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Comparison of Different Soil Tillage Methods for Sustainable Agriculture in the Transition Climate Zone in Terms of Seedbed Quality and Green Grass Yield of Triticale-Vetch Mixture

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A R T I C L E I N F O

Research Article

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A B S T R A C T

In the research conducted under the conditions of Tokat, silage triticale-vetch mixture-second crop silage corn rotation was applied. The study used four different tillage methods to compare the quality and product yield of the seedbed prepared for silage triticale-vetch mixture. Conventional tillage method (M1), conservation tillage method (M2), reduced tillage method (M3), and direct sowing (M4) methods were applied. Seedbed quality: It was evaluated regarding soil moisture content, bulk density, penetration resistance, degree of soil fragmentation, and surface roughness for depths of 0-10 cm and 10-20 cm. The effect of soil tillage methods on porosity, surface roughness, and green grass yield were statistically insignificant. Although there were statistical differences between the methods regarding soil moisture content (MC), bulk density (BD), penetration resistance (PR), and mean weight diameter values (MWD), the values are within the limit values determined for plant growth. However, crop yield is the same between soil tillage methods. This result shows that alternative tillage methods are applicable when evaluated in sustainable agriculture, which does not create a statistically significant difference in crop yield compared to conventional tillage.

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Introduction

Soil tillage is the process of regulating the condition of the soil with mechanical effects for agricultural production (Gajri et al., 2002; Özgöz et al., 2015). The creation of a favorable soil form for the cultivation of crop plants can be realized through soil cultivation (Aykas et al., 2005). The aim of tillage is to prepare a seedbed where planting can be done successfully and to effectively control weeds (Bodur, 2008). In the sowing process, the clods should be broken up more, and the soil should be pressed to make the ground where the seed is placed harder and to reduce air-filled gaps in the soil (Önal, 1995).

Qualification of the quality of a seedbed presents crucial challenges. Qualification seedbed evaluation methods are commonly classified into two categories. The first method is stated as directly measuring soil mechanical and physical properties and evaluating them in terms of yield. The second method involves combining some soil physical properties with mathematical expressions, process models, or pedotransfer functions to provide a more global assessment of the soil (Acock & Pachepsky, 1997). Soil physical properties commonly measured in the first category are penetration resistance, bulk density, particle size, mean-weight diameter, and porosity (Becher et al., 1997; Carter, 1990; Fragin, 1986; Hakansson, 1990; Luttrell, 1963; Steyn & Tolmay, 1995).

Johnson & Taylor (1960) reported that 30% of the mass of the soil in the sown layer should consist of secondary aggregates smaller than 2,5 mm in diameter. The main functions affecting plant germination and development are penetration resistance (PR), bulk density (BD), moisture content (MC), soil particle size, and surface roughness. It is reported that PR and BD values, two main criteria for soil physical quality, are widely used to decide the degree of compaction in cultivated soils and detect compacted layers (Abu-Hamdeh, 2003; Diaz-Zorita, 2000). Penetration resistance (MPa) is used to describe soil resistance. It can also provide meaningful information about the effects of soil resistance on root development and product yield. High resistance makes it difficult for plant roots to penetrate the soil and reduces root development (Barut et al., 2010).

As the soil BD increases, the moisture content, infiltration rate, and pore volume decrease, and the soil becomes less aerated. The increase in soil BD causes a reduction in plant root development (USDA-NRCS, 1996).

Compaction and particle size vary according to the soil tillage method; It affects germination, plant root development, seed contact with soil, soil aeration, and water retention capacity (Kuş & Yıldırım, 2017). As particle size values increase, soil moisture content and BD values decrease, and porosity values increase (Canbolat & Barik, 2004).

Surface roughness is a dynamic soil property that occurs on the soil surface and affects many processes (Hauer et al. 2001). Soil surface roughness is defined as irregularities in the soil surface caused by soil texture, vegetation cover, aggregate size, and land management. (Amoah et al., 2013). Tillage and meteorological conditions (wetting/drying, freeze/thaw, rainfall, etc.) change the roughness at diverse rates (Hauer et al. 2001). Soil surface roughness is affected by different tillage methods and is essential in conservation tillage methods (Bramorski et al., 2012; Vázquez et al., 2010).

Birkas et al. (2004) reported that the compaction caused by deep soil cultivation with disk tools or plows every year is at a shallow depth in the first three years, and the condensation spreads in depth from the fifth year.

Husnjak et al. (2002) compared conventional tillage, reduced conventional tillage, two different conservation tillage, and direct sowing methods in silty loam soil regarding soil physical properties and crop yield. They reported that the difference between tillage methods in terms of air and water retention capacity, porosity, and bulk density was statistically insignificant in the winter wheat period but significant in the soybean period.

Ayhan (2014) stated that soil moisture is conserved, penetration resistance and bulk density are lower, and plant emergence and product yield are better in the direct sowing application than conventional tillage method in wheat-second crop corn rotation.

Kuş & Yıldırım (2017) determined the soil moisture content, BD, soil porosity, soil resistance, change in field surface roughness ratio, MWD of the particles, and particle size distribution depending on the conditions before tillage with reduced and traditional tillage methods. They stated that minimum BD and maximum porosity values were determined with the reduced tillage method, which the tillage method affected the roughness rates at a statistically significant level, and that larger diameter particles were formed with the conventional tillage method.

This study carried out in a transitional climate zone, aimed to determine the sustainable tillage method for the region to cultivate a triticale-vetch mixture for silage. For this aim, traditional and conservation tillage methods were compared in terms of some physical properties of the soil, which indicate seedbed quality in triticale-vetch cultivation, and the effects of triticale-vetch mixture on green grass yield.

Materials and Methods

Experimental Area

The research was conducted on land belonging to the "Middle Black Sea Transitional Zone Agricultural Research Institute" in the Tokat-Kazova. Kazova is located at 40º 18′north latitude, 36º 34′ east longitude. Kazova, located between Tokat and Turhal and with an area of 29 812 ha, is a depression plain. Yeşilırmak flows through its center, and its altitude is 500-750 m above sea level (DSİ, 1974).

The research was conducted in the Yeşilırmak series, the dominant soil series in Kazova. Yeşilırmak series soils are very deep soils with a slope of 0-2%, A and C horizons, formed by the alluvium carried by Yeşilırmak. Clay content is between 36.8-42.8%. The dominant cations are Ca and Mg, and the pH is 7.72-7.90. Lime content is homogeneous along the whole profile (Oğuz, 1993).

The TAGEM project (Afacan et al., 2023) on "Comparison of Soil Properties, Yield and Energy Efficiencies in Main and Second Crop Rotations of Different Soil Processing Methods" was implemented in the trial area between 2017 and 2021. The study used experiment plots and soil tillage practices established in the TAGEM project. Silage triticale-vetch mixture was planted in the 2021-2022 production period, adhering to the applied rotation. The texture and some chemical properties of the research area soils at the beginning of the experiment are given in Tables 1 and 2.

Experiment Design and Applications

The research was carried out on 12 random plots of 50 m x 5.6 m in size, and soil tillage methods were applied in three repetitions. A 2 m space was left around the plots. The soil tillage methods detailed below were applied in the study.

M1- Conventional Tillage: Seedbed preparation was completed by using a depth of 20-25 cm with a moldboard plow, a depth of 10-15 cm with a disc harrow, and a spring tine cultivator rolling harrow combination, respectively. Sowing was done with a combined row drill.

M2- Conservation Tillage: Seedbed preparation was completed by using a depth of 20-25 cm with a chisel plow and a depth of 10-15 cm with a disc harrow, respectively. Sowing was done with a combined row drill.

M3- Reduced Tillage: Seedbed preparation was completed by processing at a depth of 15-20 cm with rotary cultivators with vertical axes. Sowing was done with a combined row drill.

M4- Direct sowing: In this method, soil tillage was not done on the parcels, and approximately fifteen days before sowing, existing weeds were killed with total herbicide (300 ml da^{-1}). Sowing was performed with a direct combined row drill.

Soil tillage and sowing practices were carried out on November 22-23, 2021. In the plots prepared by applying different soil tillage methods, 50% common vetch + 50% triticale mixture was sown at a 14 kg da^{-1} sowing rate and planted at a 3-4 cm depth. DAP at 20 kg da^{-1} norm was applied to all parcels as base fertilizer upon planting. Ammonium Sulphate (21% nitrogen and 24% sulfur) at 18 kg da^{-1} seeding rate was used as the top fertilizer on April 05, 2022. Harvesting was done on May 30, 2022.

Sampling and Measuring Soil Properties

To determine the quality of the seedbed, bulk density, penetration resistance, soil moisture content, degree of soil fragmentation, and surface roughness were measured after sowing. All samples and measurements were carried out in three replications in each plot. No sampling was done from wheel tracks.

Table 1. Textural characteristics of study area soils*

Soil Tillage Method	Depth (cm)	Texture (%)			Texture Class
		Sand	Clay	Silt	
M1	0-10	26.76	35.76	37.48	Clay loam
	10-20	27.15	34.65	38.20	Clay loam
M2	0-10	26.27	35.55	38.18	Clay loam
	10-20	26.52	35.08	38.40	Clay loam
M3	0-10	26.06	35.31	38.63	Clay loam
	10-20	26.68	34.65	38.67	Clay loam
M4	0-10	26.26	36.24	37.50	Clay loam
	10-20	26.94	33.95	39.11	Clay loam

Notes: M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct sowing. *Afacan et al. (2023)

Table 2. Some chemical properties of the study area soils at the beginning of the experiment*

Soil Tillage Method	Depth (cm)	Electrical Conductivity (mmhos /cm)	Salt (%)	pH	Lime (%)	Available Phosphorus (kg da^{-1})	Available Potassium (kg da^{-1})	Organic Matter (%)
M1	0-10	0.86	0.03	7.82	10.59	4.91	62.87	2.31
	10-20	0.81	0.03	7.80	10.98	2.54	65.66	2.37
M2	0-10	0.90	0.04	7.83	10.98	4.28	75.44	2.28
	10-20	0.85	0.03	7.82	10.59	2.18	67.79	2.19
M3	0-10	0.94	0.04	7.82	10.33	4.15	77.17	2.62
	10-20	0.85	0.03	7.81	11.50	2.52	67.49	2.23
M4	0-10	0.96	0.04	7.74	10.98	5.52	82.14	2.82
	10-20	0.91	0.04	7.71	10.72	4.52	65.59	2.48

Notes: M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct sowing.

Seventy-two undisturbed soil samples (12 plots × 3 repetitions × 2 depths) were taken from two depths (0-10 cm and 10-20 cm depths) using cylinders of 0.05 m diameter and 0.05 m height to determine soil bulk density and moisture content. The samples brought to the laboratory were weighed, left to dry in an oven at 105ºC for twenty-four hours, and weighed again (Vepraskas & Wagger, 1989). Moisture content and BD were determined using dry and wet weights of soil samples (Baver et al., 1972; Demiralay, 1993).

To determine the soil penetration resistance of soils, measurements were made using a digital penetrometer, which can measure up to 45 cm depth at 2.5 cm intervals. A conical tip with a diameter of 12.7 mm was used in the measurements. At each measurement point, the average penetration resistance values were obtained for 0-10 cm depth by averaging the values measured at 0, 2.5, 5, 7,.5, and 10 cm depths and for 10-20 cm depth by averaging the values measured at 12.5, 15, 17.5 and 20 cm depths. Porosity values of soil samples were calculated using Equation 1 (Erbach, 1987).

$$P = 1 – (BD/ P_k) \quad (1)$$

Where P is porosity, BD is bulk density (g cm^{-3}), and P_k is soil particle density (2.65 g cm^{-3}).

Approximately 5 kg of soil samples were taken from each plot in 3 replicates with the help of a shovel from the soil particle size measurement depths of the created seedbed (0–10 cm and 10–20 cm) and were transported to the laboratory without being disturbed. These air-dry samples were kept in the laboratory for two months, and sieve analysis was performed (Altıkat, 2005; Çelik, 1998). Sieve analysis used sieves with 63, 32, 16, 8, 4, 2, and 1 mm hole diameters specified in Anonymous (1974). First, the sieving time and frequency required to prevent the soil from crumbling and ensure full-size distribution were determined. Accordingly, the sieving process was carried out by applying a 30 s elimination time and 50 Hz vibration frequency (Anonymous, 1980). To express the soil fragmentation fractions after tillage and to evaluate the seedbed quality, the soil particle sizes obtained were based on three groups:>8 mm, 1-8 mm, and <1 mm (Çelik, 1998). Moreover, the mean weight diameter values were also determined using Equation 2 (Adam & Erbach, 1992; Demir et al., 1996).

$$MWD = \Sigma X_i . W_i \quad (2)$$

Where W_i is the sample weight of each size fraction (g), X_i is the mean diameter of each size fraction (mm), and MWD is the mean-weight diameter (mm).

A profilometer consisting of rods placed on a 1 m long profile at 2.5 cm intervals was used to determine the roughness of the soil surface created by soil tillage methods. The profilometer was placed perpendicular to the direction of the sowing, and measurements were made in three replications in each plot. Surface roughness was determined using Equation 3 (Çarman, 1997).

$$R = 100.\mathrm{Log10}\ S \quad (3)$$

Where S is the standard deviation, and R is surface roughness (%).

Crop Yield

In the study, the effect of tillage methods on green grass (silage) yield of the triticale-vetch mixture was also determined in addition to seedbed quality. To determine the green grass yield of the triticale-vetch mix, the plants harvested in a 1 m^2 area in three replicates in each parcel were weighed, and the green grass yield per decare (kg da^{-1}) was determined.

Statistical Analysis

First, the Kolmogorov-Smirnov (KS) test was performed on the data set created for each parameter to determine whether the data set showed a normal distribution. Then, normally distributed data sets were subjected to analysis of variance and Duncan's multiple range test. Statistical analyses were performed using the SPSS 17.0 (SPSS, 2017). As a result of these statistical analyses, the most appropriate tillage method was selected by determining the effect of tillage methods on crop yield and some soil properties used to express the quality of the seedbed.

Results and Discussion

Effects of Tillage Methods on Soil Physical Properties

Tillage methods significantly affected the MC values determined at a 0-10 cm depth at the $P<0.05$ level, with no significant effect at 10-20 cm. According to soil tillage methods, moisture content values varied between 22.95% (M3) - 29.03% (M4) and 22.38% (M3) - 27.46% (M4) at depths of 0-10 cm and 10-20 cm, respectively. It was observed that the main difference in moisture content values at the surface depth, where soil tillage methods had a statistically significant effect, was due to M4, and the other three tillage methods were statistically in the same group (Table 3).

Tillage methods affected the bulk density values measured at two depths (0-10 cm and 10-20 cm) at $P<0.01$. Soil tillage according to the mean bulk density values, tillage methods were ranked as M4>M1>M3>M2 at depths of 0-10 cm and M4>M2>M1=M3 10-20 cm at depths (Tables 3 and 4).

Hakansson & Lipiec (2000) stated that plant growth is limited when the BD is 1.60 g cm^{-3}, and the limiting BD value varies according to soil texture. Lhotsky et al. (1984) stated that the limit BD value for clay loam soils is 1.40 g cm^{-3} (Badalikova, 2010). Additionally, Pierce et al. (1983) stated that in clay loam soils, the ideal BD is <1.40 g cm^{-3}, the BD values that negatively affect the development of roots are 1.63 g cm^{-3}, and the BD that prevents the growth of roots is >1.80 g cm^{-3}. According to these values, it was determined that the BD values measured in the research area, which has a clayey loam texture, were generally below the values that limit plant root development and were close to the limit values at both depths, especially in the M4 treatment (Tables 3 and 4).

Barut et al. (2010) reported that BD increased in all methods at a depth of 0-10 cm, while it increased only in the direct sowing method at lower depths; Gürsoy & Kolay (2012) reported that the BD value was higher in conventional tillage method; Kuş & Yıldırım (2017) stated that the lowest BD values were determined in the reduced tillage method. So et al. (2009) reported that zero tillage did not change the BD in the short term but decreased the BD in the long term. Bulut (2018) reported that the highest and lowest humidity values were in the direct sowing and conventional tillage methods, respectively. In the study, similar to the results reported in the literature, it was determined that soil MC and BD were higher in the M4.

According to the results of variance analysis, the effect of tillage methods on soil porosity values at both depths is statistically insignificant (Tables 3 and 4). Maximum porosity at the surface depth was obtained in the M2 treatment (53.92%) and minimum porosity in the M4 treatment (47.28%). Bahtiyar (1996) states that the porosity value of soil in texel structure varies between 24.5% and 47.5%. Porosity and BD are parameters that can change with tillage, and their relationship is opposite. An increase in one means a decrease in the other (Ülger et al., 2002). In this study, when BD and porosity values are analyzed together, it is seen that they have an opposite relationship. M3 and M2 caused looser soil structure and higher porosity than M1 and M4.

According to the results of variance analysis, it was determined that tillage methods significantly affected soil PR values at the level of $P<0.05$ at the surface depth and at the level of $P<0.01$ at the depth of 10-20 cm. When the average soil PR values were analyzed, it was determined that the highest value was obtained in the M4 (1.2 MPa). The smallest value was obtained in the M3 (0.4 MPa) method at 0-10 cm depth, and M1, M2, and M3 methods were statistically in the same group. At the second measurement depth (10-20 cm), the maximum value was obtained in the M2 (1.7 MPa) and the minimum value in the M1=M3 (0.8 MPa) methods. At this depth, M1-M3 and M2-M4 methods were statistically in the same group (Table 4).

Table 3. Some physical properties of study area soils under different tillage methods (0-10 cm)

Soil tillage method	Moisture Content (%)	Bulk density (g cm^{-3})	Porosity (%)	Penetration resistance (MPa)
M1	23.18±2.55b	1.30±0.10b	48.86±3.56	0.6±0.20b
M2	23.28±1.61b	1.19±0.07d	53.92±1.06	0.6±0.15b
M3	22.95±1.27b	1.25±0.15bc	50.84±5.58	0.4±0.29b
M4	29.03±9.79a	1.45±0.09a	47.28±6.65	1.2±0.17a
F value	2.95*	9.60**	1.10^{ns}	6.95*

Notes: *, significant at the 0.05 level; **, significant at the 0.01 level; ns, not significant. There isn't a statistical difference between the values shown with the same letter in the columns. M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct sowing.

Table 4. Some physical properties of study area soils under different tillage methods (10-20 cm)

Soil tillage method	Moisture Content (%)	Bulk density (g cm^{-3})	Porosity (%)	Penetration resistance (MPa)
M1	23.07±2.02	1.33±0.09b	51.16±2.63	0.8±0.13b
M2	22.41±1.38	1.44±0.06a	45.63±1.56	1.7±0.18a
M3	22.38±0.81	1.33±0.12b	47.10±2.26	0.8±0.43b
M4	27.46±8.55	1.51±0.10a	46.22±2.06	1.6±0.23a
F value	2.69^{ns}	7.72**	3.98^{ns}	10.10**

Notes: **, significant at the 0.01 level; ns, not significant. There isn't a statistical difference between the values shown with the same letter in the columns. M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct sowing.

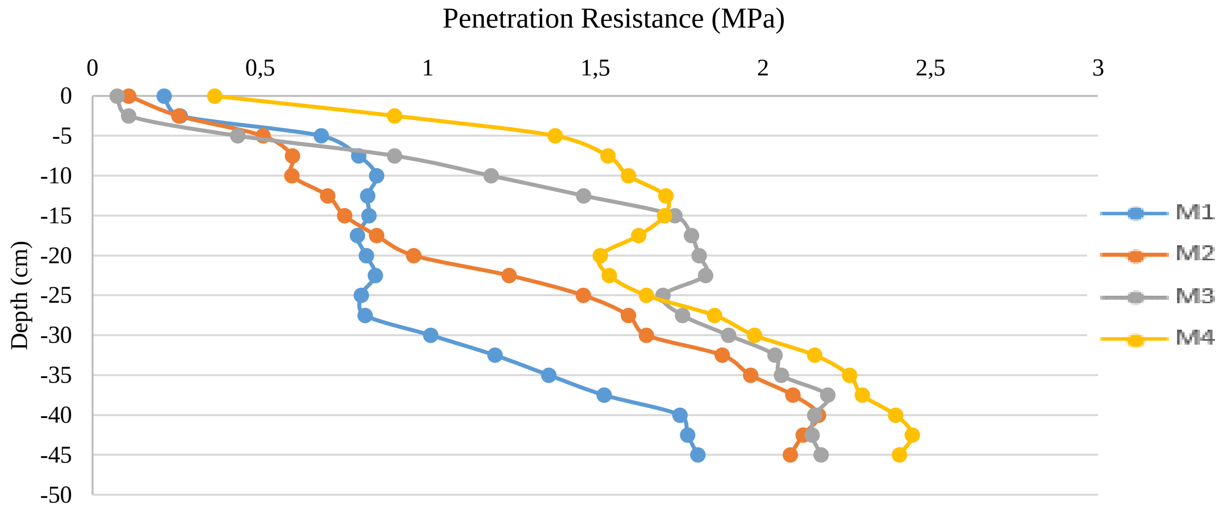

Figure 1. Variation of penetration resistance with depth (M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct sowing)

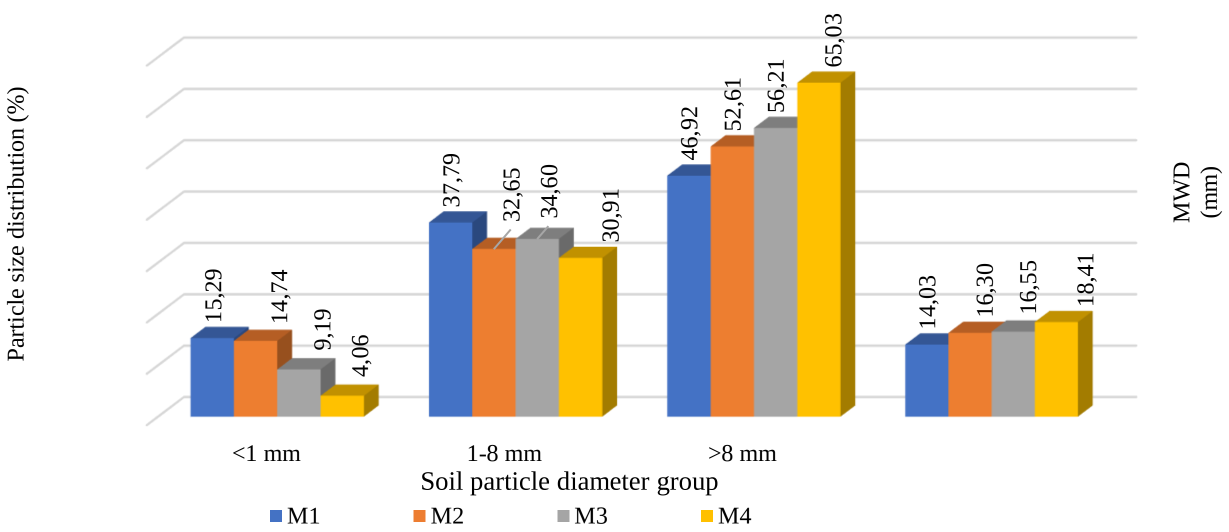

Figure 2. Soil particle size distribution (%) for 0-10 cm depth after tillage (M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct Sowing; MWD, Mean weight diameter)

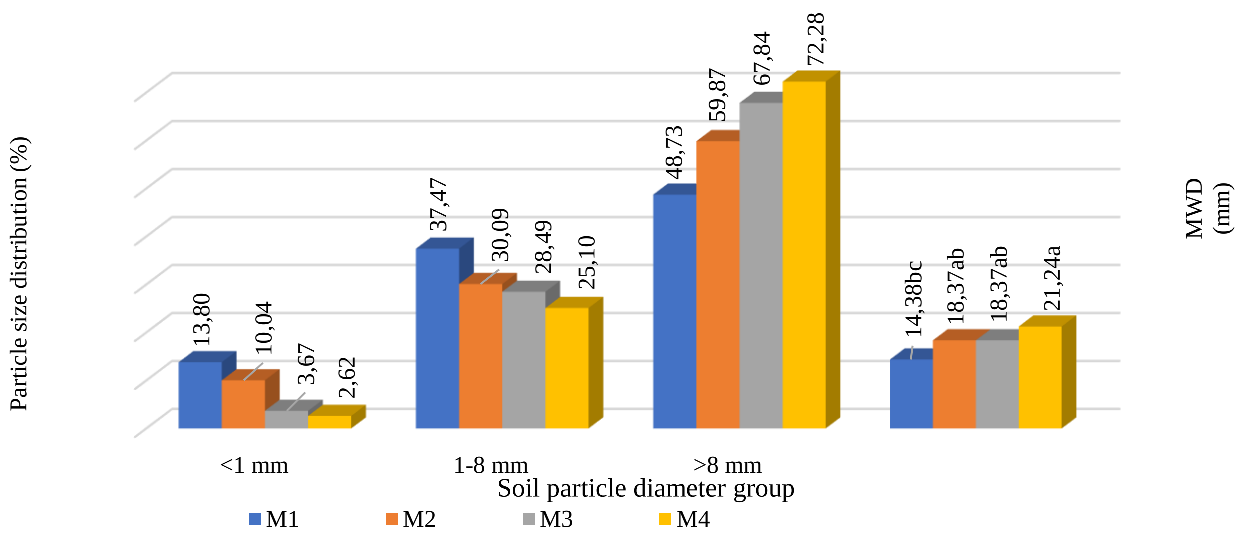

Figure 3. Soil particle size distribution (%) for 10-20 cm depth after tillage (M1: Conventional tillage, M2: Conservation tillage, M3: Reduced tillage, M4: Direct Sowing, MWD: Mean weight diameter)

The variation of soil PR with depth is given in Figure 1. When the change in PR with depth is examined, it is generally seen that the PR is lower in the M1 and higher in the M4 plots. In addition, there are no compacted layers (soil pan) in the study area, which would negatively affect plant production.

Hakansson & Lipiec (2000) stated that the limiting value of PR, which prevents root development in plants, is 3 MPa; Ehlers et al. (1983) noted that this value will vary according to the tillage method and can be used as 3.6 MPa and 5 MPa in soils where conventional tillage and direct seeding are applied, respectively. Bengough et al. (2005) accept the critical value as 2 MPa in soils without continuous root channels and cracks. However, Sa et al. (2014) reported that the limit value of 2 MPa cannot be accepted as the value limiting root development for different tillage methods and that 2 MPa should be used when the direct sowing method is applied in soils with high clay content, 3 MPa when chisel tillage is applied, and 3.5 MPa when M4 is applied (Çelik et al., 2019). The soil PR values determined in the research are generally lower than the accepted limit values for plant root development.

Gürsoy & Kolay (2012) measured the penetration resistance of the soil at 0-10 cm, 10-20 cm, and 20-30 cm depths. Researchers determined it was higher in the direct sowing method for the first two depths and in the conventional tillage method for the final depth. In the direct sowing method, Küçükalbay & Akbolat (2015) determined the maximum PR value at 0-20 cm soil depth.

The optimum seedbed is the presence of finer and pressed soil around and below the seed and coarser and unsubmerged soil above the seed (Keçecioğlu & Gülsoylu, 2002). For proper agricultural technique and successful planting, it is desired to have more soil particles with an average diameter of around 10 mm in the prepared seed bed (Gökçebay, 1986). To make a generalizing evaluation in the study, three groups, >8 mm, 1-8 mm, and <1 mm, were taken as the basis (Çelik, 1998) (Figure 2 and Figure 3). Accordingly, it was observed that particles larger than 8 mm were more and particles smaller than 1 mm were less in all soil tillage methods at depths of 0-10 cm and 10-20 cm. According to the proportion of particles<1 mm, 1-8 mm, and >8 mm at 0-10 cm depth, tillage methods were M1>M2>M3>M4, M1>M3>M2>M4 and M4>M3>M2>M1, while M1>M2>M3>M4, M1>M2>M3>M4, and M4>M3>M2>M1 for 10-20 cm depth.

While there was no statistically significant difference between the treatments at 0-10 cm depth, the difference between the treatments at 10-20 cm was statistically significant at $P<0.05$ level. MWD values ranged between 14.03 - 18.41 mm at 0-10 cm depth and between 14.38 - 21.24 mm at 10-20 cm depth. As expected, the MWD values were more significant in the plots where the M4 was applied.

To ensure proper water movement in the soil and avoid soil erosion (Hu et al., 2011), at least 50% of the soil grain size distribution must consist of particles in the range of 3.17-6.35 mm (Baver et al., 1972). Soil fragments vary depending on soil moisture content, texture, organic matter content, and the type and characteristics of the tillage tool.

The study reported that the particles suitable for plant growth were higher in the M1 method than in other methods. It is seen that this result also affects the mean-weight diameter of the soil. It was determined that the MWD values were higher in the M4 method. MWD value was found to be higher than other methods due to the higher proportion of aggregates with diameters larger than 8 mm. Kuş & Yıldırım (2017) stated that the aggregate ratio with a diameter less than 8 mm was higher in the reduced tillage method.

Effects of Tillage Methods on Surface Roughness

One of the essential parameters in seedbed preparation is surface roughness. In the analysis of variance to determine the effect of soil tillage methods on surface roughness values, the effect of tillage methods on the surface roughness of the soil was found to be statistically insignificant (Table 5).

The highest surface roughness was determined in the M4 treatment, and the lowest surface roughness was determined in the M2 treatment. When examined in terms of functional and structural properties, it was determined that the M4 treatment had the highest average values (26.44%). Kuş & Yıldırım (2017) reported that the surface roughness values determined from M1 and M3 were statistically different, and roughness rates obtained in conventional tillage were higher.

Effects of Tillage Methods on Green Grass Yield

The analysis of variance test conducted to determine the effect of tillage methods on green grass yield of silage triticale-vetch mixture showed that the effect of tillage methods on the yield was statistically insignificant (Table 6). Tillage methods are ranked as M4>M1>M2>M3 regarding green grass yield of triticale-vetch mixture for silage. Similarly, Yalçın et al. (1997) and Zeren et al. (1993) reported that the yield increased in the direct sowing method compared to other methods. Stipešević et al. (2019) found that the yield values of Sudan grass were higher in the first year in the conventional tillage method and in the second year in the reduced tillage method in which they used a disc harrow.

Table 5. Surface roughness values of study area soils under different tillage methods (%)

Soil tillage method	Surface roughness (%)
M1	24.32±7.96
M2	15.45±7.03
M3	20.08±12.23
M4	26.44±11.12
F value	1.98^{ns}

Notes: ^{ns}, not significant. M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct sowing.

Table 6. Green grass yield values under different tillage methods (kg da^{-1})

Soil tillage method	Green grass yield (kg da^{-1})
M1	2280±428.63
M2	2234±344.52
M3	2156±187.76
M4	2748±692.83
F value	2.67^{ns}

Notes: ^{ns}, not significant. M1, Conventional tillage; M2, Conservation tillage; M3, Reduced tillage; M4, Direct sowing.

Conclusion

This study evaluated soil physical properties and product yield to determine the sustainable tillage method for the region to cultivate triticale-vetch mixture for silage. Soil moisture content (MC) is critical for plant growth, and excess or insufficient water can negatively affect plant growth. Furthermore, optimum moisture content (MC) optimizes the interaction of tillage machines with the soil and prevents soil compaction. Penetration resistance (PR) indicates the effectiveness of tillage and how easily plant roots can move through the soil. Surface roughness and soil particle size are also important parameters for seedbed quality.

It was determined that the conventional tillage method was the most sustainable seedbed for plant growth. However, the effect of soil tillage methods on porosity, surface roughness, and green grass yield were statistically insignificant. The highest green grass yield was determined in the direct sowing method. Although there were statistical differences between the methods regarding bulk density, moisture content, penetration resistance, and mean weight diameter values, the values are within the limit values determined for plant growth. Although conventional tillage and seedbed preparation is one of the essential steps in plant growing processes, alternative methods have been developed in recent years within the scope of sustainable agricultural practices to protect natural resources and maintain soil health. The study results showed that the conservation tillage method is preferable to the conventional tillage method. The results obtained are essential for future generations to gain maximum benefit from agricultural soils, ensure sustainable agriculture, and minimize adverse effects on the environment. To determine sustainable soil tillage methods that can be adapted to climate change, studies should be carried out in which soil properties, crop properties, energy efficiency, management, and economic aspects of the methods are considered.

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