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Short Term Effects of Different Tillage Methods on Nitrate Content in Soil and Corn Yield

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ABSTRACT

Residual nitrate nitrogen in a soil profile is influenced by agricultural practices such as fertilisation, irrigation and cultivation. In this study, the effects of different tillage methods and timing on corn yield were investigated in relation to soil penetration resistance and variation of nitrate nitrogen (NO_3-N) through a vertisol soil depth. A field experiment was carried out with three different tillage times (Fall-at the end of October, Early-at the middle of May; and Late-at the end of May) and tillage methods (mouldboard, chisel and direct drilling) in the Black Sea Agricultural Research Institute in 2011. Nitrate nitrogen values in 0-20, 20-40 and 40-60 cm soil layers were measured for the six different soil sampling times using the potentiometric method. Corn yield values generally decreased when the first soil tillage time when mould board and chisel applications were delayed or were made at the end of May. The fall tillage treatment with mouldboard had the highest corn yield (61.1 Mg/ha) while the lowest yield value (30.9 Mg/ha) was found with the direct drilling treatment. Generally, late tillage timing at the end of May reduced corn yield due to changing soil structure with reducing penetration resistance, increasing macroporosity and nitrate leaching in the soil profile. In conclusion, fall season soil tillage using mouldboard in clay soils is suggested to achieve optimum plant growth soil conditions resulting in high corn yield, and because of nitrate leaching, it also results in beneficial effects on conservation of water pollution.

Keywords: Tillage methods, tillage timing, nitrate, soil profile, corn.

INTRODUCTION

It is known that intensive agricultural practices have significant effects on soil degradation through loss of soil organic matter and a decline in soil structure resulting in soil compaction and root growth (Usowics and Lipiec 2009; Busscher and Bauer 2003). Nitrogen is one of the most important plant nutrients in arable agricultural fields. The nitrogen cycle in soil is largely microbiologically mediated and the main components involve the transformation of organic N into plant-available mineral forms, primarily nitrate (NO_3-N) and ammonium (NH_4-N) nitrogen. This process depends on several agronomic practices, mainly cropping

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systems, soil tillage, and N fertilisation (source, amount, and time of application) (Montemurro 2009). Different nitrogen forms (e.g., urea and ammonium) in most fertilisers can be transformed into nitrate N when applied into soil in crop rotation systems (Ju *et al*. 2003; Li *et al.* 2011). A considerable amount of inorganic nitrogen, especially in residual nitrate form, accumulates in the soil profile after harvesting crops in the intensive agricultural production systems (Li *et al*. 2011). The residual soil nitrate is a key factor for optimising crop N management, improving N use efficiency, and reducing the impact of farmland N losses on the environment (Zhang *et al*. 2017).

Soil tillage has a large impact on governing plant nutrient dynamics (Pekrun *et al.* 2003). Tillage techniques affect the root absorption of macronutrients and trace elements. The distribution pattern of macronutrients and micronutrients in topsoil is usually modified by tillage systems (Ozpinar and Cay 2009). Regular soil disturbance causes a decline in soil N due to the mineralisation of organic matter (McCarty *et al.*, 1995). Cultivation exposes organic matter previously not accessible to microbial attack. Therefore most N losses occur during the first few years after cultivation (Stevenson 1965). Due to the decrease in soil disturbance in no-till, the N mineralisation rate is much slower. Lower mineralisation, higher leaching and higher denitrification (due to higher surface water content) in no-till tend to lower available N, particularly in spring (Thomas and Frye 1984). Gülser and Candemir (2012) reported that nitrate has an important role in plant nutrition as it is leached easily in a soil profile. Nitrate leaching in soils is affected by several factors such as soil texture, soil management systems, fertiliser types, irrigation process and climate conditions.

Penetration resistance provides an indicator of when soil strength becomes too great for effective penetration by crop roots. In several studies, soil penetration resistance has been used to determine tillage effect on soil physical properties and to estimate soil trafficability and soil resistance to plowing, seedling emergence and root growth (Hakansson *et al*. 1988; Bengough and Young 1993; Gülser *et al*. 2011). Root growth of most agricultural crops is reduced dramatically when penetration resistance exceeds about 1.7 or 2 MPa (Bengough and Mullins 1990; Canarache 1990; Arshad *et al*. 1996).

Also, the effects of tillage on net mineralisation are very much affected by the time of tillage and environmental conditions prevailing during and after the tillage operations. As a consequence, the timing of tillage can be used as a management tool to control the seasonal pattern of mineralisation (Pekrun *et al.* 2003). Salem *et al*. (2015) determined the short term effects of four tillage treatments on soil physical properties and maize productivity in a field experiment in the spring of 2013 on a loamy soil. They found a clear difference in corn yield between zero tillage and conventional tillage treatments due to an increase in soil compaction in conventional tillage and a decrease in soil temperature in zero tillage.

Alternative tillage systems to reduce of NO_3-N leaching is an important research subject in farming practices that reduce excess fertiliser use and improve

water quality. The effects of tillage and nitrogen management systems on N use by plants and nitrate movement through the soil profile have been studied (Ju *et al.* 2003; Al-Kaisi and Licth 2004; Li *et al.* 2011). Tillage is one of the most important factors influencing NO_3-N transport to groundwater in agricultural practices. It has a direct effect on both surface and subsurface soil water properties and leaching characteristics. Kitur *et al*. (1984) determined that 28 to 42% of fertiliser N remained in the soil depending on tillage and the N rate applied to corn. We hypothesised that soil tillage methods and timing can produce beneficial effects on soil structural properties and nitrate variation in a clay soil depth and can provide an opportunity to increase corn yield. Therefore, the objective of this research was to evaluate the effects of tillage methods and timing on penetration resistance, nitrate contents through a vertisol soil depth, and corn yield.

MATERIALS AND METHODS

This study was carried out in a field experiment at the Black Sea Agricultural Research Institute, Samsun-Turkey in 2011where the mean annual rainfall was 844 mm. The chemical and physical characteristics of the Vertisol soil determined in soil samples for each sampling depth were as follows: particle size distribution by hydrometer method, bulk density (BD) by undisturbed soil core method (Demiralay 1993), soil pH, 1:1 (w:v) soil:water suspension by pH meter, electrical conductivity (EC 25ºC) in the same suspension by EC meter, and organic C content by Walkley-Black method (Kacar 1994). According to the soil properties given in Table 1, the results can be summarised as follows: (i) soils in each depth had a clay textural class; (ii) none were saline, (iii) pH was neutral, and (iv)low in organic matter content (Soil Survey Staff 1993). Predominant clay type in the soil is was montmorillonite with a high shrink-swell potential.

The field experiment was carried out with three different tillage timings (fall (F) at the end of October, 2010; early (E) at the middle of May, 2011 and late (L) at the end of May, 2011) and three different tillage methods (Mouldboard (M), chisel (C) and direct drilling (DD)) in a factorial experimental design with three replicates. Plot dimension of each treatment was 4.2 m wide (six crop rows) and 7 m long. Except for the DD tillage method, secondary tillage applications with disc harrow and rotary tiller were applied to all plots for seedbed preparation at the same time on 6 June 2011. A corn variety known as "Karadeniz Yildizi" was used as a plant material. Sowing corn seeds with 70 cm spacing in rows using direct seeding machine was completed on 15 June 2011.

In the Black Sea Region of Turkey, corn needs around 200kg N ha^{-1} of fertiliser during the growing period. Fertilisation of 390kg ha^{-1} calcium ammonium nitrate (26%N) was made with sowing on 15 June 2011, while the second fertilisation of 300 kg/ha ammonium nitrate (33% N) was made on 26 July 2011. Nitrate (NO_3-N) values of soil samples taken from 0-20 cm, 20-40 cm and 40-60 cm depths from the plots were measured potentiometrically using Consort P903 analyser for six different soil sampling dates; 4th and 19th July, 8th and 24th August, 15th September and 28th October, 2011.

TABLE 1
Some soil properties of the experimental field

Mean values of soil properties	Soil depth, cm		
	0-20	20-40	40-60
Clay, %	74.17	75.40	75.81
Silt, %	16.40	15.22	15,45
Sand, %	9.43	9.38	8.74
Soil texture class	clay	clay	clay
Organic matter, %	2.05	1.72	1.39
EC, dS m^{-1}	0.93	0.69	0.46
pH(1:1)	6.95	7.25	7.14

Corn yield was also determined at harvest on 22nd October 2011. Two rows of plants in the middle of each plot were harvested at 3 m distance and total biomass yield was determined.

Soil penetration values were measured from soil surface to 0.45 m depth at 0.05 m intervals using a hand-held penetrometer, 16.60 mm in diameter and 30° in angle cone, at the time of soil sampling. Penetration resistance (PR) in MPa was calculated by using the following equation (Korucu 2002; Selvi 2001);

$$PR = 0.0981\ F/A \qquad (1)$$

where PR is the penetration resistance (MPa), F is recorded force value (kgf) and A is the base area of cone in cm^2.

SPSS was used for the variance analyses of the experimental data.

RESULTS

Penetration Resistance

Soil penetration resistance (PR) and gravimetric soil moisture content (W) values measured at different soil depths for each tillage treatment are given in Table 2.

Based on the results of variance analysis, effects of different tillage methods on PR values were found to be statistically significant ($P<0.05$), but the triple interactions among treatment x depth x timing were insignificant. Gravimetric soil moisture contents (W) increased from soil surface to 60 cm soil depth for all treatments. Soil moisture content in the first sampling time was higher than in the last soil sampling time. PR values generally decreased with

TABLE 2
Effects of different tillage methods on penetration resistance (PR) and gravimetric moisture content (W)at different soil depths at the first and last sampling dates

Tillage method	Soil sampling date	Soil depth					
		0-20 cm		20-40 cm		40-60 cm	
		PR, MPa	W, %	PR, MPa	W, %	PR, MPa	W, %
MF	04.07.2011	0.81	56	1.07	53	1.07	60
	28.10.2011	1.28	26	1.40	36	1.33	43
ME	04.07.2011	0.64	53	0.78	57	0.80	66
	28.10.2011	1.23	30	1.54	36	1.40	49
ML	04.07.2011	0.62	62	0.73	56	0.73	61
	28.10.2011	1.13	27	1.23	37	1.23	52
CF	04.07.2011	0.78	49	1.00	56	1.00	62
	28.10.2011	0.98	30	1.20	41	1.20	48
CE	04.07.2011	0.72	50	0.95	55	0.97	57
	28.10.2011	0.98	29	1.23	39	1.20	45
CL	04.07.2011	0.69	54	0.93	55	0.93	53
	28.10.2011	0.94	27	1.17	34	1.17	47
DD	04.07.2011	0.81	49	1.19	49	1.20	51
	28.10.2011	1.53	32	1.56	41	1.50	53
Pooled Standard Deviation		0.16	7.64	0.15	5.23	0.13	4

Notes: MF: mouldboard fall; ME: mouldboard early; mouldboard late; CF: chisel fall; CE: chisel early; CL: chisel late; DD: direct drilling.

increasing W content. PR values in chisel treatments were always lower than that in mouldboard (M) and direct drilling (DD) treatments. In each tillage method, PR value increased from surface (0-20 cm) to 20-40 cm soil depth. When the soil depth increased from surface to 40-60 cm soil layer, increments in the PR values decreased in mould board fall (MF), mouldboard early (ME), chisel early (CE) and DD treatments at the last soil sampling time. PR values in DD treatment were generally higher than in the other treatments. The highest PR value (1.53 MPa) was observed in the 0-20 cm soil depth of DD treatment (P <0.001). The lowest PR value (0.62 MPa) was observed in 0-20 cm soil depth of mouldboard late (ML) treatment in the first sampling time (P <0.001).

NO_3-N Through Soil Depth Influenced Tillage Methods and Timing

Descriptive statistics for the effects of soil tillage methods on soil NO_3-N contents measured in 0-20, 20-40 and 40-60 cm depths at the six different soil sampling times are given in Table 3. While the highest mean NO_3-N content value (296.3 mg kg^{-1}) was obtained from 0-20 cm depth of MF application, the lowest mean NO_3-N content value (134.8 mg kg^{-1}) was obtained from 20-40 cm depth of ME application. Soil NO_3-N contents showed variation during the corn growth period

TABLE 3
Descriptive statistics of NO_3-N (mg kg^{-1}) values in soil depths influenced by tillage methods

Tillage method and timing	Depth, cm	Minimum	Maximum	Mean	Standard deviation	CV, %	Skewness	Kurtosis
MF	0-20	71.5	829.2	296.3	283.8	95.8	1.67	2.91
	20-40	63.5	485.0	218.0	173.2	79.5	0.73	-1.10
	40-60	49.7	323.1	192.1	106.0	55.2	-0.19	-1.40
ME	0-20	91.9	492.4	266.5	160.7	60.3	0.25	-1.68
	20-40	63.3	196.6	134.8	55.6	41.2	-0.42	-2.00
	40-60	64.2	217.2	150.0	59.4	39.6	-0.42	-1.42
ML	0-20	66.9	331.1	195.1	95.8	49.1	0.04	-0.73
	20-40	54.7	315.9	180.4	97.5	54.0	0.12	-1.33
	40-60	49.9	236.6	158.3	69.0	43.6	-0.54	-0.21
CF	0-20	82.4	330.7	211.3	98.3	46.5	-0.04	-1.64
	20-40	99.9	271.2	185.8	71.9	38.7	0.02	-2.19
	40-60	70.1	327.1	191.2	97.9	51.2	-0.03	-1.10
CE	0-20	81.1	299.0	198.2	80.8	40.8	-0.28	-1.07
	20-40	88.3	241.5	152.0	56.6	37.2	0.51	-0.10
	40-60	61.3	238.9	152.8	63.0	41.3	-0.18	-0.35
CL	0-20	124.8	364.3	216.7	86.7	40.0	0.92	0.99
	20-40	68.8	322.6	197.1	104.5	53.0	-0.41	-1.67
	40-60	65.9	237.4	171.3	66.2	38.6	-0.70	-0.23
DD	0-20	67.6	406.5	184.2	127.8	69.4	1.21	1.01
	20-40	72.1	212.9	137.3	57.3	41.7	0.08	-2.04
	40-60	56.0	221.1	141.2	70.2	49.8	-0.07	-2.17

Notes: MF: mouldboard fall; ME: mouldboard early; mouldboard late; CF: chisel fall; CE: chisel early; CL: chisel late; DD: direct drilling.

and generally decreased from the first to last sampling date. Mean NO_3-N contents in surface soil layer (0-20 cm) were generally higher than that in subsurface soil layers (20-40 cm and 40-60 cm).

Effects of different tillage methods on mean NO_3-N values in different soil depths are given in Figure 2. The highest total mean NO_3-N contents along the soil profile (0-60 cm depth) for mouldboard (706 mg kg^{-1}) and chisel (588 mg kg^{-1}) treatments were determined when the first tillage application was done in the fall season.

Corn Yield

The effects of different tillage methods and timing on corn yield, given in Figure 3, were found to be statistically significant (P<0.01). While the highest corn yield (61.11 Mg ha^{-1}) was obtained from MF treatment, DD treatment had the lowest corn yield (30.95 Mg ha^{-1}). In both tillage treatments (mouldboard and chisel), corn yields were higher in fall tillage timing than late tillage timing. The corn

yields in all early tillage treatments were relatively higher than in the late tillage applications.

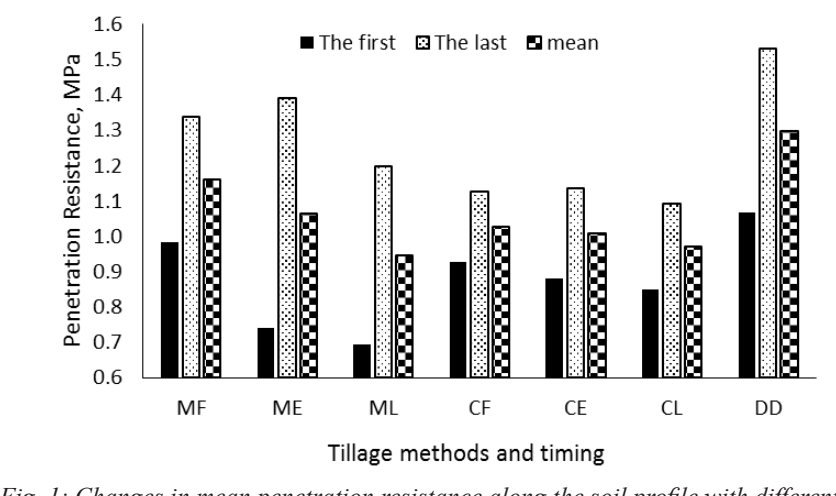

Fig. 1: Changes in mean penetration resistance along the soil profile with different tillage methods and timing.

Notes: MF: mould board fall; ME: mouldboard early; mouldboard late; CF: chisel fall; CE: chisel early; CL: chisel late; DD: direct drilling.

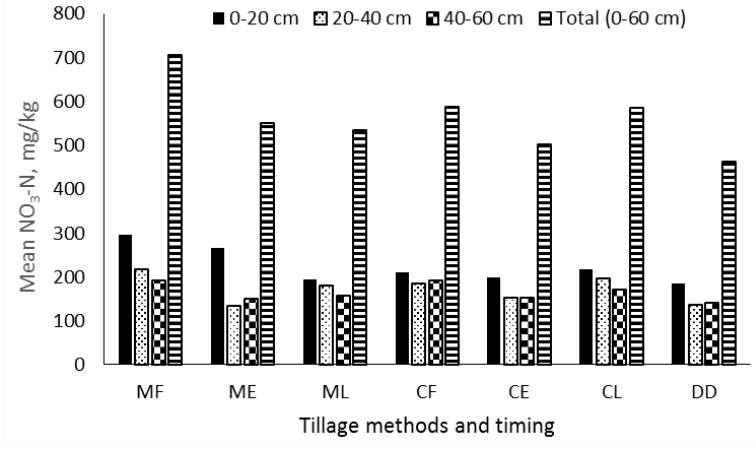

Fig. 2. Effects of tillage methods and the first tillage times on mean NO_3-N (mg kg^{-1}) contents along soil profile

Notes: MF: mouldboard fall; ME: mouldboard early; mouldboard late; CF: chisel fall; CE: chisel early; CL: chisel late; DD: direct drilling.

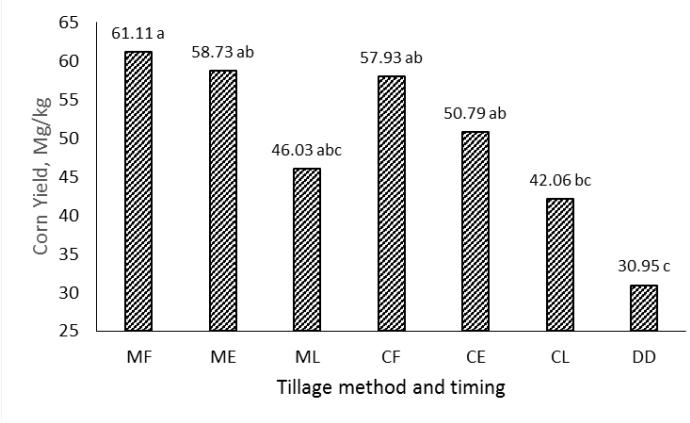

Fig. 3: Effects of tillage methods and timing on corn yield

Notes: MF: mouldboard fall; ME: mouldboard early; mouldboard late; CF: chisel fall; CE: chisel early; CL: chisel late; DD: direct drilling.

DISCUSSION

Soil penetration resistance is more sensitive than bulk density in detecting the effects of tillage management (Hammel 1989). Effects of different tillage methods on PR were more evident in the first 20 cm soil layer (Table 2). Mean PR values along the soil profile decreased when the first soil tillage was delayed from fall to late tillage time. Soil moisture contents through soil depth generally increased in all tillage treatments and moisture content in subsurface soil layers of DD treatment were generally higher than in other treatments. Soil water content is affected by tillage due to changes in soil structure and soil physical properties such as infiltration, surface runoff and evaporation (Zhai *et al.* 1990). Sarauskis *et al.* (2009) reported that the increase in soil water content in conservation tillage can be attributed to reduced evaporation, greater infiltration, and soil protection from rainfall impact. There were significant negative correlations between PR and W for 0-20 cm (-0.796**), 20-40 cm (-0.814**) and 40-60 cm (-0.714**) soil layers statistically (P<0.01). It is known that soil tillage has a loosening effect on soil structure and reduces soil bulk density and PR (Kirisci 2001). Gülser and Candemir (2012) found that increasing total porosity and soil moisture content by the application of organic wastes decreased penetration resistance of a clay soil. In DD or no tillage treatment, only natural soil loosening factors such as drying-wetting, freezing-thawing cycles or fauna activity, can reduce soil bulk density and soil strength (Hakansson and Lipiec 2000; Moraru and Rusu 2010; Gülser *et al*. 2011).

Total NO_3-N content decreased with decreasing mean PR along the clay soil profile. Except for DD and CL methods, generally fall tillage for mouldboard and chisel treatments had higher PR values and NO_3-N contents than early and late tillage applications (Figure 2). Nitrate N content in soil profile for DD

treatment was lower than in other treatments. Similarly, Sainju and Singh (2001) reported that NO_3–N accumulation in the soil profile was greater in intensive tillage systems than no-tillage using corn and a cover crop. Chisel tillage had higher total NO_3-N accumulation in the 0 to 60 cm soil depth than in other tillage systems, except for MF (Figure 2). Al-Kaisi and Licth (2004) reported that chisel plow resulted in higher residual soil nitrate buildup than strip tillage and no tillage in the 0 to 120 cm soil profile. It is known that soil hydrological properties such as water flow in soil, especially in clay soils, and leaching process are related to macropores and continuity of pores between aggregates which are mostly influenced by soil tillage applications (Addiscott and Dexter 1994; Armstrong and Harris 1996). Hillel (2004) reported that swelling of clays with wetting process imposes pressure on macropores and decreases infiltration rate with increasing micropores in soil. Dexter (2004) reported that soil compaction occurs usually because of loss or reduced size of the largest pores, increases in soil bulk density and soil strength, and decreases in macro porosity, infiltration and water-holding capacity. There was a significant positive correlation (0.793*) between PR values and sum of mean NO_3-N contents in 0-60 cm soil layer (P<0.05) (Figure 4). Therefore, it can be explained that leaching of NO_3-N in soil profile was less in fall tillage application than in early and late tillage applications due to decreasing macropores and permeability in soil profile over time.

Although the PR values in soil profile were higher in DD application compared to other applications (Figure 1), sum of mean NO_3-N contents in DD was lower than in other tillage methods (Figure 2). It can be explained that NO_3-N might be consumed by uncontrolled and excessive amount of weed population in DD plots.

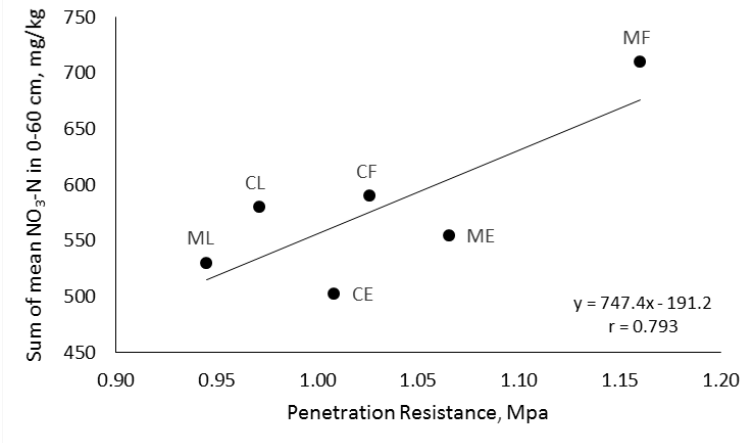

Fig. 4: Effects of penetration resistance on sum of total nitrate content through soil depth

Notes: MF: mouldboard fall; ME:mouldboard early; mouldboard late; CF: chisel fall; CE: chisel early; CL: chisel late; DD: direct drilling.

In this study, corn yield decreased with increasing soil penetration resistance. The lowest corn yield (30.95 Mg ha^{-1}) and the highest mean soil PR (1.3 MPa) were obtained in DD treatment. Similarly, other researchers reported that zero tillage in a short-term study decreased corn yield compared to conventional tillage due to higher soil compaction under zero tillage (Afzalinia and Zabihi 2014; Salem *et al*. 2015). Basamba *et al.* (2004) also indicated that the highest yield was obtained from mouldboard application compared with direct drilling application. As the soil tillage treatments were delayed from fall to late spring season, the corn yields also decreased. Similarly, Myrbeck *et al*. (2012) reported that high yields were realised with early autumn tillage practices. The lowest corn yields in CL treatment indicated that uptake of NO_3-N as well as other nutrients by corn decreased. Therefore, total NO_3-N content through soil depth of CL was higher than in CE application. There was a significant positive correlation (0.712*) between corn yield and sum of mean soil nitrate content in 0-60 cm soil layer (P<0.05) (Figure 5). Increasing NO_3-N contents in rhizosphere increased the yield of corn plant. Similarly, Varshney *et al.* (1993) reported that mouldboard tillage treatment had higher corn yield and more residual NO_3-N in the 60 cm soil profile than no-till treatment.

CONCLUSIONS

Total NO_3-N contents in fall soil tillage treatments were higher than that in the other treatments, except for CL application. While mouldboard application in fall season had the highest corn yield, DD tillage treatment had the lowest yield and total NO_3-N content through soil depth. Corn yield generally decreased when the first soil tillage was delayed for mouldboard and chisel tillage. Lower corn yield

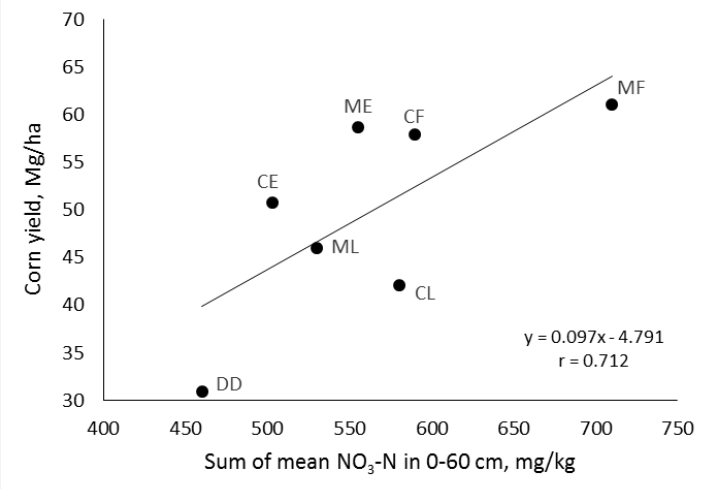

Fig. 5: Effects of sum of total nitrate content through soil depth on corn yield

Notes: MF: mouldboard fall; ME: mouldboard early; mouldboard late; CF: chisel fall; CE: chisel early; CL: chisel late; DD: direct drilling.).

in CL treatment probably decreased nitrate uptake by plants and increased total NO_3-N content through soil depth. Delaying soil tillage from fall to spring caused lower PR, higher macroporosity and leaching of NO_3-N along the soil profile. Fall season soil tillage using mould- board in clay soils can be suggested to lead to optimum plant growth conditions in soil and high corn yield. Fall season tillage timing can also produce beneficial effects on conservation of water pollution by nitrate leaching in the Black Sea Region of Turkey. This study indicated that tillage time and methods need to be evaluated for the availability of N for crop growth and to amount of NO_3-N remaining in soil profile for different crops and soil types in sustainable agricultural practices.

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