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Determining The Effect of Different Tillage Methods on Soil Penetration Resistance During Wheat Growing Season

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ABSTRACT: Conservation tillage systems are applied due to their benefits for soil properties. However, studies have reported that conservation tillage system has negative effects on soil such as soil compaction. The aim of this study was to investigate the effects of tillage systems (minimum till, conventional till) on soil compaction during wheat cultivation. For this purpose, the penetration resistance readings were collected monthly from January to June at the depth of 0-80 cm. In order to determine soil moisture content, disturbed soil samples were collected at the same time with penetration measurements at the depth of 0-20 cm. The highest values of penetration resistance were recorded in May and June at the depths of 21-80 cm. In the meantime, the lowest values of soil moisture content were observed in May and June at the depth of 0-20 cm. In 21-30 cm soil layer, according to means of depth, penetration resistance was 2.04 MPa, which is the limit value for root growth in minimum tilled plots while 1.58 MPa in conventional tilled plots at the same depth. Results showed that penetration resistance increased with increasing soil depth and decreased with increasing soil moisture content, and soil penetration resistance increased under minimum tillage.

Keywords: Soil compaction, minimum tillage, penetration resistance, soil moisture.

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INTRODUCTION

Soil is exposed to many applications which affect physical, chemical and biological properties for crop production and one of these applications is tillage. Tillage is an application to prepare a seedbed, control weeds, improve surface drainage, control flow of air and water, control plant residues, control soil erosion, breakdown large aggregates into small aggregates and incorporate organic and inorganic fertilizers (Gebhardt et al., 1985). Due to such advantages, tillage with moldboard plow has been used for many years and is still used in our country as conventional tillage.

Conventional tillage helps accelerate the mineralization of organic matter, degradation of soil structure, decrease of soil moisture content, acceleration of water and wind erosion and increase surface runoff due to uncovered soil surface and increase nutrient loss with leaching in time. Over time, new tillage systems have been developed due to disadvantages of conventional tillage. These systems are called soil conservation tillage systems.

Soil conservation tillage systems aim to reduce soil disturbance and conserve and manage crop residues on soil. They include no tillage or zero tillage, minimum tillage, reduced tillage, strategic tillage etc. Some of the benefits of these systems are improvement of soil structure, soil organic matter and an increase soil nutrients thus an increase in soil macro and microorganisms. Also, these systems reduce surface runoff, wind erosion and evaporation due to plant cover on soil surface; therefore maintain and increase storage of soil moisture content for main crop (Cavalieri et al., 2009; Dörner and Horn, 2009; Girardello et al., 2014; Calonego et al., 2017; Conyers et al., 2019; Vizoli et al., 2021). However, in addition to all these positive effects, previous studies reported that no-tillage also has some negative effects such as soil compaction (Martínez et al., 2016).

Soil compaction is the process during which the soil aggregates are rearranged to reduce pore space and brought closer with each aggregate, increasing soil bulk density (SSSA, 1996). Soil compaction is directly related to soil porosity, soil structure as soil physical properties. Compaction decreases soil porosity, air permeability, hydraulic conductivity, plant root growth and crop yields and increases soil bulk density and soil strength (resistance to penetration). Soil strength affects the development of plant roots in the soil and the measurements of soil strength are used for determining soil compaction (Horn and Rostek, 2000).

The objective of this paper was to investigate the effects of tillage systems on soil penetration resistance of a clay loam soil during wheat cultivation.

MATERIAL AND METHODS

Study site

The study was established in the experiment field of Igdır University Agricultural Research and Application Center, Turkey.

In the region, summer is hot and winter is mild due to microclimate feature of Igdır. The highest rainfall in the plain falls in May and the lowest in August. In Igdır, the annual average rainfall is 254.2 mm, and the evaporation is 1094.9 mm. The coldest month is January and the warmest is July (Anonymous, 2018) and the elevation of the region is 850 m, the slope of irrigated lands in the central district of plain is straight and nearly straight (0-2%). Some soil properties were shown in Table 1.

The study consists of cultivation of wheat in conventional tillage (moldboard plow with the depth of 40 cm, rotary tiller) and minimum-tillage (rotary tiller with the depth of 0-10 cm, wheat sowing machine). The wheat cultivation started in 2016 and continued until 2019 under minimum and conventional tillage. The wheat was planted with sowing machine in spring (March) each year.

Table 1. Results of some soil properties

	Soil properties				
Tillage systems	**Texture**	**OM, %**	**AS, %**	**EC, µmhos cm^{-1}**	**pH**
Minimum tillage	Clay loam	1.65±0.32	24±2.8	430±41	8.50±0.11
Conventional tillage	Clay loam	1.55±0.18	22±2.42	570±22	8.66±0.22

* SOM: soil organic matter; AS: aggregate stability; EC: electrical conductivity; pH: soil pH.

Penetration resistance

In the study, soil penetration resistance was measured with a 60^{o} cone and either a 1 cm^{2} base area and a 0-10 MPa range (Eijelkamp 06.15.31 Penetrologger, Nijverheidsstraat 30, NL-6987 EM Giesbeek). Penetration resistance data were recorded at the depth of 0-80 cm in 1 cm increments with the twenty readings per tillage systems on the 30th of each month since January to June under wheat cultivation in both minimum and conventional tilled plots in 2019.

Soil moisture content

It was determined gravimetrically in disturbed soil samples collected from at the depth of 0-20 cm under wheat cultivation on the 30th of each month since January to June in both minimum and conventional tilled plots.

Soil sampling and analysis

For soil physical and chemical analysis, disturbed soil samples were collected after wheat was planted in the research area from 0-30 cm soil layer in 2019.

Organic matter, aggregate stability, soil pH and electrical conductivity were determined in disturbed soil samples. Soil organic matter, aggregate stability, pH and electrical conductivity were determined according to Walkley and Black (1934), Kemper and Rosenau (1986), McLean (1982) and Rhoades (1983), respectively. Soil moisture content was determined according to Reynolds (1970).

Statistical analysis

The data were analyzed using statistical software program *SPSS* (SPSS Inc., USA). The mean values of each group were tested by ANOVA (Analysis of variance) tests. The differences between each group were detected for statistical significance ($p < 0.05$) and the differences between specified groups were determined by Duncan multiple comparison test ($p < 0.05$).

RESULTS AND DISCUSSION

The penetration resistance was significantly ($p < 0.05$) influenced by tillage systems, soil depths and months. The two-way interactions months x soil depths, months x tillage systems and soil depths x tillage systems significantly affected soil penetration resistance. The three-way interaction wasn't found to be statistically significant ($p > 0.05$).

The lowest mean value of penetration resistance was at the 0-10 cm soil depth (1.05 MPa) and highest was in 71-80 cm soil depth (2.43 MPa; Table 2). It is clear that the penetration resistance increased with increasing soil depth. Franzen et al. (1994) and Campbell and O'Sullivan (1991) reported an increase in soil penetration resistance with depth due to in shaft friction whereas Bradford (1986) reported that the increase depended on soil hardness and probe diameter. The other reason is that soil with high clay content leads to the formation of strong columnar aggregates may cause an increase in the penetration readings (Villar 1989; Atwell 1993). In the region, Şimşek et al. (2019) reported that the soil has hardness and high clay content at the depth of 0-96 cm, so the increase in penetration resistance may be due to hardness and clay content in the 0-96 cm soil layer.

Table 2. The changes of soil penetration resistance with soil depths, months and tillage systems (MPa)

Depths (cm)	Tillage systems	Months						Means of depth	Overall means
		January	February	March	April	May	June		
0-10	Ct	0.91±.07	0.82±0.07	0.74±0.11	0.96±0.09	0.61±0.06	0.99±0.09	0.84±0.15B	1.05±0.30G
	Mt	1.15±0.11	1.19±0.07	1.05±0.03	1.57±0.18	1.00±0.26	1.60±0.08	1.26±0.27A	
	Total	1.03±0.15b	1.00±0.20bc	0.90±0.18cd	1.26±0.35a	0.80±0.27d	1.30±0.33a		
11-20	Ct	1.33±0.07	1.23±0.14	1.08±0.13	1.38±0.15	0.97±0.11	1.40±0.05	1.23±0.19B	1.56±0.49F
	Mt	1.58±0.07	1.72±0.03	1.54±0.15	2.05±0.05	1.79±0.59	2.69±0.33	1.90±0.47A	
	Total	1.45±0.14c	1.47±0.28c	1.31±0.28c	1.72±0.37b	1.38±0.59c	2.04±0.72a		
21-30	Ct	1.73±0.12	1.68±0.16	1.48±0.15	1.58±0.12	1.39±0.16	1.61±0.11	1.58±0.17B	1.81±0.40E
	Mt	1.88±0.08	1.89±0.04	1.75±0.10	1.86±0.17	2.31±0.82	2.59±0.18	2.04±0.44A	
	Total	1.80±0.12b	1.78±0.15b	1.61±0.18b	1.72±0.20b	1.85±0.73ab	2.10±0.54a		
31-40	Ct	1.97±0.06	1.84±0.15	1.85±0.07	1.75±0.14	1.73±0.25	1.78±0.16	1.82±0.16B	1.97±0.29D
	Mt	2.03±0.1	1.97±0.10	1.90±0.09	1.94±0.20	2.42±0.57	2.41±0.15	2.11±0.32A	
	Total	2.00±0.08	1.91±0.14	1.88±0.08	1.85±0.19	2.08±0.55	2.10±0.36		
41-50	Ct	1.99±0.11	1.77±0.12	1.91±0.04	1.75±0.10	2.07±0.15	2.06±0.25	1.93±0.18B	2.02±0.28D
	Mt	2.11±0.15	1.92±0.16	1.84±0.09	1.91±0.21	2.47±0.40	2.48±0.13	2.12±0.33A	
	Total	2.05±0.14b	1.84±0.15c	1.88±0.08bc	1.83±0.17c	2.27±0.35a	2.27±0.29a		
51-60	Ct	1.93±0.07	1.71±0.10	1.92±0.05	1.72±0.08	2.39±0.27	2.43±0.25	2.02±0.33B	2.11±0.42C
	Mt	2.05±0.13	1.80±0.09	1.88±0.13	1.85±0.16	2.75±0.45	2.87±0.12	2.20±0.49A	
	Total	1.99±0.11b	1.76±0.10c	1.90±0.09bc	1.78±0.13bc	2.57±0.39a	2.65±0.30a		
61-70	Ct	1.91±0.11	1.68±0.07	1.98±0.09	1.71±0.06	2.84±0.24	2.94±0.27	2.18±0.54B	2.30±0.67B
	Mt	1.99±0.12	1.76±0.13	2.09±0.18	1.82±0.13	3.45±0.38	3.48±0.15	2.43±0.77A	
	Total	1.95±0.12bc	1.72±0.11d	2.03±0.14b	1.77±0.1cd1	3.14±0.44a	3.21±0.34a		
71-80	Ct	1.85±0.11	1.68±0.06	1.94±0.15	1.70±0.11	3.45±0.06	3.31±0.29	2.32±0.78B	2.43±0.86A
	Mt	1.95±0.16	1.73±0.10	2.14±0.24	1.83±0.15	3.94±0.28	3.68±0.29	2.55±0.94A	
	Total	1.90±0.14cd	1.71±0.08d	2.04±0.21c	1.77±0.14d	3.70±0.32a	3.49±0.33b		
Overall means		1.77±0.35c	1.65±0.31d	1.69±0.41d	1.71±0.27cd	2.22±0.98b	2.39±0.77a		1.91±0.64

*Ct, conventional tillage; Mt, minimum tillage.

According to the means of penetration resistance for months, the highest penetration resistance was in June (2.39 MPa) and the lowest was in February (1.65 MPa). The changes could be explained by the differences in soil water content at the time of measurement as the differences in soil moisture content between tillage systems and sampling time were found to be significant ($p<0.05$). Figure 1 shows that soil moisture content decreased throughout the months. Van Quang and Jansson (2012) reported that soil water content affected soil penetration resistance. Low soil moisture content causes a hard-set condition especially in soil which has clay texture due to swelling-shrinkage feature of clay. Han et al. (2006) also reported that soil with low soil moisture content created a hard-set form. In addition, Lopez et al. (1996) reported that the high (4-5 MPa) penetration resistance values were recorded in low moisture content.

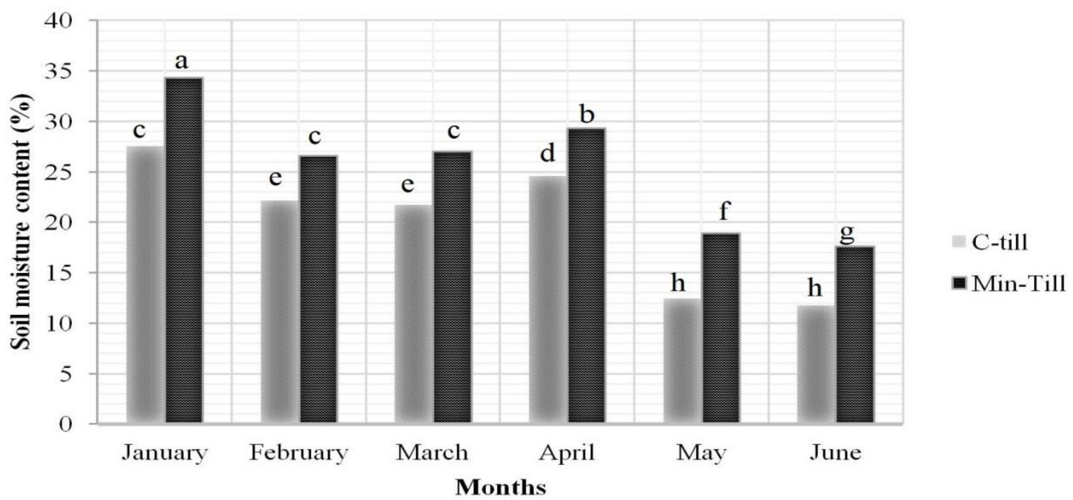

Figure 1. Soil moisture content during wheat growing season at the depth of 0-20 cm (C-till, conventional tillage; M-till, minimum tillage).

In the 0-10 cm soil layer; the lowest penetration resistance was found in conventional tilled plots (0.84 MPa). In this layer, there were significant differences between measuring times. The highest value was in June (1.30 MPa) and the lowest in May (0.80 MPa). At the 11-20 cm soil depth, the penetration resistance was 1.23 MPa in conventional tilled and 1.90 MPa in minimum tilled. The highest value for penetration resistance was in June (2.04 MPa) and lowest in March (1.31 MPa) from January to June. In the 21-30 cm soil layer, it was found higher in minimum tilled plots (2.04 MPa). In June, the penetration resistance was 2.10 MPa with the highest value and in March 1.61 MPa with the lowest value. In the 31-40 cm soil layer, it was found 1.82 MPa in conventional tilled and 2.11 MPa in minimum tilled plots. There were no significant differences between months at the depth of 21-30 cm. The penetration resistance values were higher than 2 MPa in January, May and June. At the depth of 41-50 cm, the penetration values were higher under minimum tilled plots than the conventionally tilled. The differences between months were found to be statistically significant. While the highest values were in May and June, the lowest was in April. In the 51-60 cm soil layer, it was determined higher under minimum tilled plots (2.02 MPa). The highest values were in June while the lowest were in February. At 61-70 cm soil depth, the higher values were in minimum tilled plots (2.43 MPa). The highest values between months were observed in June with In the 71-80 cm soil depth, the lower values were in conventional tillage and the higher values were in May between months (Table 2).

According to the findings, the penetration resistance decreased in conventional tillage and increased in minimum tillage. The differences could be explained by age-hardening which is the result of particle rearrangements and particle cementation under minimum tillage. Medeiros et al. (2011), de Moraes et al. (2017) and Vizioli et al. (2021) found that the higher values of penetration resistance in no-tillage practices can be referred to age-hardening of soil aggregates. Mairghany et al. (2019) detected that tillage practices reduce soil penetration resistance. Mairghany et al. (2019), Lampurlanés and Cantero-Martínez (2003) and Wulanningtyas et al. (2021) also determined that no-tillage practices increase penetration resistance. Besides, Nunes et al. (2015) determined that chiseling decreased soil penatration resistance.

Figure 2 shows that the penetration resistance is above 2 MPa, which is the limit value for plant root development in January at the depth of 31-40 cm. In February, it did not exceed 2 MPa in the 0-80 cm soil depth. The penetration resistance is above 2 MPa in March at the depth of 61-70 cm. In April, it is over 2 MPa at a depth of only 11-20 cm in minimum tillage. In minimum tillage, the penetration resistance is over 2 MPa at the depth of 21-30 cm, whereas it is over 2 MPa at the depth of 41-50 cm under conventional tillage in May. Besides, in June it is above 2 MPa in the 11-20 cm soil layer under minimum tillage nonetheless in conventional tillage, it is over 2 MPa at the depth of 41-50 cm. It is observed that penetration resistance in May and June is over 2 MPa below 21-30 cm soil depth.

CONCLUSION

The results showed that from January to June, the soil penetration resistance exceeded 2 MPa only in May and June which is close to the harvest period of wheat at a soil depth of 0-30 cm which is the root depth for wheat under minimum tillage. Therefore, it has been determined that minimum tillage for wheat growth does not pose a problem in terms of compaction. In general, as a result of minimum tillage which is performed for 4 years, penetration resistance exceeded 2 MPa below 31-40 cm soil depth where the wheat roots cannot reach. In conclusion, it can be suggested that minimum tillage should be applied for sustaining soil health and quality for wheat cultivation.

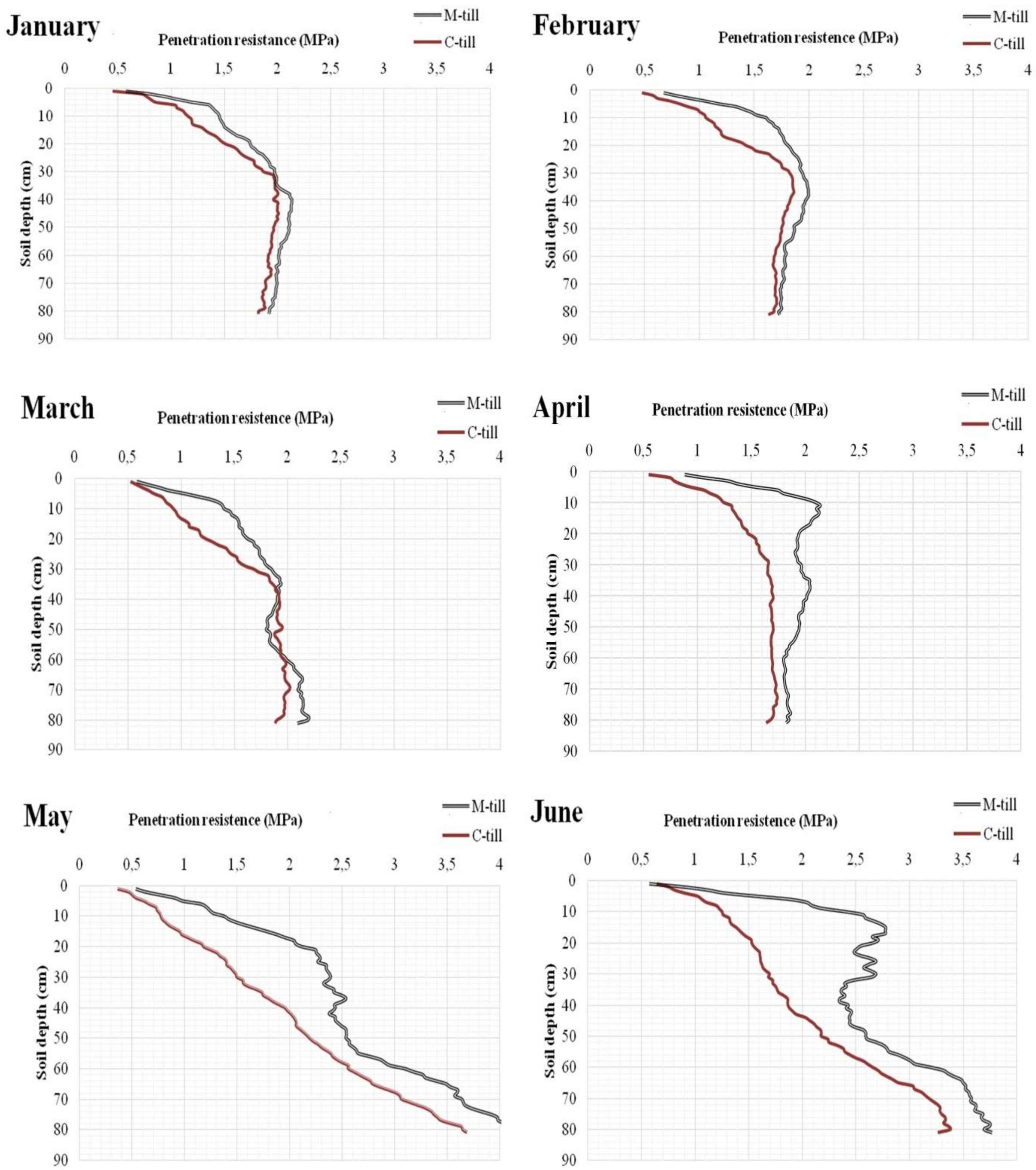

Figure 2. Soil penetration resistance from January to June at the depth of 0-80 cm (C-till, conventional tillage; M-till, minimum tillage).

Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article**.**

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