Effects of Tillage Operations on Changes of Carbon-di-oxide (CO₂) Load and Yield of Wheat (Triticum aestivum L.)

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A B S T R A C T

A field experiment was conducted with wheat to study the effect of tillage operations on the changes of the CO₂- balance and reflection thereof, if any, on the yield of the crop. The organic sources in the form of decomposed paddy straw and farm yard manure (FYM) were applied in soil and the changes of the CO₂-in and CO₂-out were observed at the conventional (CT) and zero tillage (ZT) practices. The maximum level of CO₂-in (914.06 ppm) and CO₂-out (859.43 ppm) were recorded under the CT. The magnitude of yield differences of wheat was in the order of the treatment T₉>T₆ (where, T₉; full dose of paddy straw and FYM and T₆; half dose of paddy straw and full FYM). A close correlation was observed between the CO₂- balance and ambient temperature at the proximity of the leaf surfaces corresponding to different treatments. The gradual decrease of CO₂-out (ppm) was observed upto the day five (D₅) when the maximum leaf – temperature was on day two (D₂) under each treatment.

Introduction

The soil ecosystem as well as the soil organic carbon (SOC) are influenced by tillage like conservation tillage (CT) and zero tillage (ZT) practices. It was observed that microbial carbon (MBC), particulate organic carbon (POC) and dissolved organic carbon (DOC) were higher in no-tillage in comparison to conventional tillage practice in surface soil (up to 10cm) in wheat field (Enke et al., 2015) in addition to the factors, such as root distribution, field environments and exogenous organic matter, affecting labile organic carbon in soil during growing period of the crops (Fuentes, et al., 2010 and Van den Berg, et al., 2012). Besides, input of straw and root residue can enhance soil SOC contents in surface soil due to decomposition of organic matter (Fontaine et al., 2007) although, the SOC distribution might be different in conventional tillage and no-tillage
due to different root distribution in soils (Baker et al., 2007). The soil organic C is a major component of the global C with the estimated 1500 Gt representing more than the combined stocks of the atmosphere and biosphere (Lal, 2004) which can be increased in the surface soil under conservation tillage (CT) with deeper burial of straw residues (Blanco and Lal, 2008). Emission of CO_2 from soils to the atmosphere is the result of the losses of soil organic carbon. It was observed that CO_2-flux under NT were always lower and transformation from CT to NT with crop intensification was suitable to increase carbon inputs and reduction of soil CO_2 flux (Alvaro et al., 2008).

Agricultural systems having greater potential to sequester soil carbon have been widely accepted on global climate change aspect (Ogle et al., 2003). Carbon (C) inputs through plant biomass and C loss due to the activities of soil organism resulting from the agricultural management aspects, have considerable effect on sequestration of C in soil which can be stored to a greater extent by adoption of no-till management with continuous C inputs through litter and root activity (Carter, 2005; Puget and Lal, 2005). The changes in soil-climate have impact on the global environment as SOC contents influence the agricultural productivity. Potential of soil carbon sequestration or release of C as CO_2to the atmosphere are important function for adoption of mitigation strategy as well as climate change modelling (Lal et al., 2007).

The large scale CO_2 emission from soils to the atmosphere is due to mineralization of SOC. Soil micrometeorological conditions and management practices leads to the process of soil CO_2 emission (Paustian et al., 2000), where soil temperature is one of the variables affecting soil CO_2 emissions (Bajracharya et al., 2000). The tillage practices or soil management practices can modify the soil properties causing CO_2 emissions. The conventional tillage (CT) enhances soil microbial activity due to the breakdown of soil macro aggregates under intensive tillage systems which lead to an increase in soil CO_2emissions. Hence, the SOC can be enhanced by reducing tillage intensity along with return of C inputs to the field and can decrease in CO_2 emissions (Curtin, 2000). The climatic factors, such as rainfall and maximum temperature, including vegetation cover can play a key role in controlling SOC stock (Gray et al., 2016). Nonetheless, the production of organic matter and its mineralization is controlled by climate and loss of soil SOC was found to be highest in cool moist conditions (Sanderman et al., 2010; Cotching, 2012; Badgery et al., 2013). The climate, soil type and land management altogether can meaningfully estimate SOC storage in soil (Wang et al., 2014). The soil carbon stock can mitigate increasing atmospheric-C levels occurring from human induced climate change (Smith, 2012; IPCC, 2014). The association of SOC with soil health and agricultural productivity provides an added incentive to promote soil C levels (Sanderman et al., 2010), where the precipitation and temperature- the two climatic factors are the key driver of soil SOC (Minasny et al., 2013; Hobley et al., 2015). It was found that, CO_2 emission was higher in conventional tillage compare to NT in spring and it was also observed that after establishment of the crops, soils stopped loosing C (Smith et al., 2000) and the organic matter mineralization is responsible for CO_2 production (Paustian et al., 1997). Emission of CO_2 process is dependent on soil climate, C source, nutrients other biological factors, that can be reduced by adoption of NT than CT (Lal, 2000). Due to oxidation of soil organic matter, root and microbial respiration and return of unharvested plant residue the major green house gas CO_2 is emitted from
crop lands (Sainju et al., 2008). On the other hand, by absorption of CO₂ in plant biomass through photosynthesis and conversion to soil organic matter after return of plant residue to soil resulted C sequestration. Hence, soil carbon storage depends on the balance between the amount of plant residue C fixed through photosynthesis and the rate of C mineralization as CO₂ emission from soil (Sainju et al., 2008).

Experimental results indicated that improved yield in crop may be obtained by selection of genotypes with high harvest index plant and growing of crops under elevated CO₂ results in higher biomass production (Kulshrestha and Jain, 1982; Sharma, et al., 2004). It was also observed that leaf photosynthesis rate changes with leaf age, time of the day and sink strength (Ghildiyal and Sirohi, 1986; Ghildiyal et al., 1987).

Based on the above perspectives, the study was conducted to find out the effect of conventional and zero tillage on CO₂ balance and reflection thereof, if any, towards the yield of wheat.

Materials and Methods

Experimental site

The field-experiment was carried out during 2014-15 and 2015-16 with wheat (*Triticum aestivum* L.) on the agricultural farm of Uttar Banga Krishi Vishwavidyalaya, Pundibari, Cooch Behar, 736165, West Bengal.

The agricultural farm is located within the Terai region and its geographical location is N 26°23’59.9’’ latitude and E 89°23’24’’ longitude. The farm’s elevation is 185 mt above the Mean Sea Level (MSL). The farm’s experiments were carried out during two winter season 2014-2015 and 2015- 2016.

Experimental soil

The topography of the study area was upland with good drainage facilities. The texture of the soil was sandy loam. The composite soil samples from the experimental site was collected and analyzed before starting of the field trial.

Cropping history of experimental plot

A cropping sequence of rice –wheat was practiced in the study area.

Test crop

Wheat (*Triticum aestivum* L.) Variety: K-1006

The experimental design adopted was RBD (Randomised Block Design) in which there were two different tillage operations i.e., i) conventional tillage and ii) zero tillage and nine treatments with three-fold replications making a total of 27 (twenty seven) plots for each tillage and total of 54 (fifty four) plots, each measuring 5m x 4m having total area 1596.5m² (Table 1). The row to row spacing for both zero and conventional management practices were maintained 23 cm with 2.5-3.9cm depth having a seed rate of 100 kg ha⁻¹ for raising the wheat crop.

Leaf temperature, CO₂ -input, CO₂ -output of leaf were measured for five consecutive days at flowering stage under conventional and zero tillage system respectively for nine treatments during the cropping season (2014-15 and 2015-16) with IRIGA -Hand-Held Portable Photosynthesis System. The effect of treatment on CO₂ –balance under ZT was measured for consecutive five days at flowering stage of wheat for two years. The day three (D3) had been taken as reference for observation. Statistical analysis was done by SPSS (Version 16.0) and MSTAT-C.
Results and Discussion

From the meteorological data obtained from Gramin Krishi Mousam Seva Kendra, Pundibari, Cooch behar and IMD, it was recorded that, minimum temperature in the first year was in the month of November, 2014 (10.17°C) and in the month of January, 2016 (9.48°C), during the second year of study (Figure 1), while the maximum temperature was observed during March, 2015 (30.11°C) and in March, 2016 (30.69°C) in the first and second year respectively.

The relative humidity was maximum in January, 2015 (90.28%) and in January, 2016 (91.19%) and the minimum during March, 2015 (55.93%) and March, 2016 (55.52%) in first and second year respectively. The average rainfall was recorded in January, 2015 (0.75 mm) and in January, 2016 (0.17 mm) during the first and second year respectively. Hence, a wide range of variation on temperature, humidity and rainfall was observed during 2015 — 2016 at the study area.

The effect of different treatments (T1 to T9) on the change of CO2-balances (Figure 2 to Figure 5) depicted the effects of organic input (FYM or Straw) under CT and ZT practices vis - a- vis the impact of temperature corresponding to the CO2-balances in leaf at different treatments (Figure 2 to Figure 5). The maximum value of CO2-in (ppm) under conventional tillage (CT) was found in the treatment T2 on D4 day and almost uniform trend was observed in other treatments (Figure 2). Besides, a steady trend of CO2-in was found on the remaining four days except there was a slight variation on D3 under treatment T8. The variations in leaf-temperature on experimental days corresponding to the different treatments was observed, where the minimum leaf-temperature was recorded on D1 day (Figure 2). The level of CO2-out (ppm) was different under CT on D4 day among different treatments, out of which maximum CO2-out was recorded at the treatment T6 on that day (Figure 3). The trend of CO2-out on remaining four days showed almost uniformity with different treatments. The variation of leaf-temperature was observed between D1 and D3 (Figure 3).

The variation of CO2-in under zero tillage (ZT) was observed between D4 and D5 days and the maximum CO2-in was observed on D4 day at the treatment T7 (Figure 4). The variation of CO2-in (ppm) on D3 for each treatment was observed except at the T4, T5 and T6 treatments, with little changes and for the remaining three days (D1, D2 and D3) the level of CO2-in (ppm) was almost same (Figure 4).

There was little variation on D4 in CO2-out at the treatment T8 in ZT management (Fig. 5). However, on D5 day, there was a gradual decrease in the level of CO2-out (ppm) between T1 to T3 and being uniform between T4 and T8 treatments and the lowest on D5 at the treatment T9. The maximum leaf-temperature was recorded on D2 and that of minimum on D1 under each treatment (Figure 5).

From the pool data it was observed (Table 2) that the highest value of CO2-in (914.06 ppm) and CO2-out (859.43 ppm) were recorded under the treatment T2 and lowest level of CO2-in (765.11 ppm) at T4 and CO2-out (745.14 ppm) at T7 treatment in CT. The highest CO2-in (811.42 ppm) was recorded in treatment T7 and lowest CO2-in (769.89 ppm) was at T6. The highest CO2-out (803.96 ppm) was recorded at T1, whereas, the lowest CO2-out (764.79 ppm) was at treatment T5. Experimental results showed that the balance of CO2 under different treatments (T1 to T9) was dependent on leaf temperature. At the treatment T9, better balance in CO2 release
from leaf during photosynthesis was observed than other treatments at various leaf -temperature and relative humidity considering the yield maximization of wheat (Figure 6) both under CT and ZT practices, where, the zero tillage operation had better balance in CO$_2$-in and CO$_2$-out from leaf during photosynthesis, compare to conventional tillage (CT).

The magnitude of yield differences of wheat both under CT and ZT was in the order of the treatments as $T_9>T_6>T_3$ where the organic input as FYM and decomposed straw were applied, which might have some effect on nutrient mobilization to the crop and better aggregation of soil during the crop growth period. The input of CO$_2$ through external sources along with solar energy utilization could enhance the probabilities and scope for improvement of photosynthates (Sharma and Ghildiyal, 2005) which might be enhanced during the high radiation environment.

The difference in yield both under CT and ZT could be sustained by assimilation and management of C supplied through the decomposed FYM and paddy straw for the treatment $T_6$ and $T_9$, where the ‘C’ required for grain filling was mostly provided by flag leaf photosynthesis (Evans et al., 1975) where, the sink strength is equally important as the activities of source were enhanced.

The performance under elevated CO$_2$ (Ainsworth, et al., 2004) might have some effect on ‘C’ requirement for photosynthetic performances of wheat although, the plant species and day length are other important factors on the balance of sucrose on starch content of the given species.

### Table 1 Treatment details

| Treatment details |
|-------------------|
| **Conventional Tillage** | **Doses** | **Zero Tillage** | **Doses** |
| Treatments | Doses | Treatments | Doses |
| $T_1$ | 100% (N:P:K) + $S_0$F$_0$ | $T_1$ | 100% (N:P:K) + $S_0$F$_0$ |
| $T_2$ | 100% (N:P:K) + $S_0$F$_{1/2}$ | $T_2$ | 100% (N:P:K) + $S_0$F$_{1/2}$ |
| $T_3$ | 100% (N:P:K) + $S_0$F$_1$ | $T_3$ | 100% (N:P:K) + $S_0$F$_1$ |
| $T_4$ | 100% (N:P:K) + $S_{1/2}$F$_0$ | $T_4$ | 100% (N:P:K) + $S_{1/2}$F$_0$ |
| $T_5$ | 100% (N:P:K) + $S_{1/2}$F$_{1/2}$ | $T_5$ | 100% (N:P:K) + $S_{1/2}$F$_{1/2}$ |
| $T_6$ | 100% (N:P:K) + $S_{1/2}$F$_1$ | $T_6$ | 100% (N:P:K) + $S_{1/2}$F$_1$ |
| $T_7$ | 100% (N:P:K) + $S_1$F$_0$ | $T_7$ | 100% (N:P:K) + $S_1$F$_0$ |
| $T_8$ | 100% (N:P:K) + $S_1$F$_{1/2}$ | $T_8$ | 100% (N:P:K) + $S_1$F$_{1/2}$ |
| $T_9$ | 100% (N:P:K) + $S_1$F$_1$ | $T_9$ | 100% (N:P:K) + $S_1$F$_1$ |

**N: P: K =100:60:40 kg ha$^{-1}$ (Recommended doses as 100%)**

**N: Nitrogen; P: Phosphorus; K: Potassium**

Paddy Straw (S) = 10 tons/ha (Full dose) ; Farm Yard Manure (F) = 10 tons/ha (Full dose)

$S_{1/2}$ = 5 tons/ha $F_{1/2}$ = 5 tons/ha

Where, S = Paddy Straw F= Farm Yard Manure $S_0$= No Paddy Straw $F_0$= No Farm Yard Manure; $S_{1/2}$= Half Paddy Straw $F_{1/2}$= Half Farm Yard Manure, Crop- Wheat; Variety-K 1006

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Table 2 Effects of treatment on carbon dioxide balance under CT and ZT

| Treatments | Conventional tillage | Zero-tillage |
|------------|----------------------|--------------|
|            | Temperature (°C)     | CO₂-in (ppm) | CO₂-out (ppm) | Temperature (°C) | CO₂-in (ppm) | CO₂-out (ppm) |
| T₁         | 24.52                | 777.73b      | 756.19b       | 24.44             | 800.01ab     | 803.96a       |
| T₂         | 24.60                | 914.06a      | 859.43a       | 24.56             | 791.94abc    | 792.59ab      |
| T₃         | 24.83                | 801.63b      | 775.35b       | 24.37             | 801.75abc    | 780.43ab      |
| T₄         | 24.21                | 765.11b      | 746.50b       | 23.67             | 781.49bc     | 766.83b       |
| T₅         | 24.61                | 864.78a      | 783.99b       | 24.11             | 780.30bc     | 764.79b       |
| T₆         | 24.49                | 794.32b      | 782.96b       | 23.51             | 769.89c      | 765.36b       |
| T₇         | 24.62                | 768.91b      | 745.14b       | 23.83             | 811.42a      | 770.50b       |
| T₈         | 24.86                | 798.11b      | 770.17b       | 23.90             | 797.86abc    | 803.13a       |
| T₉         | 25.06                | 774.68b      | 754.41b       | 23.77             | 777.00bc     | 767.82b       |
| SEm (±)    | -                    | 21.57        | 7.93          | -                 | 17.94        | 9.27          |
| CD (P=0.05)| -                    | 62.15        | 22.80         | -                 | 51.68        | 26.70         |
| CV (%)     | -                    | 6.55         | 2.46          | -                 | 5.67         | 2.91          |

Fig. 1 Changes of temperature and relative humidity during the crop growth period

Source: Gramin Krishi Mousam SevaKendra, Pundibari, Coochbeharand IMD.
**Fig. 2** Effect of treatments on CO$_2$-in under conventional tillage operations

**Fig. 3** Effect of treatments on CO$_2$-out under conventional tillage operations
**Fig. 4** Effects of treatments on CO$_2$–in under zero-tillage operations

**Fig. 5** Effects of treatments on CO$_2$ out balance under zero-tillage operation
Fig. 6 Effect of different treatments on yield of wheat

The temperature is a major determinant of microbial processes having a co-relation with leaf temperature during photosynthesis. The rates of organic matter decomposition along with CO$_2$-balance might have the significant effect on yield attributes (Schimel et al., 1994) which in turn could have the effect on rate of decomposition by the atmospheric temperature (Waldrop and Firestone, 2004). Thus, the CO$_2$-in and CO$_2$-out during the plant metabolic activity was governed by the different tillage operations which would regulate the 'C' sink in the soil for subsequent translocation to the plants. The yield of wheat was different due to the input of organic substances like FYM and paddy straw, which could have some effect on the CO$_2$-balance in the soil-atmosphere systems. The sequestered 'C' in soil might be a machinery to maintain the CO$_2$ balance affecting the ratio of starch/sucrose in wheat. The ambient atmospheric temperature also could play the role in CO$_2$-balance in the leaf environment, corresponding to different treatments.

Acknowledgement

This research was supported by the Uttar Banga Krishi Viswavidyalaya and Visva-Bharati. We thank Dr. Parimal Panda, Mr. Anarul Hoque of Regional Research Station, Pundibari, Cooch Behar and Mr. Mijanur Rahaman of the University for their assistance during this research work.

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How to cite this article:

Pal, D., P.K. Patra, K. Mandal and Mukhopadhyay, D. 2019. Effects of Tillage Operations on Changes of Carbon-di-oxide (CO2) Load and Yield of Wheat (Triticum aestivum L.). Int.J.Curr.Microbiol.App.Sci. 8(05): 1207-1217. doi: https://doi.org/10.20546/ijemas.2019.805.137