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Full Length Research Paper

Impact of changing crop rotation to continuous wheat on soil characteristics in semiarid areas

Mehdi Rahmati[1]*, Mohammad Reza Neyshabouri[1], Shahin Oustan[1], Mohammad Moghadam[2] and Vali Feiziasl[3]

[1]Department of Soil Science, Faculty of Agriculture, University of Tabriz, Tabriz, Iran.
[2]Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Tabriz, Tabriz, Iran.
[3]Department of Soil Science, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran.

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To evaluate the effect of crop rotation on soil structural properties and aggregate fractal dimension, three locations were selected in Maragheh and Hashtroud areas, northwest of Iran. Four crop rotations were implemented and several soil physical and chemical properties were evaluated. In wheat-chickpea and wheat-fallow rotation treatments (T2 and T4) average bulk density (BD) of 1.155 g cm^{-3} was significantly (P< 0.01) lower than continuous wheat cropping (T1) and wheat-fallow-wheat-wheat-wheat (T3) treatments with BD of 1.29 g cm^{-3}. Water aggregate stability (WAS) in *T4* became significantly (P<0.01) greater than other rotations. Saturated water content (θ_s) of T1 and T3 (0.39 cm^{3}cm^{-3}) was significantly (P< 0.01) lower than T2 and T4 (nearly equal to 0.55 cm^{3}cm^{-3}). The lowest saturated hydraulic conductivity (K_S) of about 2.0 cm h^{-1} occurred in T1 and T3, and the highest (5.27 cm h^{-1}) in T4. Soil moisture content (θ_m) in T2 and T4 during GS21 growth stage significantly exceeded those of T1 and T3. Biological yields in T2 and T4 were nearly equal (3.05 t ha^{-1}) and were significantly (P< 0.05) greater than T1 and T3 (1.5 t ha^{-1}). During growth stages of GS54 and GS87, θ_m and other measured properties were not significantly affected by crop rotations. It appears that substitution of wheat-follow or wheat-chickpea rotations by continuous wheat cropping would gradually degrade the soils and thus should be abandoned.

Key words: Crop rotation, fractal dimension, mean weight diameter, soil structure, water aggregate stability.

INTRODUCTION

Crop rotation as an important management element affects soil physical and chemical properties (Wilson et al., 1982; Hamblin, 1985). Continuous cropping of wheat or barley in long-term would tend to decline soil organic carbon (*SOC*) levels and infiltration rates (Kemper, 1993) resulting in enhanced runoff and soil erosion. This may be followed by reduction of aggregates stability, acceleration of particles dispersion, and surface sealing during precipitation. Lal et al. (1994) reported that implementing various crop rotation patterns such as corn-soybean (CS), corn-oat-meadow (COM) and continuous corn (CC) for 28 years significantly altered soil bulk density (BD), aggregation, and *SOC*. They observed highest value of *BD*, aggregation, and SOC in COM, CS, and CC, respectively. Yousefi et al. (2008) showed that corn-wheat- alfalfa- alfalfa- alfalfa (T1), wheat-corn-barley-wheat-corn (T2), and barley-rice-barley-rice-fallow (T3) crop rotations affected carbohydrate fraction of SOC but did not affect total SOC. They also found that these rotations significantly changed aggregate mean weight diameter (MWD) during five years; the lowest MWD was occurred in T3. Alvaro-Fuentes et al. (2008) also indicated that crop rotation profoundly improved soil aggregation. Beneficial effects of crop rotation on soil moisture storage (Benson, 1985; Roder et al., 1989) and soil structure (Barber, 1972; Dick and Van Doren, 1985; Griffith et al., 1988) have well been documented. Eghball et al. (1993) reported that aggregate fractal dimension in corn-soybean-corn was lower than in soybean-corn-soybean rotation under no tillage system. They attributed it to the positive effect of corn and negative effect of soybean on soil structure. Based on literature review, it is expected that conversion of the prevalent crop rotations (wheat-chickpea and wheat-fallow) to the continuous

*Corresponding author. E-mail: mehdirmti@gmail.com.

Table 1. General characters of the three studied experimental sites.

Characters	Block 1	Block 2	Block 3
Soil taxonomy	Sahand (Fluventic Haploxerepts)	Rajol Abad (Typic Cacixerepts)	Darab (Calcic HaploXerepts)
Slope %	5 to 8	5 to 8	2 to 5
Precipitation ($mm.yr^{-1}$)	353	353	322
Soil Texture	Clay Loam	Clay	Clay
Temperature§§:			
	Maximum	Minimum	
	28.4ºC	-8.1ºC	
Time of happening	August	January	

Hakimi (1985), Seiedghiasi (1991) and Banaei (1998).

wheat cropping system at the studied areas would lead to deterioration of soil structural properties and would enhance soil degradation, particularly soil erosion.

The objective of this study was, therefore, to investigate the probable adverse alterations in soil properties that may occur due to shifting in the present cropping systems in the areas under study.

MATERIALS AND METHODS

Experiment site

This research was conducted at Maragheh and Hashtroud rain-fed agriculture areas from autumn 2003 to summer 2008. The areas are located at the rangelands of Sahand Mountain, southern part of East Azerbaijan Province, Iran (37° to 37°35' N, and 45°45' to 47°06'05" E). Temperature and moisture regimes of these areas are Mesic and Xeric, respectively (Banaei, 1998). Three locations were selected in these areas and were considered as blocks. Table 1 shows some general characters of these locations.

Statistical design and treatments

A factorial experiment based on randomized complete block design with two factors and three replications (locations) was carried out in this study. Crop rotation was considered as the first factor which included continuous wheat cropping (T1), wheat–chickpea (T2), wheat-fallow-wheat-wheat-wheat (T3), and wheat–fallow (T4) rotations. The treatments were practiced for five cropping years from autumn 2003 to summer 2008. Second factor included sampling depths of 0 to 10, 11 to 20, and 21 to 40 cm. Data were examined for normality by Kolmogorov-Smirnov test. Nonadivity test was performed to verify the independence of blocks from treatments. Bartlett's test was used to test the homogeneity of within treatment variances. When either one of the assumptions was not true, a proper transformation was carried out. Multivariate analysis of variance (MANOVA) was carried out for all data to fix type 1 error. SPSS 15 and MSTATC 11 were used for the analyses.

Sampling and measurements

Disturbed and undisturbed soil samples were taken randomly from each site in June 2008. Three sampling units were taken from each treatment and average of these units was used for subsequent analyses. Disturbed samples were air-dried and sieved through a 2 mm-standard sieve. Soil moisture (θ_m) content ($g.g^{-1}$) was measured at four wheat growth stages including GS21, GS32, GS54 and GS87 (Zadoks et al., 1974). Biomass (foliage) of wheat was measured at the harvest during last week of June 2008. Percents of clay (CC), silt (Si), and sand (Sa) were determined by the hydrometer method (Kroetsch and Wang, 2006), soil organic carbon (*SOC*) by wet oxidation procedure (Skjemstad and Baldock, 2006), carbonate calcium equivalent (*CCE*) by titration with NaOH (Jackson, 1985), bulk density (BD) by core method (Hao et al., 2006), and saturated hydraulic conductivity (K_S) by falling head procedure (Reynolds, 2006). Wet-aggregate stability (WAS) was measured in 1 to 2 mm aggregates using the wet sieving apparatus (Angers et al., 2006). Aggregates in 4.75 to 8 mm range were used for wet sieving and computing of MWD (Angers et al., 2006) and mass fractal dimension (D_m) (Tyler and Wheatcraft, 1992).

Sieve series included 4.75, 2, 1, 0.5 and 0.25 mm mesh size. The duration, vertical movement, and osculation rate of sieving were 10 min, 2.6 cm, and 30 RPM, respectively. D_m was calculated by Equation 1 (Tyler and Wheatcraft, 1992):

$$\frac{M(x<X)}{M_t} = \left(\frac{x}{x_L}\right)^{3-D_m} \quad (1)$$

Where M(x<X) is the cumulative net mass of the aggregate remained on each sieve with mesh size lower than X, M_t is the mass of initial aggregate, x_L is the highest sieve diameter (8 mm), and x is the mean diameter of aggregate in each fraction. The value of $3-D_m$ was set to be the slope (S) of the regression line between the M/M_t and x/x_L in logarithmic scale; D_m was taken to be equal to 3-*S*.

RESULTS AND DISCUSSION

All variables had normal distribution except CCE; it was, therefore, transformed by $1/CCE^2$. Nonadivity tests were insignificant for all data except MWD, CC and Si. MWD data was transformed by square root. However, none of the transformation methods resulted in an insignificant nonadivitively for CC and Si; therefore, pure error (residual (1- Error = Nonadditivity + Residual)) was used to test the factors under study. Error variances were homogenous for all variables. Table 2 shows result of MANOVA. All four tests indicated the significant effect of blocks and factors under study. Based on ANOVA, no

Table 2. Multivariate analysis of variance of crop rotations and depths in terms of soil characteristics.

Effect	Test	Value
Block	Pillai's Trace	1.932**
	Wilk's Lambda	0.001**
	Hotelling Trace	79.005**
	Roy's Largest root	60.662**
Crop rotation	Pillai's Trace	2.413**
	Wilk's Lambda	0.001**
	Hotelling Trace	56.697**
	Roy's Largest root	50.607**
Depth	Pillai's Trace	1.641**
	Wilk's Lambda	0.006**
	Hotelling Trace	54.825**
	Roy's Largest root	52.892**
Crop rotation × depth	Pillai's Trace	2.842ns
	Wilk's Lambda	0.005ns
	Hotelling Trace	14.037ns
	Roy's Largest root	8.469**

**: Significant at 1% level of probability. ns: non-significant.

significant differences for CC and Si were observed among crop rotations, depths, and their interactions (Tables 3, 5 and 6). This result was expected because of soil homogeneity within each experimental site. However, significant differences among blocks for CC and Si were obtained (Table 3), because soils among the three blocks (sites) were different from each other. Statistical analysis showed no significant differences for $1/CCE^2$ among crop rotations, depths, and their combinations but there was significant difference ($P< 0.01$) among the blocks (Tables 3, 5 and 6). No significant differences were observed among crop rotations and depths for SOC after five cropping years (Tables 3, 5 and 6). This finding is somewhat different than those reported by other researchers. Azevedo et al. (1999), for example, observed that continuous sorghum cultivation as compared to its rotations with cotton and soybean decreased SOC after seven years. On the other hand, Lal et al. (1994) reported that after 28 years of cultivation, continuous corn planting led to greater SOC. It seems that many environmental, soil, and time conditions affect SOC and detailed studies and measurements are needed to explain the contrasted results.

One point that deserves to be mentioned is the nature or various fractions of the SOC rather than its total content. Although in our experiment total SOC among the treatments remained unchanged for five years, the light fractions of SOC (not measured) have been probably altered by the treatments which may has led to significant alterations in the other relevant soil attributes such as BD, K_S, and WAS. However, Yousefi et al. (2008) found that various crop rotations of wheat, corn, alfalfa, and rice significantly affected carbohydrate fraction of SOC but did not affect total content of SOC. Therefore, further clarification is needed in this regard. Results indicated that BD of T1 and T3 (1.29 g cm^{-3}) were significantly ($P< 0.01$) greater than those of T2 (1.16 g cm^{-3}) and T4 (1.15 g cm^{-3}) (Tables 3 and 5). This finding is similar to that obtained by Lal et al. (1994). On the other hand, Rachman et al. (2003) reported that various crop rotations did not significantly alter BD. Although total SOC was not significantly affected by crop rotations, but greater light fractions of soil organic matter (LF-SOM) may be the cause of BD decreasing in T2 and T4 as compared with T1 and T3. There was also significant difference ($P< 0.01$) among three depths in terms of BD (Table 3). The lowest and highest values of *BD* were observed at depths 1 (0 to 10 cm) and 3 (21 to 40 cm), respectively (Table 6). It seems that top layer of soils was loosened because of tillage practices. Crop rotations significantly affected WAS ($P< 0.01$) (Table 3). The highest WAS (71.5%) was recorded for T4 (Table 5). This outcome agreed with the results reported by Rachman et al. (2003). Increase of LF-SOM under fallow conditions may account for the enhancement of WAS in T4. On the basis of this assumption, it was expected that WAS also show an increase in T2, which was not fulfilled (Table 3). The reason is not clear and needs more investigation.

Statistical analysis indicated that crop rotations did not affect MWD after five years but there were significant differences among the blocks ($P< 0.01$) and depths ($P< 0.05$) for MWD (Table 3). Duration of the experiment (five years) probably was not long enough to observe the effectiveness of the crop rotations on MWD. The

Table 3. Analysis of variance of the effect of crop rotation and depth on the soil physical and chemical properties and moisture (only mean squares are reported).

Source of variation	df	$(1/CCE^2)^a$	SOC^a	CC^b	Si^b	BD^a	WAS^a	MWD^a	D_m^a	K_S^a	Θ_S^a	θ_m^a			
												GS21	GS32	GS54	GS87
Block	2	0.000**	0.073*	637.52**	638.28**	0.05**	167.47*	1.048**	0.262**	3.80^{ns}	0.003*	18.10^{ns}	21.23**	56.36**	9.47^{ns}
Crop rotation	3	0.000^{ns}	0.040^{ns}	20.56^{ns}	5.19^{ns}	0.054**	311.18**	0.053^{ns}	0.006^{ns}	28.54**	0.070**	42.65*	23.03**	2.57^{ns}	7.20^{ns}
Depth	2	0.000^{ns}	0.000^{ns}	5.49^{ns}	1.98^{ns}	0.061**	99.51^{ns}	0.117*	0.045**	13.25**	0.003*	237.93**	168.45**	142.72**	98.03**
Crop rotation × depth	6	0.000^{ns}	0.033^{ns}	2.56^{ns}	0.62^{ns}	0.006^{ns}	3.47^{ns}	0.022^{ns}	0.003^{ns}	1.53^{ns}	0.000^{ns}	5.00^{ns}	1.33^{ns}	1.30^{ns}	1.29^{ns}
Error§	22	0.000	0.017	8.09	8.17	0.008	31.71	0.026	0.005	1.74	0.001	12.37	3.64	8.87	2.74
Non-additivity	1	0.000^{ns}	0.006^{ns}	36.01*	61.06**	0.024^{ns}	10.38^{ns}	0.058^{ns}	0.011^{ns}	1.06^{ns}	0.002^{ns}	6.21^{ns}	13.70^{ns}	0.40^{ns}	2.45^{ns}
Residual	21	0.000	0.017	6.76	5.65	0.008	32.73	0.024	0.005	1.77	0.001	12.67	3.17	9.27	2.76
Coefficient of variation (%)		26.56	16.35	6.92	9.02	7.52	8.9	16.01	2.74	37.19	5.38	16.75	10.6	18.65	14.96

GS21, GS32, GS54, and GS87: Wheat growth stages (Zadoks et al., 1974). ns: Non-significant,* and **: Significant at 5 and 1% probability levels, respectively. § $SS_{Error} = SS_{Non\text{-}additivity} + SS_{Residual}$ (SS: sum of squares). a: Tested by the error term. b: Tested by the residual.

Table 4. Analysis of variance of the effect of crop rotation on dry-matter.

Source of variation	df	Mean square
Block	2	1.200^{ns}
Crop rotation	3	2.362*
Error	6	0.458
Nonadivity	1	0.237^{ns}
Residual	5	0.502
Coefficient of variation (%)		29.35

ns: Non-significant,* and **: Significant at 5 and 1% probability levels, respectively.

Table 5. Mean of crop rotations for measured soil characters.

Depth(cm)	CCE (%)	SOC (%)	CC (%)	Si (%)	BD (g cm^{-3})	WAS (%)	MWD (mm)	D_m	K_S (cm h^{-1})	Θ_S (cm^3 cm^{-3})	θ_m(g g^{-1})			
											GS21	GS32	GS54	GS87
0 to 10	9.39a	0.8a	41.0a	32.2a	1.16b	62.4a	0.80b	2.72a	4.74a	0.48a	16.0b	13.9c	12.1b	7.9a
11 to 20	9.93a	0.8a	41.2a	31.8a	1.21ab	60.9a	1.01ab	2.68ab	3.12ab	0.47a	22.3a	18.8b	17.2a	12.0a
21 to 40	10.48a	0.8a	42.3a	31.3a	1.30a	66.5a	1.20a	2.60b	2.77b	0.45a	24.7a	21.3a	18.7a	13.3a

In each column, means with different letters are significantly different based on Tukey's honestly significant procedure.

Table 6. Mean of depths for measured soil characters.

Crop rotation	CCE (%)	SOC (%)	CC (%)	Si (%)	BD (g cm^{-3})	WAS (%)	MWD (mm)	D_m	K_S (cm h^{-1})	DM (t ha^{-1})	Θ_S (cm^3 cm^{-3})	θ_m(g g^{-1})			
												GS21	GS32	GS54	GS87
T1	10.7a	0.86a	40.1a	31.2a	1.29a	58. 9b	1.09a	2.64a	2.01b	1.502b	0.39b	20.7ab	18.7ab	15.7a	11.7a
T2	9.5a	0.73a	42.2a	31.5a	1.16b	59.3b	0.93a	2.68a	4.89a	3.096a	0.54a	22.7a	17.9ab	15.5a	11.0a
T3	9.2a	0.84a	38.5a	33.4a	1.29a	63. 5ab	0.82a	2.70a	2.00b	1.574b	0.39b	18.0b	15.8b	16.7a	9.8a
T4	10.4a	0.75a	45.2a	30.9a	1.15b	71.5a	1.16a	2.65a	5.27a	3.051a	0.55a	22.6a	19.6a	16.0a	11.7a

In each column, means with different letters are significantly different based on Tukey's honestly significant procedure.

difference in MWD among the blocks is justifiable because of their different soil types and properties. There were no significant differences among crop rotations and blocks for D_m (Table 3). In contrast to this finding, Eghball et al. (1993) showed that different rotations with different tillage methods led to the significant alteration in D_m. There was significant difference among the three depths in terms of D_m (Table 3). The highest value of D_m was occurred in the first depth (Table 6) which may be attributed to the tillage practice on that depth. The result of data analyses showed that there were significant differences ($P< 0.01$) among crop rotations and depths for K_S (Table 3). The lowest K_S (2 cm.h^{-1}) was recorded in T1 and T3 (Table 5). This outcome was similar to the results of Katsvairo et al. (2002). The decrease in K_S under T1 and T3 as compared with T2 and T4, seems to be due to the soil structure degradation by continuous wheat cropping as it can be seen from greater BD and lower WAS of T1 and T3 (Table 5). The highest value of K_S was occurred in the topmost depth (Table 6). There were also significant differences ($P< 0.01$) among crop rotations and depths with respect to θ_s (Table 3). The highest θ_s were obtained for T2 (0.54 cm^{3}cm^{-3}) and T4 (0.55 cm^{3}cm^{-3}) and the lowest (0.39 cm^{3}cm^{-3}) for T1 and T3 (Table 5). The highest value of θ_s was also observed for the topmost layer (Table 6). The variation of θ_s among crop rotations, depths, and blocks coincided with those of BD and WAS. It seems that BD was the major factor affected θ_s.

Significant differences were also observed among both crop rotations and depths for θ_m during GS21 and GS32. At the GS54 and GS87 stages, θ_m varied significantly only among depths (Table 3). With respect to GS21, θ_m in T2 and T4 were more than T1 and T3 and in the topmost depth was lower than in the other depths. But with respect to GS32, the highest value of θ_m was obtained in T4 and in the third depth (21 to 40 cm) and the lowest value was observed in T3 and in the first depth (0 to 10 cm). These results agree with those reported by Benson (1985) and Roder et al. (1989). They found that crop rotation significantly affected the soil moisture content. Severe drought, prevailed during the last cropping year (September 2007 to May 2008), did not let to detect the possible effects of crop rotations on the soil moisture content at GS54 and GS87 stages. Dry-matter (DM) production in T2 and T4 were significantly ($P< 0.05$) increased as compared with T1 and T3 (Tables 4 and 5). Sainju et al. (2006) reported similar results. The increase of DM in T2 and T4 may be attributed to the greater K_S, WAS and especially θ_m and lower BD under these crop rotations. Improvement of nutrient conditions, probably due to greater soil nitrogen mineralization (not measured), may also have contributed to greater DM.

Conclusion

Wheat-chickpea and wheat-fallow rotations as compared with continuous wheat cropping significantly ($P<0.01$) affected BD, WAS, K_S, θ_s and θ_m. MWD and specially D_m did not respond to the imposed crop rotations. It was shown that shifting from crop rotations (wheat-chickpea and wheat-fallow) to continuous wheat cropping significantly decreased wheat biomass. It appears that continuous wheat cropping not only would decrease yield but also may lead to soil degradation, particularly enhancing soil erosion in the studied areas.

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