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Effects of wheel traffic and farmyard manure applications on soil CO_2 emission and soil oxygen content

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Abstract: This 2-year field study investigated the effects of different wheel traffic passes, manure amounts, and manure application methods on soil temperature, soil moisture, CO_2 emission, and soil O_2 content. To achieve this purpose, three different wheel traffic applications (no traffic, one pass, and two passes) were used. In the experiments, two different methods of manure applications (surface and subsurface) and three different farmyard manure amounts were used with a control plot (N0), 40 Mg ha^{-1} (N40), and 80 Mg ha^{-1} (N80). Manure was applied in both years of the experiment in the first week of April. For the subsurface application, the manure was mixed in at approximately 10 cm of soil depth with a rotary tiller. According to the results, soil temperature, soil moisture, penetration resistance, and bulk density increased with increasing wheel traffic except CO_2 emission for 2014 and 2015. CO_2 emission values decreased with traffic. Subsurface manure application caused more CO_2 emission compared to surface application. The increase in manure amounts led to an increase in CO_2 emission and soil moisture content. The effects on soil O_2 content were observed only during 2015. Maximum oxygen values were obtained in the plots where compaction was not applied. In addition, surface manure application caused more soil O_2 content compared to subsurface application.

Key words: Compaction, CO_2 emission, soil temperature, O_2 content, soil moisture

1. Introduction

One of the most important greenhouse gas is carbon dioxide (CO_2) because it makes up to 60% of the total greenhouse gases. CO_2 is released from soil by respiration. These respirations can be classified as microbial respiration, root respiration, and faunal respiration. Soil respiration occurs at the soil surface or within the upper layer of soil.

The level of agricultural mechanization and the increase in field traffic increase soil compaction (Altıkat, 2013). As a result of soil compaction, soil aggregate size distribution and soil porosity change. This situation affects the soil microbial population and functions because of the decrease in C mineralization (Grigal, 2000) and C-N ratio (Li et al., 2004). The soil pore system in compacted soil is generally unfavorable for oxic microbes because this situation generally restricts the gas-water ratio (Beylich et al., 2010) and causes a lower O_2 diffusion rate (Bilen et al., 2010).

Compaction not only prevents O_2 from being transported to the root surface, but also prevents CO_2 and toxic gases (both evolved and resident) from being removed from around the roots and vented to the atmosphere (Altıkat, 2013; Akbolat, 2009). Poor gas exchange causes the anaerobic layer to move closer to the surface and reduces rooting volume.

Application of farmyard manure in the soil generally increases CO_2 emissions (Fangueiro et al., 2008). Farmyard manure application to the soil can usually be performed with two methods: surface and subsurface applications. In subsurface application, farmyard manure is generally spread on the soil and then mixed with tillage machinery such as a plow and rotary tiller. Liquid manure can also be injected into the soil. Some researchers have reported that injection of liquid manure can reduce the nutrient transport by run-off (Daverede et al., 2004) and reduce NH_3 emissions compared to surface application (Misselbrook et al., 1996).

The purpose of this study is to determine the effect of wheel traffic, farmyard manure application technique, and manure amount on soil CO_2 emissions, O_2 content, soil temperature, and moisture content. Our specific hypotheses were as follows: 1) an increase in wheel traffic will result in a decrease in CO_2 emissions from the soil to the atmosphere, and a similar effect will be seen in the

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soil oxygen capacity; 2) the CO_2 emission from the soil to the atmosphere will be proportional to the amount of fertilizer; 3) maximum CO_2 emission will be observed in subsurface manure application.

2. Materials and methods

2.1. Study site

The field experiments were set up in Iğdır (39°48′06.69″N, 44°34′58.30″E), which is located in the east of Turkey. The experimental field's altitude is 800 m. In the experimental area the mean annual precipitation, minimum average temperature, and maximum average temperature are 256 mm, –3.3 °C, and 25.9 °C, respectively (www.mgm.gov.tr). In addition, meteorological data for Julian days are reported in Table 1.

Topsoil samples were collected from depths of 0–30 cm before farmyard manure and wheel traffic applications. The soil classification is Aridisol, the soil texture is clay loam, and the other properties of the soil are as follows: $CaCO_3$ 6.53%, EC 1228 µS cm^{-1}, pH 8.0, P 27.24 ppm, K 0.037 mEq 100 g^{-1}, and soil organic matter 1.06%. The experiments started in May 2014 and June 2015.

2.2. Experimental design

Three different experimental factors, provided to different levels, were studied as follows: i) wheel traffic (C0 = no traffic, C1 = one pass, and C2 = two passes), ii) manure application rates (N0 = control plot, N40 = 40 Mg ha^{-1}, and N80 = 80 Mg ha^{-1}); and iii) manure application methods (A1 = surface application and A2 = subsurface application).

The soil was tilled using conventional tillage systems before the experiments so that the plants and roots in the soil were removed from the experimental area. For this purpose, a moldboard plow was set to a depth of 300 mm, followed immediately by two passes with a tandem disk harrow and one pass of a shaped spring tooth harrow.

A tractor (New Holland TD85D) was driven for soil compaction (one pass and two passes) on the plots (20 × 35 m) in three blocks to account for spatial variability. The tires of the tractor were 47 cm wide, with a diameter of 61 cm, and they were inflated to a pressure of 120 kPa. The total weight of the tractor was 3.4 Mg, applying a mean vertical contact pressure of approximately 71 kPa. The mean volumetric water content of the soil surface was 31% and 30% for the 2014 and 2015 experimental periods, respectively. Fermented solid farmyard manure was used in this study. Before the application of manure, farmyard manure was stored for fermentation for about 1 year. In all plots tilled with the moldboard plow it was followed immediately by two passes with a tandem disk harrow and one pass of a shaped spring tooth harrow for avoiding plant respiration, which may otherwise affect CO_2 emissions. Manure was applied both years of the experiment in the first week of April. For the subsurface application, the manure was mixed in at approximately 10 cm of soil depth with a rotary tiller. The experimental scheme for the field analysis is given in Table 2. The properties of the manure used in the experiment are: organic matter 352 g kg^{-1}, pH 7.2, electrical conductivity 3.4 dS m^{-1}, total N 16 g kg^{-1}, P 8.2 g kg^{-1}, K 6.9 g kg^{-1}, Ca 65 g kg^{-1}, and Mg 5.8 g kg^{-1}.

2.3. Measurement of CO_2 emissions, PAR, O_2 content, moisture, temperature, and penetration resistance

In the study, an automated ACE and Soil CO_2 Exchange System (ADC BioScientific Ltd., Hoddesdon, UK) was used for determining the CO_2 emission (Figure 1). Volumetric soil moisture percentage (%) and temperature (°C) were simultaneously measured via CO_2 device sensors during the CO_2 measurement period. Soil O_2 content levels were determined with an ICT O_2 measurement instrument (ICT International Pty. Ltd., Armidale, Australia) (Figure 1).

The soil CO_2 and O_2 measurements were taken approximately 2 to 10 days from 9 May to 30 June in 2014 and from 12 May to 30 June in 2015, between 1000 and

Table 1. Meteorological data through the Julian days.

First year of the experiment (2014)											
Julian days	129	131	135	138	141	144	149	159	166	173	180
Max. temperature (°C)	25.4	27.1	25.2	30.7	23.1	26.4	27.9	26.9	32.3	35.2	31.7
Precipitation (mm)	0	0	1	0	0	2.2	10.3	0	0	0	1.1
Moisture (%)	65.9	59.5	59	48.1	60	65.8	57	55.4	31.1	23.5	41.1
Second year of the experiment (2015)											
Julian days	132	134	138	140	142	146	152	160	166	174	180
Max. temperature (°C)	19.8	20.7	27.4	30.3	26.9	28.8	31.7	30.5	31.1	36.5	35.4
Precipitation (mm)	3.9	0	0.3	0	0.2	7.1	0	0	0	0	0
Moisture (%)	71.2	55	31.9	27.8	46.2	42.4	23.2	32.8	28.5	23.2	26.8

Table 2. Experimental scheme for the field analysis.

<table>
<tr><td colspan="3">Wheel traffic (C)</td><td colspan="4">Manure amount (N)</td><td colspan="4">Method of manure application (A)</td></tr>
<tr><td colspan="3">C0: No traffic</td><td colspan="4">N0: Control plot (no manure)</td><td colspan="4">A1: Surface application</td></tr>
<tr><td colspan="3">C1: One pass</td><td colspan="4">N40: 40 Mg ha^{-1} manure amount</td><td colspan="4">A2: Subsurface application</td></tr>
<tr><td colspan="3">C2: Two passes</td><td colspan="4">N80: 80 Mg ha^{-1} manure amount</td><td colspan="4"></td></tr>
<tr><td colspan="11">2014</td></tr>
<tr><td colspan="11">CO$_2$ emission, soil temperature, and soil moisture measurements in Julian days</td></tr>
<tr><td>▨ 129</td><td>▨ 131</td><td>▨ 135</td><td>▨ 138</td><td>▨ 141</td><td>▨ 144</td><td>▨ 149</td><td>▨ 159</td><td>▨ 166</td><td>▨ 173</td><td>▨ 180</td></tr>
<tr><td colspan="11">Oxygen measurements in Julian days</td></tr>
<tr><td>▨ 129</td><td>131</td><td>135</td><td>▨ 138</td><td>141</td><td>144</td><td>▨ 149</td><td>159</td><td>166</td><td>173</td><td>▨ 180</td></tr>
<tr><td colspan="11">2015</td></tr>
<tr><td colspan="11">CO$_2$ emission, soil temperature, and soil moisture measurements in Julian days</td></tr>
<tr><td>▨ 132</td><td>▨ 134</td><td>▨ 138</td><td>▨ 140</td><td>▨ 142</td><td>▨ 146</td><td>▨ 152</td><td>▨ 160</td><td>▨ 166</td><td>▨ 174</td><td>▨ 180</td></tr>
<tr><td colspan="11">Oxygen measurements in Julian days</td></tr>
<tr><td>▨ 132</td><td>134</td><td>138</td><td>▨ 140</td><td>142</td><td>146</td><td>▨ 152</td><td>160</td><td>166</td><td>174</td><td>▨ 180</td></tr>
</table>

Shaded days are days of measurement.

Soil CO$_2$ exchange system

ICT oxygen measurement system

Figure 1. Soil CO$_2$ and O$_2$ measurement systems.

1200 hours with 7-min intervals. Every measurement took at least 10 min for CO$_2$ and O$_2$. Soil temperature and soil moisture at the depth of 10 cm were measured concurrently with CO$_2$ and O$_2$ measurements.

Cumulative CO$_2$ emissions (µmol m^{-2} s^{-1}) were calculated as follows:

$$\sum_i^n \frac{(X_i + X_i + 1)}{2} \mathrm{X}(t_{i+1} - t_i), \qquad (1)$$

where X_i is the first week's CO$_2$ reading and X_{i+1} is the following week's CO$_2$ reading at times t_i and t_{i+1}, respectively; n is the CO$_2$ measurement of the final week's events during the study period. Cumulative soil CO$_2$ emissions were then converted to Mg ha^{-1} day^{-1} of CO$_2$-C (Grote and Al-Kaisi, 2007).

A single photosynthetically active radiation (PAR) sensor (silicon photocell) was supplied as standard on every ACE station. The PAR reading has a range of 0–3000 µmol m^{-2} s^{-1} and was factory calibrated. The sensor was mounted on the ACE station close to the chamber at the end of the arm.

A penetrometer was used for determination of penetration resistance for soil compaction (FieldScout SC 900 Soil Compaction Meter, Spectrum Technologies, Aurora, IL, USA). Penetration values were determined in 0–30 cm with 5-cm intervals. Soil bulk density was determined for the depth ranges of 0–20 cm with 5-cm intervals using stainless steel rings having dimensions of 50 mm in diameter by 50 mm in height (Çelik and Altıkat, 2010). Each plot was sampled three times.

2.4. Statistical analysis

JMP 7 and SPSS statistical programs were used to determine the effects of both the main factors and their interactions. Analysis of variance (balanced ANOVA) was used to assess the significance of each treatment for soil properties and CO_2 emissions and O_2 content. Means were compared when the F-test for treatment was significant at the 5% level by using Duncan's multiple range tests.

3. Results and discussion

3.1. Penetration resistance and soil bulk density

Soil compaction primarily affects soil properties such as soil bulk density and penetration resistance. In our experiments, penetration resistance and soil bulk density were affected by wheel traffic in both 2014 and 2015 (Tables 3 and 4). Soil penetration resistance increased depending on wheel traffic and soil depth. In the 2014 experimental year, average penetration resistance (0–30 cm soil depth) in the control plot (C0) was observed as 0.907 MPa and this value was increased to 1.458 MPa and 2.166 MPa with one pass (C1) and two passes (C2), respectively. In 2015 these values were observed as 0.877 MPa, 1.43 MPa, and 1.913 MPa for C0, C1, and C2, respectively (Table 4). In

Table 3. Effects of wheel traffic on penetration resistance.

Penetration resistance (MPa) (2014, Julian days 129–149)							
Treatments	0–5 cm	5–10 cm	10–15 cm	15–20 cm	20–25 cm	25–30 cm	Average
C0	0.53 c√	0.483 c	0.581 c	0.818 c	1.519 c	1.5135 c	0.907
C1	0.895 b	1.029 b	1.257 b	1.940 b	1.904 b	1.724 b	1.458
C2	1.129 a	1.522 a	1.783 a	2.518 a	3.073 a	2.968 a	2.166
$P < 0.001$							
Penetration resistance (MPa) (2015, Julian days 132–152)							
Treatments	0–5 cm	5–10 cm	10–15 cm	15–20 cm	20–25 cm	25–30 cm	Average
C0	0.427 b	0.518 c	0.605 c	0.770 c	1.264 c	1.675 b	0.877
C1	0.562 b	0.921 b	1.198 b	1.650 b	1.977 b	2.270 a	1.430
C2	0.95 a	1.384 a	1.689 a	2.098 a	2.558 a	2.80 a	1.913
$P < 0.001$							

√: Means within the same column followed by the same letter are not significantly different.
C0: Control plot (no pass); C1: one pass; C2: two passes

Table 4. Effects of wheel traffic on soil bulk density.

Soil bulk density (g cm^{-3}) (2014, Julian days 129–149)					
Treatment	0–5 cm	5–10 cm	10–15 cm	15–20 cm	Average
C0	1.015 c √	1.064 c	1.125 c	1.146 c	1.088
C1	1.08 b	1.156 b	1.189 b	1.202 b	1.157
C2	1.26 a	1.310 a	1.220 a	1.349 a	1.285
$P < 0.001$					
Soil bulk density (g cm^{-3}) (2015, Julian days 132–152)					
Treatment	0–5 cm	5–10 cm	10–15 cm	15–20 cm	Average
C0	1.11 c	1.14 c	1.17 c	1.205 c	1.156
C1	1.16 b	1.17 b	1.225 b	1.255 b	1.203
C2	1.20 a	1.23 a	1.275 a	1.305 a	1.253
$P < 0.001$					

√: Means within the same column followed by the same letter are not significantly different.
C0: Control plot (no pass); C1: one pass; C2: two passes.

addition, increasing tractor passes had a similar effect on soil bulk density and for the first year of the experiment in the control plot (C0) 1.088 g cm^{-3}, one pass (C1) 1.157 g cm^{-3}, and two passes (C2) 1.285 g cm^{-3} were observed. In the second year of the experiment these values were 1.156, 1.203, and 1.253 g cm^{-3} for C0, C1, and C2, respectively.

Increasing field traffic is one of the most important parameters in soil compaction. Soil compaction caused by traffic of heavy vehicles and machinery results in soil structure deterioration, both in the topsoil and in the subsoil. By means of dynamic loading, soil physical properties such as pore size distribution and pore continuity are negatively affected, which entails a decrease in air and water permeability and results in increased soil strength or, in the presence of excess soil water, decreased soil strength due to kneading. Soil deformations were increased with the number of passes (Bakker and Davis, 1995; Şeker and Işıldar, 2000). While some studies stated that the critical limit of the number of passes was ten (Jorajuria and Laura, 2000), others claimed that the first pass of the wheel causes the soil compaction (Bakker and Davis, 1995). However, Balbuena et al. (2000) reported that the soil surface layer was significantly affected in 10 passes compared to 1 pass compared to the control plot at 50 cm in soil depth. In addition, axle load in excess of 9 Mg can cause increases in penetration resistance in a depth of >30 cm (Rengasamy, 2000).

Manure applications generally improve soil aggregation and produce an increase in soil organic matter. Manure applications alter soil pH and electrolyte concentrations, which can have adverse effects on soil structure (Haynes and Naidu, 1998).

3.2. Soil temperature and moisture

According to the obtained results, soil temperature and moisture contents increased with increasing compaction levels for both the 2014 and 2015 experimental periods. In the first year of the experiments average soil temperature and soil moisture content was determined as 34.25 °C and 46.19%. In the second year these values were 32.78 °C and 42.33%, respectively.

Soil compaction increased contact among soil particles and thus soil thermal conductivity increased (Guérif et al., 2001). Usowicz et al. (1996) reported that soil thermal conductivity was higher in compacted soil compared to the others. However, increasing soil compaction decreased evaporation and thus soil moisture content increased. Similar results were found in many other studies (Otten et al., 2000; Altıkat et al., 2006).

Soil temperature and moisture values were also affected by wheel traffic in both the 2014 and 2015 experimental periods (Table 5). Maximum values were observed for C2 (two passes) for both temperature and moisture for all the experimental periods (Table 6). Effects of wheel traffic on the soil moisture and temperature in terms of Julian days are given in Figure 2.

Soil temperature values were higher with the surface manure application and N0 manure amount values compared to subsurface application and other manure amounts. In the first year of the experiments, soil temperature was 34.49 °C and 34.57 °C for surface manure application and N0 manure amount, respectively (Table 6). Similar results were obtained in the second year of the experiment. In this year, soil temperature values were 32.65 °C and 33.21 °C for surface manure application and N0 manure amount, respectively (Table 6).

Values of soil moisture content in the subsurface manure application were higher compared to surface manure applications; however, the increase in the amount of manure increased soil moisture content in all of the experiments. In 2014 soil moisture content values were determined as 47.10% and 49.52% for subsurface manure applications and N80 manure amount, respectively (Table 6). Similar results were obtained in 2015. In this year, maximum soil moisture values were observed with subsurface manure applications and N80 manure amount at 43.01% and 42.98%, respectively (Table 6).

In all of the experimental periods maximum soil moisture content values were observed for C2 × N80, A2 × N80, and C1 × A1. In 3-way interactions, maximum values were determined for C2 × A2 × N80. Minimum soil temperature values were observed for A2 × N80, C0 × A2, and C0 × A2 × N80 interactions in both 2014 and 2015.

3.3. CO_2 emissions and O_2 level

CO_2 emissions were statistically significantly affected by field traffic in both years of the experiment (Table 5). It can be seen from Table 6 that the increase in field traffic caused a decrease in CO_2 emission, though the results of the second year of the experiment showed a very small decrease compared to the first year of the experiment (Table 6).

Minimum CO_2 emissions generally occurred at 129–131 Julian days in 2014 and 132–180 Julian days in 2015. However, peak volumes of CO_2 emission were observed at 159–166 Julian days and 138–180 Julian days in 2014 and 2015, respectively (Figure 3).

Effects of the method of application of manure on CO_2 emission can be seen in Figure 4. Subsurface application had higher CO_2 emissions compared to the surface application in both years of the experiment. CO_2 emission rates were also statistically significantly affected by manure amount in both experimental years (Table 5). We have found a clear positive relationship between manure amount and CO_2 emission rate and increasing the manure amount caused higher soil CO_2 emissions in both 2014 and 2015 (Table 6). The relationship between the amount of manure and CO_2 emissions can be seen in Figure 5.

Table 5. Analyses of variance for soil moisture, soil temperature, CO_2 emission, O_2 content, and cumulative CO_2 emission values.

2014					
Treatment	df	CO_2 emission	O_2 content	Soil temperature	Soil moisture
		P	P	P	P
C	2	0.001**	0.163 ns	0.001**	0.0012*
N	2	0.001**	0.940 ns	0.001**	0.001**
A	1	0.001**	0.259 ns	0.001**	0.0019*
C × N	4	0.001**	0.773 ns	0.001**	0.025*
C × A	2	0.001**	0.642 ns	0.001**	0.014*
A × N	2	0.001**	0.286 ns	0.001**	0.001**
C × A × N	4	0.001**	0.836 ns	0.001**	0.001**
2015					
Treatment	df	CO_2 emission	O_2 content	Soil temperature	Soil moisture
		P	P	P	P
C	2	0.0001**	0.0001**	0.001**	0.0012*
N	2	0.0001**	0.0003**	0.001**	0.001**
A	1	0.0005**	0.0001**	0.001**	0.0019*
C × N	4	0.479 ns	0.773 ns	0.001**	0.025*
C × A	2	0.045 ns	0.001**	0.001**	0.014*
A × N	2	0.289 ns	0.0001**	0.001**	0.001**
C × A × N	4	0.896 ns	0.0001**	0.001**	0.001**
Variance analyses for cumulative CO_2 emission					
Treatment	df	2014	2015		
		P	P		
Wheel traffic (C)	2	0.001**	0.001**		
Manure amount (N)	2	0.958 ns	0.001**		
Methods of application (A)	1	0.0587 ns	0.001**		
C × N	4	0.882 ns	0.479 ns		
C × A	2	0.352 ns	0.045*		
A × N	2	0.568 ns	0.289 ns		
C × A × N	4	0.993 ns	0.896 ns		

C: Wheel traffic, N: manure amount, A: methods of manure application, df: degrees of freedom; ns: nonsignificant, *: statistically significant ($P < 0.05$), **: statistically highly significant ($P < 0.01$).

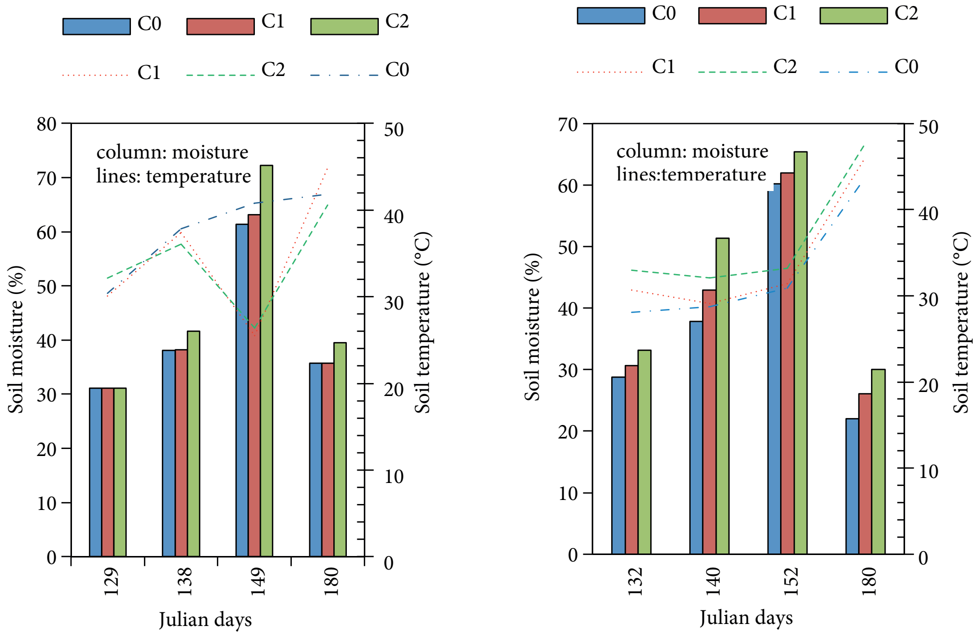
Cumulative CO_2 emission values are given in Table 6. By increasing the amount of manure, higher CO_2 emissions could be obtained. Furthermore, the application methods of manure were important. Subsurface manure application had higher CO_2 emissions in comparison to surface manure application.

One of the key factors influencing production of CO_2 is fertilization of arable soils (Bouwman et al., 2002). The effects of fertilization on CO_2 at the soil surface tend to occur within the initial 8 to 10 weeks following N application (Phillips, 2007), but the magnitude of these effects likely vary with temperature at the time of application. Manure application in soil can increase CO_2 emission because organic C in the soil is an immediate source of C for soil microorganisms, which in turn emit CO_2 (Rao and Pathak, 1996). Several studies have indicated that microorganism activities happening in the sublayer of soil increase the CO_2 gas emission (Bilen et al., 2010; Altikat et al., 2012; Altıkat, 2013). Rochette and Gregorich (1998) reported that manure doubled CO_2 emissions compared to artificial fertilizer and the increase in the amount of CO_2 emission was highly related ($r^2 = 0.75$) to soil temperature. Gregorich et al. (1998), in another study conducted to determine the effects of manure on CO_2 emission, found that an

Table 6. Effects of factors on the soil moisture, soil temperature, CO$_2$ emission, and O$_2$ concentration values.

Treatments			Soil temp. (°C)	Soil moist. (%)	CO$_2$ emission (μmol m^{-2} s^{-1})	Cumulative CO$_2$ (Mg ha^{-1} day^{-1})	O$_2$ content (%)
2014	Wheel traffic (C)	C0	34.08 b[√]	44.76 b	5.26 a	0.206 a	19.97 ns
		C1	34.34 a	46.37 a	4.40 b	0.170 b	19.94 ns
		C2	34.39 a	47.44 a	3.81 c	0.137 c	19.87 ns
	Manure Amount (N)	N0	34.57 a	40.78 b	3.84 c	0.172 ns	19.94 ns
		N40	34.27 ab	48.26 a	4.36 b	0.171 ns	19.94 ns
		N80	33.98 b	49.52 a	5.28 a	0.170 ns	19.92 ns
	Application (A)	A1	34.49 a	45.28 b	4.14 b	0.166 ns	19.95 ns
		A2	34.05 b	47.10 a	4.84 a	0.176 ns	19.91 ns
2015	Wheel traffic (C)	C0	31.08 c	38.25 c	5.20 a	0.197 a	19.98 a
		C1	32.59 b	41.67 b	4.39 b	0.166 b	19.79 b
		C2	34.48 a	45.40 a	3.75 c	0.142 c	19.59 c
	Manure Amount (N)	N0	33.21 a	40.73 b	3.57 c	0.135 c	19.83 a
		N40	32.41 b	41.61 b	4.33 b	0.165 b	19.86 a
		N80	31.53 c b	42.98 a	5.44 a	0.207 a	19.67 b
	Application (A)	A1	32.65 a	40.53 b	4.26 b	0.176 b	19.91 a
		A2	32.12 b	43.01 a	4.64 a	0.162 a	19.67 b

√: Means within the same column followed by the same letter are not significantly different.
C0: Control plot (no pass); C1: one pass; C2: two passes, N0: control plot (0 Mg ha^{-1} manure amount), N40: 40 Mg ha^{-1} manure amount, N80: 80 Mg ha^{-1} manure amount, A1: surface manure application, A2: subsurface manure application, ns: nonsignificant.



2014 2015

Figure 2. Effect of wheel traffic on soil moisture and soil temperature.
C0: Control plot (no pass); C1: one pass; C2: two passes.

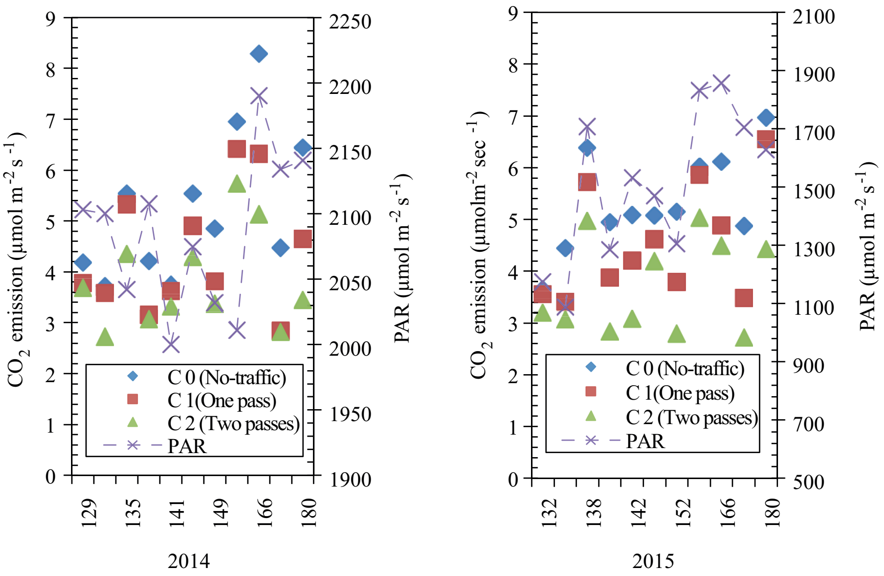


Figure 3. Effect of wheel traffic on soil CO$_2$ emissions on Julian days.
C0: Control plot (no pass); C1: one pass; C2: two passes. PAR: Photosynthetically active radiation.

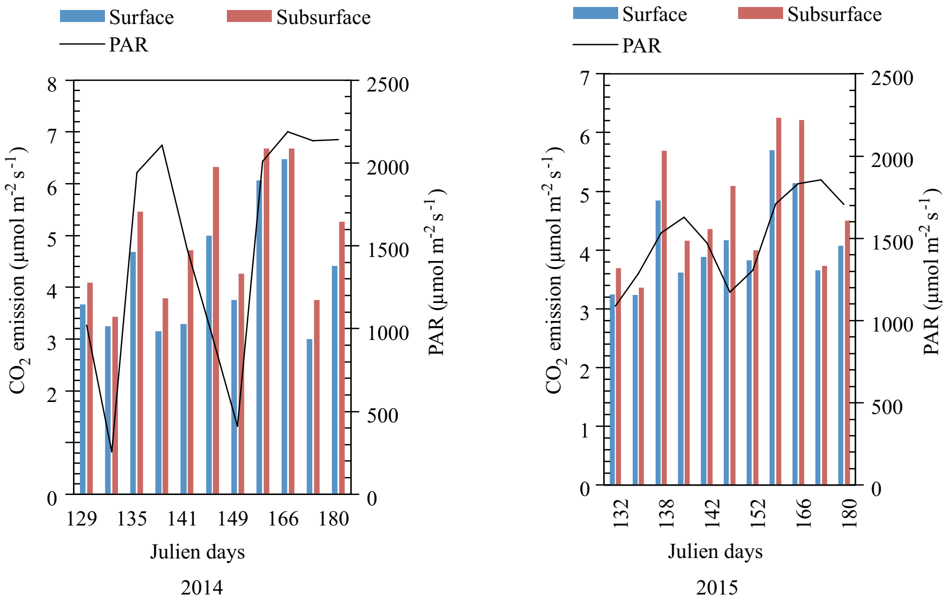


Figure 4. The changes of CO$_2$ emission and PAR depending on manure application form on Julian days.
PAR: Photosynthetically active radiation.

increase in the amount of manure resulted in higher CO$_2$ emission. Kimble et al. (1995), using manure at 1 t C ha^{-1}, could allocate more or less 2–5 t CO$_2$ ha^{-1} year^{-1} and the net benefits of manure application ranged from 5.3 to 7.2 t CO$_2$ ha^{-1} year^{-1} equivalent, with higher gains for SOC-poor than SOC-rich sites. Dong and Ouyang (2005) investigated effects of chicken manure, swine waste, and cattle manure on the CO$_2$ and CH$_4$ emissions of a farmland planted with summer maize. Their results showed that CO$_2$ emissions had the same trends under different organic manure applications, which were influenced by soil temperature and soil water content.

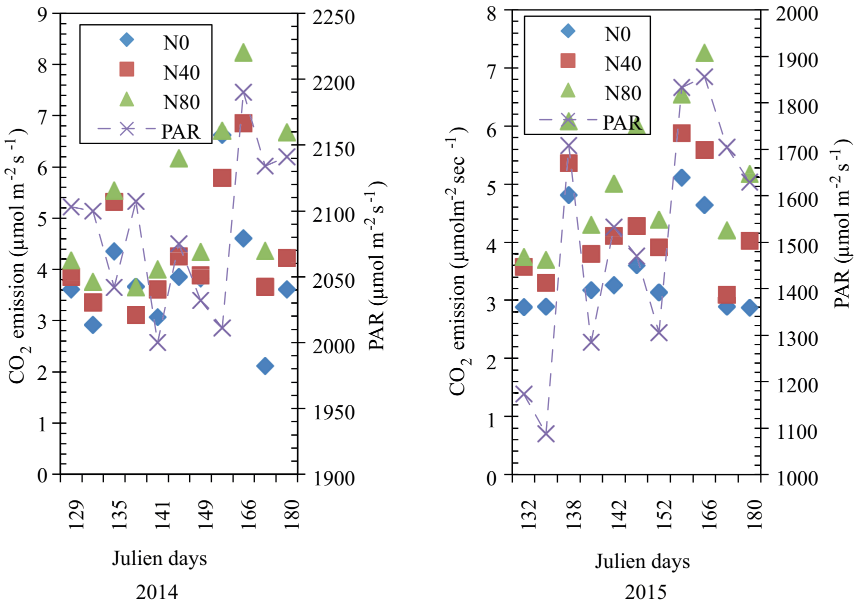


Figure 5. Effects of manure amount on CO_2 emissions on Julian days.
N0: Control plot (no manure), N40: 40 Mg ha^{-1} manure amount; N80: 80 Mg ha^{-1} manure amount, PAR: photosynthetically active radiation.

Manure amounts and their interactions with the O_2 content were highly significant ($P < 0.01$) but this effect was not observed in the first year of the experiment (Table 5). Generally, in the experiments, increasing wheel traffic level decreased soil O_2 content (Table 6). Similar results were found in many other studies. In these studies, microbial processes took place in more anaerobic conditions in compacted soils, documented by lower O_2 diffusion rate (Torbert and Wood, 1992; Whalley et al., 1995). In the second year of the experiment increased manure amount decreased soil O_2 content. However, subsurface application also decreased the soil O_2 content (Table 6). When the results of interactions for the 2014 experimental year were examined, the lowest O_2 content was determined in the plot with C2 × A1 × N80.

In the compacted soils, physical changes in pore systems commonly led to less favorable conditions for toxic microbes. This situation was mainly attributed to restriction of gas fluxes due to reduced porosity (Otten et al., 2000; Beylich et al., 2010). Decreased soil microbial activity reduced soil respiration levels. Changes in CO_2 emissions from structured soils were shown to be highly variable and highly affected by structural changes influenced by mechanical loading and soil management (Mordhorst et al., 2014). Soil compaction mostly leads to reduced CO_2 emissions. Goutal et al. (2012) and Akbolat (2009) stated that lower cumulative soil CO_2 fluxes were recorded plots exposed to traffic compared to the control plots.

3.4. Conclusions

In agricultural practices, soil compaction, manure amount, and manure application techniques directly affect agricultural production. In this study, increased wheel traffic levels caused a reduction in CO_2 emission and O_2 content. In general, due to increase of wheel traffic, the penetration resistance and soil bulk density increases. In this case, CO_2 emissions and soil O_2 capacity are reduced. Increased manure amount increased both CO_2 emissions and soil moisture but decreased soil temperature. As an expected result, the increased carbon level in the soil led to an increase in CO_2 emission. In addition to these results, the subsurface manure application increased CO_2 emissions and soil moisture. Subsurface manure application is advisable for fertilization in terms of CO_2 emissions, but in this situation soil organic matter may be more slowly soluble compared to surface manure application.

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