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Full Length Research Paper

Effects of strip and full-width tillage on soil carbon IV oxide-carbon (CO_2-C) fluxes and on bacterial and fungal populations in sunflower

Serdar Bilen[1]*, Ahmet Çelik[2] and Sefa Altıkat[2]

[1]Department of Soil Science, Faculty of Agriculture, University of Ataturk, Erzurum, Turkey.
[2]Department of Agricultural Machinery, Faculty of Agriculture, University of Ataturk, Erzurum, Turkey.

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In strip tillage system, planting lines are cultivated while the inter-row spaces are left undisturbed. The objective of this study is to determine the effects of strip tillage and full-width tillage treatments on soil carbon IV oxide-carbon (CO_2-C) fluxes, bacterial and fungal populations in growing period of sunflower (*Helianthus annus*). A row-crop rotary hoe with C type blades was used to create three strip widths by changing the connection of blades of the rotary hoe on the flanges. Strip widths were 22.5 (T30), 30.0 (T40) and 37.5 cm (T50). The full-width tillage practice (moldboard plow + disc harrow + leveler) gave 100% surface soil disturbance (T100) and was included in the experiment to make comparisons with the strip tillage system. A randomized complete block design with three replications was used. During the growth of the sunflower, periodic measurements of CO_2-C fluxes and bacterial and fungal populations were made. Significant ($p < 0.01$) differences in CO_2-C fluxes, microbial populations, soil bulk density and total porosity were observed between the different tillage systems. Highest CO_2-C fluxes, bacteria populations and total porosity were observed in the full-width T100 application and the lowest values were observed in the T30 treatment during flowering and harvesting periods. Increasing tillage intensity increased soil CO_2-C fluxes and bacteria population, but decreased fungi population and soil bulk density.

Key words: Carbon IV oxide-carbon flux, soil bacteria and fungi, strip tillage, full-width tillage, sunflower.

INTRODUCTION

Soil is an open system and can be a net source of carbon IV oxide (CO_2) released to the atmosphere due to elevated soil organic carbon mineralization caused by disruptive agricultural practices. Soil organic carbon (C) plays an essential role in determining many soil properties and thus, greatly influences the fertility of the soil. The C in organic matter is more resistant to decomposition than the residues from which it is derived. The distribution of the organic C is also changed from that in a plowed soil and stratification often occurs. If soil is not tilled, plant roots and various natural soil processes continue to increase the levels of organic C from the surface of the soil downward (Triplett and Dick, 2008).

The two most important processes affecting C balance of terrestrial ecosystems are photosynthesis of above-ground vegetation and soil respiration. The relationship between soil organic matter production and decomposition determines whether a system is a sink or a source of atmospheric CO_2. Soil can function as a net sink for sequestering atmospheric CO_2 under appropriate soil and crop management systems, thus reducing atmospheric CO_2 (Paustian et al., 1992; Lal et al., 1995). In contrast, soil respiration can release large quantities of CO_2–C from the soils to the atmosphere. Changes in land use and soil management practice (tillage, use of fertilizers, organic residues and pesticides) are largely responsible for increases in atmospheric CO_2 from terrestrial ecosystems because they induce transformation of soil organic

*Corresponding author. E-mail: sbilen@atauni.edu.tr. Tel: +90 442 231 1646. Fax: +90 442 236 0958.

Abbreviations: ST, Strip tillage; **EC,** electrical conductivity; **CFU,** colony forming units; **PBS,** phosphate-buffered saline solution; **SEA,** soil extract agar; **DPA,** dextrose-peptone agar.

C to atmospheric CO_2 (Bouwman, 1990).

Different tillage systems using common soil tillage implements (e.g. disk harrow, reversible disk plow, rotary tiller and chisel plow) produced different levels of CO_2 fluxes (La Scala et al., 2001). Measurements of soil CO_2 flux for different tillage treatments and cropping systems are important for identifying management practices that may affect this flux and thus affect the global C balance (Houghton et al., 1983; Post et al., 1990). The CO_2 loss is related to volume of soil disturbed by the tillage operation and maximum CO_2 loss was observed for moldboard plow, with various conservation tillage tools losing only 30% of that lost by the plow (Reicosky, 1999). The use of the moldboard plow creates two major soil effects: (1) Loosening and inverting the soil to allow rapid CO_2 loss and oxygen entry and (2) incorporation or mixing the residues, which leads to enhanced microbial attack (Reicosky and Lindstrom, 1995). Moldboard plowing at increasing depths has generally resulted in reductions in soil C pool sizes when compared to grasslands or native ecosystems (Potter et al., 1999; Soussana et al., 2004).

Strip tillage is a form of conservation tillage that involves cultivation of narrow bands, or strips in the row area, separated by bands of undisturbed soil. Strip tillage has the potential advantages of providing a suitable seedbed for various row crops establishment while leaving surface residues in the inter-row area to reduce soil erosion (Peterson et al., 1996; Wilhoit et al., 1990). Strip tillage is hypothesized to decrease the amount of CO_2 loss relative to plowing. Only a relatively small amount of CO_2 was detected immediately after strip tillage and this amount was related to the volume of soil disturbed (Reicosky, 1999).

Intensive tillage often involves using the moldboard plough to invert the soil followed by secondary tillage tools to break up and homogenize soil clods. One effect of such intensive tillage is to increase compactness, which decreases space between pores, thereby changing the pathway for CO_2 diffusion (Sanchez et al., 2002). Tillage accelerates soil CO_2 emission by improving soil aeration, disaggregating soil, increasing the contact between soil and crop residue, and speeding organic C decomposition (Logan et al., 1991; Angers et al., 1993; Kern and Johnson, 1993; Al- Kaisi and Yin, 2005).

Soil microbial biomass C and soil enzyme activities are affected by no-tillage in a manner similar to that of organic C (Franzluebbers, 2002; Dick, 1984). When the crop production system is changed to less intensive tillage system, the microbial biomass and the biologically active C and N pools respond rapidly and the changes are more easily measured than changes in total C and N. No-tillage changes both the profile distribution of biological activity and the biological community itself, with fungi becoming more dominant under no-tillage (Six et al., 2006). Fungal dominated soil communities may enhance C storage and slow soil organic matter turnover due to both the fungal alteration of soil physical properties and to fungal physiology (Nakas and Klein, 1979; Tisdall and Oades, 1982). Ecosystems with soils dominated by fungi thus reduce CO_2-C flux and sequester more C than systems with lower fungal abundance (Six et al., 2006).

Soil organic matter is a resource for soil biota and there is a strong relationship between the abundance of soil organisms and the content of organic matter (Wardle et al., 2001; Nakamoto and Tsukamoto, 2006). Many soil organisms receive benefits because of a reduction in soil disturbance and an increase in surface crop residues.

The purpose of this study is to evaluate the effects of different widths strip tillage system and full-width inversion tillage system on soil bulk density, porosity, CO_2-C fluxes and on bacterial and fungal populations, in sunflower (*Helianthus annus*).

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the research farm of Ataturk University (39° 54' N and 41° 13' E, altitude 1883 m), Erzurum, Turkey. The soil on the experimental sites was classified as Ustorthents according to the United States Department of Agriculture (USDA) soil taxonomy (Soil Survey Staff, 1999). The slope of the experiment area was under the 0.5% and there was no erosion problem. Some climatic data relating to the experimental area are provided in Table 1. The initial crop was winter wheat. Wheat was machine harvested from the experimental area at the end of August 2005. Stubble height was left around 10-12 cm. Soil tillage and sunflower planting were performed after wheat harvest during the third week of May 2006.

Experimental design

Plots were arranged in a randomized complete block design with three replications. Each treatment plot was 3 by 30 m in size and plots were separated by buffer areas that were one-half the size of the treatment plots. A strip tillage (ST) system with three different strip widths (22.5 cm) 30%, soil surface disturbance (T30) 30.0 cm, 40% soil surface disturbance (T40) and 37.5 cm, 50% soil surface disturbance (T50) was compared with a full-width inversion tillage system with 100% soil surface disturbance (T100). The three strip widths were achieved by changing the connections of blades of the rotary hoe on the flanges (Figure 1). Tilled zones of 30, 40 and 50% of the field area were obtained by use of two, three or four blades, respectively. The rotary hoe was operated at constant rotor rotational speed of 370 rpm. Tillage in the full-width inversion system (T100) involved the use of a moldboard plow followed by a disk harrow and a soil leveler. The tillage depth was kept constant at 12 cm for the strip tillage systems and 20 cm for the full-width inversion tillage system. The tractor operating speed was 1.5 m s^{-1} by using a DJRVS II speed radar and a DJCMS100 monitor made by Dickey-John (5200 DICKEY-John Road Auburn, IL).

Soil tillage was performed on 16 May 2006. After the seedbed preparation on 19 May 2006, all plots were sown using a four row pneumatic planter, commonly used in sunflower planting in Turkey, with 70 cm inter-row spacing. Urea fertilizer (50 kg N ha^{-1}) and triple super phosphate (70 kg P_2O_5 ha^{-1}) was applied at planting. Weed control was accomplished by hand hoeing twice per month.

Soil sampling and laboratory analysis techniques

Plots which have the same physical and chemical properties were

Table 1. Monthly rainfall means temperature and average relative humidity for 2006.

Month	Monthly rainfall (mm)	Mean temperatures (°C)	Average relative humidity (%)
January	17.8	-11.2	81.6
February	10.9	-5.6	77.0
March	13.4	1.2	73.5
April	77.4	7.2	74.4
May	41.6	11.4	67.3
June	19.2	18.4	56.7
July	20.7	20.3	62.5
August	3.5	22.6	50.9
September	29.2	14.1	60.2
October	90.1	8.6	76.0
November	25.3	-0.1	70.9
December	8.3	-9.8	75.4

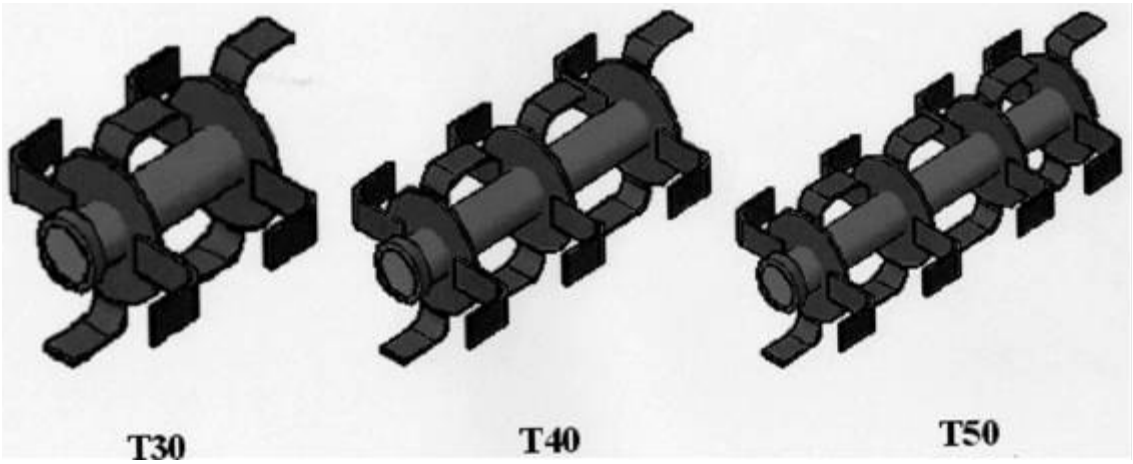

Figure 1. Application of tillage strip width by modification of rotary hoe. T30 = Strip width of 22.5 cm, 30% soil surface disturbance and two blade; T40 = strip width of 30.0 cm, 40% soil surface disturbance and three blade; T50 = strip width of 37.5 cm, 50% soil surface disturbance and four blade.

sampled for soil at three different sunflower growing periods that included planting (June 20), flowering (August 10) and dough maturity (September 12). Depth of sampling was 0 - 20 cm for initial soil chemical and physical properties and samples were removed from the field using a 5 - cm diameter borer. Separately, on 10 May, before sunflower sampling, the soil was sampled and this sample was used as an untreated control. Three soil samples were collected from Ap horizon of each plot in each three period every day during a couple of weeks. Collected soil samples were sieved through a 2-mm mesh opening on the field and brought to the laboratory for initial chemical, physical and microbial analysis. After soil tillage systems application, depth of sampling was 0 - 12 cm for strip tillage and 0 - 20 cm for full-width inversion tillage system for soil bulk density, porosity, CO_2-C analysis and soil microbial population analysis at the sowing, flowering, and harvesting period and plant growth.

Soil organic C was determined by the Smith-Weldon method (Tiessen and Moir, 1993), $CaCO_3$ content was determined using a Schleibler calcimeter (Tee et al., 1993), total nitrogen (N) was determined by using the micro Kjeldahl method (McGill and Figueiredo, 1993), soil pH was determined by using a glass electrode pH meter (1:2.5, soil: water), exchangeable cations and cation exchange capacity were determined by atomic absorption spectrophotometer after the method of Handershot et al. (1993), available P was determined by the Na_2CO_3 extraction method (Olsen and Sommers, 1982), field water capacity was determined by the tensiometer method (Topp et al., 1993), soil texture b was determined by the Bouyoucus hydrometer method (Shieldrick and Wang, 1993), electrical conductivity (EC) was determined by using an EC meter according to the method of Janzen (1993), and soil bulk density and particle density were determined by the core method and total porosity was calculated from bulk density and particle density (Blake and Hartge, 1986). Measured chemical and physical properties of the experimental site soil are shown in Table 2.

Microbial population analysis

Determinations of viable microbial bacteria and fungi counts were carried out at four different growing periods (initial, sowing, flowering and harvesting) of sunflower. Gentle tapping separated the rhizosphere soil adhering to the root, and this recovered soil was analyzed the same day.

Table 2. Some initial chemical, physical and microbiological properties of the experimental site.

Soil property	Value
pH (1:2.5)	7.16
Organic matter, g kg^{-1}	2.29
Lime ($CaCO_3$), g kg^{-1}	1.11
Total N, g kg^{-1}	0.14
Plant Available P mg kg^{-1}	4.71
Exchangeable cations, cmol kg^{-1} soil	
Ca	22.49
Mg	7.27
K	2.61
Na	0.29
Microelements, mg kg^{-1}	
Fe	5.97
Cu	1.79
Zn	1.17
Mn	9.52
Cation exchange capacity, cmol kg^{-1}	35.0
Electrical conductivity, dS m^{-1}	0.65 x 10^3
Salt, %	0.016
Field capacity at 1/3 atm, g kg^{-1}	26.7
Wilting capacity at 15 atm, g kg^{-1}	15.4
Particle size distribution, g kg^{-1}	
Sand	32.3
Silt	44.1
Clay	23.6
Bulk density, Mg m^{-3}	1.51
Porosity, vol. %	42.25
Microbiological properties	
Number of bacteria, CFU* g^{-1} soil	2.55 x 10^7
Number of fungi, CFU g^{-1} soil	2.45 x 10^5
Total C respired as CO_2, mg m^{-2} h^{-1} (CO_2-C)	3.2 (0.27 Mg C ha^{-1} y^{-1})

*CFU, Colony-forming units.

Culturable bacteria and fungi (colony forming units, CFU) were enumerated by the spread soil dilution plate method. For this method, each 10 g soil sample was homogenized in 100 ml phosphate-buffered saline solution (PBS, 0.15 M potassium phosphate, 0.85% NaCl, pH 7.0). The sample was centrifuged for 7 min at 250 ×*g* and the supernatant decanted into a sterile flask. The pellet was resuspended and washed twice by centrifugation in sterile PBS. All fractions were pooled in a sterile flask and serially diluted (10^6 – 10^7) in PBS (McDermott, 1997). For bacteria, 0.1 ml of each dilution of the series was placed onto a Petri dish with soil extract agar (SEA) (Ogram and Feng, 1997), for fungi, 0.1 ml of each dilution was placed onto a Petri dish with dextrose-peptone agar (DPA). To inhibit fungal growth during bacterial measurements, 30 mg l^{-1} cycloheximide was added to the SEA. To inhibit bacterial growth during fungi measurements, 30 mgl^{-1} streptomycin were added to the DPA. (Alef, 1995b). Three replicate dishes were made for each dilution. The agar plates were aerobically incubated at 30°C for 7 days to obtain bacterial counts and at 25°C for 7 days for fungi counts. After the incubation period, the CFU of the bacteria and fungi developed on the respective agar plates were enumerated using an automated colony counter. The averaged CFU per gram of oven-dried soil was calculated for each soil sample (Canbolat at al., 2006; Madigon and Martinko, 2006) and results are reported in Table 2.

CO_2-C analysis

The estimation of CO_2-C evolved from soil during incubation was conducted using a closed system. CO_2 was trapped in a NaOH solution, which was then titrated with HCl. For this experiment, 50 g sieved soil was placed in a beaker and the beaker placed in the bottom of a one-liter jar. A total of 25 ml NaOH (0.05 M) was pipetted into the jar and the jar was immediately sealed to make it airtight using a rubber ring and two crossing pegs. Other jars with NaOH (0.05 M) but without soil were used as controls. The jars were incubated up to 3 days at 25°C. At the end of incubation, the beakers were removed from the jars and the external surface of the beaker was rinsed with CO_2-free water and this water was added to the the NaOH solution in the jar. Five mille of $BaCl_2$ solution (0.5 M)

Table 3. Effect of soil tillage intensity on soil bulk density, porosity and CO_2-C fluxes at sowing, flowering, and harvesting periods of sunflower (*Helianthus annus*) and Duncan's multiple range tests.

Tillage system	Sowing period			Flowering period			Harvesting period		
	Bd	P	CO_2-C fluxe	Bd	P	CO_2-C fluxe	Bd	P	CO_2-C fluxe
T30	1.52a	43.46d	3.48 (0.301†)c*	1.49a	42.10d	4.36 (0.377)c	1.48a	40.15c	4.90 (0.423)c
T40	1.45ab	45.15c	3.51 (0.303)c	1.45ab	44.85c	4.40 (0.380)c	1.43ab	44.08b	4.96 (0.429)b
T50	1.39b	47.08b	3.64 (0.314)b	1.38b	46.53b	4.56 (0.394)b	1.38b	47.15ab	5.02 (0.434)b
T100	1.33c	49.62a	3.72 (0.321)a	1.34c	48.93a	4.65 (0.402)a	1.34c	48.23a	5.08 (0.439)a
Average	1.42A	46.32A	3.58 (0.309)C	1.41A	45.60B	4.49 (0.387)B	1.40A	44.90C	4.99 (0.431)A

*Means with the same letter are not statistically significant ($p < 0.01$); Bd, bulk density (Mg m^{-3}); P, total porosity (vol. %); CO_2-C fluxes (mg m^{-2} h^{-1}); †variables in parentheses Mg C ha^{-1} y^{-1} are indicator of the stability of the soil organic carbon in the soil; T30 = strip width of 22.5 cm, 30% soil surface disturbance, two blade; T40 = strip width of 30.0 cm, 40% soil surface disturbance, three blade; T50 = strip width of 37.5 cm, 50% soil surface disturbance, four blade; T100 = conventional tillage (moldboard plow + disk harrow +l eveler), %100 soil surface disturbance.

was then added to the NaOH solution along with some drops of phenolthelein indicator. The unreacted NaOH was titrated with standard HCl (0.5 M) with continuous stirring until the color changes from red to colorless. CO_2 that evolved from the soil during the exposure of alkali was calculated using the formula reported by Anderson (1982) and Alef (1995a).

Statistical analysis

Analysis of variance (ANOVA) was used to evaluate the significance of each treatment on soil properties and CO_2 fluxes and on bacterial and fungal populations. Comparison of means was performed, when the F-test for treatment was significant at the 5% level, using Duncan's multiple means tests.

RESULTS AND DISCUSSION

CO2 Fluxes

Average CO_2-C fluxes as affected by tillage treatments and time periods were found to be significantly ($p < 0.01$) different. The highest CO_2-C fluxes from soils in sowing, flowering and harvesting period were observed for T100 system (3.72, 4.65, 5.08 mg C m^2 h^{-1}, respectively). The minimum CO_2-C fluxes were observed for the T30 system at all periods (3.48, 4.36, 4.90 mg C m^2 h^{-1}). The CO_2-C fluxes increased with increasing strip widths. Among the strip widths, the highest fluxes were observed for the T50 systems and the lowest for the T30 systems (Table 3). The CO_2-C fluxes from the T30, T40 and T50 treatments were not statistically ($p < 0.05$) different. The same tendency was observed for all sampling periods.

The highest CO_2-C fluxes were observed at the harvesting period (during the summer period) and the minimum fluxes were observed at the sowing period. At the harvesting period, plant root growth, soil biomass and soil microbial activity had increased and these increases contribute to increased CO_2-C fluxes. Increasing strip tillage width increased CO_2-C fluxes at all sampling periods. Carbon dioxide fluxes from soil are due to the decomposition of organic material by microorganisms and root respiration. Tillage increased the rate of organic C decomposition. Data of the stability of the soil organic carbon in the soil are shown in parenthesis as Mg C ha yr^{-1} in Table 3. These measurements showed that carbon is more stable in the strip-tilled than in the T 100 plots.

Average bulk density and total porosity of the soil as affected by tillage treatments and plant growing periods were found to be significantly ($p < 0.01$) different. Total porosity of the soil increased with increasing strip widths, while bulk density of the soil decreased. The highest bulk density was observed in T30 treatment and the lowest bulk density was observed in T100 treatment at the sowing, flowering and harvesting period of plant growth (Table 3).

Changes in land use and soil management practice (tillage) also induce changes in soil organic C levels and CO_2-C fluxes (Bouwman, 1990; Al- Kaisi and Yin, 2005, Logan et al., 1991). T100 treatment caused the highest CO_2-C fluxes because tillage loosens the soil, increases the exposure of soil organic matter and speeds up organic matter oxidation (Reicosky and Lindstrom, 1993).

Soil tillage is among the important factors affecting soil physical properties (Khurshid et al., 2006). The tillage treatments affected the soil physical properties, especially when similar tillage system has been practiced for a longer period (Jordhal and Karlen, 1993, Mielke and Wilhelm, 1998). Structure of the Ap horizon is largely influenced by soil tillage system and the implements used for tillage (Lal, 1991). All tillage tools reduced the bulk density and raised porosity to the depth of tillage (Ferreras et al., 2000). In our study, we observed that strip tillage and a full-width inversion tillage system effected soil bulk density and soil porosity.

Bacterial and fungal population

The effects of soil tillage systems (between the strip tillage and full-width inversion tillage) on average bacterial numbers were statistically significant ($p < 0.05$). Similar results were observed in different growing periods. The

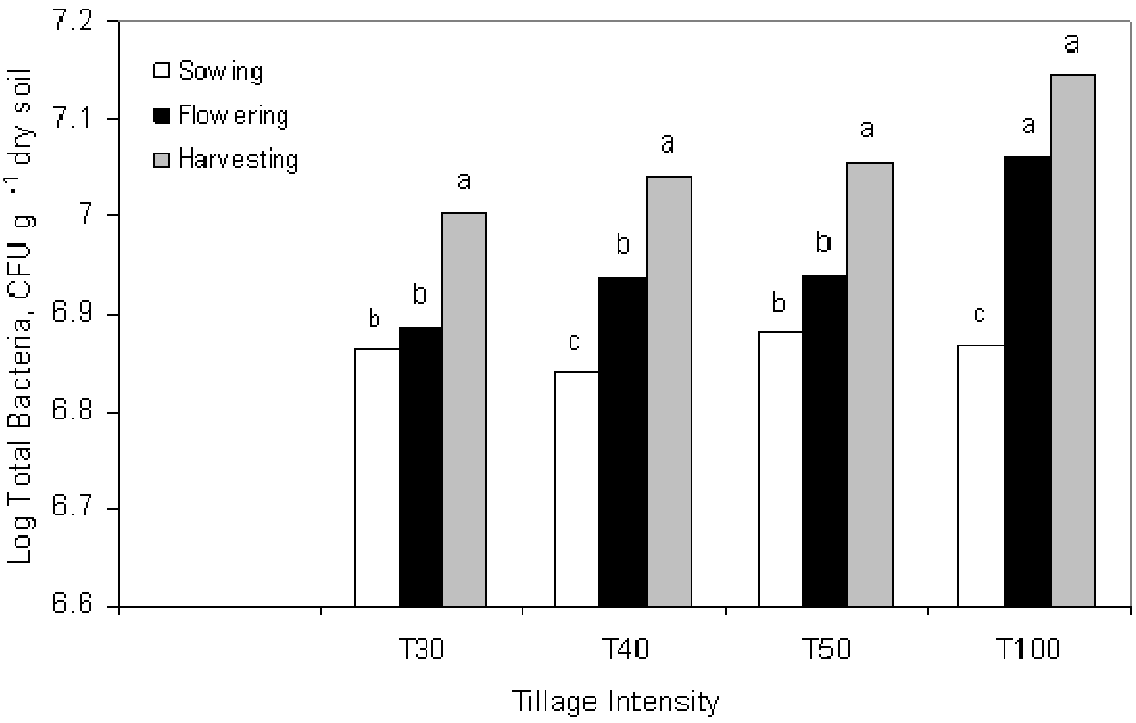

Figure 2. Effect of soil tillage intensity on soil bacteria populations at sowing, flowering and harvesting periods of sunflower (*Helianthus annus*). T30 = Strip width of 22.5 cm, 30% soil surface disturbance and two blade; T40 = strip width of 30.0 cm, 40% soil surface disturbance and three blade; T50 = strip width of 37.5 cm, 50% soil surface disturbance and four blade and T100 = conventional tillage (moldboard plow+disk harrow+leveler), %100 soil surface disturbance.

highest bacterial numbers were observed for the T100 system at flowering and harvesting periods (7.06 and 7.14 CFU g^{-1} dry soil), respectively. Among the strip tillage systems, the T30 plots supported the lowest bacterial numbers (6.88 and 7.00 CFU g^{-1} dry soil) and the T50 plots supported the highest bacterial numbers (108.6 and 142.6 CFU g^{-1} dry soil) at flowering and harvesting periods, respectively (Figure 2).

Similar results were observed for fungi population. The effects of soil tillage systems (between the strip tillage and full-width inversion tillage) and growing periods on average fungi populations were statistically significant ($p < 0.05$). Among the strip tillage systems, the highest fungi populations were observed in T30 system at flowering and harvesting periods (7.13 and 7.30 CFU g^{-1} dry soil), respectively, and T100 supported the lowest fungi numbers (6.94 and 7.11 CFU g^{-1} dry soil). The highest average fungi populations were observed in harvesting period (7.30 CFU g^{-1} dry soil) (Figure 3).

As tillage intensity increased, similar to the CO_2-C fluxes, the population of bacterial and fungal increased. The T100 tillage system produced the highest fungi and bacterial populations when compared with the three strip tillage treatments. Although microbial activity is strongly dependent on plant, soil and climatic conditions, soil tillage intensity had a definite effect on microbial activity (Figures 2 and 3).

Among the sampling periods, the harvesting period supported higher bacterial and fungi populations when compared with the other two periods. At both flowering and harvesting periods, the highest bacterial populations were observed for the T100 system and minimum values were observed for the T30 system. However, the highest fungi populations were observed for the T30 system and minimum values were observed for the T100 system (Figures 2 and 3). Tillage decreases soil organic matter (Gebhart et al., 1994), and when the crop production and tillage systems change, the microbial biomass and the biologically active C and N also rapidly change (Six et al., 2006). Tillage causes immediate changes in microbial community structure, but little concomitant change in total microbial biomass (Jackson et al. 2003). The cumulative effect of tillage and many cropping rotations has been 30 - 50% decrease in soil C that causes an undesirable change in soil physical, chemical and biological properties (Reicosky and Archer, 2007). Similar results were obtained in this study.

Conclusion

The present study demonstrated that increased tillage

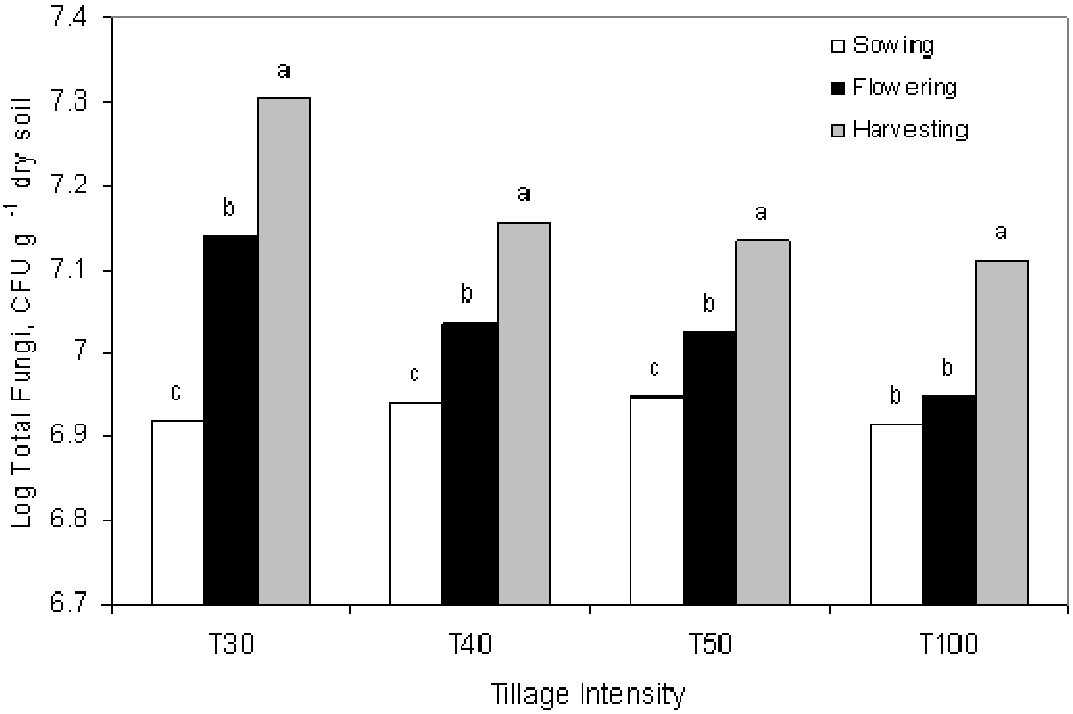

Figure 3. Effect of soil tillage intensity on soil fungi populations at sowing, flowering and harvesting periods of sunflower (*H. annus*). T30 = Strip width of 22.5 cm, 30% soil surface disturbance and two blades; T40 = strip width of 30.0 cm, 40% soil surface disturbance and three blades; T50 = strip width of 37.5 cm, 50% soil surface disturbance and four blades and T100 = Conventional tillage (moldboard plow + disk harrow + leveler), %100 soil surface disturbance.

intensity increased total porosity and CO_2-C fluxes of the soils. Especially, the T100 system exhibited large CO_2-C flux from soil. The increase in CO_2-C flux was related to tillage intensity with the smallest flux associated with the T30 treatment and the largest flux associated with the full-width inversion tillage (T100). This is because increasing tillage intensity disaggregates soil and improves soil aeration. Tillage treatments affected the soil physical and biochemical properties. Increasing tillage tools reduced the bulk density but increased total porosity to the depth of tillage.

The full-width inversion T100 tillage system showed the highest population levels of bacteria and the T30 treatment showed the lowest levels. But, T30 tillage system shoved the highest population levels of fungi and the T100 treatment shoved the lowest levels. As tillage systems change, the microbial biomass and the biologically active C fraction in soil also rapidly change. To preserve soil C and soil microbial populations, reduced tillage systems, such as the strip tillage systems evaluated in this study, can effectively decrease CO_2 emission.

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