

SOIL CO₂ EMISSIONS UNDER CONVENTIONAL AND CONSERVATIONAL TILLAGE METHODS IN SOYBEAN CULTIVATION IN CUKUROVA PLAIN OF TURKEY

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Abstract

In this study, the carbon dioxide (CO₂) emissions for soybean cultivated in Adana province according to conventional tillage practices for chisel tillage with stubble burning (CT), and conservational tillage practices with stubble for disc tillage (DT), rotary tillage (RT) and direct seeding (DS) were determined. Soil carbon dioxide (CO₂) emission measurements were started after tillage using a portable CO₂ measurement system and were carried out at various intervals over a period of 55 days.

According to the obtained results, CO₂ emissions in CT, DT, RT and DS treatments were determined as 0.028, 0.036, 0.029, and 0.025 g CO₂ m⁻² h⁻¹, respectively. It was determined that the CO₂ emission level in the DS treatment was lower in comparison with those of the other three treatments. The soil evaporation (H₂O) amounts were determined for CT, DT, RT and DS treatments as 4.37, 4.38, 4.21 and 3.50 g H₂O m⁻² h⁻¹, respectively. Soil temperature was measured on average for CT, DT, RT and DS treatments as 28.7, 28.8, 28.7 and 28.9°C, respectively. The average soil evaporation of DS treatment was found to be lower than the other three treatments. The difference between the soil moisture depending on treatment was not significant.

Key words: direct seeding, seedbed preparation, soil CO₂ emission, soybean, tillage systems.

INTRODUCTION

Soil management practices such as tillage and fertilization affect carbon build up in soil or the amount of atmospheric CO₂ (Nyakatawa et al., 2012). Soil mixing intensity has an effect on the amount of carbon (C) that disappears from the soil in the form of CO₂. In other words, increasing aeration in the soil usually increases soil CO₂ emissions due to decomposition (Dao, 1998). The amount of soil CO₂ emissions also depends on soil moisture and temperature regime, soil type, land usage and production method as well as the amount of soil organic carbon (Johnson et al., 2007; Chianese et al., 2009; Shrestha et al., 2009; Davidson et al., 2000). It has been reported that higher amounts of soil CO₂ emissions are obtained from rotary tillage with residue in comparison with rotary

tillage without residue treatment in sugarcane production (Teixeria et al., 2011). It has been stated that emissions of CO₂ decreased by 1.2 times in burned soil compared to soil where residue was incorporated, but emissions of N₂ increased by 4.1 times and the increase in inorganic N from N mineralization was 1.4 times (Montoya-González et al., 2009). Brye et al. (2006) determined that the soil surface CO₂ flux when using a conventional tillage system including stubble burning was 37.6% higher in comparison with that of a no-till system in wheat-soybean double crop production in Mississippi. In a study to determine the effect of tillage practices with or without residue on soil CO₂ emission, higher emission rates were found in tillage with residue than in tillage without residue in sugarcane production (Teixeria et al., 2013).

Soil CO₂ emission rates are generally lower with less intensive alternatives relative to moldboard plowing, with the greatest difference occurring at the time immediately following tillage practices. Al-kaisi & Yin (2005) found that cumulative soil CO₂ emissions were 19% to 41% lower for less intensive tillage treatments than for moldboard plowing and that it was 24% lower for no-tillage with residue than without residue during a 480-h measurement period.

CO₂ emission rate decreases as the number of tillage equipment is reduced during tillage. In studies carried out to determine CO₂ emissions from the soil due to tillage equipment used, Akbolat et al. (2009) found that the highest CO₂ emission rate was from plowing tillage, whereas the lowest CO₂ emission rate was observed in the no-till method. Another study comparing conventional tillage (CT), reduced tillage (RT) and no-till (NT) systems in terms of CO₂ emissions has yielded that the highest C sequestration was obtained in NT treatment, followed by RT and CT treatments (Zhang et al., 2012). In a short term study examining CO₂ emissions in sugar beet cultivation via conventional, reduced and no-till cultivation systems, the highest CO₂ emission rate was recorded in the conventional system, followed by reduced and no-till systems (La Scala et al., 2006). Short term studies during which CO₂ emissions are determined from soil, it is stated that CO₂ emission rate rapidly increases following tillage, after which it decreases to low levels probably due to the discharge of gases accumulated in the pores and cavities prior to the process or an attack of rapidly developing microorganisms (Reicosky, 2002; Rasmussen & Rohde, 1998). These results indicate that seedbed preparation methods for different growing plants affect soil CO₂ emissions. Also, seedbed preparation practices differ according to the plant grown. Winter wheat-summer soybean rotation allows farmers to produce two crops per year but the extensive application of this rotation has increased stubble burning in the Cukurova plain. The objective of this study is to determine the effect of chisel tillage without stubble (CT), disc tillage with stubble (DT), rotary tillage with stubble (RT) and direct seeding with stubble

(DS) practices used for second crop soybean cultivation on soil CO₂ emission.

MATERIALS AND METHODS

Study area

The study was carried out during June 3rd and July 26th, 2010 at Cukurova University Research Farm in Adana province located in Cukurova plain. Cukurova University Research Farm is located between 37° 03'47" N latitude and 35°20'12"E longitude with an altitude of 23 m. The soil texture of the study area is clay (C) class consisting of 50% clay, 33 % silt and 17% sand with an organic matter content of 0.9% (Barut et al., 2012). A characteristic Mediterranean climate prevails in the study area.

Summers are hot and dry whereas winters are mild and rainy. The annual average precipitation is 625 mm. Temperatures differ between -8,1°C and +45,6°C and most of the rain falls during the winter. Rain is very scarce in summer (Anonymous, 2013). Definitions regarding the methods used in the trials are given in Table 1.

Table 1. The description of treatments used in seed bed preparation

Treatments	Description
CT (Chisel tillage)	<i>Stubble burning, Chisel tillage</i> one pass (tillage depth 35 cm), <i>disc harrow</i> two pass (depth of 15 cm) followed by <i>scraper</i> two pass (depth of 5 cm), plus <i>Single single-seed pneumatic planter</i> (seeding depth of 5 cm).
DT (Disc tillage)	<i>Stubble chopping, Heavy disc harrow</i> , two pass (tillage depth of 18 cm, tillage width of 200 cm) followed by <i>scraper</i> , two pass (tillage depth of 5 cm, tillage width of 200 cm) plus <i>single-seed pneumatic planter</i> (seeding dept of 5 cm).
RT (Rotary tillage)	<i>Stubble chopping, Rototiller</i> , one pass (tillage depth of 15 cm, tillage width of 200 cm, followed by <i>scraper</i> , two pass (tillage depth of 5 cm, tillage width of 200 cm), plus <i>single-seed pneumatic planter</i> (seeding dept of 5 cm).
DS (Direct seeding)	<i>Direct seeder</i> , (working width of 200 cm, seeding depth of 5 cm)

Plot width and length used in the trial was 12 and 40 m, respectively. A randomized complete block design with three replications was selected for the trial.

A 52 kW tractor was used during the trials. The engine speed was held constant at 2000 rpm. Wheat stubble except from CT treatment was chopped and spread on the soil surface before

seedbed preparation. Stubble was burned in CT treatment before seedbed preparation. The average stubble amount was determined as 2500 kg per hectare in DT, RT and DS treatments. The average stubble height was around 30 cm. Wheat residues except from stubble were removed from the soil surface before seedbed preparation.

Soil CO₂ measurement

In-situ soil respiration was measured using a CFX-2 soil CO₂ flux system (PP Systems, Hitchin, UK) consisting of an integral CO₂ analyzer and H₂O sensor, soil respiration chamber, and soil temperature probe (Akbolat et al., 2009). Measurements of soil net CO₂ emissions in g m⁻² h⁻¹ are based on concentration differences between air entering and leaving the chamber and the flow rate under normal soil atmosphere exchanges, with an accuracy better than 1% and 2% for CO₂ and H₂O concentrations, respectively. A soil CO₂ emission chamber was installed 1.5 cm deep into the randomly selected locations for the plots, and thus was isolated from the outer atmosphere. The records were made more frequently during the days following tillage, whereas afterwards they were carried out at wider intervals. The measurements were taken 0, 1, 4, 5, 7, 8, 11, 13, 19, 22, 30, 37, and 55 days after tillage. First the measurements of soil CO₂ emissions were taken five minutes after tillage. Nine records were taken on the same randomly selected points from every plot for each measurement. The trial was completed when CO₂ emission reached constant level. In addition, evaporation (H₂O emissions) and soil temperature were concomitantly measured.

Soil sampling and analyzing

Volumetric soil moisture content in 0-20 cm soil depth was determined using a Field Scout TDR 300 portable moisture meter (Spectrum Technologies, Inc., Plainfield, IL, USA). Soil moisture records were not determined on the first two days due to irrigation. Organic matter was determined according to the Walkley-Black, (1934) method, whereas texture was determined according to the Bouyoucos hydrometer Bouyoucos (1951) method.

Statistical procedure

The data were analyzed using the General Linear Model (GLM) procedures of SAS (SAS Inst. Inc. Cary, NC) by including treatments in the model, and PDIF statements were used to compare treatment means for dependent variables (SAS, 1999). As for the significance level, (P<0.05) was accepted to be statistically significant.

RESULTS AND DISCUSSIONS

The treatment of CT is mostly used for seedbed preparation in second crop soybean cultivation in Cukurova plain. In this treatment stubble is burned intensively after the wheat harvest. Therefore, this treatment has negative effects in terms of soil conservation and environmental protection. In this research the soil CO₂ emission rates were determined in the conservation tillage treatments (DT, RT, and DS) and conventional tillage (CT) treatment. The results of the experiment based on tillage practices are given in Table 2. The maximum soil CO₂ emission from all tilled treatments excluding the the 30th day was observed immediately after tillage practices.

Table 2. The means of soil carbon dioxide emission, evaporation, temperature and moisture content

Treatments	Soil CO ₂ emission (g CO ₂ m ⁻² h ⁻¹)	Soil Evaporation (g H ₂ O m ⁻² h ⁻¹)	Soil Temperature (°C)	Soil moisture content *(%)
CT (n=350)	0.028 ^{ab}	4.37 ^a	28.7 ^c	20.2
± SD	0.0030	0.15	0.045	0.27
DT (n=351)	0.036 ^a	4.38 ^a	28.8 ^{ab}	20.0
± SD	0.0029	0.14	0.044	0.27
RT (n=351)	0.029 ^{ab}	4.21 ^a	28.7 ^{bc}	19.6
± SD	0.0029	0.14	0.044	0.27
DS (n=342)	0.025 ^b	3.50 ^b	28.9 ^a	20.3
± SD	0.0030	0.15	0.046	0.27

Means followed by the same capital letter within a column are not significantly different according to Duncan's test at the 5% level. *Sample number for soil moisture content of CT, DT, RT and DS is 99, 99, 98 and 96 respectively.

The average soil CO₂ emissions from maximum to minimum were determined from DT, RT, CT and DS respectively (Table 2). The averages of the soil CO₂ emissions were measured for CT, DT, RT and DS treatments as 0.028, 0.036, 0.029 and 0.025g CO₂ m⁻² h⁻¹ respectively. The cumulative soil CO₂ emissions were determined for DT, RT, CT and DS treatments as 48.5, 41.9, 40.0 and 34.1 g CO₂ m⁻² respectively in the experimental period. A positive linear relationship between cumulative CO₂ emission and time was observed. This result was in accordance with Al-Kaisi & Yin (2005).

When the CO₂ emissions on different days of the experiment were examined, it was observed that the difference between the treatments were statistically significant for days 0, 1, 4, 11, and 19. There were no differences among CT, RT and DS treatments in terms of average soil CO₂ emissions, but that the soil CO₂ emission was statistically ($p < 0.05$) lower in DS treatment than DT treatment.

Although the tillage depth of CT treatment was higher than it was for DT and RT, the soil CO₂ emission rate in this treatment was equal or

very close to those of the other treatments. Therefore, high CO₂ emissions in the CT would be expected in comparison to the treatment of DT and RT. Scala et al. (2001) reported that the soil CO₂ emission rate for the chisel plow was the highest of the all treatments. Therefore, stubble is removed in CT treatments, as stated by Montoya-González et al. (2009) and Teixeira et al. (2011).

The lowest CO₂ emission rate was determined in DS treatment on days 0, 11, 13, 19 and 37 (Figure 1a). CO₂ emissions reached their lowest value on the 22nd day after tillage and the lowest emission was observed in the RT treatment. The highest CO₂ emissions were observed on the 30th day after the first tillage operation. However, differences between the treatments were not significant ($p > 0.05$) on that day since the measurement was taken soon after irrigation. As has been reported (Orchard & Cook 1983), high soil moisture content increased soil CO₂ emissions by soil microbial respiration. Negative CO₂ emission values were recorded 0 and 11 days after tillage in the DS treatment.

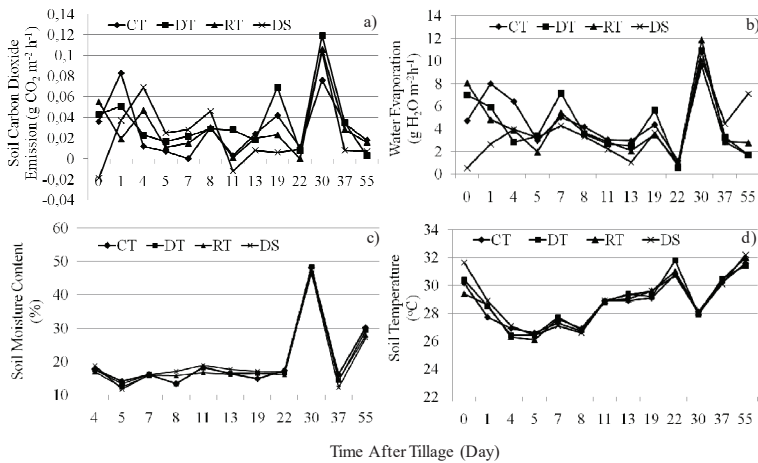


Figure 1. Soil Carbon Dioxide (CO₂) Emission, soil water evaporation, soil moisture content, and soil temperature after the tillage

CO₂ emissions measured in all treatments immediately after tillage were high and had a tendency to decrease. A sharp increase in CO₂ emissions immediately following tillage is often attributed to an increase in soil aeration due to disturbance (Dong et al., 2009). Reicosky & Lindstrom (1993) have also

reported that a greater CO₂ emission rate immediately after tillage was due to greater physical CO₂ emission from soil. The CO₂ emission found in the study is lower than those determined by Akbolat et al. (2009) in semi-arid climatic conditions. However, in the same study, a CO₂ emission of 0.030 g CO₂ m⁻² h⁻¹

obtained for the no-till system was extremely close to the emission of $0.025 \text{ g CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ obtained in our study.

Statistical differences among the treatments were significant on the recording days of 0, 1, 4, 11, and 19. No difference was determined between the treatments regarding CO_2 emission (5, 7, 8, 13, 22, 30, 37 and 55th days) on other days. The lowest CO_2 emission value was determined during the first record of the DS treatment. One of the reasons for the lowest CO_2 emission value for the DS treatment is the lowest evaporation value in this recording. The evaporation of DS treatment was $0.52 \text{ g H}_2\text{O m}^{-2}\text{h}^{-1}$ in the first record (Figure 2). The lowest average water evaporation value was determined in the DS treatment. There was a linear relationship between the soil CO_2 emission and water evaporation values in these records (day 0 and 1).

The averages of soil evaporation values were measured for CT, DT, RT and DS treatments as 4.37, 4.38, 4.21 and $3.50 \text{ g H}_2\text{O m}^{-2}\text{h}^{-1}$ respectively. Soil evaporation that was generally parallel with CO_2 emission was determined to be quite high for all treatments except for DS treatment at the time immediately following tillage but it gradually decreased in the following days. Soil evaporation values of DS treatment during the first and second records were lower in comparison with other treatments (Figure 1b).

The average soil moisture values measured for CT, DT, RT and DS treatments were 20.2%, 20.0%, 19.6% and 20.3%, respectively. In terms of average soil moisture content, no statistically significant ($p>0.05$) differences were found between the treatments. Whereas no difference in the soil moisture values was detected on most record days, a lower soil moisture value was determined for the DS treatment on the 37th and 55th days (Figure 3). Soil moisture content of the DS treatment was statistically higher than those of the other three treatments on only the 7th day. High soil moisture content for the DS treatment was explored with soil thermal conductivity (Silva-Olaya et al., 2013). In addition, this pattern indicates that tillage methods involving less physical disturbance help conserve soil moisture.

The soil moisture content of treatments on the 30th day was higher than for all other record days (Figure 1c). The reason for this was that the measurement was taken soon after irrigation. In the other words, irrigation increased the soil water content.

The averages of soil temperature values (Figure 1d) were measured for CT, DT, RT and DS treatments as 28.7 °C, 28.8 °C, 28.7 °C, and 28.9 °C respectively. While the average soil temperature of DS treatment was higher than those of CT and RT treatments, it was not different from DT treatment (Table 2). No linear correlation between soil temperature and CO_2 emissions was found. These results are in accordance with the study by Akbolat et al. (2009). Differences between the temperatures of 0, 1, 4, 5, 7, 19, 22, 55th records were significant. The average soil temperature of DS treatment in our study is higher than for the other treatments, as was the case in the study carried out by Akbolat et al. (2009).

However, this average difference of soil temperature did not increase soil CO_2 emission. The difference in average soil temperature among the treatments was very low. Thus, there were other parameters besides temperature and moisture that changed the soil CO_2 emission in different treatments.

The lowest CO_2 emission was obtained in direct seeding treatment during this study carried out in order to determine the soil CO_2 emissions for tillage practices applied in second crop soybean cultivation in the Cukurova plain of Turkey. The differences between soil temperatures do not support differences between CO_2 emissions. However, the differences between average soil water evaporation support differences between soil CO_2 emissions.

As was the case in our study, the lowest soil CO_2 emission rate in many tillage studies is obtained for DS treatment in a no-till system. According to the obtained results, the cumulative CO_2 emissions obtained for CT, DT, RT and DS treatments were 40.0, 48.5, 41.9 and $34.1 \text{ g CO}_2 \text{ m}^{-2}$, respectively. It was observed that the cumulative CO_2 emission rate in the DS treatment was 1.4 times lower than that of DT treatment, 1.2 times lower than that of CT treatment, and 1.2 times lower than that of RT treatment.

CONCLUSIONS

As a result, chisel based tillage practice characterizes regional seedbed preparation methods. Higher soil CO₂ emissions would be expected in this treatment due to deep tillage. However, soil CO₂ emission of this treatment was lower in contrast to the references due to burned stubble.

Although the soil CO₂ emission was lower, the chisel based tillage with stubble burning method cannot be recommended because of the environmental effects and the decreases in soil organic carbon.

The importance of direct seeding method increases due to lower inputs in comparison with other methods as well as high organic matter gain in the long run for the soil along with environmental friendliness.

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