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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

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ABSTRACT
Effects of different cover crops on soil quality parameters and yield of an apple orchard located in Develi town of Kayseri province of Turkey were investigated in this study. *Trifolium repens* L. (TR), *Festuca rubra* subsp. *rubra* (FRR), *Festuca arundinacea* (FA), *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture (TFF), *Vicia villosa* (VV) and *Trifolium meneghinianum* (TM) were used as the cover crops in an apple orchard with sandy loam soil. Experiments also included plots mechanically cultivated (MC), herbicide treatment (HC) and control (C) plot without cover crops. Soil samples were taken from two different depths (0-20 and 20-40 cm) in each plot. Experiments were conducted in randomized complete blocks design with four replications. The cover crop treatments improved soil quality parameters like organic matter (OM), basal soil respiration, bulk density (BD), aggregate stability, saturated hydraulic conductivity (Ks), available water capacity compared to the soil of a nontreated control plot. Mean OM contents at 0-20 cm soil depth was ordered as; HC (0.56%)<C (0.62%)<MC (0.67%)<FRR (1.03%)<TM (1.06%)<TFF (1.09%)<FA (1.10%)<VV (1.34%)<TR (1.36%). The highest cover crop dry biomass mean was found in TFF treatment (45.5 ton ha^{-1}), and the lowest was found in TM treatment (2.6 ton ha^{-1}) in the apple orchard. While the highest mean apple yield was obtained from VV (23.9 ton ha^{-1}) and TR (23.8 ton ha^{-1}) treatments, the lowest mean apple yield (13.7 ton ha^{-1}) was obtained from MC treatment. It was concluded based on the obtained findings that cover crops, especially *Trifolium repens* and *Vicia villosa* could be incorporated into cropping systems to improve soil quality and apple yield.

Keywords: Cover crops; Organic matter; Sandy loam soil; Soil quality; Available water capacity; Yield

1. Introduction

Apple is a product of economic importance in Turkey and the World as whole. Apple production in the world was realized in 4.9 million ha area according to FAO statistics. The apple production in the world was 83.1 million tones in the same year. The most important share in production belongs to China (49.8%), USA (6.2%), Turkey (3.6%), and India (2.7%), respectively. Turkey comes thirth in terms of apple production with 3.6% of the world total production (FAOSTAT 2017). Apple growing areas are generally concentrated in the regions of Niğde-Nevşehir-Kayseri, Amasya-Tokat, Bursa-Yalova-Çanakkale, Antalya and Isparta-Burdur in Turkey (Gül & Erkan 2001). Apples can be grown in almost all parts of the Turkey and apple production constitutes 9% of total fruit areas and 20% of total fruit production. 2.82% of the total apple production of Turkey is supplied from Kayseri province. In the province of Kayseri, approximately 69 938 tons of apple are produced 6088 ha in each year (TURKSTAT 2018). Many soils in Turkish apple orchards are low in organic matter and nutrients, resulting in poor soil structure and nutrient deficiencies in the fruit trees (Zengin et al 2016). This situation

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negatively affects the growth of apple trees, which is detrimental to the yield and the quality of the fruit. The use of cover crops as a source of organic matter and nutrients may be potential solution to these problems. Cover crops have been used to improve soil aquality and reduce nonpoint sources of nutrient pollution, e.g., NO_3 (Daliparthy et al 1994). Therefore, it is significant from both an environmental and economic standpoint to indicate how cover crop systems effect soil organic matter characteristics and the biogeochemical cycling of carbon. Legume and grass species are the most significant annual and perennial forage crops in Turkey and are preferred by farms because of providing sufficient plant cover and improving the percentage of organic matter (Nyakatawa et al 2001). Soil-structure improvements associated with legume based rotations also increase the drought tolerance of soils and moisture-holding capacity (Goldstein 1989).

The ability of soils to provide optimum conditions for plant development and growth is defined as soil fertility or soil quality. Soil quality is expressed in several physicals, chemical and biological attributes such as organic matter content, bulk density, salinity, microbial activity, nutritional composition etc. (Stott et al 2010). Long-term soil fertility in conventional and organic farming can be achieved only with sustainable practices (Price & Norsworthy 2013). Farming systems should generally take effects of agricultural practices on the environment and human health into consideration. Excessive synthetic fertilizers applied in conventional farming may exert serious risks both on soils and environment (Stolze et al 2000). Cover crops can decrease the use of external inputs such as fertilizers and can improve and maintain soil fertility.

Establishing cover crops also has an important effect on improving soil chemical, physical and biological properties and hence on increasing the yields of successive row crops (Fageria et al 2005). Plant residues or cover crop species are commonly used to improve organic carbon contents and soil quality (Demir & Gülser 2015). Crude protein production largely depends on dry matter yield and crude protein concentrations vary with the plant species (Albayrak et al 2008). Leguminous crops are quite rich in nitrogen and can fix atmospheric nitrogen into the soils. In this way, they reduce or replace synthetic fertilizers used for nitrogen supply in conventional farming (Gselman & Kramberger 2008).

Recent environmental and ecological awareness has started a resurgence in cover crop use in Turkey. Although cover crops have been used for centuries, today's modern farmer has grown up in a generation which has replaced the use of cover crops with widespread use of fertilizers and herbicides. Cover crops have an important role in successful sustainable farming systems. Cover crops control soil erosion, improve soil quality and fertility, suppress weeds and provide insect control (Sarrantonio 2007). At the same time cover crops are suitable implements for weed control in orchards (Mennan et al 2009; Işık et al 2009). Using cover crops for weed control in apple orchards is one of the broadly applied alternative methods to the mechanically cultivated and herbicide treatment. Herbicide application and mechanical cultivation treatment are important among the current weed control practices in apple farming. Herbicide and mechanical cultivation treatment are expected to provide weed-free apple fields. However, coverless (bare) apple fields may bring about increased erosion and run-off, reduced organic matter and moisture contents, and damage the soil chemical and physical properties (Keesstra et al 2016). In addition, a few other problems are also associated with the use of herbicides for weed control in apple fields. Evolution of herbicide resistance in weeds and environmental pollution are the most important among these (Annett et al 2014). In addition, the effects of herbicide and mechanical control applications used in weed control on soil quality are not known.

Agricultural lands of Turkey are particularly prone to erosion after the crop harvests in August until the re-establishment of soil cover in November. Severe rainstorms in these months negatively affect physical properties of the bare soil by deteriorating aggregates and clogging macropores leading to an increased erosion risk. Choosing a crop that increases aggregate stability during the growing season is one strategy to reduce the risk for post-harvest erosion (Yakupoglu et al 2011). Thus, crop residue management is a key element of sustainable crop production. Crop residues were incorporated into cropping systems in previous studies to improve and maintain soil structure and fertility. It is important to use cover crops to achieve the objectives of sustainable cropping systems (Ruffo & Bollero 2003). Therefore, new approaches should be evaluated for sustainable soil management, environmental protection, and human health. While there are many studies on cover crops, number of studies about the effects of the *Trifolium repens* L. (TR), *Festuca rubra rubra* L. (FRR), *Festuca arundinacea* (FA), *Trifolium repens* (40%)+*Festuca rubra rubra* (30%)+*Festuca arundinacea* (30%) mixture (TFF), *Vicia villosa* (VV) *and Trifolium meneghinianum* (TM) on soil quality of an apple orchard is quite limited. The objectives of this study were: i) to determine the changes in some soil quality variables of a sandy loam soil of an apple orchard with different cover crop treatments including plots mechanically cultivated (MC), herbicide treatment (HC) and control plot (C), ii) to determine the relationships between soil quality variables iii) to determine the effects of all treatments on apple yield.

2. Material and Methods

2.1. Experimental site

Experiments were conducted in the experimental semi-dwarf apple orchard of Erciyes University Agricultural Faculty between the years of 2012-2014. Experimental site is located between 38.22 N - 35.27 E in Develi town of Kayseri province of Turkey. The annual average temperature was 10.6 °C and the average annual precipitation were 384.3 mm. At the beginning of this study in 2012, the apple trees in the orchard were 7 years old. Each plot was 35 m^2 (5×7 m) and consisted of 5 semi-dwarf apple trees.

2.2. Cover crop treatments

The cover crop treatments consisted of *Trifolium repens* L. (TR), *Festuca rubra rubra* L. (FRR), *Festuca arundinacea* (FA), *Trifolium repens* (40%) + *Festuca rubra rubra* (30%) + *Festuca arundinacea* (30%) mixture (TFF), *Vicia villosa* (VV) and *Trifolium meneghinianum* (TM). *Vicia villosa* and *Trifolium meneghinianum* are annual legume plants and *Trifolium repens* L. are perennial legume plants. *Festuca rubra rubra* L. and *Festuca arundinacea* are perennial grass cover plants. The experiment was established in a randomized complete block design with four replications including plots mechanically cultivated (MC), herbicide treatment (HC) and control plots without cover crops (C). Consecutive plots were separated with a buffer zone with no cover crop. Soil preparation was made according to local practices for Orchards. Cover crops were manually seeded on 10 April 2012, annual species (VV and TM) seeded again 27 October 2012, and 2 November 2013. The cover crop seeds were broadcasted and then incorporated into the soil with a shallow cultivator. Primary tillage and chisel plowing, followed by disking with a harrow. Seeding rate was 50 kg ha^{-1} for *Trifolium repens* L., 80 kg ha^{-1} for *Festuca rubra rubra* L., 70 kg ha^{-1} *Trifolium repens* (40%) + *Festuca rubra rubra* (30%) + *Festuca arundinacea* (30%) mixture, 100 kg ha^{-1} *Vicia villosa* and 40 kg ha^{-1} *Trifolium meneghinianum. Trifolium meneghinianum* seeds were obtained from Black Sea Agricultural Research Institute and the others were purchased from private seed companies. The cover crop treatments were maintained in the same plots throughout the experiments. During the vegetation period, no fertilizer was applied. Cover crops mowed when *Festuca* spp. in the flag leaf periods, others were at the beginning of the flowering periods (Işık et al 2014; Tursun et al 2018). Cover crops were mowed and incorporated into the soil by disking. Apple harvest was performed on 11 October 2012 and 19 October 2013, but not in 2014 due to hail storm decimated almost all of the yield. Prior to treatments (mowing) of the cover crops, above ground biomass samples of the cover crops were collected from randomly selected 50 x 50 cm quadrat in each plot. Cover crops were dried at 70 °C for 48 h to obtain dry biomass (Mennan et al 2009; Işık et al 2009). Glyphosate isopropylamine salt (360 g a.i L^{-1}) was applied at 2880 mL ha^{-1} (1.39 kg a.i ha^{-1}) in the herbicide control plots. Glyphosate was applied at 3 atm pressure (303.97 kPa) with 250 L ha^{-1} spraying volume with a portable hand sprayer (Honda WJR 2225 model).

2.3. Soil sampling

Soil samples were taken from 0-20 and 20-40 cm depths in each plot 90 d after plant harvest using a corkscrew-shaped soil drill and soil quality parameters were determined. Samples were sieved through 2 mm sieve and made ready for physicochemical analyses. Some physical and chemical properties of the soil at the start of the experiment were given in Table 1. Soil analyses revealed that soils (at 0-20 cm) in the experimental field site have a coarse-textured soil (74.40% Sand, 15.23% Silt, 10.37% Clay), were slightly alkaline (7.57), and low organic matter (0.61) contents (Soil Survey Staff 2014).

Table 1- Some physical and chemical properties of the soil at the start of the experiment

Soil properties	*Depth, cm*		*Soil properties*	*Depth, cm*	
	0-20	*20-40*		*0-20*	*20-40*
Sand, %	74.40	73.51	OM, %	0.61	0.53
Silt, %	15.23	15.41	Ca, me 100 g^{-1}	6.24	6.36
Clay, %	10.37	11.08	Mg, me 100 g^{-1}	2.40	1.96
Soil texture	SL	SL	Na me 100 g^{-1}	0.32	0.31
BD, gr cm^{-3}	1.52	1.50	K, me 100 g^{-1}	0.25	0.20
pH (1:1)	7.57	7.55	$CaCO_3$, %	0.71	0.67
$EC_{25°C}$, ds m^{-1}	0.45	0.44	P, mg kg^{-1}	7.33	6.91

BD, Bulk density; SL: Sandy loam; pH, Soil reaction; EC, Electrical conductivity; OM, Organic matter; Ca, Exchangeable calcium; Mg, Exchangeable magnesium; Na, Exchangeable sodium; K, Exchangeable potassium; P, Available phosphorus

2.4. Soil chemical analysis

Soil reaction (pH) was measured by using a pH meter with glass electrode in a 1:1 (w:v) ratio soil-water suspension (Jackson 1958). Electrical conductivity ($EC_{25°C}$) was measured with an EC meter in a 1:1 (w:v) ratio soil-water suspension (Richards 1954).

Exchangeable cations (Ca, Mg, K, Na) were determined with the 1N ammonia acetate (NH_4OAc) extraction (Rowell 1996). Available P contents were determined through extraction with 0.5 M $NaHCO_3$ at pH 8.5 by Olsen's method (Olsen et al 1954). Organic matter was determined by the modified Walkley-Black method (Black 1965). Total N was determined by the LECO model Tru-Spec CHN elemental analyzer (Dumas 1831). Lime content was determined by Scheibler Calcimeter (Nelson 1982).

2.5. Soil biochemical analysis

Basal soil respiration (BSR) was measured in accordance with Isermayer (1952) through measuring CO_2 productions at 22 ºC. The CO_2 production at the end of the 24 h incubation period was expressed in mg CO_2 100 g^{-1}.

2.6. Soil physical analysis

Soil particle size distribution was determined by using Bouyoucos hydrometer method (Bouyoucos 1953). Bulk density (BD) was carried out with the cylinder method (Black 1965). Soil field capacity (FC) and the permanent wilting point (PWP) were determined according to Hillel (1982). After saturating soil samples with tap water for 24 hours, soil water content at the field capacity was determined through equilibrating soil moisture for 24 hours at 33 kPa on a ceramic plate, and the permanent wilting point was measured through equilibrating soil moisture for 96 hours at 1500 kPa on a pressure plate apparatus (Hillel 1982). Available water content (AWC) was then calculated as the difference between FC and PWP (Hillel 1982). Volumetric water content (θ) was estimated from the following equation (Hillel 1982);

$$\theta = \text{gravimetric water content (W) (g } H_2O \text{ g}^{-1} \text{ soil at the sampling time) x soil bulk density (g cm}^{-3}) \quad (1)$$

Then, Equation. 2 was used to calculate the total porosity (F) (Hillel 1982):

$$F = 1 - (BD/2.65) \quad (2)$$

Hydrometer method and the following equation were used to determine soil structural stability index (SSI):

$$SSI = \sum b - \sum a \quad (3)$$

Where "b" is percent clay and "a" is silt + clay (Leo 1963). A wet sieving device was used to assess the aggregate stability (AS) (Yoder type) (Kemper & Rosenau 1986). Constant head permeameter was used to measure saturated hydraulic conductivity (Ks) of the soil samples (US Salinity Lab. Staff 1954). Following Darcy equation was sued to calculate saturated hydraulic conductivity (Ks, cm h^{-1});

$$Ks = \frac{Q}{A\,t}\left(\frac{S}{S+H}\right) \quad (4)$$

Where, Q: volume of outflow (cm^3), A: cross sectional area of soil column (cm^2), t: time (hour), S: length of soil column (cm), H: water head over the soil column (cm).

Dry sieving method was used to calculate mean weight diameter (MWD) (Hillel 1982):

$$MWD = \sum_{i=1}^{k} W(i)\,\bar{x}i \quad (5)$$

2.7. Statistical analysis

Experimental results were subjected to statistical analyses with SPSS. Data were subjected to ANOVA and treatment means were compared with Duncan's multiple range test at the 0.01 and 0.05 probability levels. Correlation analyses were performed to express the relationships between experimental parameters (Yurtsever 2011).

3. Results and Discussion

3.1. Soil chemical quality variables

3.1.1. Soil organic matter (SOM)

Cover crop treatments increased soil organic matter contents at 0-20 cm soil depth as compared to the soil of an untreated control plot (Table 2). Cover crop treatments increased SOM content from 0.59% in the control treatment to 1.29% in *Trifolium repens* L. (TR) treatment in the first year of the experiments (2013). Soil organic matter contents at 0-20 cm soil depth in the second year of the experiment (2014) were ordered as; HC (0.59%) < C (0.64%) < MC (0.67%) < FRR (1.06%) < TM (1.09%) < TFF (1.13%) < FA (1.14%) < VV (1.41%) < TR (1.42%) (Table 2). SOM contents varied significantly between experimental years. The mean OM values of the control plots without cover crops were 0.62% for 0-20 cm and 0.53% for 20-40 cm. Percent changes in chemical soil quality parameters as compared to control are provided in Table 3. The soil quality is assessed through physicochemical and biological soil quality parameters. The soil characteristics, environmental factors, and land management practices significantly influence all these quality parameters (Stott et al 2010). Organic carbon is one of the most significant quality indicators for soils because it has a variety of significant impacts on other soil quality attributes. Cropping treatments are also used to improve soil organic carbon contents and thus soil quality and fertility (Demir & Gülser 2015). Organic matter contents significantly increased from 0.64% in the control to 1.42% in *Trifolium repens* (TR) treatment at 0-20 cm soil depth. Gülser (2004) reported that cropping treatments increased the organic matter content from 2.28% for bare soil to 3.18% for bromegrass treatment. In addition, Gülser (2004) determined that such increases in SOM content due to different cropping regimes were obtained in the following order: control < crownvetch < subterranean clover < alfalfa < ryegrass < small burnet < bromegrass. Ramos et al (2010) was reported in a previous study that two cover crop (oat-*Avena sativa* L. and oat-vetch-*Vicia sativa* L.) treatments increased soil organic carbon content (55.6% and 66.7%, respectively) and aggregate stability. Obi (1999) found that cover crops (*Axonopus compressus, Cynodon plectostachyum, Panicum maximum, Pennisetum polystachion, Stylosanthes gracilis and Pueraria phaseoloides*) on degraded sandy clay loam soil improved mean organic carbon level (by 28.1%) over value for the control soils. In this study, the greatest increases in soil organic matter contents at 0-20 cm soil depth of apple orchard as compared to the control in both years of the experiment were observed in *Trifolium repens* (TR) treatment respectively with 117.8 and 120.1%. A closely related species, *Trifolium repens* has a robust root system that could provide drought resistance as compared to grass cover crops (Roumet et al 2006). Bertin et al (2003) reported that soil organic matter content was increased in the cover crops through root activity, i.e. exudation of low-molecular weight organic compounds. In addition, the root systems of perennials are more randomly branched and have larger diameter roots than annual (Roumet et al 2006). This may explain the nutrient conservative strategy of perennials and the high nutrient uptake capacities of annuals (Roumet et al 2006). On the other hand, salt tolerance in *Trifolium repens* appears to be correlated with (i) a capacity to restrict and regulate the transport of these ions from the roots to the shoots, leading to lower concentrations of Na^+ and Cl^- in the shoot, and (ii) lower uptake rates of Na^+ and Cl^- per unit of root tissue (Rogers et al 1997).

The differences in SOM contents were not found to be significant for the 20-40 cm soil depth in both years of experiments (Table 4). SOM contents ranged from 0.51% in herbicide treatment to 0.64% in mixture (*T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%)) treatment for the 20-40 cm soil depth in 2013. SOM contents ranged from 0.52% in herbicide treatment to 0.73% in *Festuca arundinacea* (FA) treatment for the 20-40 cm soil depth in 2014 (Table 4).

Table 2- Effects of treatments on chemical soil quality variables at 0-20 cm soil depth

2013										
	pH, (1:1)**	*EC, dS m^{-1**}*	*OM, %***	*N, %***	*NH$_4$OAc extractable, me 100 g^{-1}*				*P, mg kg^{-1} ***	*BSR, mg CO$_2$ 100 g^{-1**}*
					Ca	*Mg*	*K*	*Na*		
TR	7.22e	0.91a	1.29a	0.086a	6.2	2.7	0.32	0.25c	12.4a	5.8a
FRR	7.46bc	0.75b	1.00c	0.065abc	6.4	2.4	0.34	0.26c	11.0a	5.4ab
FA	7.36d	0.87a	1.06bc	0.072abc	6.3	2.2	0.35	0.30abc	11.6a	5.3ab
TFF	7.42cd	0.84b	1.05bc	0.075ab	6.4	2.6	0.34	0.29abc	11.8a	5.6a
VV	7.33d	0.89b	1.26ab	0.085a	6.8	2.5	0.35	0.25c	13.0a	6.0a
TM	7.49bc	0.65b	1.02c	0.075ab	6.7	2.5	0.34	0.27bc	12.1a	5.7a
HC	7.53b	0.46c	0.53d	0.045c	6.8	2.2	0.27	0.35a	7.3b	2.4b
MC	7.54b	0.49c	0.66d	0.049bc	6.3	2.2	0.29	0.29abc	7.3b	2.5b
C	7.65a	0.45c	0.59d	0.047bc	6.7	2.4	0.26	0.34ab	7.2b	2.3b
2014										
	pH, (1:1)**	*EC, dS m^{-1**}*	*OM, %***	*N, %***	*NH$_4$OAc extractable,me 100 g^{-1}*				*P, mg kg^{-1} ***	*BSR,mg CO$_2$ 100 g^{-1**}*
					Ca	*Mg*	*K**	*Na***		
TR	7.17d	0.92a	1.42a	0.100a	6.1	3.0	0.36ab	0.14b	13.3a	9.7a
FRR	7.48bc	0.75ab	1.06b	0.071bc	6.2	3.0	0.36ab	0.24ab	12.2a	7.3bc
FA	7.28cd	0.98a	1.14b	0.074bc	6.7	2.7	0.37a	0.23ab	12.0a	6.2c
TFF	7.39bc	0.92a	1.13b	0.082ab	6.4	2.8	0.36ab	0.19b	12.2a	8.4ab
VV	7.25d	0.99a	1.41a	0.102a	6.1	2.9	0.38a	0.21ab	14.0a	9.8a
TM	7.40bc	0.75ab	1.09b	0.085ab	6.2	2.5	0.36ab	0.15b	12.6a	8.6ab
HC	7.51b	0.45c	0.59c	0.042d	6.6	2.3	0.25b	0.33a	7.0b	2.9d
MC	7.50ab	0.55bc	0.67c	0.056cd	6.3	2.4	0.26b	0.32a	7.6b	4.2d
C	7.62a	0.47c	0.64c	0.053cd	6.1	2.7	0.25b	0.31a	7.4b	3.4d

**, $P < 0.01$; *, $P < 0.05$; TR, *Trifolium repens* L.; FRR, *Festuca rubra* subsp. *Rubra;* FA, *Festuca arundinacea;* TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa;* TM, *Trifolium meneghinianum;* MC, Mechanically cultivated; HC, Herbicide treatment; C, Control; pH, Soil reaction; EC, Electrical conductivity; OM, Organic matter; N, Total Nitrogen; Ca, Exchangeable calcium; Mg, Exchangeable magnesium; K, Exchangeable potassium; Na, Exchangeable sodium; P, Available phosphorus; BSR, Basal soil respiration; CO_2, Karbondioksit

Table 3- Percent changes in chemical soil quality variables as compared to control at the 0-20 cm soil dept (%)

2013										
Treatments	*pH*	*EC*	*OM*	*N*	*NH$_4$OAc extractable*				*P*	*BSR*
					Ca	*Mg*	*K*	*Na*		
TR	-5.6	99.2	117.8	83.7	-7.4	14.3	22.8	-25.6	72.0	151.1
FRR	-2.5	65.3	68.4	40.1	-4.4	0.7	28.4	-22.8	52.8	133.2
FA	-3.7	91.5	79.4	54.9	-6.1	-6.4	31.3	-13.3	60.5	129.9
TFF	-3.0	85.9	77.9	61.0	-5.8	9.6	28.4	-14.7	64.1	144.6
VV	-4.1	95.7	113.2	82.4	0.6	4.1	31.3	-26.3	80.6	162.5
TM	-2.1	43.4	72.7	60.5	-0.9	7.7	28.4	-21.3	67.2	147.8
HC	-1.5	1.2	-10.6	-3.5	0.9	-5.6	0.8	2.1	1.3	5.4
MC	-1.4	7.2	11.8	4.6	-6.4	-6.0	8.6	-13.9	1.6	6.5
2014										
TR	-5.9	95.1	120.1	91.3	-0.4	13.6	46.2	-56.0	78.9	181.2
FRR	-1.8	57.5	65.3	35.7	2.2	11.2	47.0	-24.8	64.2	113.4
FA	-4.5	107.2	77.0	41.4	9.7	2.0	48.8	-26.4	61.6	81.4
TFF	-3.1	93.9	75.8	56.2	5.8	6.4	44.2	-40.0	64.5	143.3
VV	-4.9	108.9	119.7	94.8	0.9	9.5	50.9	-31.9	88.1	186.3
TM	-2.9	59.2	70.0	61.9	2.3	-4.3	47.2	-53.4	69.9	151.3
HC	-1.4	-4.1	-8.2	-21.0	8.7	-12.5	0.5	4.0	-5.4	-15.5
MC	-1.5	15.4	3.8	5.7	3.1	-8.9	4.6	0.8	1.6	22.4

TR, *Trifolium repens* L.; FRR, *Festuca rubra* subsp. *rubra*, FA, *Festuca arundinacea;* TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa*; TM, *Trifolium meneghinianum;* MC, Mechanically cultivated; HC, Herbicide treatment; C, Control; pH, soil reaction; EC, Electrical conductivity; OM, Organic matter; N, Total nitrogen; Ca, Exchangeable calcium; Mg, Exchangeable magnesium; K, Exchangeable potassium; Na, Exchangeable sodium; P, Available phosphorus; BSR, Basal soil respiration

Table 4- Effects of treatments on chemical soil quality variables at 20-40 cm soil depth

Treatments	*pH (1:1)*	*$EC_{25°}$, dS m^{-1}*	*OM, %*	*N, %*	*NH_4OAc extractable, me 100 g^{-1}*				*P, mg kg^{-1}*	*BSR, mg CO_2 100 g^{-1} soil*
					Ca	*Mg*	*K*	*Na*		
2013										
TR	7.49	0.429	0.56	0.031	6.21	1.98	0.22	0.30	7.14	0.013
FRR	7.59	0.412	0.60	0.030	6.15	2.12	0.19	0.31	7.31	0.012
FA	7.59	0.473	0.62	0.030	6.70	2.17	0.20	0.35	7.68	0.012
TFF	7.58	0.409	0.64	0.029	6.73	2.07	0.21	0.34	7.13	0.012
VV	7.52	0.443	0.56	0.028	6.09	2.04	0.21	0.30	7.26	0.013
TM	7.64	0.414	0.54	0.030	6.03	2.00	0.22	0.32	7.12	0.013
HC	7.70	0.412	0.51	0.027	6.70	1.91	0.22	0.30	6.94	0.011
MC	7.64	0.400	0.54	0.027	6.63	1.83	0.21	0.32	6.90	0.011
C	7.70	0.406	0.52	0.028	6.95	1.93	0.21	0.32	6.98	0.012
2014										
TR	7.40	0.534	0.60	0.032	6.17	2.20	0.21	0.28	7.55	0.015
FRR	7.39	0.428	0.65	0.032	6.16	2.54	0.21	0.30	7.01	0.015
FA	7.42	0.501	0.73	0.032	6.72	2.42	0.22	0.27	8.06	0.014
TFF	7.45	0.512	0.69	0.032	6.16	2.56	0.20	0.30	7.73	0.015
VV	7.48	0.457	0.68	0.031	6.20	2.51	0.23	0.31	7.25	0.014
TM	7.43	0.509	0.62	0.032	5.99	2.28	0.23	0.27	7.22	0.015
HC	7.45	0.433	0.52	0.029	6.49	2.04	0.21	0.30	6.72	0.012
MC	7.51	0.488	0.59	0.029	6.82	2.10	0.23	0.28	7.05	0.014
C	7.50	0.451	0.56	0.030	6.22	2.26	0.21	0.30	7.14	0.012

TR, *Trifolium repens* L.; FRR, *Festuca rubra* subsp. *rubra*, FA, *Festuca arundinacea*, TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa;* TM, *Trifolium meneghinianum*; MC, Mechanically cultivated; HC, Herbicide treatment; C, Control; pH, soil reaction; EC, Electrical conductivity; OM, Organic matter; N, Total nitrogen; Ca, Exchangeable calcium; Mg, Exchangeable magnesium; K, Exchangeable potassium; Na, Exchangeable sodium; P, Available phosphorus; BSR, Basal soil respiration; CO_2, Karbondioksit

3.1.2. Total N

Cover crop treatments increased total N at 0-20 cm soil depth as compared to the soil of an untreated control plot in both years of the experiments (Table 2). The highest total N values (0.086%) were seen at 0-20 cm in 2013 in the TR treatment while the lowest total N value (0.045%) was seen in HC treatment (Table 2). Total N significantly increased from 0.053% in the control to 0.102% in VV treatment at 0-20 cm soil depth in 2014. Gülser (2004) found that present increases in the total N over the control were between 8.85% for the crownvetch and 36.46% for the alfalfa treatment. Ramos et al (2010) reported in a previous study that two cover crop (oat- vetch-*Vicia sativa* L. and oat-*Avena sativa* L.) treatments increased total N (32.5%) according to control. In this study, percent increases in the total N over the control soil varied between 40.1-83.7% in 2013 and 35.7-94.8% in 2014 (Table 3). The leguminous family is the most commonly used cover crop because it ensures self sufficiency in N, recycles macro and micronutrients, has usually a deep and extensive root system, is able to extract nutrients from deeper soil layers, and provides large amounts of organic matter in soil (Alagöz & Yılmaz 2009). Soil organic carbon and nitrogen are the main nutritiens used for vegetation growth. These parameters are also used in soil quality assessment and sustainable land use management practices (Liu et al 2011). The soil organic carbon and N not only reflect the soil fertility level but also explain the evolution of the regional ecological system. The relationship between them can be represented as the soil C/N ratio, a sensitive indicator of soil quality and for assessing carbon and nitrogen cycling of soils (Zhang et al 2011). The high soil C/N ratios decelerate decomposition rate of organic matter and nitrogen through limiting soil microbial activity, whereas the low soil C/N ratios accelerate the process of microbial decomposition of organic matter and nitrogen, which is not conducive for carbon sequestration (Wu et al 2001). In this study, the highest soil C/N ratio was observed in FA treatment (8.94) and the lowest was found in HC treatment (6.83) at 0-20 cm soil depth of the apple orchard. For 20-40 cm the soil depth, the soil C/N ratio ranged from 13.08 for the FA to 10.32 for the HC treatment. Mean C/N values of the control plot were found be 7.55 for 0-20 cm and 11.01 for 20-40 cm soil depth. Nitrogen plays a catalyzer role in organic matter formation. In this study, cover crops increased N supply through improving the availability of residual N and through N_2 fixation with legume crops. Cover crops, especially the legumes, fixate atmospheric nitrogen into the soils and thus increase total N contents. The N release from cover crops varies based on lignin, carbohydrate and cellulose content of the residues. Hoagland et al (2008) reported that a cover of mixed legumes established in an apple orchard raised the organic carbon and total N, soil biological activity and potentially available N for trees over a two-year period.

The differences in total N values were not found to be significant for the 20-40 cm soil depth in both years of experiments (Table 4). Total N values at 20-40 cm soil depth varied between 0.027-0.031% with a mean value of 0.029% in 2013 and between 0.029-0.032% with a mean value of 0.031% in 2014 (Table 4).

3.1.3. Soil reaction (pH)

Cover crop treatments significantly reduced pH from 7.65 in control to 7.22 for the *Trifolium repens* (TR) treatment at the 0-20 cm soil depth in 2013 (Table 2). As compared to control, percent decreases in pH values at the 0-20 cm soil depth in 2014 varied between 1.4% in herbicide treated (HC) and 5.9% in *Trifolium repens* (TR) treatments (Table 3). Such decreases were mainly because of CO_2 release into the soil ambient, decomposition of organic wastes and conversion of these organic wastes into carbonic acid (H_2CO_3) through reactions with water. Besides, when the organic matter is mineralized there is a production of organic acids that could raise the soil acidity (Garcia & Rosolem 2010). Gülser (2004) found that values of soil pH importantly reduced with the cropping treatment and percent decreases in pH compared the control soil were between -5.96% for crownvetch and -0.31% for bromegrass treatment. In present study, as compared to control, percent decreases in pH values the aired between -2.1% in TM and -5.6% in TR treatments in 2013 and between 1.8% in FRR and 5.9% in TR treatments in 2014 (Table 3). Cover cropping significantly reduced pH (Demir & Işık 2019a; Demir & Işık 2019b; Demir et al 2019b), due to the acidic root exudates, and this may alter nutrient availability at the root surface (Chapin 1980).

The differences in soil pH values were not found to be significant for the 20-40 cm soil depth in both years of experiments (Table 4). The mean pH values for 20-40 cm soil depth were 7.61 in 2013 and 7.45 in 2014 (Table 4).

3.1.4. Electrical conductivity (EC)

Cover crop treatments increased soil electrical conductivity values at 0-20 cm soil depth as compared to the soil of an untreated control plot (Table 2). The highest EC values was obtained from *Trifolium repens* L. (0.91 dS m^{-1}) in 2013 and *Vicia villosa* (0.99 dS m^{-1}) in 2014. EC significantly increased from 0.47 dS m^{-1} in the control to 0.99 dS m^{-1} in VV treatment at 0-20 cm soil depth in 2014. The greatest increase in the soil EC values was observed in VV (0.99 dS m^{-1}) and the least increase was observed in MC (0.55 dS m^{-1}). The soil electrical conductivity is a significant indicator of dissolved nutrients and can be used to monitor organic matter mineralization (Candemir & Gülser 2010). Previous researchers also reported increasing the EC values with organic matter and compost treatments. Gülser (2004) reported that highest percent change in EC values over the control plots was obtained as 124.60% for alfalfa treatment while lowest percent increase in EC values was 15.97% for bromegrass treatment. In this study, EC values significantly increased with the cropping treatment and percent increases in EC over the control soil were between 43.4% in TM and 99.2% in TR treatments in 2013 and between 57.5% in FRR and 108.9% in VV treatments in 2014 (Table 3).

The differences in EC values were not found to be significant for the 20-40 cm soil depth in both years of experiments (Table 4). EC values ranged from 0.400 dS m^{-1} in mechanically cultivated (MC) treatment to 0.473 dS m^{-1} in *Festuca arundinacea* (FA) treatment for the 20-40 cm soil depth in 2013. EC values ranged from 0.433 dS m^{-1} in herbicide treatment to 0.534 dS m^{-1} in *Trifolium repens* L. (TR) treatment for the 20-40 cm soil depth in 2014 (Table 4).

3.1.5. Exchangeable cations (Ca, Mg, K, Na)

Cover crop treatments increased extractable K at 0-20 cm soil depth as compared to the soil of an untreated control plot (Table 2). In addition, significantly higher exchangeable K was obtained in 2014 than in 2013. While the exchangeable K contents varied between 0.25 me 100 g^{-1} in C and HC and 0.38 me 100 g^{-1} in VV treatments; exchangeable Na contents ranged from 0.33 me 100 g^{-1} in HC to 0.14 me 100 g^{-1} in *Trifolium repens* (TR) treatment in 2014. Cover crop treatments significantly reduced exchangeable Na from 0.31 me 100 g^{-1} in control to 0.14 me 100 g^{-1} in *Trifolium repens* (TR) treatment in 2014 (Table 2). As compared to control, percent decreases in exchangeable Na value at the 0-20 cm soil depth in 2014 varied between 24.8% in FRR and 56.0% in *Trifolium repens* (TR) treatments (Table 3). Demir et al (2019a) cover crop treatments in an apricot orchard with clay soil significantly reduced exchangeable Na and pH from 0.35 me 100 g^{-1} and 7.47 for the bare control treatment to 0.20 me 100 g^{-1} for the *Vicia pannonica* Crantz treatment and to 7.02 for the *Vicia villosa* Roth and *Vicia pannonica* Crantz treatments, respectively. A number of chemical properties (nutrient availability and cycling, pH, buffering capacity, and cation exchange capacity) are affected by organic matter content in the soil (Tisdall et al 1986).

The differences in the exchangeable cations (Ca, Mg, K, Na) were not found to be significant for the 20-40 cm soil depth in both years of experiments (Table 4). The exchangeable Ca values varied between 6.1-6.8 me 100 g^{-1}, the exchangeable Mg values between 2.2-3.0 me 100 g^{-1}, the exchangeable K values between 0.26-0.38 me 100 g^{-1}, the exchangeable Na values between 0.14-0.35 me 100 g^{-1} (Table 4).

3.1.6. Available P

Cover crop treatments significantly increased available P at 0-20 cm soil depth as compared to the soil of an untreated control plot in both years of experiments (Table 2).

In 2013, available P value was the lowest in the control followed by HC = MC <FRR < FA < TFF < TM < TR < VV treatments (Table 2). Available P significantly increased from 7.4 mg kg^{-1} in the control to 14.0 mg kg^{-1} in VV treatment at 0-20 cm soil depth in 2014 (Table 2). P uptake of succeeding crops was improved by the cover crops (Cavigelli & Thien 2003). Vavoulidu et al (2004) indicated increased available P contents with organic matter treatments. Obi (1999) found that legume and grass cover crops (Axonopus compressus, Cynodon plectostachyum, Panicum maximum, Pennisetum polystachion, Stylosanthes gracilis and Pueraria phaseoloides) on degraded sandy clay loam soil increased mean phosphorus levels (by 112%) compared with the initial conditions. In the present study, cover crop treatments significantly increased P contents and such increases varied between 61.6% in FA and 88.1% in VV treatment (Table 3). Gates & Wilson (1974) reported that available P values was higher for legume cover crops than for grass cover crops, probably due to higher P requirements for legumes due to the mechanisms involved in nitrogen fixation.

The differences in available P were not found to be significant for the 20-40 cm soil depth in both years of experiments (Table 4). Available P values at 20-40 cm soil depth varied between 6.90-7.68 mg kg^{-1} with a mean value of 7.16 mg kg^{-1} in 2013 and between 6.72-8.06 mg kg^{-1} with a mean value of 7.30 mg kg^{-1} in 2014 (Table 4).

3.2. Soil biochemical quality variable

In both years of the experiment, the basal soil respiration (BSR) significantly increased with cover crop treatments. In 2013, BSR value was the lowest (2.3 mg CO_2 100 g^{-1}) in the control followed by C < HC < MC < FA < FRR < TFF < TM < TR < VV treatments. The highest BSR values (9.83 mg CO_2 100 g^{-1}) were seen at 0-20 cm in 2014 in the VV while the lowest BSR value (2.90 mg CO_2 100 g^{-1}) was seen in HC treatment (Table 2). Demir et al (2019a) found that highest basal soil respiration values (41.5 mg CO_2 100 g^{-1}) was obtained in the *Vicia villosa* Roth treatment while the lowest BSR values (12.5 mg CO_2 100 g^{-1}) was in the control in the apricot orchard. In this study, the greatest increase in BSR was observed in VV treatment (186.29%) and the least increase was observed in MC treatment (22.38%) (Table 3). Basal soil respiration is used as an indicator of CO_2 released through the decomposition of organic matter and respiration of the roots. The soil organic matter is largely decomposed through the microbial activity, thus the basal soil respiration is also used as a well-indicator of soil health, organic matter content and organic matter decomposition. The basal soil respiration rates also improved through crop residues and organic matter supplementing agricultural practices (Kladivko 2001).

The differences in the BSR were not found to be significant for the 20-40 cm soil depth in both years of experiments (Table 4). The mean BSR values for 20-40 cm soil depth were 0.012 mg CO_2 100 g^{-1} in 2013 and 0.014 mg CO_2 100 g^{-1} in 2014 (Table 4).

3.3. Soil physical quality variables

3.3.1. Bulk density (BD) and total porosity (F)

There were significant decreases in bulk density (BD) values ($P<0.05$) and significant increases in total porosity (F) (P<0.01) with cover crop treatments at 0-20 cm soil depth when compared to values of the control (Table 5). As compared to control, the percent changes in bulk density and total porosity are provided in Table 6. BD values at 0-20 cm soil depth in 2013 were ordered as; MC > C=HC > TM > FRR > FA > TFF =TR > VV treatments. The greatest increase in total porosity (16.5%) and the greatest decrease in bulk density (13.0%) were observed in *Trifolium repens* (TR) treatment in 2014. Total porosity values increased with decreasing bulk densities. While the highest BD was found in HC (1.53 g cm^{-3}), the lowest bulk density was obtained in *Trifolium repens* (TR) treatment (1.30 g cm^{-3}) at 0-20 cm soil depth in 2014. Cover crop treatments may significantly improve moisture retention capacity, soil structure, density and consistency. Such treatments also modify soil porosity, conductivity, aeration, infiltration rates and hydraulics. The decay of roots or plant residues increases the size and quantity of macropores (Sultani et al 2007). Gülser (2004) reported that cropping treatments significantly decreased bulk density from 1.45 g cm^{-3} for control plot to 1.27 g cm^{-3} for bromegrass treatment. In addition, due to cropping effects, total porosity significantly increased from 45.28% for control plot to 52% for bromegrass treatment. The increases in total porosity were determined in the following order; control < ryegrass < alfalfa < crownvetch < small burnet < subterranean clover < bromegrass treatments.

Table 5- Effects of treatments on physical soil quality variables at 0-20 cm soil depth

2013										
	BD, gr cm^{-3*}	*FC, %***	*PWP, %*	*AWC, %**	*F, %***	*Θ, %***	*Ks, cm h*$^{-1**}$	*AS, %**	*MWD, mm*	*SSI, %*
TR	1.33b	19.2a	11.7	7.5a	49.8b	18.3b	10.5b	20.7a	0.45	13.3
FRR	1.37ab	19.1a	11.6	7.5a	48.3c	13.7e	9.8b	19.4ab	0.44	13.1
FA	1.35b	18.9a	11.3	7.6a	49.1c	14.6d	9.5b	19.3ab	0.44	13.0
TFF	1.33b	19.1a	11.4	7.7a	49.8b	16.3c	10.3b	19.5ab	0.44	13.3
VV	1.30b	19.4a	11.9	7.5a	50.9a	18.7a	12.7a	20.2a	0.46	13.4
TM	1.41ab	18.7a	11.3	7.4a	46.8d	14.7d	10.4b	19.7ab	0.45	13.2
HC	1.52a	16.4b	10.4	6.0b	42.6e	10.1g	6.1c	17.1b	0.42	12.1
MC	1.53a	16.5b	10.5	6.0b	42.3e	10.5f	6.8c	17.2b	0.41	12.0
C	1.52a	16.4b	10.4	6.1b	42.6e	10.4f	6.4c	17.2b	0.40	12.1
2014										
	BD, gr cm^{-3*}	*FC, %***	*PWP, %**	*AWC, %**	*F, %***	*Θ, %***	*Ks, cm h*$^{-1**}$	*AS, %***	*MWD, mm**	*SSI, %***
TR	1.30b	19.7a	12.0a	7.8ab	50.6a	19.0a	12.1ab	21.4a	0.49a	13.4a
FRR	1.39ab	19.3a	11.7ab	7.6ab	47.5c	15.8c	10.8b	19.7b	0.45ab	12.9ab
FA	1.35b	19.5a	11.7ab	7.8a	49.1b	15.4d	10.2b	19.8b	0.45ab	13.1a
TFF	1.31b	19.1a	11.8ab	7.3ab	50.6a	17.4b	12.1ab	20.1ab	0.46ab	13.2a
VV	1.33b	20.0a	12.0a	8.0a	49.8ab	19.1a	13.4a	21.5a	0.50a	13.5a
TM	1.39ab	19.1a	11.8ab	7.3ab	47.6c	15.4d	9.8b	20.6ab	0.46ab	13.3a
HC	1.53a	16.3b	10.3b	6.0b	42.6d	10.1e	6.1c	17.1c	0.41b	12.1b
MC	1.52a	16.5b	10.4b	6.1b	42.6d	10.4e	7.0c	17.4c	0.42b	12.2b
C	1.50a	16.4b	10.3b	6.1b	43.4d	10.1e	6.4c	17.2c	0.41b	12.2b

**, P <0.01; *, P<0.05; TR, *Trifolium repens* L.; FRR, *Festuca rubra* subsp. *Rubra;* FA, *Festuca arundinacea;* TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa*, TM, *Trifolium meneghinianum;* MC, Mechanically cultivated; HC, Herbicide treatment; C, Control, BD, Bulk density; FC, Field capacity; PWP, Fermanent wilting point; AWC, Available water content; F, Total porosity; θ, Volumetric water content; Ks, Saturated hydraulic conductivity; AS, Aggregate stability; MWD, Mean weight diameter; SSI, Structural stability index

Table 6- Percent changes in physical soil quality variables as compared to control at the 0-20 cm soil dept (%)

Treatments	*BD*	*FC*	*PWP*	*AWC*	*F*	*Θ*	*Ks*	*AS*	*MWD*	*SSI*
2013										
TR	-12.2	16.7	12.9	23.4	16.8	75.7	65.1	20.4	12.7	9.7
FRR	-9.6	16.3	11.9	23.9	13.3	31.4	54.0	12.9	10.0	8.6
FA	-11.2	15.3	9.2	25.7	15.0	39.9	49.0	12.5	9.5	7.6
TFF	-12.2	16.1	9.9	26.7	16.8	56.3	62.8	13.5	9.7	10.3
VV	-14.7	18.5	14.8	24.7	19.5	79.6	99.1	17.8	14.7	10.6
TM	-7.4	13.9	8.8	22.6	9.7	41.4	63.4	14.8	12.3	9.4
HC	0.3	-0.2	0.2	-0.9	0.0	-2.7	-4.4	-0.3	3.6	0.3
MC	1.0	0.8	1.7	-0.7	-0.9	0.7	7.4	0.4	3.0	-1.0
2014										
TR	-13.0	20.7	16.4	27.9	16.5	88.3	89.4	24.3	20.0	10.2
FRR	-7.3	18.0	13.3	25.9	9.6	56.7	69.2	14.6	8.7	5.6
FA	-10.4	19.3	13.5	29.1	13.0	52.8	60.4	15.4	9.5	7.5
TFF	-13.0	16.8	14.9	20.1	16.5	72.5	89.8	16.7	12.7	8.7
VV	-11.7	22.4	16.8	31.9	14.8	89.1	109.8	24.9	21.0	10.7
TM	-7.5	16.6	14.7	19.8	9.6	52.2	52.8	19.0	12.1	8.8
HC	0.8	-0.3	-0.1	-0.7	-1.7	-0.1	-5.2	-0.8	-1.0	-0.4
MC	1.2	0.6	0.7	0.3	-1.7	2.7	10.4	1.4	1.1	-0.2

TR, *Trifolium repens* L.; FRR, *Festuca rubra* subsp. *Rubra*; FA, *Festuca arundinacea;* TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa*; TM, *Trifolium meneghinianum*; MC, Mechanically cultivated; HC, Herbicide treatment; C, Control; BD, Bulk density; FC, Field capacity; PWP, Permanent wilting point; AWC, Available water content; F, Total porosity; θ, Volumetric water content; Ks, Saturated hydraulic conductivity; AS, Aggregate stability; MWD, Mean weight diameter; SSI, Structural stability index

The differences in BD and F values of cover crop treatments were not found to be significant for the 20-40 cm soil depth in both years of the experiment. The BD values varied between 1.47-1.54 g cm^{-3}, the F values between 41.5-44.5% (Table 7).

Table 7- Effects of treatments on physical soil quality variables at 20-40 cm soil depth

Treatments	*BD, gr cm^{-3}*	*FC, %*	*PWP, %*	*AWC, %*	*F, %*	*Θ, %*	*Ks, cm h^{-1}*	*AS, %*	*MWD, mm*	*SSI, %*
2013										
TR	1.48	15.9	10.0	5.9	44.3	10.6	6.2	15.3	0.39	10.2
FRR	1.50	16.5	10.0	6.5	43.4	10.1	6.3	15.1	0.42	9.6
FA	1.49	16.4	10.2	6.3	43.8	9.9	6.3	15.1	0.41	10.0
TFF	1.48	16.0	10.1	5.9	44.2	9.6	6.1	14.9	0.40	10.0
VV	1.47	15.8	9.9	5.9	44.5	10.9	7.0	15.3	0.40	9.8
TM	1.50	16.6	10.1	6.5	43.4	10.0	6.0	15.3	0.39	10.1
HC	1.50	15.7	9.8	6.0	43.4	9.1	5.9	15.0	0.40	9.8
MC	1.51	15.2	9.6	5.6	43.0	9.4	6.1	15.0	0.41	9.7
C	1.51	16.1	9.8	6.3	43.0	9.3	5.9	14.9	0.40	9.9
2014										
TR	1.49	16.1	10.0	6.1	43.7	11.7	6.1	15.5	0.40	10.4
FRR	1.50	16.4	10.5	5.9	43.4	10.5	6.9	16.1	0.40	10.2
FA	1.52	16.3	10.1	6.2	42.6	10.1	6.5	15.6	0.42	10.0
TFF	1.50	15.7	10.0	5.6	43.4	10.1	6.2	16.1	0.42	10.2
VV	1.50	16.1	10.4	5.7	43.4	11.8	6.9	16.1	0.40	10.0
TM	1.50	15.7	10.5	5.1	43.4	10.1	5.9	15.7	0.40	10.5
HC	1.55	15.5	9.8	5.7	41.5	9.7	6.4	15.9	0.42	10.1
MC	1.52	16.0	10.2	5.7	42.6	10.1	6.7	15.4	0.40	10.0
C	1.54	16.1	10.0	6.2	41.9	9.8	6.2	15.6	0.41	10.3

TR, *Trifolium repens* L.; FRR, *Festuca rubra* subsp. *Rubra*; FA, *Festuca arundinacea;* TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa;* TM, *Trifolium meneghinianum;* MC, Mechanically cultivated; HC, Herbicide treatment; C, Control; BD, Bulk density; FC, Field capacity; PWP, Permanent wilting point; AWC, Available water content; F, Total porosity; θ, Volumetric water content; Ks, Saturated hydraulic conductivity; AS, Aggregate stability; MWD, Mean weight diameter; SSI, Structural stability index

3.3.2. Soil field capacity (FC) and the permanent wilting point (PWP) and available water content (AWC)

There were significant increases in field capacity ($P<0.01$), permanent wilting point ($P<0.05$), available water capacity ($P<0.05$) with cover crop treatments at 0-20 cm soil depth in the second year of the experiment (2014) as compared to control (Table 5). As compared to control, the percent changes in available water capacity, field capacity, permanent wilting point are provided in Table 6. Percent increases in AWC values as compared to the control treatment at 0-20 cm soil depth in 2013 varied between 22.6% in *Trifolium meneghinianum* treatment and 26.7% in mixture (*T. repens* (40%)+*F. rubra rubra* (30%)+*F. arundinacea* (30%)) treatment (Table 6). As compared to control, the greatest increase in FC, PWP and AWC values was respectively observed as 22.4%, 16.8% and 31.9% in VV treatment in 2014. Improved organic matter contents also provide better aggregation and aggregate stability, water holding capacity and reduce soil bulk density. Soil organic matter supplementation to soils improves water holding capacity (Candemir & Gülser 2010; Demir & Gülser 2015; Demir 2019; Demir 2020). Cover crops can increase soil moisture due to higher water holding capacity of the soil from increased soil C input and aggregation (Augé et al 2001). Demir et al (2019a) reported that highest rises were in the *Vicia villosa* Roth treatment, diminishing the BD by 12.7% while rising the SOM by 63.5%, Ks by 248.7%, AWC by 19.4% and SSI by 9.4% in the 0-20 cm soil depth in the apricot orchard with clay soil.

The differences in FC, PWP and AWC values of cover crop treatments were not found to be significant for the 20-40 cm soil depth in both years of the experiment. The FC values varied between 15.2-16.6%, the PWP values between 9.6-10.5%, the AWC values between 5.1-6.5% (Table 7).

3.3.3. Saturated hydraulic conductivity (Ks) and *volumetric water content (θ)*

There were significant increases ($P<0.01$) in saturated hydraulic conductivity values (Ks) and volumetric water content (θ) with cover crop treatments when compared to values of the control in both years of the experiment (Table 5). As compared to control, the percent changes in Ks and θ are provided in Table 6. The greatest increases in Ks and θ values at 0-20 cm depth in the apple orchard in 2013 were observed in *Vicia villosa* treatments (99.1% and 79.6%, respectively). The greatest increase in saturated hydraulic conductivity and volumetric water content were observed in VV (respectively as 109.8% and 89.1%) and the smallest increase in saturated hydraulic conductivity and volumetric water content was observed in TM (respectively as 52.8% and 52.2%) at the 0-20 cm soil depth in 2014. Volumetric water contents generally increased with decreasing bulk densities of cover crop treatments. Among the physical soil quality variables, the greatest increase was observed in Ks values of soil samples with cover crop treatments. Gülser (2004) found that due to cropping effects, volumetric water content value increased from 18.7% for control soil to 26.5% for the ryegrass treatment.

The differences in Ks and θ values of cover crop treatments were not found to be significant for the 20-40 cm soil depth in both years of the experiment. Ks values ranged from 5.9 cm h^{-1} in control and herbicide treatment to 7.0 cm h^{-1} in *Vicia villosa* (VV) treatment for the 20-40 cm soil depth in 2013. Ks values ranged from 5.9 cm h^{-1} in *Trifolium meneghinianum* (TM) treatment to 6.9 cm h^{-1} in *Vicia villosa* (VV) and Festuca rubra subsp. rubra (FRR) treatments for the 20-40 cm soil depth in 2014 (Table 7). The mean θ values for 20-40 cm soil depth were 9.88% in 2013 and 10.43% in 2014 (Table 7).

3.3.4. Aggregate stability (AS) and mean weight diameter (MWD)

As compared to control, cover crop treatments significantly increased the aggregate stability (AS) and mean weight diameter (MWD) values at 0-20 cm soil depth in both years of the experiments (Table 5). Cover crop treatments increased AS value from 17.2% in the control treatment to 20.7% in *Trifolium repens* L. (TR) treatment in 2013. The greatest AS value (21.5%) was observed in VV and least (17.1%) in HC in 2014. The greatest increases in MWD values at 0-20 cm depth in the apple orchard in both years were observed in *Vicia villosa* treatments (14.7% in the first and 21.0% in the second year) (Table 6). Improved aggregate stability increased crop yield and organic matter returns (Demir & Gülser 2015; Demir & Işık 2019c). Yakupoglu et al (2011) reported that annual *V. lutea* L. (wild) L. and *sphaericus* L. (wild) under Mediterranean climate significantly increased aggregate stability by 73% and 63%, respectively, in surface soil when compared to values of the control plot. According to the studies of Parlak et al (2015), the lowest aggregate stability (31.19%) was determined in control while the highest (66.29%) one in vetch treatmnet in olive orchards. Increasing vegetative cover also increases root development. Close relationships between plant roots and soil erodibility and indicated improved soil strength, shear strength, structural stability and aggregate stability with improved soil properties

(Zhou & Shangguan 2007). However, any root related parameters were not observed in this study. In our study, wet aggregates stability increased in the presence of the cover crops. Several authors (Tisdall & Oades 1979; Tisdall & Oades 1982; Six et al 2004) have reported that the organic substances supplied by roots, i.e. root debris and exudates, may stabilize aggregates directly or indirectly by providing a source of energy for microorganisms in the rhizosphere which may produce stabilizing materials such as mucilaginous polysaccharides. Ramos et al (2010) reported that two cover crop (oat-*Avena sativa* L. and oat- vetch-*Vicia sativa* L.) treatments increased mean MWD values (%15) as compared to control. Changes in the mean weight diameter showed that aggregates were more resistant to physical abrasion under cover crops.

The differences in AS and MWD values of cover crop treatments were not found to be significant for the 20-40 cm soil depth in both years of the experiment. AS values at 20-40 cm soil depth varied between 14.9-16.1% with a mean value of 15.44% (Table 7). The mean MWD values for 20-40 cm soil depth were 0.40 mm in 2013 and 0.41 mm in 2014 (Table 7).

3.3.5. Structural stability index (SSI)

The highest SSI value was obtained from in *Vicia villosa* (VV) *in* 2013 (13.4%) and in 2014 (13.5%) (Table 5). Percent increase in the SSI values with cover crop treatments as compared to control varied between 5.6% in the FRR and 10.7% in VV in 2014 (Table 6). Many studies indicated that cover crops sustained a better soil structure, increased soil total porosity, aeration and water holding capacity and thus decreased bulk density (Steele et al 2012). Similarly, Demir et al (2019a) determined that different cover crops (*Vicia pannonica* Crantz, *Vicia pannonica* Crantz (70%)+*Triticale* (30%) mixture, *Phacelia tanacetifolia* Benth., *Vicia villosa*, and *Fagopyrum esculentum* (Moench.) increased available water capacity, field capacity, permanent wilting point, volumetric water content, total porosity, aggregate stability and saturated hydraulic conductivity values and significant decreases in bulk density values in an apricot orchard with clay soil. Gülser (2004) found that due to cropping effects, SSI values increased from 57.4% for control soil to 63.0% for the bromegrass treatment.

The differences in SSI values of cover crop treatments were not found to be significant for the 20-40 cm soil depth in both years of the experiment. Mean SSI values at 20-40 cm soil depth varied between 9.6-10.5% (Table 7).

3.4. Relationships among the soil quality variables

Significant correlations were observed between EC and OM (0.801**), between EC and BSR (0.753*), between the OM and P (0.816**), between the pH and Na (0.749*), between the total N and K (0.876**) and between the OM and K (0,802**). Gülser (2006) reported reduced the bulk density and increased total porosity with increasing the organic carbon contents. The organic matter is the primary binding agent among soil aggregates. Therefore, manure or sludge rich in organic carbon improves aggregate stability. The OM had significant positive correlations with Ks (0.960**), AS (0.915**), FC (0.827**) and significant negative correlations with BD (-0.761**).

3.5. Comparison between different types of cover crop

All cover crop treatments increased organic matter, total N, electrical conductivity, exchangeable K, available P, basal soil respiration, available water content, saturated hydraulic conductivity, total porosity, volumetric water content, aggregate stability, mean weight diameter and structural stability index while decreasing soil pH, exchangeable Na and bulk density values as compared to control without cover crops. However, legume cover crops (*Trifolium repens* L. (TR), *Vicia villosa* (VV) and *Trifolium meneghinianum* (TM)) were found mostly more effective non-legume (*Festuca rubra rubra* L. (FRR) and *Festuca arundinacea* (FA)). Cover crops improve nutrient utilization when the species have root systems that are able to extract and mobilize nutrients from deeper layers and the legumes can add nutrients to the soil by biological fixation (USDA 1996). Therefore, in this study, the improvements in soil quality were more pronounced with legume and grass cover crops mixture (*T. repens* (40%)+*F. rubra rubra* (30%)+*F. arundinacea* (30%)) than with grass cover (*Festuca rubra* subsp. *rubra* and *Festuca arundinacea*) treatments. It is clearly known that legume and grass cover crops have positive effects on soil quality variables, but these effects vary depending on plant species. Thus, a particularly careful selection of suitable cover crops is significant to improve soil quality besides their yields for specific ecological conditions. Cropping systems improve soil structure through several mechanisms such as aggregate enrichment by fine roots and associated fungal hyphae, modified soil-water relationships or stimulation of microbial carbohydrate production

(Tisdall & Oades 1979; Obi 1999; Tisdall & Oades 1982). Cover crops, especially *Vicia villosa* and *Trifolium repens* could be incorporated into cropping systems to improve soil quality and to increase apple yield and to provide sustainable soil management. The improvements were more pronounced with legume covers than with grass covers.

3.6. Biomass yield of cover crops

In general, importantly higher biomass was produced in 2013 than in 2014 (Figure 1). *Trifolium repens* (40%)+*Festuca rubra rubra* (30%)+*Festuca arundinacea* (30%) mixture produced significantly higher fresh biomass (Figure 1a) than the other species in both years of the experiment (respectively as 57790 kg ha^{-1} and 33193 kg ha^{-1}). The lowest cover crop dry biomass (Figure 1b) was obtained from *Trifolium meneghinianum* (2125 kg ha^{-1}) in 2013 and *Vicia villosa* (590 kg ha^{-1}) in 2014.

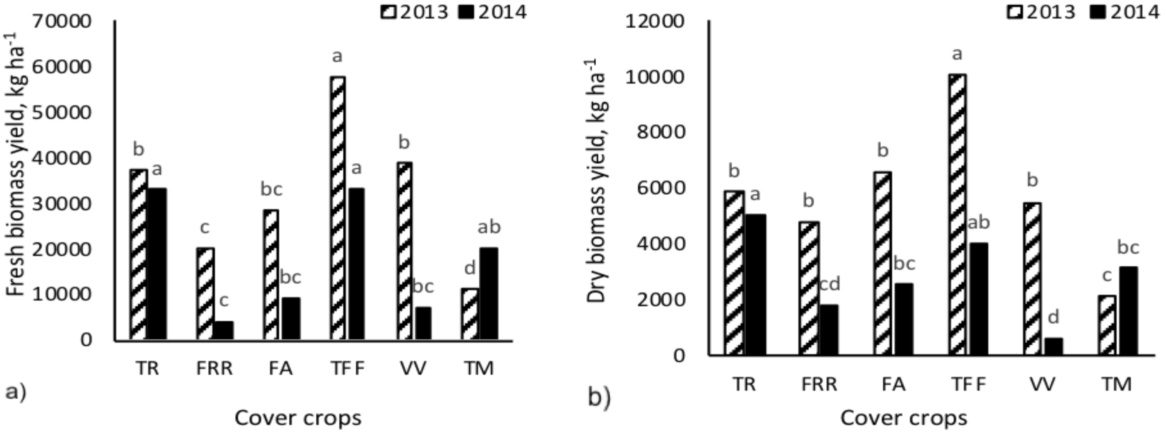

Figure 1- Fresh (a) and dry (b) biomass yield values of cover crops (TR, *Trifolium repens* L.; FRR, *Festuca rubra* subsp. *rubra*; FA, *Festuca arundinacea*; TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa*; TM, *Trifolium meneghinianum*; MC, Mechanically cultivated; HC, Herbicide treatment; C, Control) (P<0.05)

3.7. Apple yield

Cover crop treatments increased yield in the apple orchard compared to the control in both years of the experiment, and these increases were statistically significant (P<0.05) (Figure 2). Cover crop treatments increased apple yield content from 20.1 ton ha^{-1} in the control to 26.0 ton ha^{-1} in *Trifolium repens* L. (TR) and *Vicia villosa* (VV) treatments in the first year of the experiments. Apple yield in the second year of the experiment were ordered as; MC (12.4 ton ha^{-1}) < HC (14.7 ton ha^{-1}) < C (16.6 ton ha^{-1}) < FRR (18.0 ton ha^{-1}) < FA (19.6 ton ha^{-1}) < TM (20.6 ton ha^{-1}) < TR (21.6 ton ha^{-1}) < TFF = VV (21.8 ton ha^{-1}) (Figure 2). While the highest mean apple yield (23.9 ton ha^{-1}) was obtained from VV, the lowest mean yield (13.7 ton ha^{-1}) was obtained from MC treatment. Perennial cover crops, a mixture of legumes and grasses increased apple yield. Regarding the effect of cover crops on the apple yields, the lowest yield was obtained from the MC plots. Since the plow in the orchards damages the tree roots, mechanical weed control was practiced in the form of mow. Such a case then, caused the weeds to germinate again and thus increased the yield loss. Mullinix & Granatstein (2011) reported that *Trifolium repens* led to improved tree growth, greater fruit yield and lower water use than bare ground in a mature apple orchard. Işık et al (2014) reported that regarding the impacts of cover crops on hazelnut yields, the lowest yield was obtained from control (1439.3 kg ha^{-1}), while the highest yield was determined from *F. Arundinacea* (1546.3 kg ha^{-1}) treatment. Demir et al (2019a) found that cover crop treatments (*Vicia pannonica* Crantz, *Vicia villosa* Roth, a mixture of *Vicia pannonica* Crantz (70%) and *Tritikale* (30%), and *Fagopyrum esculentum and Phacelia tanacetifolia* Benth) generally increased mean yield levels in apricot orchard with clay soil as compared to control without cover crops. Even with the use of cover crops the addition of organic fertilizers is necessary in order to maintain good yields and sufficient tree vigor (Sánchez et al 2007). Present findings comply with the results of earlier studies (Reddy 2003; Harrington et al 2005). Crop yields primarily depend on organic matter contents of soils (Mann et al 2002). Organic matter directly improves physico-chemical and biological quality attributes of the soils, thus improves yield levels (Franzluebbers 2002). However, the amount of increase in crop yield depends upon crops grown. In addition, species of cover crop also have effects on yield increases (Chalk 1998).

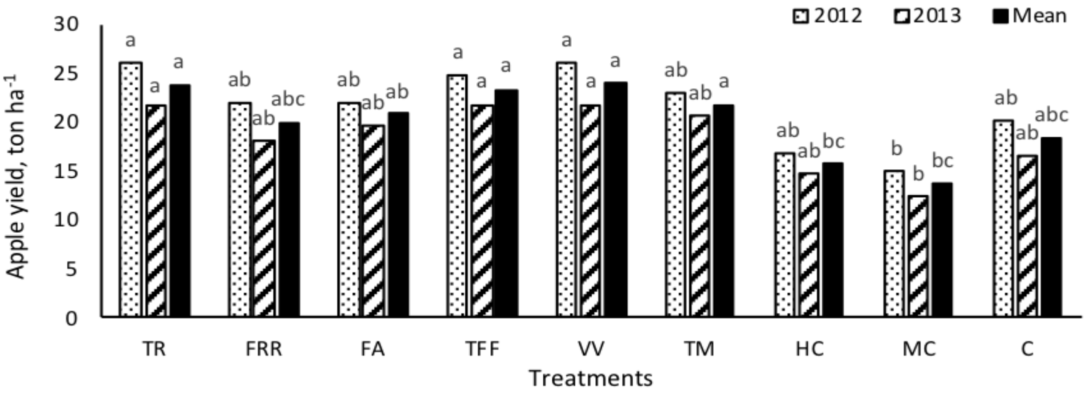

Figure 2- Effects of treatments on apple yield (TR, *Trifolium repens* L.; FRR: *Festuca rubra* subsp. *rubra;* FA, *Festuca arundinacea*; TFF, *T. repens* (40%) + *F. rubra rubra* (30%) + *F. arundinacea* (30%) mixture; VV, *Vicia villosa*, TM, *Trifolium meneghinianum*; MC, Mechanically cultivated; HC, Herbicide treatment; C, Control) (P<0.05)

4. Conclusions

In the present study, cover crop treatments generally improved soil quality variables at 0-20 cm soil depth and increased apple yield compared to the control. The cover crop treatments improved soil quality variables like soil organic matter, basal soil respiration, bulk density, aggregate stability, saturated hydraulic conductivity, available water capacity compared to the soil of a nontreated control. The organic matter is one of the primary soil quality properties and has significant correlations with the other soil quality variables. The improvements were more pronounced with the legume covers (*Trifolium repens* L., *Vicia villosa* and *Trifolium meneghinianum*) than with the grass covers (*Festuca rubra* subsp. *Rubra* and *Festuca arundinacea*). While the highest mean apple yield was obtained from *Vicia villosa* and *Trifolium repens* L. treatments, the lowest mean apple yield was obtained from mechanically cultivated treatment. According to control, the differences in the physical and chemical soil quality variables and basal soil respiration values of all treatments were not found to be significant for the 20-40 cm soil depth in both years of experiments. Mechanically cultivated and herbicide treatments were not found to be significant for the 0-20 and 20-40 cm soil depths as compared to control. However, in coverless (bare) apple fields may result in increased erosion and run-off. In addition, the results of this study are important in the perspective of organic fruit production. It was concluded based on current findings that cover crops, especially *Vicia villosa* and *Trifolium repens* could be incorporated into cropping systems to improve soil quality and to increase apple yield and to provide sustainable soil management. Furthermore, the cover crops could enhance soil, water, and environmental quality by reducing the use of chemical fertilizers.

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