Tillage impacts on aggregate stability and crop productivity in a clay-loam soil in central Iran

M.A. Hajabbasi[*], A. Hemmat

Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan 84154, Iran

Abstract

To take advantage of conservation tillage systems (including direct drilling and non-inversion) in central Iran, it is important to study the effects of different cultivation practices on soil structural stability as a physical indicator. A four-year study was conducted to investigate the effects of seven tillage systems on aggregate properties of a clay-loam soil (Calcic Cambisol) with continuous wheat (*Triticum aestivum* L.) production. Crop productivity was also evaluated. Tillage treatments were moldboard plowing+disking (MD) as conventional tillage; chisel plowing +disking (CD); chisel plowing+rotary tilling (CR); chisel plowing (twice)+disking (2CD); plowing with Khishchi (a regional rigid cultivator)+disking (KD) as non-inversion methods; and till-planting with cultivator combined drill (TP); and no-till (NT) as direct drilling methods. A randomized complete block design consisting of four replications was used. Samples were taken from three different soil depths. A wet sieving method was used to determine aggregate size distribution (ASD), and mean weight diameter (MWD) as indices of soil aggregate stability. Soil organic carbon was also determined. For the first three years of the experiment, ASD and MWD at 0–15 cm were similar in different tillage treatments, except for direct drilling which had a significantly higher amount of aggregate greater than 2 mm and 2–1 mm diameter compared to the conventional method. At the second and third sampling depths all treatments had similar influence on ASD and MWD. Tillage treatments showed a significant effect on ASD and MWD in the fourth year of the experiment in all three depths. Almost 70% of the aggregates in the MD system were less than 0.25 mm, while only 55% of the aggregates in the direct drilling methods were less than 0.25 mm diameter. The four-year yield average for conventional and non-inversion tillage systems was 7264 and 6815 kg ha^{-1}, respectively. Although, direct drilling improved soil structural stability, its lower yield (5608 and 4731 kg ha^{-1} for TP and NT, respectively) potential would indicate that reduced tillage systems (i.e. CD) appear to be the accepted alternative management compared to conventional practice (MD). © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Arid soils; Aggregate characteristics; Cultivation; Wheat; Tillage; Iran

1. Introduction

The overwhelming interest in agricultural sustainability is attributed to several changes facing intensive agriculture, such as excessive fertilizer application, risks of environmental pollution and degradation of soil and water resources. Conservation tillage systems, rather than plow-based methods of seedbed preparation, have the potential to provide sustainable usage of soil resources. Cultivation can alter soil physical, chemical, and biological properties, whereby plant growth, development and yield could be influenced (Blevins and Thomas, 1983; Grant and Lafond, 1993). There are many examples of inappropriate agricultural

* Corresponding author. Tel.: +9831-891-3480; fax: +9831-891-2254.
E-mail address: hajabbas@cc.iut.ac.ir (M.A. Hajabbasi).

management resulting in deterioration of soil quality (Mullins et al., 1990). Several studies have reported the effects of management such as tillage and rotation on soil structural characteristics, especially stability and size distribution of aggregates (Angers, 1992; Ismail et al., 1994). Bear et al. (1994) reported that residue cover in no-till method improved soil aggregation and organic carbon content. Carter and Rennie (1982) also reported a higher soil organic carbon at the soil surface in no-till system. In a 28-year study on Ohio soils, Lal et al. (1994) reported that no-till improved soil aggregate stability. Tisdall and Oades (1982), Elliott (1986), and Kay (1990) reported that cultivation can cause a disruption of soil aggregates and loss of soil organic carbon. Hamblin (1980) found that no-till system could result in a smaller aggregate mean weight diameter (MWD).

Tillage systems are location specific, so the degree of their success depends on soil, climate, and management practices. Although little differences in soil structural characteristics have been reported among tillage systems (Bauer and Black, 1981), low precipitation and high temperature in arid and semi-arid regions result in a lower potential for soil organic carbon accumulation. After 11 years of study on a sandy-loam soil in a semi-arid region, Campbell and Souster (1982) reported that due to equal residue production of both systems, neither tillage nor fallow elevated soil organic carbon content. Measurement of aggregation characteristics as indicators of soil structure has been reported extensively in the literature (Caron et al., 1996; Hajabbasi et al., 1999).

No-till systems in the arid region of central Iran have had an adverse effect on crop yields (Hemmat and Khashoei, 1997; Hemmat, 1998b; Mirlohi et al., 2000). The reason for this could be the heavy textured soil and low organic carbon, and an overall initial weak soil structure. Studying the changes in soil aggregation properties, as soil structural indices, under different tillage systems could provide information on the sustainability of cultivation methods. As part of a four-year experiment on conventional and conservation tillage influences on irrigated winter wheat production (Hemmat, 1998a), the objective of this research was to characterize the impacts of seven different tillage systems on soil aggregate size distribution and stability.

2. Materials and methods

2.1. Study site

The effect of seven different tillage systems on soil aggregation and organic carbon was studied during 4 years (1994–1997) at the Kabootarabad Research Station of Isfahan Agricultural Research Center, 40 km southeast of Isfahan (central Iran). The soil (fine-loamy mixed, Typic Haplocambids) (Calcic Cambisol) at the initiation of the study had a clay loam texture in the 0–20 cm surface layer (240 g kg^{-1} sand, 400 g kg^{-1} silt, and 360 g kg^{-1} clay) and a clay texture in the 20–65 cm depth (120 g kg^{-1} sand, 440 g kg^{-1} silt, and 440 g kg^{-1} clay). The pre-tillage soil bulk density and organic carbon at 0–15 and 15–30 cm depths were 1.41 and 1.43 Mg m^{-3} and 9.4 and 8.6 g kg^{-1}, respectively. Total available N, P and K were 890, 21.9 and 171.7 mg kg^{-1} at 0–15 cm depth, and 810, 13.9 and 176.7 mg kg^{-1} at 15–30 cm depth, respectively.

Before the beginning of the experiment the straw was removed and the previous crop residues for all except the no-till treatment were burned. The plots were irrigated and emerged weeds were sprayed with paraquat herbicide (1 kg ha^{-1}). Experimental plots were 10 m wide by 45 m long with borders 6 m wide and a main border 10 m wide between each block. Tillage treatments were as follows: (1) moldboard plow+disk (MD), (2) chisel plow+disk (CD), (3) chisel plow+rotary tiller (CR), (4) twice chisel plow (normal to each other)+disk (2CD), (5) Khish-chi+disk (KD), (6) till-planting with a cultivator combined drill (which is as a John Shearer Trash Culti Drill model) (TP), and (7) no-till with a cultivator combined drill with no cultivator shank (NT). Khish-chi is a locally made secondary tillage implement used in the region. It has 15 straight rigid shanks, fixed on a two-row chassis at a spacing of 14 cm with a vertical clearance of 35 cm. Each shank is equipped with a triangular 5 cm wide point with a rake angle of 44°. The MD, CD, CR, 2CD and KD systems are called tilled treatments and all except MD would be termed non-inversion tillage systems. The TP and NT are direct drilling systems. The implements for the primary and secondary cultivation were pre-determined for each treatment, but the number of secondary tillage operation was chosen according to the soil conditions

at the time of land preparation. The plowing depth in moldboard, chisel and Khishchi plowing for the first year was 20, 20 and 15 cm, respectively, but for the other three years was 20, 15 and 10 cm. A winter wheat (*Triticum aestivum* L.) cultivar (Ghouds) was seeded at a rate of 180 kg ha^{-1} using a grain drill with a row spacing of 12 cm in the tilled treatments. The row spacing for the cultivator combined-drill was 18 cm. Fertilizer was applied at the rate of 135 kg ha^{-1} N in the form of urea, and 40 kg ha^{-1} P in the form of ammonium phosphate. Half of the N, and all of the P fertilizer was applied as top dressing before the secondary tillage operation, the other half of N was applied at the end of March of the following year. Wheat was planted in November and harvested in July. Land preparation and planting was established in a dry soil and then irrigated to bring the soil moisture to field capacity. The field was irrigated six times from March to harvesting time. To control broadleaf weeds, 2–4-D was applied at a rate of 1.5 l ha^{-1} in the spring of each year.

2.2. Soil properties

All soil physical and chemical properties were determined using the methods suggested by Klute (1986) and Page et al. (1986). Soil organic carbon was determined using the method proposed by Walkey and Black (1934). During the first three years of the study, three samples out of each plot were taken from the 0–15, 15–30, and 30–45 cm soil depth. A hand spade was used to take the samples. Evaluating the results of aggregate characteristics for the first three years showed no differences among the treatments. One reason could be the uniformity of the sampling depth among the treatments, while the affected cultivating zones were varied. Therefore, for all the treatments during the fourth year, the depth of cultivation was considered as the first depth of sampling (0–20 cm for MD and 0–15 cm for other treatments). To be comparable with the other treatments, 0–15 cm was also taken as the first sampling depth for the direct drilling system. The second and third depths of sampling were 10 and 20 cm, respectively, below the first sampling depth of each treatment.

For aggregate characteristic determinations, soil samples were obtained during early May of each year.

The wet sieving method of Kemper and Rosenau (1986) with a set of sieves of 2, 1, 0.5, and 0.25 mm diameter was used. After passing the soil samples through a 8 mm sieve, approximately 50 g of the soil was put on the first sieve of the set and was gently moistened to avoid sudden rupture of the aggregates. After moistening, the set was sieved in water at 50 oscillations per minute. After 10 min of oscillation, soil remaining on each sieve was dried, then sand and aggregates were separated (Gee and Bauder, 1986).

The mean weight diameter was calculated by the relationship

$$MWD = \sum (X_i W_i) \tag{1}$$

where X (in millimeter) is the average diameter of the openings of two consecutive sieves, and W the weight ratio of aggregates remained on the ith sieve. For determination of aggregate size distribution (ASD) the weight ratio of aggregates of each sieve (>2, 2–1, 1–0.5, 0.5–0.25, and <0.25 mm) to the total weight of aggregates was calculated. Analysis of variance of the results was conducted using the SAS (SAS Institute, 1985) program, and the means of the results were compared using the Duncan new multiple range test (Steel and Torrie, 1986).

2.3. Crop yield measurements

Winter wheat (*Triticum aestivum* L.) was harvested at maturity (early July) using a small plot combine. Grain yield was obtained from a 1.44 m×43 m sample area within each plot. The dry matter content was determined and yields corrected to a standard moisture content of 130 g kg^{-1}.

3. Results and discussion

Due to the similarity in the last tillage operation (disking) and similar results, the data for the systems CD, 2CD, and KD, were combined. The TP plus NT were also combined together, while MD and CR were treated individually. Thus, the results are presented as these four groups. Generally, the quantity of fine aggregates (<0.25 mm) was much higher than coarse aggregates (>0.25 mm). About 5% of the aggregates were larger than 2 mm, 7% between 1 and 2 mm, 13%

between 1 and 0.5 mm, about 20% were in the range of 0.5–0.25 mm, and almost 65% of the aggregates had the size smaller than 0.25 mm. Other studies of soils with more stable structure and high in organic carbon resulted in 40–80% of the aggregates with a size larger than 2 mm (Angers et al., 1992; Elliott, 1986). In comparison, in the arid and semi-arid regions almost 5% of the aggregates have sizes larger than 2 mm, indicating a low structural stability in these soils (Unger, 1997; Hajabbasi et al., 1999). The first three years of the study showed similar results for the effects of tillage practices on ASD and aggregate stability (MWD), therefore, the results are presented as the average values of all three years. Due to the variation in depth of sampling in tillage treatments during the fourth year, the data of this year are analyzed and reported separately.

3.1. Tillage effects on aggregate properties in the first three years

The overall results of the experiment revealed a weak influence of tillage practices on aggregate characteristics for the first three years, at the first soil depth (0–15 cm) (Table 1) and no influences at the second (15–30 cm) and the third (30–45 cm) depth. The reason could be related to the low amount of initial soil organic matter, and other unfavorable soil aggregating conditions (low precipitation and high temperature) (Bear et al., 1994). Aggregate size distributions were significantly ($P > 0.05$) influenced by tillage treatments at the 0–15 cm depth (Table 1). Aggregates <2 mm in the direct drilling tillage category were significantly higher (4.4%, average values of TP and NT) than conventional (MD) and non-inversion (average values of CD, 2CD and KD) methods (3.2 and 3.4%, respectively). The direct drilling

methods also had the highest amount of 1–2 mm aggregates (5.9%), while the non-inversion methods contained the lowest amount of this size of aggregates (4.5%). The percentage of the aggregates with other sizes (1–0.5, 0.5–0.25 and <0.25 mm) were similarly influenced ($P > 0.05$) by different tillage practices. Mean weight diameter of water stable aggregates at depth 0–15 cm was significantly influenced by the tillage treatments (Table 1). The direct drilling methods had the highest (0.525 mm, average values of TP and NT), and the non-inversion methods had the lowest (0.438 mm, average values of CD, 2CD and KD) MWD. Lal et al. (1994) also reported that the MWD of water stable aggregates were greater in no-till compared to the intensive tillage methods. However, Unger (1997) reported that MWD was smaller in no-till than other tillage practices.

3.2. Four years tillage effects on soil organic carbon

Analysis of variance of data comparing the first three years and the fourth year of the experiment showed significant differences between the effects of tillage treatments on aggregate characteristics (Tables 1 and 2). After 4 years of tillage practices, at the first depth (0–15 cm), a decrease of 11% in soil organic carbon in the conventional tillage treatment (MD) was observed (comparing 9.4–8.4 g kg^{-1}), while an increase of 4 and 2% of organic carbon in the non-inversion (average of CD, 2CD and KD) and CR tillage treatments were seen, respectively (Table 2). Avoiding disturbance of the soil and/or burning the residues caused a 14% increase in soil organic carbon (compared to the first year) in the conservational tillage practices (average of TP and NT). Decreasing organic carbon in the conventional tillage system could be the result of greater exposure

Table 1
The effect of tillage systems on ASD in percentage and MWD at the first depth (0–15 cm) (average of the first three years of the experiment)[a]

Tillage treatment	Size classes (mm)					MWD (mm)
	>2	2–1	1–0.5	0.5–0.25	<0.25	
MD	3.6 a	5.6 ab	11.7 a	19.5 a	59.6 a	0.472 ab
CD, 2CD, KD	3.4 a	4.8 a	10.5 a	17.3 a	64.0 a	0.438 a
CR	3.9 ab	5.3 ab	10.0 a	7.7 a	63.1 a	0.468 ab
TP, NT	4.7 b	6.3 b	11.4 a	18.8 a	58.8 a	0.525 b

[a] The mean values in each column followed by the same letter are not significantly ($P < 0.05$) different.

Table 2
The effects of tillage practices on ASD in percentage, MWD, and OC at the first depth (the fourth year of the experiment)[a]

Tillage treatment	Size classes (mm)					MWD (mm)	OC (g kg^{-1})
	>2	2–1	1–0.5	0.5–0.25	<0.25		
MD	3.0 a	5.8 a	8.9 a	12.5 a	69.8 a	0.406 a	0.84 a
CD, 2CD, KD	3.4 a	6.5 a	11.7 cb	17.7 b	60.7 b	0.475 a	0.98 b
CR	4.2 a	5.2 a	10.4 ab	13.7 a	66.5 ab	0.463 a	0.96 b
TP, NT	15.9 b	9.9 b	13.3 c	15.7 ab	55.1 c	0.623 b	1.07 b

[a] First depth for MD: 0–20 cm, and 0–15 cm for other treatments. The mean values in each column followed by the same letter are not significantly ($P < 0.05$) different.

of residues to the atmosphere in the MD compared to the other systems, which may have enhanced decomposition. There were no significant differences for soil organic carbon among the years and treatments at the 15–30 cm depths (data not shown).

3.3. Tillage effects on aggregate characteristics in the fourth year

During the fourth year of experiment, when the cultivation layer was taken as the first sampling depth, the different tillage systems produced significantly different aggregate property values (Table 2). Although the soil was initially low in organic carbon and had a weak structure, avoiding soil disturbance and accumulating residues caused the organic carbon level and MWD to be increased. Larger aggregates were found with direct drilling methods compared to the other systems. At the first sampling depth, only 30% of the aggregates in MD system were greater than 0.25 mm, while about 45% of the aggregates in the direct drilling method were greater than 0.25 mm (Table 2). Aggregates in the range >2, 2–1, 1–0.5, and 0.5–0.25 mm were all significantly ($P > 0.05$) higher in the direct drilling method compared to other treatments. Generally, soil organic carbon is a basic factor affecting aggregation (Elliott, 1986). Bear et al. (1994) reported that aggregates ranging from 2 to 0.25 mm in size need to be protected by organic carbon binding agents otherwise, under heavy and intensive cultivation, the aggregates would be disrupted. Angers and Mehuys (1989) also reported that in a clay soil of a humid region applying a no-till system resulted in conserving a higher amount of organic carbon and more stable aggregates compared to other tillage treatments.

Aggregate size distribution at the first sampling depth was directly correlated with the soil organic carbon in the corresponding tillage treatment ($R^2 = 0.55$). A direct correlation between the stability and size of the aggregates to soil organic carbon has been reported by several authors (e.g., Angers and Mehuys, 1989). Tisdall and Oades (1982) concluded that the stability of macro-aggregates (>0.25 mm) was controlled by soil management (such as tillage, rotations, etc.), but the stability of micro-aggregates (<0.25 mm) depends on the amount and stability of organic cementing agents and seems to be independent of soil management.

The MWD of the aggregates in the direct drilling method (0.623 mm) was significantly ($P > 0.05$) higher than MWD of MD, non-inversion and CR methods (Table 2). Tillage operations also appeared to influence aggregate characteristics at the lower depths in the fourth year of the experiment (Table 3). At the second sampling depth, compared to the other methods, direct drilling had the highest amount of large aggregates (>0.25 mm) and the lowest amount of fine aggregates (<0.25 mm). Almost 30 and 51% of the aggregates in the direct drilling method were greater than 0.5 and smaller than 0.25 mm, respectively, whereas these values for the MD method were 17 and 69%. Mean weight diameter of the aggregates in MD system was also about 32% less than MWD in direct drilling methods. For the third layer, samples were only taken and analyzed for the MD, non-inversion and CR methods (Table 4). There, too, as the number of tillage operations decreased the percentage of large aggregates increased. The conventional tillage system (MD) resulted in a higher amount of fine aggregate (66.8%) compared to the non-inversion and CR methods (58.6 and 58.8%,

Table 3
The effects of tillage practices on ASD in percentage and MWD at the second depth (the fourth year of the experiment)[a]

Tillage treatment	Size classes (mm)					MWD (mm)
	>2	2–1	1–0.5	0.5–0.25	<0.25	
MD	3.4 a	4.6 a	8.9 a	14.1 a	69.0 a	0.416 a
CD, 2CD, KD	4.2 ab	7.4 b	11.8 b	15.0 a	61.6 b	0.507 b
CR	4.5 ab	6.9 ab	12.2 b	17.2 a	59.3 bc	0.518 b
TP, NT	5.3 b	9.7 b	15.5 c	18.2 b	51.3 c	0.611 b

[a] Second depth for MD: 20–30 cm, and 15–25 cm for other treatments. The mean values in each column followed by the same letter are not significantly ($P < 0.05$) different.

Table 4
The effects of tillage practices on ASD in percentage and MWD at the third depth (the fourth year of the experiment)[a]

Tillage treatment	Size classes (mm)					MWD (mm)
	>2	2–1	1–0.5	0.5–0.25	<0.25	
MD	3.9 a	5.4 a	9.5 a	14.4 a	66.8 a	0.451 a
CD, 2CD, KD	5.0 a	8.9 b	12.6 b	14.9 ab	58.6 b	0.561 b
CR	4.4 a	7.8 ab	12.5 b	16.5 ab	58.8 b	0.530 ab

[a] Third depth for MD: 30–40 cm, and 25–35 cm for other treatments. The mean values in each column followed by the same letter are not significantly ($P < 0.05$) different.

respectively). Mean weight diameter of the MD system was about 20% smaller than MWD of non-inversion, but significantly similar to MWD of the CR method.

3.4. Tillage effects on wheat production

Annual cultivation of this almost structureless soil was associated with a good yield performance. As the

Table 5
The effect of tillage systems on wheat production (average of 4 years)[a]

Tillage treatments	Yield (kg ha^{-1})[b]
MD	7264 a
CD	6814 ab
CR	6752 ab
2CD	7094 ab
KD	6599 b
TP	5608 c
NT	4731 d

[a] The mean values followed by the same letter are not significantly ($P < 0.05$) different.
[b] Grain moisture was adjusted to constant water content of 130 g kg^{-1}.

number and depth of tillage operation increased, the yield production increased too. Table 5 shows the mean values of the yield for 4 years of each tillage practice. Average yield for all treatments over the years was 6427 kg ha^{-1} (CV = 10.2) (Hemmat and Khashoei, 1997). The conventional tillage system (MD) had the highest (7264 kg ha^{-1}), while no-till system had the lowest grain (4731 kg ha^{-1}) production. The chisel plowing+disking (CD) tillage system had a comparable yield with MD system (6814 kg ha^{-1}). The other treatments had yield quantities that ranged between conventional and no-till systems.

4. Conclusion

Low soil organic carbon and consequently weak structural stability are common attributes of arid soils. The effect of four years of different tillage practices resulted in changes in the organic carbon content and soil aggregate characteristics of a clay-loam soil in central Iran. Soil conservation systems including residue management and direct drilling could help to conserve or improve soil structure, however, changes

in aggregation appeared to be numerically low and negligible. Direct drilling improved soil structural stability but such improvements did not provide a positive response for crop productivity. Although not disturbing the soil and restoring residues on the surface avoids further soil degradation and results in larger aggregates, the initial heavy soil texture and low initial organic matter of soil in this region obligates the use of tillage implements to maintain crop productivity.

Acknowledgements

References

Angers, D.A., 1992. Changes in soil aggregation and organic carbon under corn and alfalfa. Soil Sci. Soc. Am. J. 56, 1244–1249.

Angers, D.A., Mehuys, G.R., 1989. Effects of cropping on carbohydrate content and water-stable aggregation of a clay soil. Can. J. Soil Sci. 69, 373–380.

Angers, D.A., Peasant, A., Vigneus, J., 1992. Early cropping included changes in soil aggregation, organic carbon, and microbial biomass. Soil Sci. Soc. Am. J. 56, 115–119.

Bauer, A., Black, A.L., 1981. Soil carbon, nitrogen, and bulk density comparison in two cropland tillage systems after 25 years in virgin grassland. Soil Sci. Soc. Am. J. 45, 1160–1170.

Bear, M.H., Hendrix, P.F., Coleman, D.C., 1994. Water stable aggregates and organic carbon fractions in conventional and no-tillage soils. Soil Sci. Soc. Am. J. 58, 777–786.

Blevins, R.L., Thomas, G.W., 1983. Changes in soil properties after 10 years of continuous non-tilled and conventional tilled corn. Soil Till. Res. 3, 135–146.

Campbell, C.A., Souster, W., 1982. Loss of organic carbon and potentially mineralizable nitrogen from Saskatchewan soils due to dropping. Can. J. Soil Sci. 62, 651–656.

Caron, J.C., Espindola, C.R., Angers, D.A., 1996. Soil structural stability during rapid wetting; influence of land use on aggregate properties. Soil Sci. Soc. Am. J. 60, 901–908.

Carter, M.R., Rennie, D.A., 1982. Changes in soil quality under zero tillage farming system: distribution of microbial biomass and mineralizable C and N potential. Can. J. Soil Sci. 62, 587–597.

Elliott, E.T., 1986. Aggregate structure and carbon, nitrogen and phosphorous in native and cultivated soils. Soil Sci. Soc. Am. J. 50, 627–633.

Gee, G.W., Bauder, J.W., 1986. Particle size analysis. In: Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, Soil Science Society of American Agronomy Monograph No. 9, 2nd Edition, pp. 383–411.

Grant, C.A., Lafond, G.P., 1993. The effects of tillage and crop sequences on bulk density and penetration resistance on a clay soil in southern Saskachewan. Can. J. Soil Sci. 73, 223–232.

Hajabbasi, M.A., Mirlohi, A.F., Arhami, M.S., 1999. Effects of two different tillage systems on soil physico-chemical properties in Lavark (Isfahan). J. Agric. Natural Resour. Sci. Technol. 3, 123–128.

Hamblin, A.P., 1980. Changes in aggregate stability and associated organic carbon properties after direct drilling and plowing on some Australian soils. Aust. J. Soil Sci. 18, 27–36.

Hemmat, A., 1998a. Conservation and conventional tillage systems for irrigated winter wheat production in central Iran. In: Proceedings of the International Conference on Engineering in Agriculture, Perth, Western Australia, Paper No. SEAG 98/022.

Hemmat, A., 1998b. Seedbed characteristic effect on wheat emergence in conventional and conservation tillage system. In: Bartali, E.H., Daoudi, M. (Eds.), Proceedings of 13th International Congress of Agricultural Engineering. Rabat, Morocco, pp. 123–132.

Hemmat, A., Khashoei, A., 1997. Effects of direct-drilling, non-inversion, and conventional tillage systems on yield of irrigated winter wheat. Iran J. Agric. Sci. 28, 19–34.

Ismail, I., Blevins, R.L., Frye, W.W., 1994. Long term no-tillage effects on soil properties and continuous corn yields. Soil Sci. Soc. Am. J. 58, 193–198.

Kay, B.D., 1990. Rates of change of soil structure under different cropping systems. Adv. Soil Sci. 12, 1–52.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution. In: Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, Soil Science Society of American Agronomy Monograph No. 9, 2nd Edition, pp. 425–440.

Klute, A. (Ed.), 1986. Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, Soil Science Society of American Agronomy Monograph No. 9, 2nd Edition.

Lal, R., Mahboubi, A., Fausey, N.R., 1994. Long term tillage and rotation effects on properties of central Ohio soils. Soil Sci. Soc. Am. J. 58, 517–522.

Mirlohi, A.F., Hajabbasi, M.A., Ghanaati, E., 2000. Tillage effects of yield of six maize genotypes. J. Agric. and Wat. Rev. Sci. and Tech. 4 (1), 78–87.

Mullins, C.E., McLeod, D.A., Northcote, K.H., Tisdall, J.M., Young, I.M., 1990. Hard setting soils: behavior, occurrence and management. Adv. Soil Sci. 11, 37–108.

Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), 1986. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, Soil Science Society of American Agronomy Monograph No. 9, 2nd Edition, pp. 325–340.

SAS Institute, 1985. SAS User's Guide: Statistics, Version 5. SAS Institute, Cary, NC.

Steel, R.B.D., Torrie, J.H., 1986. Principles and Procedures of Statistics, 2nd Edition. McGraw Hill, New York.

Tisdall, J.M., Oades, J.M., 1982. Organic carbon and water stable aggregates in soils. J. Soil Sci. 33, 141–161.

Unger, P.W., 1997. Measurement of induced aggregate and organic carbon content in the surface layer of a Torrertic Paleosol. Soil Till. Res. 42, 185–205.

Walkey, A., Black, I.A., 1934. An examination of the effect of the digestive method for determining soil organic matter and a proposed modification of the chronic and titration method. Soil Sci. 37, 29–38.