Journal of Crop Nutrition Science
ISSN: 2423-7353 (Print) 2538-2470 (Online)
Vol. 10, No. 3, 2024
https://jcns.ahvaz.iau.ir/ OPEN ACCESS

Maize (*Zea mays* L.) and Soil Response to Applying Different Management Tillage and Nitrogen Fertilizer

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RESEARCH ARTICLE

ARTICLE INFO.
Received Date: *30 Jun. 2024*
Received in revised form: *29 Jul. 2024*
Accepted Date: *1 Sep. 2024*
Available online: *7 Sep. 2024*

To Cite This Article:
Alireza Safahani, Behrooz Mohseni. Maize (*Zea mays* L.) and Soil Response to Applying Different Management Tillage and Nitrogen Fertilizer. ***J. Crop. Nutr. Sci.,*** 10(3): 57-78, 2024.

ABSTRACT

BACKGROUND: In the most parts of Iran, wheat 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.

OBJECTIVES: 1) to determine the effect on physical and chemical soil quality 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 maize yield and minimum N loss; 2) to determine the relationship between the soil quality and the crop yields.

METHODS: A 7-years (2006−2012) field study was carried out at the agriculture 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) N rates: 0 (control), 100, 200 and 300 kg N ha^{-1} (N1-N4).

RESULT: After 7 years of continuous practice, ZT produced 40% greater maize seed yield than CT, whereas +R increased seed yield by 33% compared to -R. Seed yield of maize increased with N rate up to N3. Soil moisture content was higher under ZT than CT and with +R than -R in the 0–15 cm depth, with the highest moisture content in the ZT+R treatment in many cases. After seven crop seasons, total organic C (TOC) and N (TON), respectively, were greater by 1.275 Mg C ha^{-1} and 0.031 Mg N ha^{-1} with +R than -R, and also greater by 0.563 Mg C ha^{-1} and 0.044 Mg N ha^{-1} under ZT than CT. There was no effect of tillage, straw and N fertilization on the NH4-Nin soil in most cases, but +R treatment had higher NO_3-N concentration in the 0–15 cm soil than -R. The NO_3-N concentration in the soil layers increased (though small) with increasing N rate. The +R treatment had 6.7% lower proportion of fine (<0.83 mm diameter) and 8.6% greater proportion of large (>38.0 mm) dry aggregates, and 4.5 mm larger mean weight diameter (MWD) compared to -R treatment. 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 yield (R= 0.87 for maize).

CONCLUSION: The finding suggests that ZT+R would improve some soil properties, and may also be better for the sustainability of high crop production. Nitrogen fertilization, although improves crop production and some soil quality attributes, it also increases the potential for NO_3-N leaching especially when applied in excess of crop requirements for optimum yield.

KEYWORDS: *N fertilizer, Tillage, Soil quality, Wheat residue, Zea mays.*

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1. BACKGROUND

In the most parts of Iran, wheat (*Triticum aestivum*L.) residues have been traditionally burned or removed; that is often criticized for soil organicand 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 (Bakht *et al*., 2009). There is not enough information on the effects of residue management and N rates on maize in northern part of Iran.

2. OBJECTIVES

With this background, a seven-year field experiment on wheat-maize was undertaken at the Baikola research station in Mazandran province, Iran, with the following objectives: 1) to determine the effect on physical and chemical soil quality 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 maize yield and minimum N loss; 2) to determine the relationship between the soil quality and the crop yields.

3. MATERIALS AND METHODS

3.1. Site description

The research 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 Baikolais classified as sub-humid. The average maximum and minimum temperatures and rainfall during maize-growing season were, respectively, 25.46°C, 19.43°C, and 1.03 mm.day^{-1}. Soil condition was sandy-loam with low organic carbon (0.6%) and slightly alkaline soil (pH= 7.9). Other soil test parameters were total N= 0.06%, available P= 10.8 mg.kg^{-1}, exchangeable K= 174 mg.kg^{-1} and EC= 2.3 ds.m^{-1}.

3.2. *Treatments and field operations*

The experimental site had been previously sown with winter dryland 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 system, conventional tillage (CT) and zero tillage (ZT) and sub-plots were four N rates, 0 as a control,100, 200 and 300 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. Fertilizer one-third of N was applied at planting time and rest of the nitrogen at two stages, i.e. at knee high (5-6 leaf stage of maize) and tasseling stage as top dressing. The irrigation was applied in the crop according to crop growth stages, before and after each irrigation, soil samples were collected at 15 cm interval up to 90 cm depth and soil moisture contents were measured gravimetrically and then depth of irrigation water was determined. Individual plots are7.5m by 10 m and present a micro-relief with a slope of <0.3%. Standard practices include the use of recommended crop cultivar, with maize planted at 66,000 plants ha^{-1}, maize spacing was 75 cm × 20 cm inter-row and intra row, respectively. All plots were kept weed free by hand pulling and no disease or insect pest controls are utilized, except for seed treatments applied by commercial seed sources. Planting of maize is usually done between June 5 and 15, using a customized John Deere no-till planter and harvested on 27 Oct. 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. The residue was removed using a commercial baler. Retained residues were incorporated, if tilled, or left on the surface with zero tillage.

3.3. *Maize traits determination*

Yields were measured in the five rows in the center of each plot. No soil sampling disturbance has occurred in this area over the 7 years of experimentation. 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. Grain yields were expressed considering as 12% moisture content and expressed as a percentage of the highest yield. 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).

3.4. *Soil sampling and analyses*

Soil was sampled after harvest of maize, i.e. September, in 2012. 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. Physical characteristics (resistance to penetration, moisture and bulk density) were determined in situ at eight points in each plot (Govaerts *et al*., 2007a).

Table 1. Protocol of measurements for each indicator

Indicator	Protocol	Ref.
Total N	Kjeldahl[a]	Bremner (1960)
$NO3^-$	KCl extraction	Stieg (1993a)
$NH4^+$	KCl extraction	Stieg (1993b)
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)

[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.

Bulk density was measured by the method described by Blake (1965). Penetration resistance, cone index (CI), was measured with a Rimick CP20 (Toowoomba, Queensland, Australia, ASAE Standard S313) recording penetrometer from soil surface to 15 cm depth, at 2.5 cm depth intervals. The CI obtained from each sampling point and at each depth interval is the average of three measurements. Double ring infiltrometer was used to measure the infiltration rate of the soil (Bouwer, 1986). The diameters of outer and inner rings of the infiltrometer were 30 and 55 cm, respectively. The infiltrometers were placed in plots of all tillage-crop residue combinations after harvest of crop and measurement was taken at 30, 60, 120, 150, 195, 210, 240, and 300 min, until the steady-state infiltration rate was achieved. 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 cycles 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 (Van Bavel, 1950). Any coarse roots detected in the soil after sieving were removed by hand.

3.5. *Statistical analysis*

Statistical analysis was done with SAS GLM, PRINCOMP (SAS Institute, 1994). 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 were analyzed 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). Moreover, a scree test (Cattell, 1966) was performed to corroborate primer results. A VARIMAX rotation was performed to enhance interpret ability 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 maize 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.

4. RESULT AND DISCUSSION

4.1. *Crop yield*

After 7 years, the highest yields for the last two years were obtained for maize in the ZT+R treatment (Fig. 1). Lowest yields were obtained with ZT-R: nearly 37% less than the same management with full residue retention (Fig. 1). Residue was significant only when practicing ZT. 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.There were no significant effects of straw treatments on maize seed yield for the first two years (Fig. 2). The effect of straw on crop growth and yield is communicated mainly through change in soil properties, which is a slow process. But, tillage had significant effect on seed yield in whole the seasons analyzed (Fig. 2). Seed yield of maize responded strongly to applied N, with average increase of 30%, with the first 100 kg N ha^{-1} compared to no N (Fig. 1). Compared to no N, seed yield increased significantly with application of 100 kg N ha^{-1} (i.e. N2) under ZT, but yield increase under CT was significant only with application of 200 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 NT and where N fertilizer was broadcast, 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 to N ratio (80:1) and also possible allelopathy effects (Huang *et al*., 2013; Rice, 1984). The fertilizer value of crop residues for maize production may depend on both soil fertility and fertilizer management regimes. Thus, site-specific management practices should be developed to reduce inorganic fertilizer requirement without reducing maize yield under residue retention, thereby increasing the profitability of crop production.

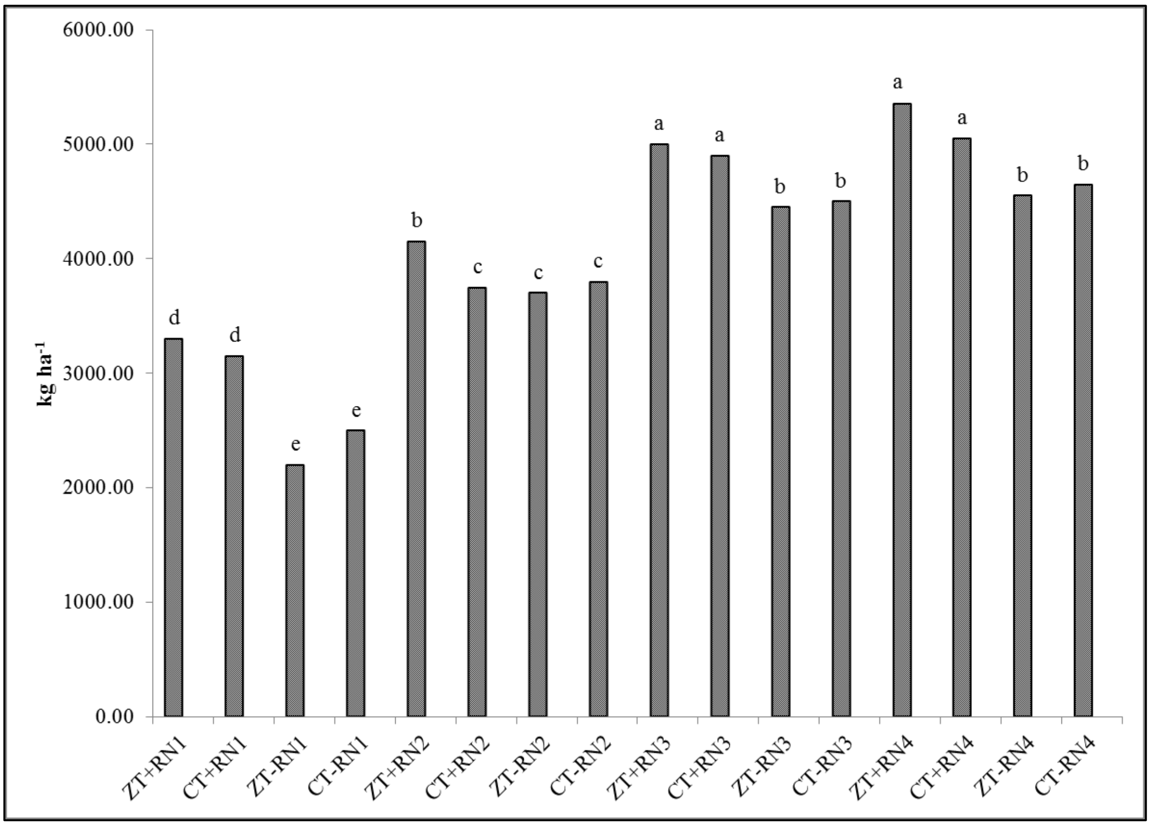

Fig. 1. Average grain yields of maize (12% moisture) from 2010 to 2012,in soils subjected to zero tillage (ZT) and conventional tillage (CT), nitrogen fertilizer (0, 100, 200 and 300 kg N ha^{-1}; N1-N4), with residues (+R) and without residues (−R). Letters indicate asignificant difference between treatments at $P < 0.05$.

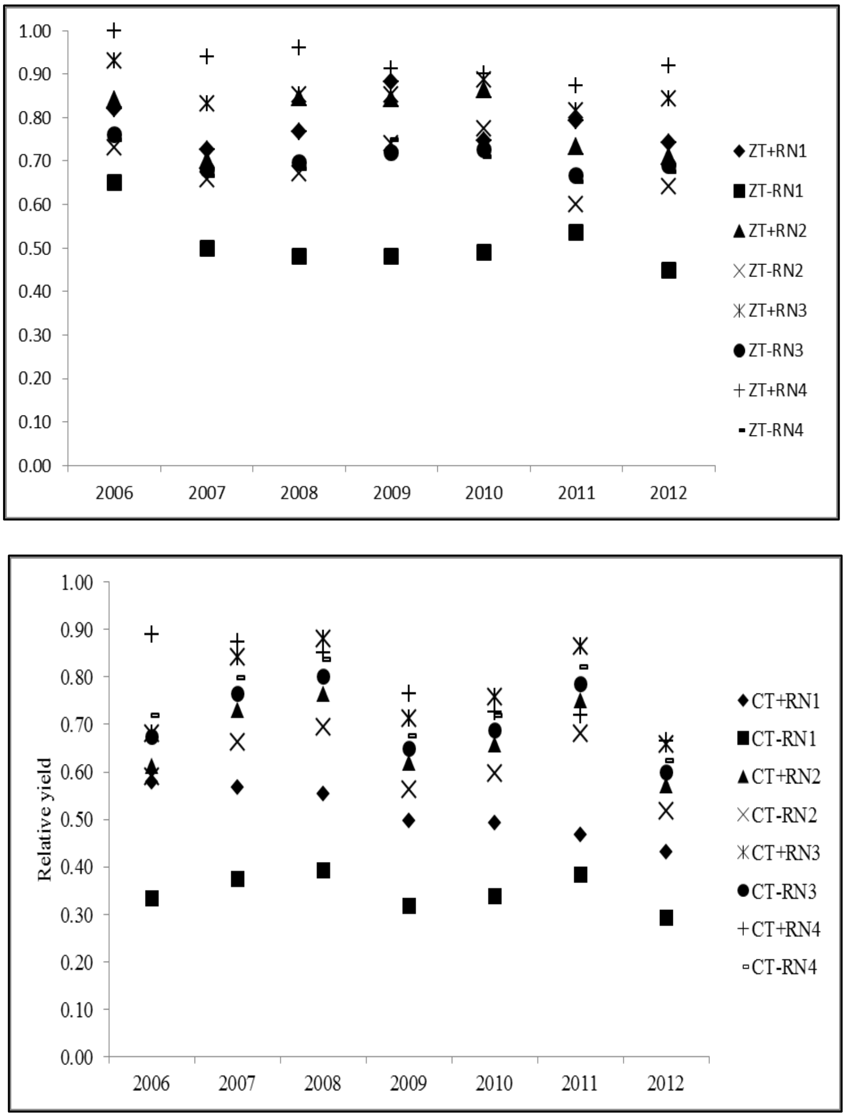

Fig. 2. Maize yields per treatment per year from 2006 to 2012, expressed relative to the highest yield of that year for zero tillage (ZT) treatments (A) and conventional tillage (CT) treatments (B). Nitrogen fertilizer (0, 100, 200 and 300 kg N ha^{-1}; N1-N4), with residues (+R) and without residues (−R).

In summary, it took some time before the full benefits of ZT with residue retention appeared. After a transition period, yields under ZT with residue retention were higher and more stable than those of alternative management practices. A period of 5 years was needed before the advantages of the ZT treatments with residue retention resulted in higher yields, compared to the alternative treatments. In addition to, maize plant populations are less dense and more rainfall runoff occurs (especially in wet years), this treatment (ZT+R) benefits from the additional moisture captured by the residue. A good management practice has led to both high and stable yields. The beneficial effect of straw retention on relative yield thus appeared to be generally greater with NT than with CT. When residues are removed, ZT results in very instable yields (Fig. 2).

4.2. *Soil physical and chemical properties*

4.2.1. *Soil moisture content*

The soil moisture content showed no effect of N rate, but it was higher with +R than -R in the 0–15 cm depth in all years and in the 15–30 cm depth in 2002, and it was also higher under ZT than CT (Table 2). 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 (Saha and Mishra, 2009). 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. Tillage*straw interaction effect on soil moisture was significant for the 0–15 cm (data not shown). This resulted from highest soil moisture in the ZT+ R treatment in many cases. Also, the presence of the residue on the surface of the soil had mulching effects on the soil surface (Waddington *et al*., 2003) while in the conventionally tilled plots there was incorporation of residue into the soil which limits the residue to act as the mulch and hence more evaporation on the soil surface. This agrees with the work done by Githinji *et al*. (2011) which reported increased soil drying rates and decreased water contents after tillage due to vapour movement being enhanced by increased macro porosity within the ploughed layer. Tillage*N rate interaction was significant only forth 15–30 cm depths, with highest soil moisture content under ZT at300 kg N ha^{-1} rate in two of three cases (data not shown). Straw*N rate interaction effect was significant for only the 0–15 cm depth, where soil moisture content was highest in +R treatment at 300 kg N ha^{-1} rate. Moreover, N fertilizer was associated with increased biomass. Probably the differences in the moisture content are caused by the amount of cover crop on the soil surface, thus reducing substantially the rate of evaporation.

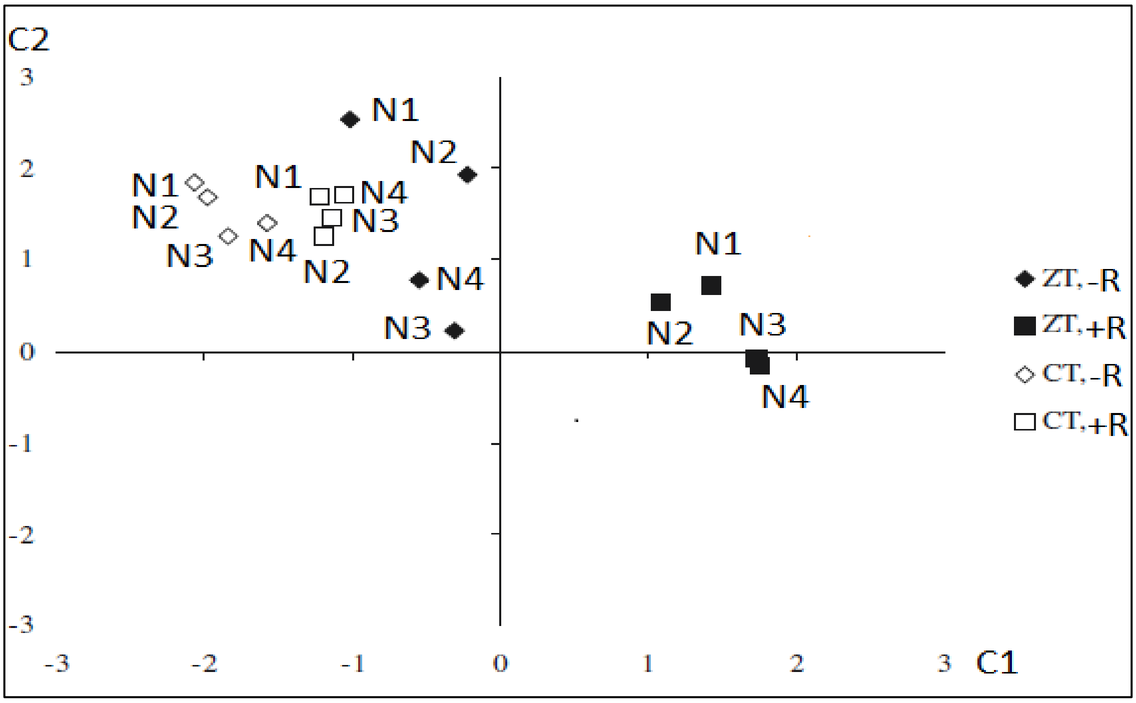

Fig.3. Biplot of the principal components representing chemical and physical soil quality; with zero tillage (ZT) and conventional tillage (CT); Nitrogen fertilizer (0, 100, 200 and 300 kg N ha^{-1}; N1-N4); with residues (+R) and without residues (−R).

For instance, those plots with the more rate of N application had a lot of biomass, thus giving shade effect on the soil surface and therefore leading to reduced evaporation rate. More soil water enables crop to grow during short-term dry periods and reduces sensitivity to drought stress of the system, which is especially important in semiarid environmental as Mediterranean climate. Generally, the increased infiltration with residue retention in zero tillage systems and adequate soil fertility was reflected in conserving more water in soil during irrigation throughout the growing seasons.

4.2.2. *Soil aggregate size distribution*

Dry aggregates <0.83 mm in the present study were considered wind-erodible fraction (Skidmore *et al*., 1986). 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). On the other hand, proportion of large aggregates (>12.7 mm) under ZT compared to CT was about three times greater for the >38 mm size and 37% greater for the 12.7–38.0 mm size. The ZT systems tended to have lower percentage of wind erodible aggregates and higher percentage of large aggregates than CT under both +R and -R.

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 $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ 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.

Addition of straw increased the proportion of larger aggregates by 3% for >38 mm and by 1% for 12.7–38.0 mm size and decreased the proportion of wind erodible aggregates by 1% for 0.42–0.83 mm and by 3% for <0.42 mm size. 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 under both CT and ZT. This indicates reduced potential for soil erosion when crop residues were retained. The management of previous crop residues is key to soil structural development and stability since organic matter is an important factor in soil aggregation. Fresh residue forms the nucleation center for the formation of new aggregates by creating hot spots of microbial activity where new soil aggregates are developed (De Gryze *et al*., 2005). In addition, the retention of crop residue on the soil surface decreases the breakdown of aggregates by protecting them against raindrop impact (Le Bissonnais, 1996). The beneficial influence of ZT+R was also reflected in mean weight diameter (MWD) of aggregates, which was on average 72% greater with ZT as compared with CT and 23% greater with +R than with -R (Table 2). 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. The MWD was greatest in the ZT+R treatment (15.1 mm) and smallest in the CT-R treatment (7.3 mm).These observations are consistent with findings reported by Kihara *et al*. (2012) and Fuentes *et al*. (2009), where minimum tillage resulted in higher aggregate MWD. On the other hand, Guto *et al*. (2011) reported that conventional tillage resulted in higher aggregate MWD, there is no clear explanation for the contrary findings. They speculate that the very heavy rains during experiments and wetting and drying had a destructive effect on soil aggregates. The proportion of large aggregates tended to increase and proportion of fine aggregates significantly decreased with increasing N rate from 0 to 300 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).These characteristics could have helped the soil to recover the physical condition after soil disturbance. As the quality of soil structure in the seed bed is strongly related to size distribution of air dry aggregates, these results indicate a better seed-bed soil structural condition and lowest potential for soil erosion by wind where tillage is omitted and crop residues are retained on the soil. The aggregation data indicated much greater impact of ZT on improvement of soil structure than straw management. Also, (Kihara *et al*., 2012) reported that the benefits of soil aggregation in the reduced tillage system couldn’t fully translated into increased yields and this is partly due to the fact that no ripping or sub-soiling was done at the establishment of the trials. It has been suggested that sub-soiling is necessary at the onset since the soils have been subjected to years of degradation with likely hard-pans.

4.2.3. *Soil bulk density*

Soil bulk density was affected significantly by tillage and residue management (Table 2), but it showed no effect of N rate. The soils planted showed also a higher soil bulk density in the ZT+R, CT+R treatments than in the ZT-R and CT-R. 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 BD increases due to ZT implementation.

4.2.4. *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 a 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) (Table 2). Water flows more easily from the highest to the lowest part of the plot in the ZT-R or CT-R treatments as no residues remained on the soil surface and the surface was sealed because of the decreased aggregate stability. The variation for resistance to penetration between treatments resulted from only residue management and not tillage or interaction between these. 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. The residue intercepts rainfall and releases it more slowly afterwards (Scopel and Fideling 2001).

4.2.5. *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). In CT+R, CT-R and ZT+R treatments, pH ranged from 6.0 to 6.5, but the ZT-R at N4 soil showed a pH 5.3. The EC in the different layers of soil cultivated with maize 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).

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 $P \le 0.10$, $P \le 0.05$, $P \le 0.01$, $P \le 0.001$ 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 acidification caused by mineral fertilizations, ammoniac and ureic fertilizers, in particular, would have a marked effect on the pH, due to the absorption ofthe 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 5.3as opposed to the initial valued when the experiment was started of pH 6.5 (Etchevers *et al*., 2000). This strong acidification could reduce the availability of some nutrients (Ca, K, N, Mg, Mo, P, S) (Etchevers *et al*., 2000). 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 was higher in these treatments (ZT+R 6618 kg ha^{-1}, CT+R 5098 kg ha^{-1} and CT-R4133 kg ha^{-1}) compared to ZT-R (3785kg ha^{-1}) (Fig. 1). This means there is a greater demand of nutrients in the former plot and the existing moisture conditions allow the availability of such fertilizers. Our results agree with Githinji *et al*. (2011), they reported that conservation-tilled plots showed the lowest value pH, however, minimal differences were observed between treatments.

4.2.6. *Soil organic C, organic N and mineral N*

At the end of seven growing seasons, mass of TOC and TN in the 0–15 cm soil depth were significantly greater under +R than under -R (Table 3). Compared to -R, the +R treatment increased TOC by 25% and TN by 28%. 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. The decline of soil C and N with removal of straw suggests that the practice of removing straw from fields for on-farm and industrial uses in the long run may result in soil degradation (Kihara *et al*., 2012).Previous research has shown an increase of233 kg C ha^{-1}under ZT compared to CT (Halvorson *et al*., 1999). AlsoTOC 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, 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). This could have been enhanced by the removal of residue from the surface and mixing with the subsurface soil under conventional tillage compared to conservation tillage where residues are left on the surface, increasing organic matter inputs (Chivenge *et al*., 2004). 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. Campbell *et al*. (1998) reported that 6 years of ZT did not increase TOC or TN, but removal of straw in a fallow–wheat–wheat rotation tended to reduce TOC and TN.27It is peculiar that residue retention combined with mineral fertilizer did not have a beneficial impact on upper soil C as found in numerous other studies (Chivenge *et al*., 2011; Anyanzwa *et al*., 2010), also they reported that a possible explanation could be the low residue cover in these studies. The effect of tillage and straw management on soil NO3-N concentration was not significant (Table 3), although NO3-N in 0–15 cm depth tended to be higher under CT compared to ZT and under +R compared to –R (P <0.1). The NO_3-N concentration increased considerably with increasing N rate to ≥100 kg N ha^{-1} in the 0–15 cm and to 300 kg N ha^{-1} in the 15–30 and 30–60 cm depths. Other researchers also reported accumulation of nitrate-N in the soil profile when excessiverate of N fertilizer was applied (Campbell *et al*., 1994; Guillard *et al*., 1995). The soil NO_3-N level in annual cropping system was observed to increase with N rate and greatest increase was at the highest rate (101 kg N ha^{-1}) (Halvorson *et al*., 1999).There was no effect of tillage, straw management and N rate on the NH_4-N concentration in soil.

4.3. *Principal component analysis of maize cultivated treatments*

Loading parameters obtained after VARIMAX rotation are given in Table 3. PCA was performed using soil parameters that were significantly different between the treatments. Two PCs were retained with Eigenvalues >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 0–5 cm and 5–10 cm layer, water content and aggregates. pH in the 0–5 cm 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 (Fig. 3). The ZT treatments with residue retention, independent of nitrogen rate, are rich in organic C in the 0–5cm 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 and PC2. They are lower in organic C content, the aggregates are less stable and the water content is lower compared to the ZT+R and ZT+R treatments, but pH in the 0–5cm and 10–20cmlayer is lower and the penetration resistance is higher.

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

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 Eigenvalues >1 and that explain >10% of the total variance were retained.
[c] Parameters with significant loadings on the within column principalcomponent.

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 farm and environmental management goals for the vegetable production systems they considered. 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 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, soilstructure, 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; Mohanty *et al*., 2007). 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 maize 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 maize, 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 and 20-year average profit was associated with CT.

Table 5. Regression between maize 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*

* $P \leq 0.05$, ** $P \leq 0.01$.

5. 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 maize 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 plotssubjected to zero and conventional tillage was the reduction inboth 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 maize in the agro-ecological zone studied.

ACKNOWLEDGMENT

This study was funded by Payame Noor University, Tehran, I.R. Iran.

FOOTNOTES

AUTHORS' CONTRIBUTION: All authors are equally involved.

CONFLICT OF INTEREST: Authors declared no conflict of interest.

FUNDING/SUPPORT: This study was done by scientific support of Payame Noor University.

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