Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi
Journal of Agricultural Faculty of Gaziosmanpasa University
http://ziraatdergi.gop.edu.tr/

Araştırma Makalesi/*Research Article*

JAFAG
ISSN: 1300-2910
E-ISSN: 2147-8848
(2016) 33 (2), 219-232
doi:**10.13002/jafag1072**

Effects of reduced tillage and residue management on soil physical properties, organic carbon and wheat yield components in Middle Anatolia

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Alındığı tarih (Received): 23.06.2016 Kabul tarihi (Accepted): 19.08.2016
Online Baskı tarihi (Printed Online): 31.08.2016 Yazılı baskı tarihi (Printed): 26.09.2016

Abstract: The sustainability of crop production systems depends on the preservation of soil physical quality over time. This study aimed to determine the effects of conventional tillage and alternative reduced tillage on soil properties and yield components of wheat in Middle Anatolia, the importance management practices in the preservation or improvement of soil structure quality under no-tillage system. The five tillage systems investigated were: conventional tillage (CT); reduced tillage with a vertical shaft rotary tiller (RT1); reduced tillage with a horizontal shaft rotary tiller (RT2); reduced tillage with a winged chisel (RT3); and direct seeding (DS). Depending on the applications, the change in the amount of stubble on the surface was within the range 99.33–224 g m^{-2}, and the ratio of burying changed between 11.22% and 60.70% after tillage. After tillage, the minimum stubble amount remaining on the field and the maximum burying ratio (60.70%) were determined in CT. The stability index of the soil at a depth of 0–10 cm varied from 3.25 to 3.82 after the tillage and from 3.5 to 4.83 after the harvest. The highest soil stability index was obtained in the treatment of direct seeding. In direct seeding, it was established that approximately four days after tillage, soil moisture content preservation was 17.47% higher than those of the other alternative practices due to the elevated surface covering ratio of stubble. The mean content of soil organic carbon between tillage and harvesting period varied from 7.92 to 9.33 g kg^{-1} as a depending on different applications. The least mean content value of soil organic carbon was found in CT.

Keywords: crop residue (stubble), reduced tillage, soil organic carbon, stability index.

Orta Anadolu'da Buğdayın Verim Unsurlarının, Organik Karbon ve Toprağın Fiziksel Özelliklerinin Anız Yönetimi ve Azaltılmış Toprak İşlemeye Etkileri

Öz: Bitkisel üretim sistemlerinin sürdürülebilirliği toprağın fiziksel kalitesinin korunması bağlıdır. Bu çalışmanın amacı Orta Anadolu'da, geleneksel toprak işleme, alternatif azaltılmış toprak işleme yöntemlerinin buğdayın verim unsurlarına ve toprağın özelliklerine olan etkilerinin belirlenmesidir. Çalışmada beş farklı toprak işleme yöntemi kullanılmıştır, bunlar; geleneksel toprak işleme (CT); dikey milli (RT1) azaltılmış toprak işleme; yatay milli (RT2) azaltılmış toprak işleme; kanatlı çizelli (RT3) azaltılmış toprak işleme ve doğrudan ekimdir (DS). Uygulamalara bağlı olarak toprak işleme sonrası, yüzey üzerinde anız miktarındaki değişim aralığı 99,33-224 gr m-2 ve anız gömme oranı % 11,22 ve % 60,70 arasında değişim göstermiştir. Toprak işleme sonrası, tarla yüzeyinde minimum anız miktarı kalıntısı ve maksimum gömme oranı (60.70%) geleneksel toprak işleme (CT) uygulamasından elde edilmiştir. 0-10 cm derinlikte toprak stabilite indeksi toprak işleme sonrası 3.25 ile 3.82, hasat sonrası ise 3.5 ile 4.83 arasında değişim göstermiştir. En yüksek toprak stabilite endeksi doğrudan ekim uygulamasından elde edilmiştir. Doğrudan ekim uygulamasının toprak nem içeriği koruması diğer alternatif uygulamalardan % 17.47 daha yüksek olduğu tespit edilmiştir. Ortalama toprak organik karbon içeriği toprak işleme ve hasat dönemi arasındaki 7.92 ile 9.33 kg-1 arasında farklı bir uygulamalara bağlı olarak değişim göstermiştir. En düşük ortalama toprak organik karbon içeriği geleneksel toprak işleme (CT) uygulamasından elde edilmiştir.

Anahtar Kelimeler: Anız, azaltılmış toprak işleme, toprak organik karbon, stabilite indeksi

1. Introduction

Middle Anatolia is one of the largest agricultural regions in Turkey and has 7.26 million ha of agricultural land. Dry farming plays an important role in agriculture in Turkey. Middle Anatolia hosts a large dryland region that accounts for approximately 30.3% of the nation's total cultivated area and approximately 32.5% of the cereal production. In this area, conventional soil management practices include intensive soil cultivation, low manure input, crop residue removal and burning (TUIK, 2015). These practices promote the loss of soil, nutrients, and water, and contribute to the decrease in soil organic matter content and worsen the soil physical structure.

Residue coverage prevents moisture by reducing evapotranspiration, contributes to retaining higher soil water content and soil structural stability, and provides more effective prevention of soil erosion (Romaneckas et al., 2013) and higher economic efficiency (Sarauskis et al., 2013).

Conservation tillage methods such as no tillage and reduced tillage have become more prevalent for many reasons. For example, conservation tillage protects the soil from water and wind erosions (Morris et al., 2010), improves the physical (Martinez et al., 2008), chemical (Guzman et al., 2006) and biological properties of soil (Fernandez et al., 2010). At the same time, conservation tillage saves time in preparing seed bed, conserves the soil moisture (Verch et al., 2009) and reduces the cost of production (Uzun et al., 2012).

Crop residues are an important component of soil health. There are many benefits from leaving standing stubble in the field, including snow trapping, minimizing water and wind erosion, and returning valuable nutrients to the soil.

Stubble management practices are directed at modifying crop stubble levels to reduce clumping problems at seeding. Stubble management begins at harvest by setting the cutting height of the header and the spread pattern of the stubbles, which enables the seeding bar to get through the stubble. However, farmers often minimize the management of stubbles at harvest due to the higher cost of running the header and the reduced speed of harvest. In these situations, post-harvest management options to diminish stubble levels are necessary. Stubble height affects sowing depth and uniformity (Bahrani et al., 2007). Long stubble leads to a decrease in sowing depth and sowing uniformity and hampers the further even distribution of seeds in the environment.

Seeding bar design and set-up can both lead to reduced clumping and blockages at seeding. Stubble retention protects soil from erosion and facilitates soil moisture storage through better infiltration, reduced surface run-off, and lower evaporation rates. The ground cover provided by stubble may also help maintain soil structure by increasing soil microbial activity. Despite the benefits, large stubble loads can present challenges, blocking machinery at sowing. Careful planning and selecting of the right machinery can solve these issues, but burning is also an option.

To determine the value of ground cover for wind erosion control, the percentage of the covered ground is to be assessed by visual inspection and judgment from a position that is directly above the space evaluated. In the application of conservation tillage techniques, the percentage of the critical ground cover is 30% in standing stubble (30–60 cm high) and 50–60% for prostrate stubble. Retained stubble improves water infiltration and increases soil moisture retention, particularly in the soil surface layer during pre-sowing and early crop development (Scott et al., 2010).

Marakoglu and Çarman (2015) reported that stubble burying ratios were found to be 2.37 – 17.59% lower in reduced tillage treatments when compared to the conventional treatment. Different tillage treatments had a significant impact on the burying ratio. The mount of stubble in the field was found to decrease CO_2 emission.

Karadaş et al., (2011) reported that vetch–fallow–wheat rotation system under organic agriculture in Erzurum province was the most profitable among the rotation systems of fallow–wheat, wheat–wheat and vetch–fallow–wheat. Also, this rotation system increased the soil organic matter content. Conventional tillage increases the CO_2 in the atmosphere by promoting the loss of soil organic matter, while instead of conventional tillage, conservation tillage increases soil organic matter with the passage of time and available water content and soil aggregation. Wilson and Al-Kaisi (2010) reported 23% less emission of CO_2 from the soil fertilized with 270 kg N/ha as compared to the soils fertilized with 0 and 135 kg N/ha in a continuous corn and a corn-soybean rotation.

Ernst and Emmerling (2009) found that soil organic carbon was increased by about 10 to 24% in the topsoil under conservation tillage compared to conventional tillage. But, conventional tillage had higher soil organic carbon at deeper levels. Küstermann et al. (2013) conducted a long-term study in southern Germany. There was a change in soil organic carbon of 258 to 290 kg ha^{-1} at 8 cm soil depth with conservation tillage which was more than 10 times higher at 18 cm soil depth. The same trend was noted with soil organic nitrogen. Lowering the depth of soil loosening and mixing, soil organic carbon content was higher in the soil close to the surface. Soil organic carbon content decreased with increasing soil depth. Ulrich et al. (2010) brought forth findings from a very long study (1965 to 2001) which also supports the results from the above-mentioned studies. They highlighted that C and N content changed in the topsoil with different tillage systems. The vertical distribution of soil organic carbon and total N content in topsoil were 23 to 36% and 14 to 29% respectively higher under conservation tillage management as compared to conventional tillage management.

Yield associated with various methods of tillage has been studied by many researchers. Karlen and Gooden (1987) reported that, chisel plowing compared to the moldboard plowing leads to significantly higher yield quantities. In the case of chisel plowing, because of preservation of soil moisture and improvement of soil physical properties compared to other tillage methods, highest levels of grain yield was reported (that is 1841.9 kg ha^{-1}). Abdipur et al. (2012) investigated the effects on wheat yield under rainfed conditions of different tillage systems. Chisel plow + disc harrow treatment compared with other tillage treatments, especially conventional tillage with save soil moisture and prevent to high impact of moisture and heat stress on wheat at the end of the production season has led to yield stability. These results are conform with those reported by Çarman (1997), Tabatabaeefar et al. (2009) and Moreno et al. (1997) reports.

Management practices decreasing soil disturbance are widely adopted to reduce farming costs, nutrient leaching and soil erosion as well as to improve soil quality and conserve water (Yang et al., 2013). No tillage or reduced tillage have the potential to conserve soil organic carbon by reducing mineralization (Abdalla et al., 2013) and enhancing soil aggregation. However, not all of the observed differences in the soil organic carbon content can be directly addressed to management effects. Differences in the stratification of carbon in the soil profile, soil compaction, yield levels, and erosion, for example, may also contribute to the measured changes (Yang et al., 2013).

Tillage is assumed to have a major influence on soil carbon emissions. Tillage-induced soil carbon loss has been shown to be important especially in the short-term periods. There are many reports in support of the finding that soil tillage accelerates organic carbon oxidation, resulting in the release of high amounts of CO_2 into the atmosphere only in a few weeks (La Scala et al., 2006; 2008).

Conservation tillage facilitates the retention of more plant residues on the soil surface and leads to increased contents of near-surface soil carbon in comparison with conventional tillage. This is especially valid in cool and humid climate conditions, in which, due to the reduced soil-residue contact, the decomposition of plant residues after conservation tillage is slower than that of the residues that are completely incorporated by conventional tillage (Drury et al., 2006).

By enhancing carbon sequestration, soil CO_2 emissions can be decreased. Cultivation practices can stimulate the biodegradation of the initially physically protected carbon in soil, and hence it could be responsible for the decrease of soil organic carbon levels. Conservation tillage systems promote the retention of greater amounts of crop residues on the soil surface leading to a soil organic carbon concentration in the surface layer that is higher than that in conventional tillage (Hutchinson et al., 2007).

The degradation of land (agricultural, pasture, and forest) has accelerated in Middle Anatolia reaching 83% of the total land, which is evident from the increased soil erosion, occurrence of more frequent floods and landslides, significantly declining groundwater tables, and the drying out of wetlands. By reducing the productivity of arable lands and pastures, this process poses high risks for agricultural production in the area of Middle Anatolia. In addition, reduced vegetative cover has led to marked reductions in soil moisture content, subjecting agricultural lands to significantly higher vulnerability to drought. This negative outcome has been evidenced by the decreased underground water table, increased salinization in arable lands, and the most frequent appearance of sinkholes. In recent years, the number and magnitude of wind erosion and dust storms in the region have increased considerably due to degradation of pastures and inappropriate agricultural practices in arid conditions.

Therefore, by conducting this study, we aimed to quantify the effects of the components of conservation agriculture on soil quality and crop yields. More specifically, the objectives were: 1) to determine the single and interactive effects of tillage and residue management on soil physical properties and soil organic carbon, 2) to determine the single and interactive effects of tillage and residue management on crop yields.

2. Methodology

The experiments were conducted in the field of Soil, Water and Combating Desertification Research Station during the period 2013–2014. The station is situated 10 km away from Konya Province, which is located in the Middle Anatolia region of Turkey. Some soil properties are presented in Table 1, and the seasonal weather data at the experimental station are given in Table 2.

The tillage methods are given as follows: CT – the conventional method: plough + cultivator – float (2 times), RT1 – vertical shaft rotary tiller-roller, RT2 – horizontal shaft rotary tiller (L type) – roller, RT3 – winged chisel-roller, DS – direct seeding.

The specifications of the equipment's used in the experiment are listed in Table 3. New Holland TD90 tractor was utilized in the trials. In determination of paces, measurements were made with John Deere branded speed measuring radar.

Soil moisture was determined by a TDR (time-domain reflectometer) device and calibrated via the gravimetric method. Measurements were made in each parcel, before and after tillage, in 0–15 cm-depths with 10 recurrences at the 2nd, 12th, 24th, 48th and 96th hours after tillage to monitor soil moisture changes depending on the different tillage practices applied. A soil penetrometer, with a cone angle of 30° and a cone diameter of 12.83 mm, was used to determine soil penetration resistance. It was pushed by hand into the soil to a depth of 20 cm, and the resistance for each 1 cm depth interval was recorded (Marakoglu and Çarman, 2015). The soil shear testing device was used in order to determine the soil shearing strength which has a 10 cm diameter (d) and 12 cm height (h). Torque arm having a measuring range of 0-80 Nm was impaled on shear vane.

Table 1. Some physical and mechanical properties of the soil in the experiment field

Sand (%)	36.88
Clay (%)	42.94
Silt (%)	20.18
Bulk density (g cm^{-3}) (0–20 cm)	1.18
Moisture content (%) (0–20 cm)	15.90
pH	8.20
EC (micromos cm^{-1})	0.67
Organic matter (%)	1.21

Table 2. Summary of long-term and seasonal weather data at the experimental station

Weather parameters	Seasons			
	autumn	winter	spring	summer
Long-term (64 years) average precipitation (mm)	74.5	105.9	103.1	36.2
Minimum air temperature (°C)	0.8	-3.9	0	12.8
Maximum air temperature (°C)	26	7.1	22.3	30.2
Average air temperature (°C)	12.3	1.03	10.8	22.3
Average relative humidity (%)	59.6	75.4	59.4	44.5
Average wind speed (km h^{-1})	6.6	7.32	8.6	9.5
Sampling season average precipitation (mm)	38.4	116.6	72.4	68
Minimum air temperature (°C)	8	−2.2	7.6	19.5
Maximum air temperature (°C)	17.5	3.8	15.4	24.9
Average air temperature (°C)	12	1.4	11.8	23.1
Average relative humidity (%)	48.7	74.8	53.5	38
Average wind speed (km h^{-1})	7.9	4.7	7.56	10.7

Table 3. The specifications of the tools used in experiment

Tool	Average speed (km h^{-1})	Working depth (cm)	Working width (m)
Plough	5.5	22	1.20
Cultivator-float combination	7.0	12	2.10
Vertical shaft rotary tiller – roller combination	3.2	18	2.30
Horizontal shaft rotary tiller (L type) – roller combination	2.6	13	2.60
Winged chisel – roller combination	2.9	23	2.30
Seeding machine	6.5	4	1.68
Direct seeding machine	5.5	4	1.68

The maximum torque was obtained via soil shear testing device as shearing strength (t) was obtained by the following equation (Ekinci and Carman, 2015):

$$\tau = T / [\pi d2 (h/2 + d/6)] \qquad (1),$$

where: τ – cutting resistance of soil (N cm^{-2}), T – maximum turning moment (Ncm), d – diameter of paddle switch (cm), h – wing height (cm).

To determine the soil stability index (SI), soil samples taken from a depth layer of 0–15 cm in each application plot were brought to the laboratory and dried at room temperature. Then, soil fractions were obtained by rotary sifting by a set of sieves with pore sizes of 0.42, 0.84, 2.0, 6.4 and 12.7 mm that were interwoven cylindrically, and the percentages of the soil fractions were estimated based on their general weight as described earlier (Demiryürek et al., 2007):

$$SI = \frac{A}{B} \qquad (2),$$

where A – percentage of nonabrasive dry aggregates larger than 0.84 mm, B – percentage of abrasive dry aggregates smaller than 0.84 mm.

Surface relief was measured using a surface profilometer consisting of a set of vertical rods, spaced at 2.5 cm intervals, sliding through an iron bar of 100 cm in length. The surface roughness was calculated by using the equation reported (Ekinci and Carman, 2015):

$$R = 100 Log_{10} S \qquad (3),$$

where R – surface roughness (%), S – standard deviation.

Soil organic carbon was determined on sample ground to pass through a 0.5mm sieve by the using the TruSpec CN Carbon/Nitrogen determinator (LECO Corporation 2006). Measurements were made before soil tillage, and then they were conducted monthly until harvest.

To determine the amount of stubble, 1 m^{-2} frames were successively thrown onto the space of each experimental parcel before tillage, and the stubble in the frames from ground level was collected and its weight measured. The amount of stubble was determined as (g m^{-2}) by weighing with three recurrences in the parcel with each of the treatments. The surface covering ratio of stubble was established by taking images with a digital camera (13 mega pixels). The images obtained were saved in image format in a computer environment. The MATLAB program was used to digitize the stubble surface covering ratio. The intensity of stubble was determined by the images in JPG format in MATLAB program (Korucu and Yurdagül, 2013).

Seed and biomass yields were measured with three replications in the plots of 100 m long and 6 m wide. Yields were measured through samples taken from 3.5 m^2 areas at harvesting time.

The data were analyzed using statistical software *MSTAT* for analysis of variance. LSD test was utilized to compare the means of the values obtained in this research.

3. Results and Discussion

The operating specifications of the machines employed in the different practices are given in Table 3. Similar working depths at conventional tillage and winged chisel applications were obtained. A minimum working depth was achieved by the use of the horizontal shafted rotary tiller and roller combination. Some physic-mechanical features of the soil after tillage practices and stubble burying ratio of are given in Figures 1–7.

Penetration resistance

The effects of different tillage applications on penetration resistance are presented in Figure 1.

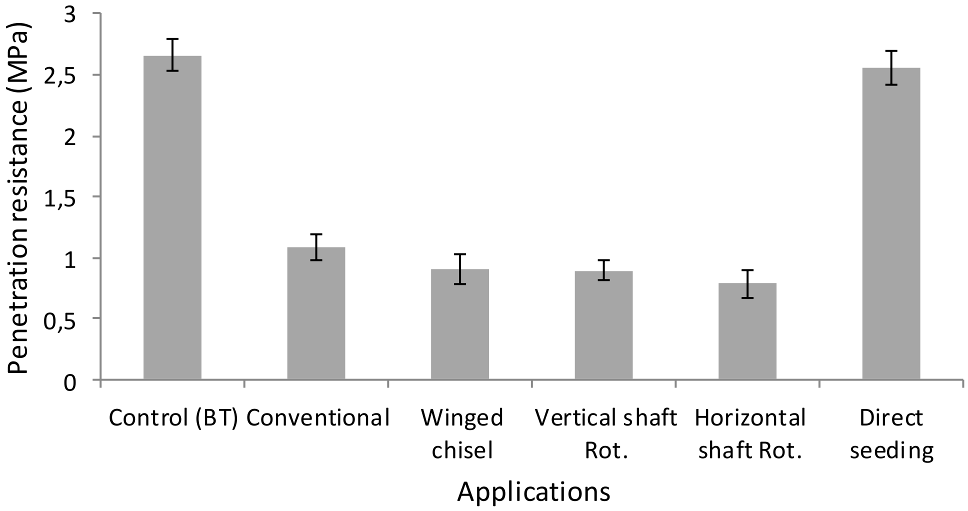

Figure 1. The effects of different tillage applications on penetration resistance

Soil penetration resistance values varied in the range 0.79–2.56 MPa as depending on the specific tillage practice performed. Soil penetration resistance changed most pronouncedly in the horizontal shaft rotary tiller with a decrease of 70.3%. The differences among the effects of the different applications on soil penetration resistance were statistically significant ($P < 0.01$).

The effects of tillage practices on soil physical properties vary dramatically according to the type of tillage. A soil penetration resistance is one of the basic soil properties affected by tillage practices (Badalíkova, 2010). Generally, higher soil penetration resistances values were obtained in no tillage treatments compared to other conservation or more conventional tillage systems (Aikins and Afuakwa, 2012).

Soil the shear stress

The details of the impact exerted by the specific machines on the shear stress of soil are given in Figure 2.

Depending on the different tillage practices implemented, soil the shear stress values were in the range 0.34–2.01 N cm^{-2}. The maximum change in this indicator, a decrease of 83.3% was obtained when the soil was cultivated with the vertical shafted rotary tiller. The differences between the effects of the different applications on the shear stress of soil were significant ($P < 0.01$).

Soil surface roughness

In the different tillage treatments, the values of soil surface roughness varied between 11% and 29% (Fig. 3). While the maximum value of the surface roughness of soil (29%) was obtained in the variant with winged chisel plowing, the minimum value of this parameter was established in the direct seeding treatment (11%). The different applications had statistically significant variations in their impact on soil surface roughness ($P < 0.01$).

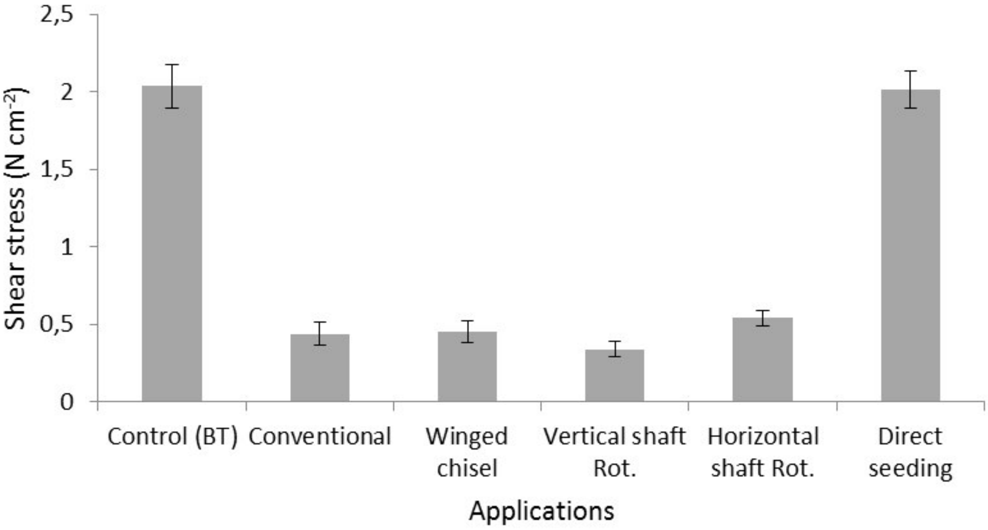

Figure 2. The effects of machines on shear stress of soil

The amount of stubble

The influence of machines on the amount of stubble remaining on the field after tillage and the rates of stubble incorporation in the soil are depicted in Figure 4. Depending on the practices, the amount of stubble after tillage was in the range 99.3–224 g m^{-2}, and stubble burying rates were between 11.2% and 60.7%. The application of conventional tillage resulted in the lowest amount of stubble on field surface after tillage, accounting for a decrease of 60.7% and a burying rate of 60.7%. The differences among the effects of the different applications on the burying rate of stubble in soil were significant ($P < 0.01$).

Surface covering rates of stubble

Surface covering rates of stubble remaining after tillage changed from 4.85% to 50.73% (Fig. 5). The maximum covering ratio (50.73%) was obtained from direct seeding with an increase of 1.38% in comparison to the control plot. The variations in the effects on surface covering ratio of stubble after tillage were significant ($P < 0.01$).

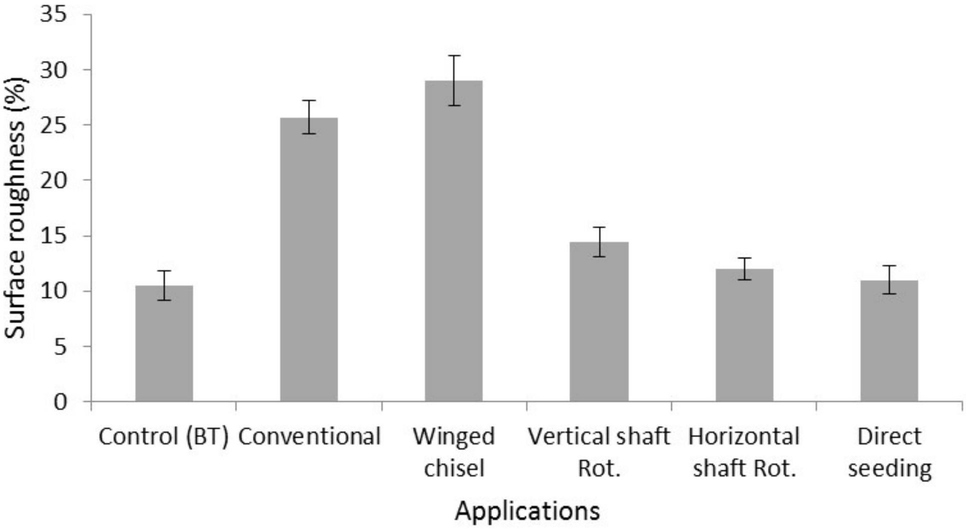

Figure 3. The effects of different tillage organs on surface roughness of soil

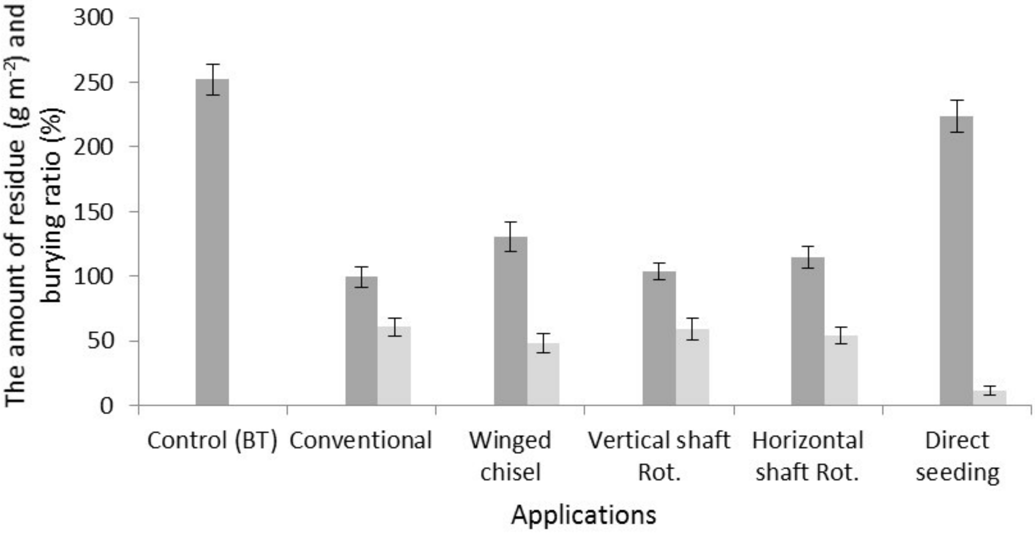

Figure 4. The amount of residue burying ratio

The influence of the use of a vertical and horizontal shafted rotary tiller on stubble covering ratio was similar. The stubble covering ratio obtained in the winged chisel and direct seeding treatments were above the acceptable limit values (at least 30% of the soil surface is to be covered with residues after tillage) when evaluated as conservation tillage applications.

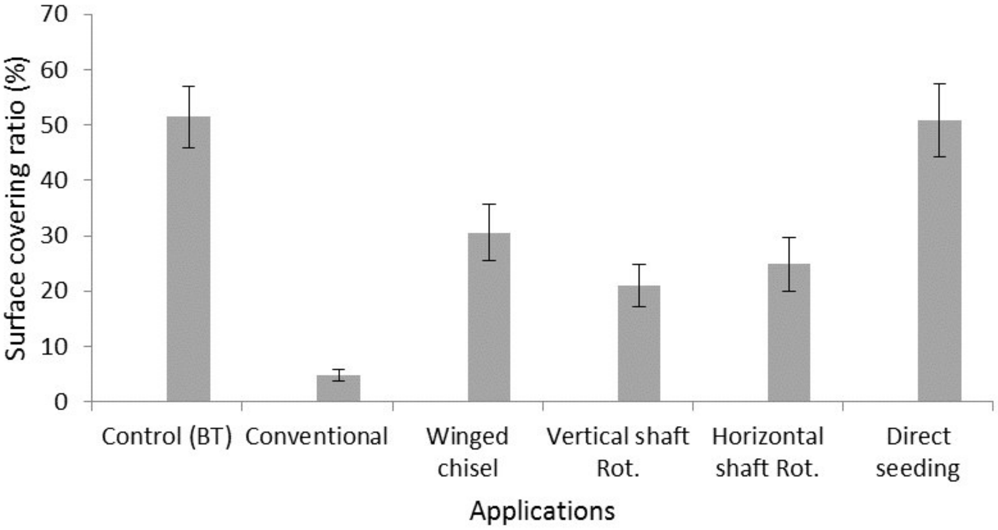

Figure 5. Surface covering ratio

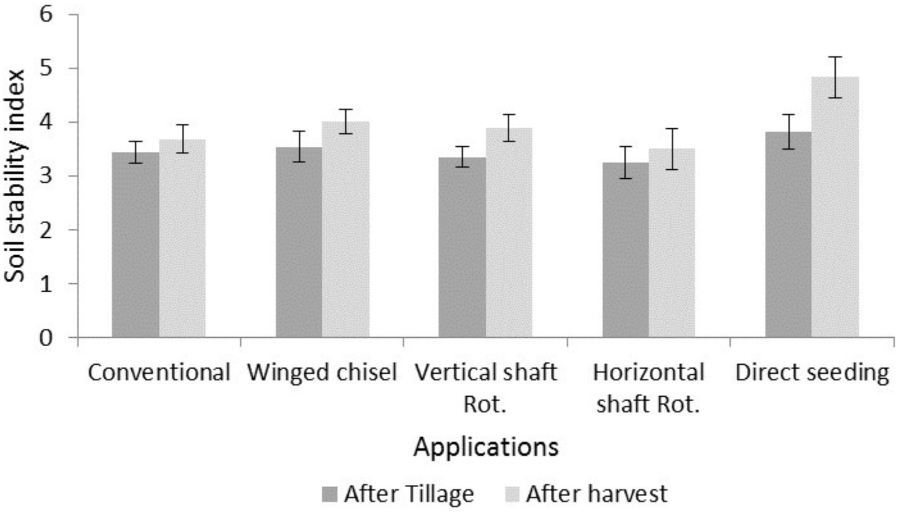

Figure 6. Soil stability index

Stability index

Stability index values of soils showing erosion characteristics or resistance against erosion varied from 3.25 to 4.83 depending on the applications (Fig. 6). Average stability index of the applications following soil tillage was 3.48; it increased by 14.4% following harvest and became 3.98. The greatest stability index values after both soil tillage and harvest were obtained in the direct seeding application. The greatest change in the stability index (31.3%) after soil tillage was obtained in the rotations with a horizontal shaft. The fact that the stability index values of the topsoil in all applications was more than the limit value 1.5 illustrates that these soils are resistant to erosion (Demiryürek et al., 2007). The effect of the applications on the stability index of soil was found to be significant ($P < 0.01$).

Moisture content

The effect of the treatments on moisture content exchange of the soil was dependent on the time that passed after tillage (Fig. 7). Depending on the practices, the mean moisture content values of the soil at the 96th hour varied between 10.9% and 13.1%. A nonlinear relationship between the time passing after tillage and soil moisture content for the five different applications was determined. The variation in soil moisture content (Y) over time after tillage can be represented by the following equation:

$$Y = 14.664e^{-0.002x} \qquad (R^2 = 0.99).$$

The maximum change in soil moisture content after tillage was obtained when a vertical shafted rotary tiller was utilized (a decrease of 25.6%), and minimum change was established in the direct seeding treatment (a decrease of 13.8%). At the 96th hour after tillage, approximately 17.47% more pronounced moisture preservation was detected in the direct seeding when covering ratio of stubble after tillage (50.73%) in this treatment indicates that it preserves soil moisture better than the other. The effect of the applications on the change of moisture content of soil was significant ($P < 0.01$).

The aim of tillage practices is to create comfortable seedbed and growth conditions for crops. In semi-arid regions, the conservation of soil water content is of vital importance for seed germination. The no tillage treatment could decrease evaporation due to higher surface residue. Therefore, water conserve in the no tillage plots increased (Gözubuyuk et al., 2013). Fernández-Ugalde et al., (2009) found that the water content was higher at with no tillage than the conventional tillage treatment in the top soil depth of 30 cm. Also, Czyż and Dexter (2008) observed that the reduced tillage provided higher water content compared to the traditional tillage treatment.

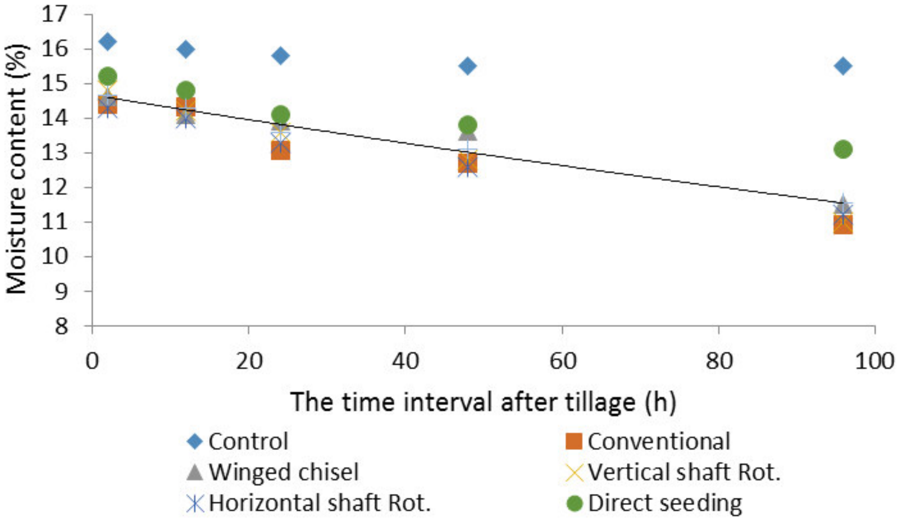

Figure 7. The effect of the treatments to moisture content exchange of soil

Soil organic carbon

The mean content of soil organic carbon was 7.92 g kg^{-1} in the tillage period and 9.33 g kg^{-1} in the harvesting period (Fig. 8). After harvesting, the mean content of soil organic carbon in the 0–15 cm layer under the DS application was 4.2% higher than that under the RT3 application, 13.6% higher than that under the RT1 application, 13.7% higher than that under the RT2 application, and 17.8% higher than that under the CT application.

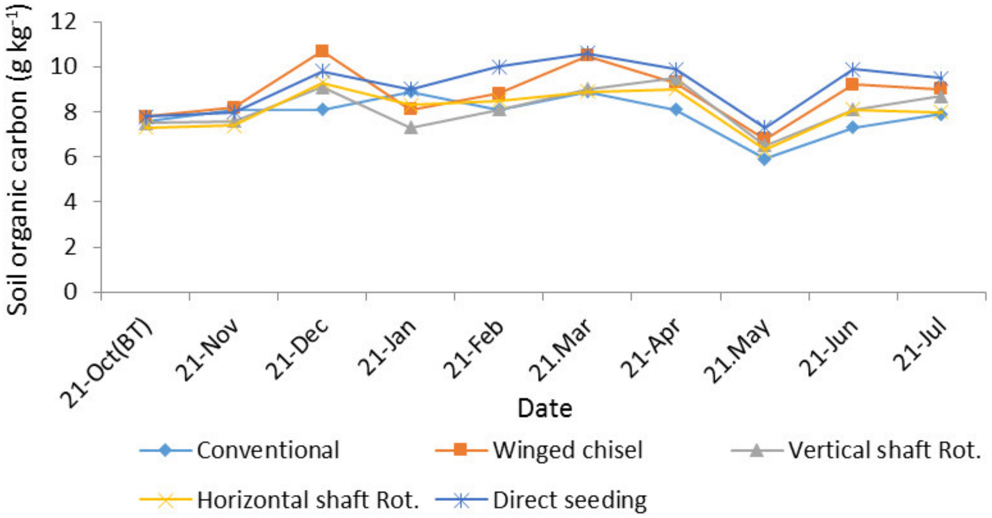

Figure 8. Soil organic carbon

No tillage (direct seeding) with or without crop residues increases soil organic carbon, limits soil disturbance, and enhances soil aggregation. The least soil organic carbon content (7.92 g kg^{-1}) was found in the CT application that was characterized by the least residue covering ratio (4.85%), soil penetration resistance and shear stress. The low values of soil bulk density indicate higher soil air-filled porosity and Russ et al. (2007) assumed that the greater air-filled porosity may be the reason for the greater flux of CO_2 immediately after plough tillage in the field without cover in comparison with that in the residue-covered field.

Seed and biomass yield

The different tillage practices significantly affected the yield of wheat. The direct seeding treatment had the greatest yield, which was significantly higher than that of the reduced tillage and conventional treatments. Wheat seed yield in the treatment with the horizontal shafted rotary tiller was approximately 2410 kg ha^{-1}, which was 21.2% lower than the yield established in the direct seeding variant. Moreover, the yield of biomass in the direct seeding treatment was higher than that of the reduced tillage and conventional practices. The results of the present study indicate that the zero tillage (direct seeding) significantly promoted the seed yield of wheat (Fig. 9).

In similar research, field experiments were conducted by Carman (1997) on clay soil entisol to determine the effect of different tillage on the wheat yield in Middle Anatolia. He reported that tillage systems had a significant effect on wheat yield. The greatest yield was obtained with a stubble cultivator, followed by disc harrowing treatment. Lyon et al. (1998) found an 8.0% greater winter wheat yield with conventional tillage than with no-till. Moreno et al. (1997) reported higher winter wheat yield under conservation than traditional tillage, but differences were not significant.

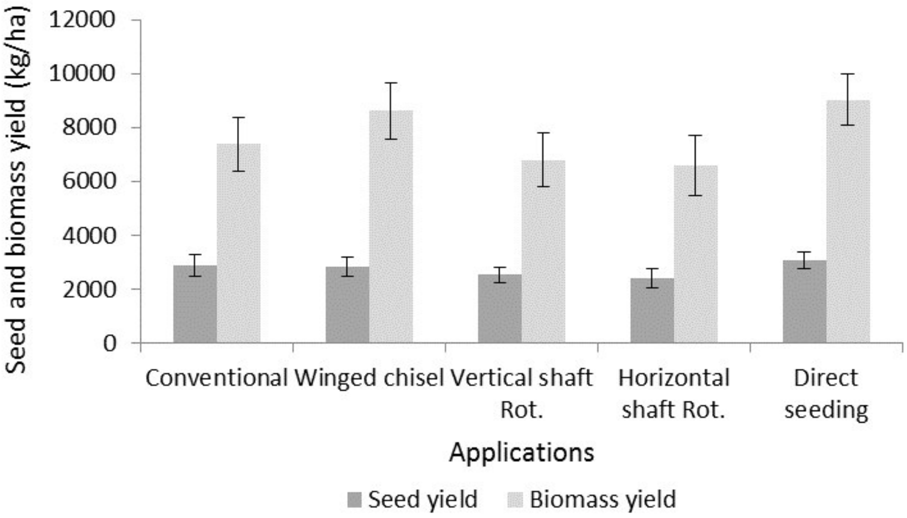

Figure 9. Seed and biomass yield.

4. Conclusions

1. There are statistically significant differences in the effects exerted by the various tillage treatments on soil properties, such as penetration resistance, shear stress, and surface roughness.

2. The machines used for tillage exert an important effect on the amount of stubble remaining on the field and the rate of stubble incorporation in the soil.

3. The application of conventional tillage methods leads to the remaining of minimum amounts stubble on the field and a maximum residue burying ratio after tillage.

4. While the surface covering ratio of stubble after tillage varied between 4.85% and 50.73%, the maximum surface covering ratio (50.73%) was obtained in the direct seeding treatment: a decrease of 1.38% compared to the control plot.

5. The practice of direct seeding approximately four days after tillage, contributes to soil moisture preservation that is 17.47% higher than that obtained when other alternative practices are implemented.

6. Soil moisture protection and surface covering ratio of stubble (the limit was above 30%) of direct seeding (DS) and winged chisel-roller (RT3) applications are higher than those of the other practices. Therefore, both treatments are more appropriate soil tillage techniques for the region of investigation.

7. Wheat seed yield in the direct seeding application (approximately 3060 kg ha^{-1}) is greater than the yield in the conservation tillage practice by 5.9%.

8. Tillage practices can stimulate the biodegradation of the initially physically protected carbon in soil, and hence they could be responsible for the decrease of soil organic carbon. Agricultural soils can achieve their maximum capacity as a carbon source if improved residue management and reduced tillage systems are adopted.

Acknowledgements

This project was supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK, project code: 111 O 182).

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