, pH, EC), were positively correlated with yield (Table 5). There is a relation between a higher quality soil and higher yields in sunflower, as shown in plots subjected to ZT+R and CT+R. In contrast, the plots under ZT−R produced the lowest yields and had lower soil quality, i.e. low contents of organic C and total N, low stability of aggregates, compaction, lack of moisture and acidity. Karlen et al. (2006) showed that the lowest soil quality index values and20-year average profit were associated with CT.

Table 5. Regression between sunflower yields and the principal components of the different parameters.

	R	Slope	
		PC (organic C, total N, aggregates, moisture content)	PC (compaction, pH, electrolytic conductivity)
Sunflower	0.87	0.74**	0.47*

* significant P ≤ 0.05, significant ** P ≤ 0.01.

CONCLUSION

Organic C, total N, moisture, aggregates stability, penetration resistance, pH and EC were the factors that defined the difference in soil quality between conventional tillage and zero tillage. Zero tillage practiced for 7 years, with crop residues retained in the field resulted in a soil with a better quality and, in addition, producing higher sunflower yields than the plots subjected to conventional tillage (either with and without residues) and zero tillage without residues. Zero tillage without residues showed the lowest soil quality and yields. The penetrometer and soil moisture determinations showed that zero tillage with retaining all residues did not cause significant compaction in the soil as compared to the conventional tillage treatment with residues. One of the benefits of retaining residues in the plots subjected to zero and conventional tillage was the reduction in both moisture spatial variability and soil mechanical resistance. The results of the present study showed that the zero tillage with residue retention is a feasible management technology for farmers producing sunflower in the studied agro-ecological zone and other the same conditions. From ecological point of view, the results confirmed this frequently claimed opinion that beneficial effects of sustainable-based approaches such as conservation methods will appear in long time periods. This was demonstrated by those traits that were determined as the most affecting factors on the soil quality between conventional tillage and zero tillage.

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