Journal of Agricultural Sciences
(Tarim Bilimleri Dergisi)

J Agr Sci-Tarim Bili
e-ISSN: 2148-9297
jas.ankara.edu.tr

JAS

Effects of tillage method, drainage management and temporal variability on some soil physical properties and organic matter

Mahmoud Shabanpour[a], Salman Fekri[a], Iraj Bagheri[b], Sayed Hossein Payman[b], Fatemeh Rahimi-Ajdadi[b*]

[a] *Department of Soil Sciences, Faculty of Agricultural Sciences, University of Guilan, P.O. box: 41996-13776, Rasht, Iran*
[b] *Department of Biosystems Engineering, Faculty of Agricultural Sciences, University of Guilan, P.O. box: 41996-13776, Rasht, Iran*

ARTICLE INFO

Research Article

Corresponding Author: Fatemeh Rahimi-Ajdadi, E-mail: rahimi_a61@yahoo.com
Received: 08 January 2021; Received in Revised Form: 07 July 2021, Accepted: 14 July 2021

AUTHORS ORCID ID:

(Fatemeh Rahimi-Ajdadi: 0000-0002-3547-0403)

Effects of tillage method, drainage management and temporal variability on some soil physical properties and organic matter

Mahmoud Shabanpour[a], Salman Fekri[a], Iraj Bagheri[b], Sayed Hossein Payman[b], Fatemeh Rahimi-Ajdadi[b*]

[a] Department of Soil Sciences, Faculty of Agricultural Sciences, University of Guilan, P.O. box: 41996-13776, Rasht, Iran
[b] Department of Biosystems Engineering, Faculty of Agricultural Sciences, University of Guilan, P.O. box: 41996-13776, Rasht, Iran

Abstract

Tillage is one of the most important practices affecting soil physical and hydraulic properties. Its effects may vary intensely according to the tillage method. This study aims to evaluate the effects of tillage methods (B1: moldboard plow+disk harrow, B2: moldboard plow+rotary tiller and B3: chisel plow+disk harrow), drainage (A1: subsurface drainage and A2: non-drainage) methods and temporal variability (T1: after planting and T2: after harvesting) on physical properties and organic matter of a clay loam soil under winter-wheat crop. The experiment was conducted in split-plot in time statistical design. Soil bulk density, soil particle density, aeration porosity, aggregate mean weight diameter (MWD), saturated moisture content and water infiltration rate were determined at two different times of T1 and T2. Results revealed that the tillage method had significant effect on organic matter content, such that the highest (1.35%) values were observed in chisel treatment. Tillage effect was significant on saturated moisture content, MWD, aeration porosity and infiltration rate. The effect of time was significant on all investigated factors. The effect of drainage was significant on MWD and infiltration rate. Evaluating the effects of tillage and drainage indicated that the contribution of drainage on changing MWD is higher than the tillage methods. Further, in non-drainage condition, the tillage method had a significant effect on aeration porosity ($p<0.05$), so that moldboard plow makes much more aeration porosity (25.48%) compared to chisel (17.17%). Conversely, the MWD of moldboard plow (2.4 mm) was significantly lower than that of chisel (2.8 mm), in non-drainage conditions ($p<0.05$). According to the result, the lowest and highest values of MWD were obtained in the treatments of A1B1 and A2B3, respectively. The application of chisel is not recommended in no-

drained areas having high level groundwater, because of the highest saturated moisture content and MWD along with the lowest aeration porosity compared to moldboard plow.

Keywords: Aeration porosity, infiltration rate, mean weight diameter, moldboard plow

Introduction

Soil is one of the slowly renewable natural resources that its conservation or degradation depends on agricultural management (Mirzaee & Mahmoodabadai 2014). The main duty of soil is to provide optimum conditions for plant development and growth that is defined as soil fertility or soil quality (Demir & Isik 2019), which greatly relates to the soil structure (Abbaspour-Gilandeh & Rahimi-Ajdadi 2016). Fundamentally, granular soil structure is the most desirable (Rahimi-Ajdadi et al 2016) and it is achieved by tillage practices that is considered as the key step in agricultural productions. Tillage is performed through soil physical disturbance in order to provide a proper seedbed, eliminate soil compaction and weed control with the aim of increasing crop production (Al-Suhaibani & Ghaly 2013). It is also affecting soil hydraulic and physical properties (Jabro et al 2009) including bulk density, total porosity, pore size distribution, soil resistance against infiltration, water storage, infiltration rate, hydraulic conductivity, and aggregate stability (Gill 2012). While, the quality of soil structure, in turn depends on tillage methods (Alletto & Coquet 2009). Many farmers carry out the tillage practices without knowledge of its effects on soil physical properties and crop yield (Aikins & Afuakwa 2012). Inappropriate soil tillage operations can cause hardpan in subsoil, which in turn causes poor soil aeration, reduction of microorganism activity, limitation of root development, formation of runoff and eventually soil erosion (Asghari Meidani et al 2012; Abbaspour-Gilandeh & Rahimi-Ajdadi 2016). Further, knowing that the tillage operation consumes more than half of the energy consumption of agricultural productions (Rahimi-Ajdadi et al 2016), inappropriate soil tillage operations can cause great energy losses. Different tillage systems have different effects on the soil physical properties and consequently the quantity and quality of the final agricultural products (Gozubuyuk et al 2014). Preparing seedbed or tillage operation are often carried out using moldboard plow in a conventional system. This makes some disadvantages as soil destruction, soil compaction, soil wind erosion and water erosion, which eventually cause crop yield losses (Seyed Olama et al 2016). Another tillage method is minimum tillage with reduced soil manipulation. For instance, tillage operation with a chisel plow only loosens surface layers of the soil (Sadeghnezhad & Eslami 2006) and does not turn the soil over. Despite, mechanical manipulation due to conventional tillage improves soil porosity and buries crop residues, manures, and weeds; it leads to increased soil erosion and loss of soil organic carbon, aggregate stability, and moisture (West & Marland 2002; Tadesse et al 2020). Due to importance of tillage effects on soil properties, many studies were conducted to investigate the effect of tillage type, including conservation tillage (no till and reduced tillage) and conventional tillage on soil properties. Some researchers investigated the effect of tillage system on some soil properties, especially soil organic carbon (Liu et al 2015; Hati et al 2015; Wang et al 2019; Jiang et al 2015; Wang et al 2020; Naseri et al 2020).

Drainage management is one of the key factors affecting soil physical properties. At the global level, 146 million hectares of cultivable lands have drainage problem and require management to improve soil physical properties (e.g. soil aeration, water retention and aggregate formation) and the reduction of soil erosion. (Randall & Iragavarapu 1995). Low water infiltration rates, high groundwater levels, melting of snow and heavy rain in the spring will intensify the need for drainage management to increase and maintain stable high level of agricultural production (Nakajima & Lal 2014). If the land that requires drainage are not drained, the growth of plants is undesirably affected by lack of aeration, decrease in O_2 concentration and increase in CO_2 and CH_4 concentration (Lal & Taylor 1969).

Briefly, the selection of a proper tillage system that preserve the physical properties of the soil is essential for the successful growth of agricultural products (Jabro et al 2009). The key points is that applied tillage system in a farm intensely affect drainage and this case has been ignored in most previous researches. Hence, these two issues were examined together in the present study. On the other hand, in addition to tillage methods and drainage condition, the effect of temporal variability was investigated in this research. Because, it has been reported as important factor for the medium- and fine-textured soils (Van Es et al., 1999, Alletto and Coquet, 2009). Van Es et al. (1999) showed that temporal processes are a large source of variability, even more effective than spatial sources.

Based on above, the purpose of this study was to investigate the effect of different soil tillage methods, drainage managements and temporal variability on organic matter and some soil physical properties including bulk density, particle density, total porosity, aeration porosity, mean weight diameter of aggregates, soil infiltration rate, and saturated moisture content.

Materials and methods

The study was carried out in Moghan region, the north of Ardebil province, Iran (near the border of Azerbaijan Republic and Aras River) with area of about 900 km^2 and the geographical location of 39° 23' to 42° 39' N latitude and 47° 25' to 48° 23' E longitude. This wide and fertile plain has been created by alluvial deposits of the Aras River and its distributaries and is considered as one of the most important agricultural and livestock areas of the country. The average annual precipitation and temperature are 275 mm and 14.6 °C, respectively. The average altitude of the region is 45 m above sea level and the climate of region is semi-arid having cold winters and warm summers (Pars Abad synoptic weather station). The studied soil had a clay loam texture with Entisol classification. Some properties of the studied soil are represented in Table 1. The measurements were separately reported for each plot (drainage and no drainage).

Table 1: Initial soil properties at the depth of 0-20 cm

Treatment	Clay (%)	Silt (%)	Sand (%)	Texture	O. M (%)	pH	EC (dS/m)	ρ_b (g/cm^3)	ρ_s (g/cm^3)	ρ (%)	K_s (cm/h)	MWD (mm)
A_1	34.0	44.0	22.0	Clay loam	1.8	7.8	0.7	1.50	2.74	45.25	1.03	2.23
A_2	34.0	46.0	20.0	Clay loam	1.8	7.8	2.80	1.36	2.79	51.25	1.54	1.81

A_1: Drainage, A_2: No drainage, K_s: Saturated soil hydraulic conductivity, ρ_b: Bulk density, ρ_s: Particle density, MWD: Mean weight diameter, OM: Organic matter, EC: Electrical conductivity and ρ: Total porosity

Experimental design was set as a split plot design in time in order to investigate the effect of tillage and drainage methods on some soil physical properties. First, two main plots were considered: one plot had underground drainage at a depth of 1.5 m (A1) and the other land plot had no underground drainage (A2). The average depth of groundwater was measured about 160 and 100 cm for the plot of A1 and A2, respectively. The plots had the same dimensions (90 × 90 m^2), organic matter and pH and they were 500 m apart. In each plot, nine subplots of 30 × 20 m^2 were prepared so that the total number of plots was 18 (Fig. 1). Tillage operation was done in three treatments by three replications. Tillage levels are given below:

B1: Moldboard plow + disk harrow (as a conventional method in the region)

B2: Moldboard plow + rotary tiller

B3: Chisel plow+ disk harrow

The moldboard plow and chisel plow were set at a depth of 25 cm.

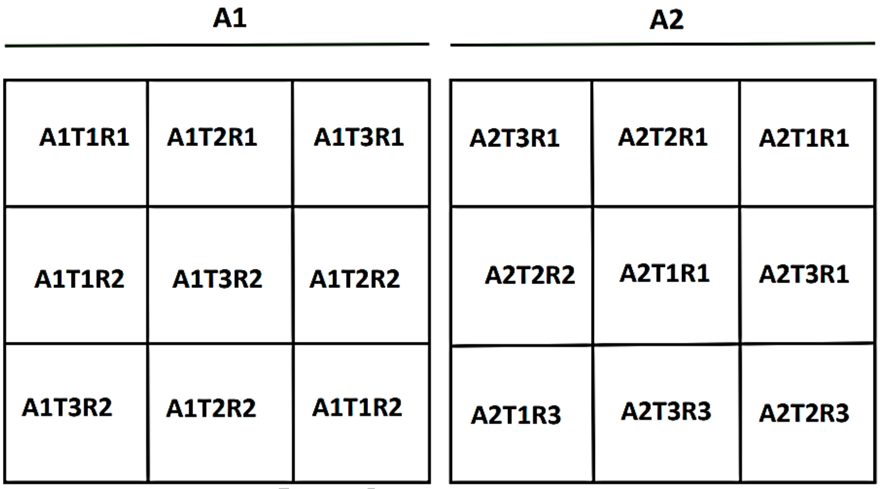

Fig. 1. Schematic diagram showing experimental design

Soil samples were taken from 0-20 cm depth and 10 days after wheat planting in early November (T1) and 10 days after harvest in late June (T2). The samples were passed through a sieve with the mesh of 2 mm after air-drying. The soil texture, organic carbon and pH were measured respectively by the hydrometer method (Gee & Or 2002), Walkley-Black method (Nelson & Sommers 1996) and pH meter in saturated paste (Thomas 1996). In addition, soil bulk density using the cylinder method, the mean particle density of samples using Pycnometer, soil infiltration rate (υ_w) by double ring method, mean weight of aggregate diameter (MWD) by wet sieving method (Kemper & Rosenau 1996) and total porosity (P) by calculation method were measured. To calculate the aerial porosity, first, the soil was reached to field capacity (FC) moisture and then the moisture content of FC was measured. The aeration porosity (P_a) was obtained from Equation 1:

$$P_a = M_s - M_{FC} \qquad [1]$$

Where:

M_s is saturated moisture content of soil and M_{FC} is the soil moisture content at Field capacity condition.

The data were analyzed using analysis of variance (ANOVA) and means comparison were done using Tukey test in MSTAT-C software to determine the effects of tillage method, drainage management and their interactions on the soil physical properties.

Results and Discussion

The results of analysis of variance relating to the effect of tillage methods and drainage management on some soil properties showed that the effect of time was significant on the soil bulk density and mean particle density ($p<0.01$). The simple effect of time on soil porosity was significant, too ($p<0.05$). The tillage effect (B) on the bulk density, mean particle density and porosity was not significant. Drainage effect was significant on all of water infiltration rate, soil organic matter and MWD ($p<0.01$). The effects of studied factors on some soil physical properties are explained in the following.

Time

Results of mean comparison of time on some soil properties are given in Table 2. The results showed that the soil mean particle density after planting time was less than after harvesting. The reason can be attributed to decreased soil organic carbon at harvesting time, because, tillage operation causes the air to enter the soil which accelerate the oxidation of soil organic matter, reduce the soil organic matter and consequently the mean particle density increases. Another reason relates to a shorter time between tillage operation (seed preparation) and T_1 (after planting) than T_2 (after harvesting). Since, tillage operation initially pulverize the soil aggregates, causes to reduce the soil bulk density. However, over time the soil bulk density increases due to irrigation and displacement of soil fine particles. The obtained result is in accordance with Roldan et al (2007).

The results also showed that the simple effect of time on soil porosity and soil aeration porosity was significant ($p<0.05$). The soil porosity after planting time (T_1) were much more than after harvesting time (T_2) and also, the soil aeration porosity in T_1 was more than T_2 (Table 2). The reason is that, as time passes, the pores created by the tillage operation decreases caused by soil compaction, and hence the porosity of the soil decreases. This result is in consistent with Osunbitan et al (2005). They stated that over time, the gradual compaction of soil happens due to rain and consequently, porosity decreases and bulk density increases.

Table 2: Mean comparison relating to the effect of sampling time on some soil properties

Time	ρ_b (g/cm^3)	ρ_s (g/cm^3)	P (%)	P_a (%)	M_s (%)	O. M (%)	MWD (mm)	υ_w (cm/h)
T_1	1.20^b	2.66^b	54.96^a	25.92^a	53.04^b	1.29^a	1.4^b	2.23^a
T_2	1.35^a	2.70^a	45.29^b	18.66^b	62.97^a	1.21^b	2.7^a	2.09^b

Columns marked with the same letter do not differ significantly ($p \leq 0.05$).

According the ANOVA results, the effect of time on the organic matter was significant ($p<0.05$). Soil organic matter content measured after planting stage was more than after harvesting stage (T2) (Table 2).

The reason can be explained that as time passed, soil organic matter decreased. Over time, degradation of soil organic matter occurs and tillage operation causes it to speed up.

The effect of time on soil saturated moisture content was significant ($p<0.01$). The percentage of soil saturated water content in T_1 was less than T_2 (Table 2). Soil disturbance due to tillage operation just before planting increases total soil porosity and aeration porosity in T_1 compared to T_2. In addition, most of the porosity in T_1 relates to the soil coarse porosity. However, over time (after harvesting) the pore size of the soil is finer and more capable of water storage. This result is in incompliance with Kribaa et al (2001).

The effect of time on MWD was significant ($p<0.01$). The results showed that MWD at postharvest stage was greater than post-planting stage (Table 2). Therefore, MWD increased with passing time after tillage operation.

Surveying the effect of time on soil infiltration rate revealed that the water infiltration rate in the post-planting stage was greater than the post-harvest treatment (Table 2). The reason is that soil porosity reduces by tillage operations over time, which in turn decrease the water infiltration rate. This result complies with Osunbitan et al (2005).

Tillage method

The tillage effect on bulk density and mean particle density was not significant. This result is consistent with the results obtained by Hill & Cruse (1985) and Bayat et al (2008) who did not observe any significant effect between different tillage systems (no till, minimum and conventional tillage) and bulk density. However, they reported that the bulk density increased with increasing depth. Many researchers measured a higher bulk density in no till system than the conventional tillage system (Celik 2011; Rashidi & Keshavarzpour 2011; Aikins & Afuakwa 2012). The effect of tillage methods (moldboard plow, subsoiler and subsoiler with de-compactor) on some physical properties of a silty clay soil were studied by Ghasemi Abdoalmalaki et al (2015). Their results showed that the lowest and highest values of bulk density belonged to the subsoiler and moldboard plow, respectively.

The effect of tillage methods in a sandy loam soil relating to a potato field were evaluated by Rasooli-Sharabiani & Abbaspour-Gilandeh (2008). They reported that soil bulk density after tillage operation was decreased in all treatments and the most reduction was obtained in the moldboard plow with disk harrow treatment. They explained that the reason of the further reduction of bulk density in this treatment was due to more soil loosening and increased soil porosity. Gozubuyuk et al (2014) studied the effect of four different tillage practices including T1: Conventional tillage (moldboard plow + disk harrow + combined harrows + precision seeder); T2: Reduced tillage-I (cultivator + combined harrows + precision seeder); T3: Reduced tillage-II (rotary power harrow + precision seeder) and T4: No till. They observed a significant difference between soil bulk density (and porosity) and tillage treatments at depth 0-10 cm, so that the no-till treatment had the highest bulk density and the traditional tillage had the lowest bulk density. Similarly, Sekwakwa & Dikinya (2012) also measured the least amount of bulk density in no-till treatments. In general, it can be concluded that soil bulk density in tillage systems was lower than no-till systems (Osunbitan et al 2005) and these differences can be ranked as follows: no-tillage > chisel plow > moldboard plow.

Although the effect of different tillage methods on soil porosity was not significant, however, soil porosity rank in different tillage treatments was $B_1 > B_2 > B_3$, respectively. It should be mentioned that all of tillage treatments studied in this research were categorized as conventional or minimum tillage and no till was not applied. The insignificant effect of tillage treatments on bulk density and porosity can be attributed to the closeness of degree of pulverization of soil aggregates in the applied tillage treatments. Roseberg & McCoy (1992) and Safadoust et al (2007) obtained the same result. They explained that although conventional tillage (moldboard plow) increases the total porosity of the soil, but it reduces the number, stability, and coherence of large pores (effective pores in water transfer).

The effect of different tillage methods on soil aeration porosity was significant ($p<0.05$). Results of mean comparison showed that B_3 and B1 treatments had the least and highest amount of aeration porosity, respectively (Table 3). The reason is that a moldboard plow creates large air-filled pores in soil because of increased soil disturbance compared to a chisel plow. Elder & Lal (2008) in a research farm in Ohio studied the effect of different tillage methods, and measured less bulk density and more aeration porosity for moldboard plow treatment.

Table 3: Mean comparison relating the effect of tillage practice on some soil properties

Tillage	*Pa* (%)	*P* (%)	M_s (%)	O.M (%)	υ_w (cm/h)	ρ_b (g/cm^3)	ρ_s (g/cm^3)	*MWD*
B1	24.37 ^{a}	48.00	54.03 ^{b}	1.18 ^{b}	2.30 ^{b}	1.43 ^{a}	2.76 ^{a}	2.25
B2	22.12 ^{ab}	49.00	58.02 ^{ab}	1.24 ^{ab}	2.38 ^{b}	1.42 ^{a}	2.76 ^{a}	2.12
B3	20.08 ^{b}	48.00	61.36 ^{a}	1.35 ^{a}	3.26 ^{a}	1.44 ^{a}	2.76 ^{a}	2.78

Columns marked with the same letter do not differ significantly ($p \leq 0.05$).

The effect of tillage method on soil organic matter was significant ($p<0.05$). Results of mean comparison showed that the lowest and highest amounts of organic matter were obtained for moldboard plow (B1) and chisel plow treatments, respectively (Table 3). Abasi et al (2014) also measured the lowest amount of organic matter in the moldboard plow treatment.

The effect of tillage method on saturated moisture content was significant at 5% of probability level. In B3 and B1, the highest (61.36%) and lowest (54.03%) amounts of saturated moisture content were obtained, respectively (Table 3). The reason for this case is the low intensity of tillage and the higher percentage of small pores in the chisel plow compared to the moldboard plow. Many researchers have obtained less saturated moisture content in moldboard plow (traditional tillage) than minimum tillage method. The reason for this is that in the moldboard plow, there is a less amount of micro-pores, which play a major role in water storage in the soil (Fernandez-Ugalde et al 2009; Gozubuyuk et al 2014).

Effect of tillage method was insignificant on soil aggregate MWD. In this case, there are different results obtained in other studies, depending on treatments and their conditions.

For instance, Hajabbasi & Hemmat (2000) reported that different tillage systems consisted of conventional and conservation tillage system has no significant effect on the stability of aggregates in the first year. However, after four years, conservation tillage system has a positive and significant effect on the stability of the soil structure. Hajabbasi et al (1999) also reported that tillage increased the percentage of fine aggregates (smaller than 0.25 mm) during a two-year study. However, Ghasemi Abdoalmalaki et al (2015) in a study on soil aggregate stability obtained a significant difference between different tillage treatments. They measured the highest stable aggregate when the moldboard plow was used. Safadoust et al (2007) stated that the stability of the aggregate is significantly affected by different tillage methods and soil aggregate stability increased with this order, no till > chisel plow > moldboard plow. Baker et al (2004) reported similar results. They stated that by increasing the intensity of tillage, the amount of organic carbon decreased and MWD was reduced.

The effect of tillage methods on infiltration rate showed that B_3 had the highest infiltration rate and B_1 had the lowest value (Table 3). The reason can be explained by the fact that the conservation of the continuity of pores in the chisel plow is more than moldboard plow treatment. This result is consistent with the findings of Freebarin et al (1986). Ghasemi Abdoalmalaki et al (2015) stated that although tillage at the early times increases water infiltration rate of soil, it decreases over time. They measured the minimum of infiltration rate in the moldboard plow treatment. Gozubuyuk et al (2014) reported that water infiltration rate in the soil may be increased by appropriate methods of tillage operations, resulting in cracks in the soil. They measured higher infiltration rate in minimum tillage and no till compared to conventional tillage (moldboard plow with disk harrow). They also explained that it might be due to the extra stable aggregates and pores continuity in the minimum tillage and no tillage treatments.

Drainage

The effect of drainage on MWD was significant ($p<0.01$). In this study, MWD in drainage treatment was less than no drainage treatment (Table 4). The results showed that drainage reduces MWD in the surface layer. The reason can be explained by reducing the organic matter in the drainage treatment (Table 4). In other words, drainage provides the necessary conditions for organic matter decomposition; it reduces organic carbon and thus reduces MWD. Baker et al (2004) examined the effect of drainage and subsurface irrigation on MWD. Their results showed that MWD in the surface layers of 0-20 and 20-30 cm in drainage treatment was lower than subsurface irrigation treatment. However, in lower layers, MWD was larger in drainage treatment. They stated that soils in lower layers that are under irrigated condition couldn't be dried. Therefore, small aggregates or primary micro particles cannot form a larger aggregate.

Table 4: The effect of drainage on MWD, water infiltration rate and organic matter

Drainage management	*Pa* (%)	*P* (%)	M_s (%)	O.M (%)	υ_w (cm/h)	ρ_b (g/cm^3)	ρ_s (g/cm^3)	*MWD* (mm)
Drainage	24.00	45.00	49.00	1.17 ^{b}	2.34 ^{b}	1.50	2.74	1.57 ^{b}
Non-drainage	26.00	51.00	58.00	1.32 ^{a}	2.97 ^{a}	1.36	2.79	2.5 ^{a}

Columns marked with the same letter do not differ significantly ($p < 0.05$).

The water infiltration rate in drained treatment was less than that of no drainage treatment (Table 4). The reason is that leaching of salts in the drained treatment layer decreases the EC, resulting in the dispersion of soil particles and finally reduction of water infiltration rate in the soil. Similarly, Chaudhry & Sidhu (2001) reported a decrease in EC and water infiltration rate in the drained layer.

Interaction effect of drainage and tillage method

The interaction effect between drainage and tillage methods was classified into three groups (Table 5). The results showed that A_2B_1 treatment and A_2B_3 had the highest (25.48%) and lowest (17.17%) aeration porosity, respectively. The means comparison indicated that there was no significant difference among A_1B_3, A_1B_2 and A_1B_1 treatments regarding aeration porosity (Table 5). Consequently, application of moldboard plow in drained condition cannot significantly affect increasing the aeration porosity. However, the significant difference between A_2B_1 and A_2B_3 treatments indicated that selecting tillage method has an important and effective role on aeration porosity in no drainage condition. In other words, when the drainage is not applied, moldboard plow makes more aeration porosity in the soil compared to chisel plow.

Table 5: The interaction of drainage and tillage methods on aeration porosity, saturation moisture and MWD

	A_1B_1	A_2B_1	A_1B_2	A_2B_2	A_1B_3	A_2B_3
P_a (%)	23.32 ^{ab}	25.48 ^{a}	22.34 ^{ab}	22.41 ^{ab}	23.02 ^{ab}	17.17 ^{b}
M_s (%)	54.65 ^{b}	53.70 ^{b}	58.41 ^{ab}	58.43 ^{ab}	54.41 ^{b}	66.5 ^{a}
MWD (mm)	1.72 ^{c}	2.40 ^{b}	1.58 ^{c}	2.59 ^{ab}	1.55 ^{c}	2.8 ^{a}

Columns marked with the same letter do not differ significantly ($p \leq 0.05$).

The interaction effects of drainage and tillage methods on saturation moisture content are represented in Table 6. The results showed that A_2B_1 and A_2B_3 treatments had the lowest (53.70%) and highest (66.50%) saturated moisture content, respectively (Table 5). A higher saturated moisture content measured in the chisel plow treatment and no drainage condition, indicates that the inefficiency of the chisel in developing aeration porosity in such condition. There was significant difference between A_2B_3 and A_1B_3 treatments, in terms of saturated moisture content; however, there was no significant difference between A_1 and A_2 in other tillage methods. Therefore, the application of chisel plow is not recommended in no-drained areas.

The interaction effects between drainage and tillage methods were investigated on MWD (Table 5). The results showed that A_1B_3 treatment with 1.55 mm had the least MWD and A_2B_3 treatment with 2.80 mm had the highest MWD. There was a significant difference between A_2B_3 and A_1B_1, A_1B_2 and A_1B_3 treatments, but there were no significant differences between A_1B_1, A_1B_2 and A_1B_3 treatments. Therefore, it can be concluded that the effect of drainage on changes of MWD was higher than the tillage methods. The results also showed that the tillage treatments were significantly effective in no drainage lands, conversely drainage conditions.

Interaction effect of time and drainage

The interaction effect between time and drainage was investigated on water infiltration rate (Fig. 2).

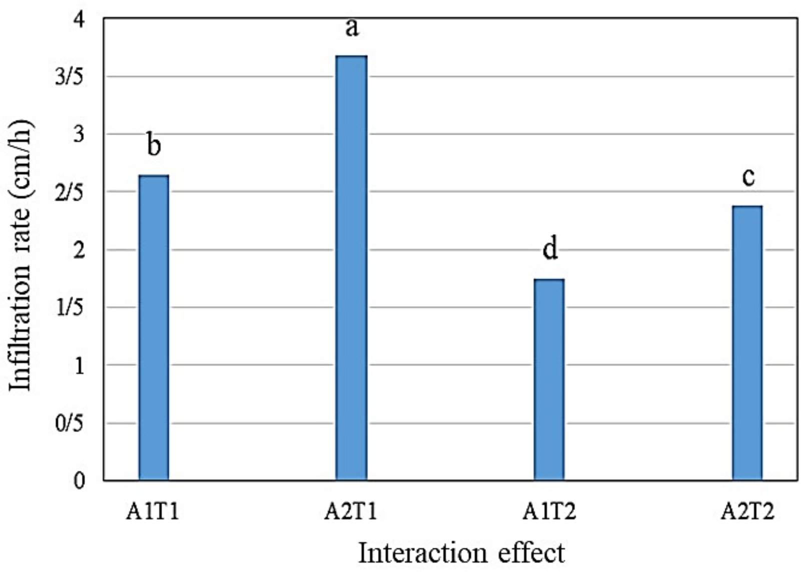

Fig 2. The interaction effect of drainage and time on water infiltration rate

The results showed that A_2T_1 treatment had the highest infiltration rate and A_1T_2 treatment had the lowest rate. All treatments had the significant difference, together. As observed, the infiltration rate decreased in T_2 compared to T_1, and this decrease were 37% and 32% in no drainage and drainage treatments, respectively. Therefore, it can be concluded that the drainage contributes to the continuity of infiltration.

Interaction effect of time and tillage method

The combination of time and tillage methods was represented in Fig. 3. The results showed that the highest infiltration rate was observed for T_1B_3 treatment, and the lowest one was obtained for the T_2B_1 followed by T_2B_2. The difference among T_1B_1, T_1B_2 and T_2B_3 were insignificant. According to the results, infiltration rate after harvesting decreased compared to after planting in all tillage treatments (Fig. 3). According to Van Es et al. (1999), tillage and time is a significant factor for infiltrability in the medium and fine-textured soils. The reason for the higher infiltration rate at T1 is that a little time has passed between tillage operation and sampling, and as a result the soil porosity is high. But at T2, the consecutive irrigations and traffic of agricultural machinery (between planting and harvesting) cause more soil compaction and thus reduce porosity. Alletto and Coquet (2009) reported similar results for inter-row position and attributed it to the low stability of porosity created by tillage (Osunbitan et al., 2005).

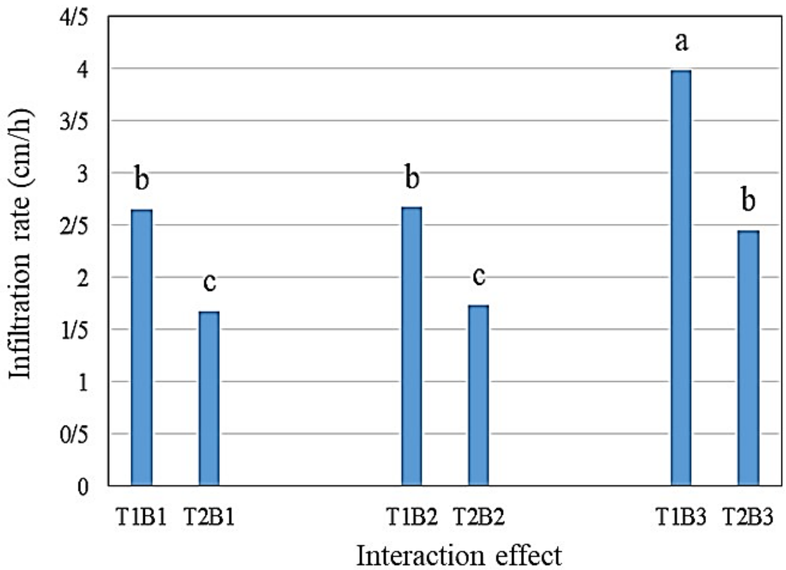

Fig 3. The interaction effect of interaction of time and tillage on water infiltration rate

Triple effect of the factors

The triple combination among the levels of time, drainage and tillage methods on MWD were investigated (Fig. 4).

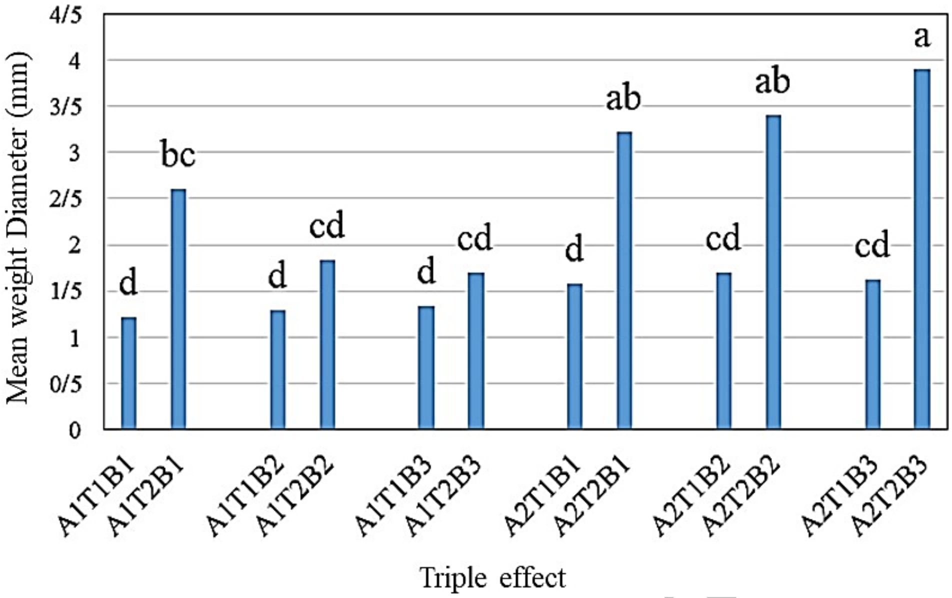

Fig 4. The interactions among, time, drainage, and tillage methods on MWD

The results showed that $A_1T_1B_1$ treatment (drainage, after planting and moldboard plow) had the lowest MWD and $A_2T_2B_3$ treatment (no drainage, after harvest and chisel plow) had the highest MWD.

The difference between $A_2T_2B_3$ treatment and $A_2T_2B_1$ and $A_2T_2B_2$ treatments was not significant. This indicates that in no drainage condition, the tillage methods do not have significant effect on MWD at postharvest time. However, there was a significant difference between $A_2T_2B_3$ and 11 other treatments. According to Fig. 4, in all treatments, MWD increased over time, in both no drainage and drainage conditions. Overall, this increase was higher in no drainage treatment compared to the drainage treatment. The reason relates to the high amount of organic carbon in no drainage treatment compared to the drainage treatment.

Conclusions

The effect of tillage methods on soil aeration porosity is completely related to drainage conditions. It was insignificant under drained conditions, however, in non-drainage condition, when moldboard plow is used, the soil aeration porosity will be 48.41% higher than that of chisel. In addition, the soil prepared by chisel has 23.84% more saturated moisture content than moldboard plow. As a result, it is recommended to use a moldboard plow (B1) instead of a chisel in non-drained conditions. Similarly, the choice of tillage method is very critical on MWD in non-drainage condition so that the size of aggregates created by the chisel is about 16.7% larger than moldboard plow (B1) in non-drainage condition. The contribution of drainage on changing MWD is higher than the tillage methods. Infiltration rate after harvesting decreases compared to after planting due to irrigation and traffic of machinery. According to the results of MWD, it increased over time, in all treatments. This was higher in non-drainage treatments compared to the drainage. Overall, the treatments of A1T1B1 (drainage/ after planting/moldboard plow+disk harrow) and A2T2B3 (non-drainage/ after harvesting/ chisel plow+disk harrow) have the lowest and highest MWD, respectively.

References

Abasi H, Khodaverdiloo H, Ghorbani Dashtaki S & Ahmadi Moghadam P (2014). The effect of some tillage methods on soil physical quality index in arid and semi-arid region. Journal of Agricultural Mechanization 1(2): 37-45 (In Persian)

Abbaspour-Gilandeha Y & Rahimi-Ajdadi F (2016). Design, construction and field evaluation of a multiple blade soil mechanical resistance sensor. Soil & Tillage Research 157: 93–100. https://doi.org/10.1016/j.still.2015.11.013

Aikins S H M & Afuakwa J J (2012). Effect of four different tillage practices on soil physical properties under cowpea. Agriculture and Biology Journal of North America 3: 17–24. DOI: 10.5251/abjna.2012.3.1.17.24

Alletto L & Coquet Y (2009). Temporal and spatial variability of soil bulk density and near saturated hydraulic conductivity under two contrasted tillage management systems. Geoderma 152: 85–94. https://doi.org/10.1016/j.geoderma.2009.05.023

Al-Suhaibani S A & Ghaly A E (2013). Comparative study of the kinetic parameters of three chiselPlows operating at different depthsand forward speed in a sandy Soil. The International Journal of Engineering and Science (IJES) 2: 42-59

Asghari Meidani J, Karimi E & Mousavi S B (2012). Tillage Effects on Wheat Yield and Soil Water Content and Bulk Density in Dryland Wheat-Fallow Rotation in Maragheh. Journal of Science and Technology of Agriculture and Natural Resources 16: 119-129

Baker B J, Fausey N R & Islam K R (2004). Comparison of soil physical properties under two different water table management regimes. Soil Science Society of America Journal 68 (6): 1973-1981. DOI: 10.2136/sssaj2004.1973

Bayat H, Mahbobi A A, Hajabbasi M A & Mosaddeghi M R (2008). Tillage and Tractor Effects on Bulk Density, Cone Index and Structural Stability of a Sandy Loam Soil. Journal of Science and Technology of Agriculture and Natural Resources 11(42): 451-461

Celik I (2011). Effects of tillage methods on penetration resistance, bulk density and saturated hydraulic conductivity in a clayey soil conditions. Journal of Agricultural Science 17: 143–156. DOI: 10.1501/Tarimbil_0000001166

Chaudhry M & Sidhu M (2001). Impact of sub surface drainage on soil salinity and crops yield under farmers management practices. Journal of Drainage and Water Management 5 (2): 35-45. https://doi.org/10.1023/B:IRRI.0000019475.42469.33

Demir Z & Isik D (2020). The impact of different cover crops, mechanical cultivation and herbicide treatment on the soil quality variables and yield in apple (Malus domestica Borkh.) orchard with a coarse-textured soil. Journal of Agricultural Sciences (Tarım Bilimleri Dergisi) 26: 452-470. DOI: 10.15832/ankutbd.527445

Elder J W & Lal L (2008). Tillage effects on physical properties of agricultural organic soils of north central Ohio. Soil & Tillage Research 98(2): 208–210. https://doi.org/10.1016/j.still.2007.12.002

Fernandez-Ugalde O, Virto I, Bescansa P, Imaz M J, Enrique A & Karlen D L (2009). No tillage improvement of soil physical quality in calcareous degradation-prone semiarid soils. Soil Tillage Research 106: 29–35. https://doi.org/10.1016/j.still.2009.09.012

Freebarin D M, Wockner G H & Silburn D M (1986). Effects of catchment management on runoff, water quality and yield potential from Vertisols. Agricultural Water Management 12: 1-19. https://doi.org/10.1016/0378-3774(86)90002-8

Gee G W & Or D (2002). Particle-size analysis. In: J H Dane & C Topp G C (Eds.), Methods of Soil Analysis, Part 4- Physical methods. Agronomy Monograph, Madison, pp. 255-293

Ghasemi Abdoalmalaki Y, Ghajar Sepanlou M & Bahmanyar M A (2015). Effects of Different Methods of Tillage on Some Physical Characteristics of Soil. Journal of Soil Research 29(3): 309-320 (In Persian)

Gill S M (2012). Temporal variability of soil hydraulic properties under different soil management practices. PhD Thesis, University of Guelph. Ontario, Canada. DOI: 10.13140/RG.2.2.12625.94566

Gozubuyuk K, Sahin U, Ozturk I, Celik A & Cemal Adiguzel M (2014). Tillage effects on certain physical and hydraulic properties of a loamy soil under a crop rotation in a semi-arid region with a cool climate. Catena 118: 195-205. https://doi.org/10.1016/j.catena.2014.01.006

Hajabbasi M A & Hemmat A (2000). Tillage impacts on aggregate stability and crop productivity in a clay-loam soil in central Iran. Soil Tillage Research 56: 205-212. https://doi.org/10.1016/S0167-1987(00)00140-9

Hajabbasi M A, Mirlohi A F& Sadrarhami M (1999). Impact of converting Rangelands to cultivated Land on physical and chemical properties of soils in West and Sounwest of Isfahan. Journal of Science and Technology of Agriculture and Natural Resources 3(3): 18-24

Hati K M, Chaudhary R S, Mandal K G, Bandyopadhyay K K, Singh R K, Sinha N K, Mohanty M, Somasundaram J & Saha R (2015). Effects of tillage, residue and fertilizer nitrogen on crop yields, and soil physical properties under soybean–wheat rotation in vertisols of central India. Agricultural Research 4 (1): 48–56. https://doi.org/10.1007/s40003-014-0141-7

Hill R L & Cruse R M (1985). Tillage effect on bulk density and soil strength of two Mollisols. Soil Science Society of America Journal 74: 1270-1273. https://doi.org/10.2136/sssaj1985.03615995004900050040x

Jabro J D, Stevens W B, Evans R G & Iversen W M (2009). Tillage effects on physical properties in two soils of the Northern Great Plains, Applied Engineering in Agriculture 25(3): 377–382. DOI: 10.13031/2013.26889

Jiang X, Hu Y, Bedell J H, Xie D & Wright A L (2015). Soil organic carbon and nutrient content in aggregate-size fractions of a subtropical rice soil under variable tillage. Soil Use Manage. 27(1): 28–35. doi: 10.1111/j.1475-2743.2010.00308.x

Kemper W D & Rosenau R C (1996). Aggregate Stability and size distribution. In: A Klute (Ed.), Methods of soil Analysis, Part 1: physical and Mineralogical Methods, 2nd Ed.,) American Society of Agronomy. Madison, W.I. pp. 425-442. https://doi.org/10.2136/sssabookser5.1.2ed.c17

Kribaa M, Hallaire V, Curmi P & Lahmar R (2001). Effect of various cultivation methods on the structure and hydraulic properties of a soil in a semi-arid climate. Soil and Tillage Research 60: 43-53. DOI: 10.1016/S0167-1987(01)00171-4

Lal R & Taylor G S (1969). Drainage and nutrient effects in a field lysimeter study. Corn yield and soil conditions. Science Society of America Journal 33(6): 937–941. https://doi.org/10.2136/sssaj1969.03615995003300060039x

Liu E, Chen B, Yan C, Zhang Y, Mei X & Wang J (2015). Seasonal changes and vertical distributions of soil organic carbon pools under conventional and No-till practices on Loess Plateau in China. Soil Science Society of America Journal 79: 517–526

Mirzaee M & Mahmoodabadai M (2014). The effect of kind and different crop residues management on some of physical properties and infiltration. Iranian journal of Soil and Water Research 28(4): 659-671 (In Persian)

Nakajima T & Lal R (2014). Tillage and drainage management effect on soil gas diffusivity. Soil & Tillage Research 135: 71–78. https://doi.org/10.1016/j.still.2013.09.003

Naseri H, Gholami Parashkoohi M, Ranjbar I & Mohammad Zamani D (2020). Sustainability of quantitative and qualitative indicators of sugarcane production under different tillage systems (case study:

Khuzestan province of Iran). Environmental and Sustainability Indicators 8, 100046. https://doi.org/10.1016/j.indic.2020.100046

Nelson D W & Sommers L E (1996). Total carbone organic carbone and organic matter. In: D L Sparks (Ed.), Methods of soil analysis, Part 3- chemical methods. Agronomy Monograph, ASA and SSSA, Madison, WI. Pp. 961-1010. https://doi.org/10.2136/sssabookser5.3.c34

Osunbitan J A, Oyedele D J & Adekalu K O (2005). Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. Soil & Tillage Research 82: 57-64. https://doi.org/10.1016/j.still.2004.05.007

Rahimi Ajdadi F, Abbaspour Gilandeh Y, Mollazade K & Hasanzadeh R P R (2016). Application of machine vision for classification of soil aggregate size. Soil & Tillage Research 162: 8–17. https://doi.org/10.1016/j.still.2016.04.012

Randall G W & Iragavarapu T K (1995). Impact of long-term tillage systems for continuous corn on nitrate leaching to tile drainage. Journal of Environmental Quality 24: 360–366. https://doi.org/10.2134/jeq1995.00472425002400020020x

Rashidi M & Keshavarzpour F (2011). Effect of different tillage methods on some physical and mechanical properties of soil in the arid lands of Iran. World Applied Science Journal 14: 1555–1558

Rasooli-Sharabiani V & Abbaspour-Gilandeh Y (2008). Effects of tillage methods on soil physical properties. In: Proceeding of the 5th National Congress on Agricultural Machinery Engineering and Mechanization of Iran, 27-28 August, Mashhad, pp. 1-7

Roldan A, Salinas-Garsia J R, Alguacil M M & Caravaca F (2007). Soil sustainability indicators following conservation tillage practices under subtropical maize and bean crops. Soil & Tillage Research 93: 273-282. https://doi.org/10.1016/j.still.2006.05.001

Roseberg R J & McCoy E L (1992). Tillage- and traffic-induced changes in macroporosity and macropore continuity: air permeability assessment. Soil Science Society of America Journal 56: 1261-1267. https://doi.org/10.2136/sssaj1992.03615995005600040042x

Sadeghnezhad H R & Eslami K (2006). The comparison of wheat yield under different tillage methods. Journal of Agricultural Sciences 12 (1): 103-112

Safadoust A, Mosaddeghi M R, Mahboubi A A, Nouroozi A & Asadian G (2007). Short-Term Tillage and Manure Influences on Soil Structural Properties. Journal of Science and Technology of Agriculture and Natural Resources 11(41): 91-101 (In Persian)

Sekwakwa O & Dikinya O (2012). Tillage-induced compaction: effects on physical properties of agricultural loamy soils. Scientific Research and Essays 7: 1584–1591. DOI: 10.5897/SRE11.2203

Seyed Olama S N, Asadi H & Zavareh M (2016). Effect of Tillage Erosion on Soil Displacement and productivity (Case Study: Tutkabon, Guilan). Journal of Soil and water Research 46(4) 769-780 (In Persian)

Tadesse H K, Moriasi D N, Gowda P H , Wagle P, Starks P J, Steiner J L, Talebizadeh M, Neel J P S & Nelson A M (2020). Comparison of Evapotranspiration and Biomass Simulation in Winter Wheat under Conventional and Conservation Tillage Systems using APEX Model. Ecohydrology & Hydrobiology 21(1) 55-66. https://doi.org/10.1016/j.ecohyd.2020.08.003

Thomas G W (1996). Soil pH and soil activity. In: D L Sparks (Ed), Methods of soil analysis, Part 3-Chemical Methods. Agronomy Monograph, ASA and SSSA, Madison. WI, pp. 475-490. DOI: 10.4236/gep.2016.45008

Van Es H M, Ogden C B, Hill R L, Schindelbeck R R, Tsegaye T (1999). Integrated assessment of space, time, and management-related variability of soil hydraulic properties. Soil Science Society of America Journal 63: 1599–1608. DOI: 10.2136/sssaj1999.6361599x

Wang X, Qi J Y, Zhang X Z, Li S S, Virk A L, Zhao X, Xiao X P & Zhang H L (2019). Effects of tillage and residue management on soil aggregates and associated carbon storage in a double paddy cropping system. Soil & Tillage Research 194: 104339. https://doi.org/10.1016/j.still.2019.104339

Wang H, Wang S, Yu Q, Zhang Y, Wang R, Li J & Wang X (2020). No tillage increases soil organic carbon storage and decreases carbon dioxide emission in the crop residue-returned farming system. Journal of Environmental Management 261: 110261. https://doi.org/10.1016/j.jenvman.2020.110261

West T O & Marland G (2002). A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agriculture, Ecosystems & Environment 91(1-3): 217–232 doi:10.1016/S0167-8809(01)00233-X.

Abbreviations and Symbols

Symbol	Definition
MWD	Mean weight diameter
A1	Subsurface drainage
A2	Non-drainage
B1	Moldboard plow + harrow
B2	Moldboard plow + rotary tiller

B3	Chisel plow + disk harrow
T1	After planting
T2	After harvesting
FC	Field Capacity
P_a	Aeration porosity
P	Porosity
υ_w	Infiltration rate
M_s	Saturated moisture content condition
M_{FC}	Soil moisture content at Field capacity
ρ_b	Bulk density
ρ_s	Mean particle density
K_s	Saturated hydraulic conductivity
O.M	Organic matter