Influence of conservation tillage on Greenhouse gases fluxes and crop productivity in spring-wheat agroecosystems on the Loess Plateau of China

Abdul-Rauf Malimanga Alhassan [1,2], **Guopeng Chen** [1,2], **Chuangjie Yang** [2], **Weiwei Ma** [2], **Li Guang** [Corresp. 2]

[1] Department of Agriculture, Northern Regional Coordinating Council, Tamale, Northern Region, Ghana

[2] College of Forestry, Gansu Agricultural University, Lanzhou, Gansu, China

Corresponding Author: Li Guang
Email address: liguang468@yahoo.com

This study examined the effect of tillage on crop productivity and seasonal variations of greenhouse gas fluxes in spring wheat agroecosystems on the semi-arid Loess Plateau of China. Four tillage treatments were tested including: conventional tillage (CT), conventional tillage with straw mulch (CTS), no-till (NT) and no-till with straw mulch (NTS). The results indicated that NTS, NT and CTS increased soil water content (SWC), soil organic carbon (SOC) and total nitrogen (TN) compared with CT but reduced soil temperature (ST). NTS and NT reduced ecosystem respiration, net CO_2 emission and increased net CH_4 absorption. However, there were slight emissions of N_2O in all treatments which were greater in NTS, NT and CTS than in CT. Global warming potential (GWP) and Greenhouse gas intensity (GHGI) were also significantly reduced under NT and NTS compared with CT. The growing season showed higher emission rates of greenhouse gases (GHGs) than the non-growing season. There was significant positive correlation between soil organic carbon and grain yield and between total nitrogen and grain yield. Ecosystem respiration highly and significantly correlated with SWC and ST, while CH_4 flux highly correlated with ST. Overall, NT reduced net GHG emissions but increased crop yield slightly while NTS improved crop yield and reduced net GHG emissions significantly compared with CT. No-till with straw retention (NTS) is recommendable for sustainable crop production in arid and semi-arid regions as it significantly increased grain yield and reduced GHG emissions.

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Abdul-Rauf Malimanga Alhassan[1,2], Guopen Chen[1], Chuangjie Yang[1], Weiwei Ma[1], Guang Li[1]

[1] College of Forestry, Gansu Agricultural University, Lanzhou, Gansu province, 730070, P.R. China.
[2]Northern Regional Coordinating Council, Department of Agriculture, P.O. Box 14, Tamale, Ghana.

Corresponding Author:
Guang Li[1]
730070, Lanzhou, Gansu Province, 730070, China
Email address: liguang468@yahoo.com

Abstract

This study examined the effect of tillage on crop productivity and seasonal variations of greenhouse gas fluxes in spring wheat agroecosystems on the semi-arid Loess Plateau of China. Four tillage treatments were tested including: conventional tillage (CT), conventional tillage with straw mulch (CTS), no-till (NT) and no-till with straw mulch (NTS). The results indicated that NTS, NT and CTS increased soil water content (SWC), soil organic carbon (SOC) and total nitrogen (TN) compared with CT but reduced soil temperature (ST). NTS and NT reduced ecosystem respiration, net CO_2 emission and increased net CH_4 absorption. However, there were slight emissions of N_2O in all treatments which were greater in NTS, NT and CTS than in CT. Global warming potential (GWP) and Greenhouse gas intensity (GHGI) were also significantly reduced under NT and NTS compared with CT. The growing season showed higher emission rates of greenhouse gases (GHGs) than the non-growing season. There was significant positive correlation between soil organic carbon and grain yield and between total nitrogen and grain yield. Ecosystem respiration highly and significantly correlated with SWC and ST, while CH_4 flux highly correlated with ST. Overall, NT reduced net GHG emissions but increased crop yield slightly while NTS improved crop yield and reduced net GHG emissions significantly compared with CT. No-till with straw retention (NTS) is recommendable for sustainable crop production in arid and semi-arid regions as it significantly increased grain yield and reduced GHG emissions.

Keywords: conservation agriculture; crop productivity; global warming potential; ecosystem respiration, methane, nitrous oxide, soil properties.

Introduction

Agriculture accounts for one-third of global warming effect through increased GHG emissions (Cole et al., 1997). Recently, food systems have been reported to emit between 19 and 29% of global anthropogenic greenhouse gases (Oertel et al., 2016). Agricultural soils are largely sources of carbon dioxide (CO_2), nitrous oxide (N_2O) and may act as source or sink of methane (CH_4) (Smith et al., 2008). However a number of factors such as crop and soil conditions may influence the GHG source or sink nature of agricultural soils and determine the functions of agroecosystems. For instance soil structure influenced ecosystem functions while the type of cropping system and management also affects GHG emissions. Smith et al. (2008) indicated that through improved management of cropping systems, agriculture carbon sequestration rate could range between 5.5 and 6.0 Pg CO_2-eq per year by 2030. Paustian et al. (2006) also posited that though agriculture is a substantial source of GHGs, it also has great potential to reduce the accumulation of these gases in the atmosphere. Zhang et al. (2015) postulated that improved management of soil and water resources may lead to reduced carbon emissions, food security and high resource use efficiency.

Conservation agriculture in the form of no-till and residue incorporation in soils have been widely disseminated with the aim of increasing long term crop productivity while minimizing adverse effects of crop production on the environment. Long term sustainability of arid production systems are strongly linked to soil properties; because crop yields are limited by soil physical conditions (Indoria et al., 2016), soil chemical and biological properties (Woźniak & Gos, 2014). Properly implemented CA systems may improve soil quality and ensure sustainable agriculture in the long term. Conservation Agriculture may improve soil moisture, increase soil organic carbon, improve soil structure, increase soil water infiltration, reduce soil erosion, and increase water use efficiency (Li et al., 2014), thereby resulting in high crop productivity. As shown by Pittelkow et al. (2015), no-till with residue retention significantly enhanced yield by 7.3% under rainfed agriculture in dry climates. Furthermore, avoiding or reducing conventional tillage practice could result in substantial benefits to the environment through improving the sink capacities of soils and reducing emissions of GHGs. Adoption of conservation tillage is likely to increase soil carbon stocks (Paustian et al., 2006). For instance, Ogle et al. (2005) reported in crease of soil carbon stock by10-20% under NT compared with CT in the top soil zone over 20 years of NT adoption in the United States (U.S). Due to less use of machinery under CA, carbon emissions due to burning of fossil fuel may be reduced. Analyzing carbon emission due to fossil fuel combustion in the U.S, the adoption of NT resulted in 70% reduction in CO_2 emission while minimum tillage reduced CO_2 emission by 40% compared with that of CT (West &Marland, 2002).

Intensifying crop production could result in increased radiative forcing in the atmosphere. There is the need to design agricultural systems that would meet global food demand through high productivity while conserving the already stressed environment (Lal, 2005) through less emission of GHGs. A number of studies have been conducted on the impacts of conservation tillage on GHGs on the Loess Plateau but with less emphasis into the seasonal variations of

GHGs. In drylands, fallow periods are common and occupy a substantial area in a given year (Liebig et al., 2010). Understanding fluxes all year round will deepen our understanding of the dynamics of GHG emissions from cultivated soils and the influence of conservation tillage on trace gas emissions. This study was conducted (1) to examine the influence of conservation tillage on crop productivity (2) examine dynamics of ecosystem respiration (R_{eco}), methane (CH_4) and nitrous oxide (N_2O) fluxes as affected by conservation tillage (3) unravel the seasonal variations of these fluxes in the dryland region of northwestern Loess Plateau of China.

Materials & Methods

Description of study area

This experiment was conducted for two years (2017-2018) in the Anjiapo catchment on the western Loess Plateau in Gansu province at the Soil and Water Conservation Research Institute in Dingxi (35° 34' 53"N, 104° 38' 30"E; 2000 m above sea level). Forty two years (1971-2012) continuous climate data shows average annual precipitation of 385 mm, evaporation of 1531 mm; sunshine duration of 2448 h, temperature of 7.1°C, and a frost free period of 153 days. The soil is formed from Loess with a sandy-loam texture, with average soil bulk density of 1.26 gcm^{-3}. Average soil organic carbon (SOC) is 6.21 gkg^{-1} while total nitrogen content is 0.61 gkg^{-1}. Precipitation, maximum and minimum temperatures for the period of the experiment are shown in Fig. 1. Cumulative precipitation for the growing seasons (March-July) were 177.80 and 291.60 mm for 2017 and 2018 respectively (Fig. 1 a,b). Temperature in the growing seasons varied between -1.46 and 29.96 °C in 2017 while in 2018 it varied between 0.15 and 24.51 °C (Fig. 1c, d).

Fig. 1. Rainfall amounts for 2017 (a), 2018 (b) and Mean, maximum and minimum temperatures for 2017 (c) and 2018 (d) in the Anjiapo catchment in Dingxi

Experimental design

Four tillage treatments were established in a randomized complete block design. The treatments included conventional tillage (CT), conventional tillage with straw mulch (CTS), no-till (NT) and no-till with straw mulch (NTS). Sowing was conducted in spring (mid-March) in both years while crops were harvested in late July to early August. In the tilled plots, soils were tilled at two different times by manual inversion with shovels to a depth of 20 cm; first in October of the previous year and again in March, just before planting. Glyphosate (30%) herbicide was applied to control weeds in plots. Wheat straw (3.75 ton/ha) was spread uniformly on all straw-treated plots immediately after planting. Planting was done manually by the drill method in rows with row spacing of 25 cm while fertilizers were applied to all the plots using Di-ammonium phosphate, ($N+P_2O_5$) at a rate of 146 kg/ha and urea (46%) at a rate of 63 kg/ha.

Sampling and measurement of grain yield

Three rows per plot were harvested for determination of aboveground and below ground plant products at physiological maturity. Aboveground biomass was determined by oven drying of plants at 80 ^{o}C to constant weight (Alhassan et al. 2018), while grain yields were determined by oven-drying at 105^{o}C for 45 minutes (Yeboah et al. 2016a). These were used to obtain the harvest index (HI) expressed as grain yield divided by sum of grain yield and straw yield (aboveground biomass).

Measurements of soil water content, soil temperature and chamber temperatures

Soil water content and soil temperature at 0-10 cm depth were measured using EM50 data logger and GS3 soil moisture, temperature and EC sensor (Decagon Devices, Inc., Pullman, Washington). The sensor was set to take data every 2 minutes during sampling period and the average value was used. The data was then transferred onto the computer using the ECH_2O software. Chamber temperature was recorded using a handheld digital thermometer (JM624, Jinming Instrument Co., Tianjing, China). Soil moisture and temperature data were taken concurrently with gas sampling.

Measurement of soil organic carbon

Soil organic carbon was determined by the Walkley-Black dichromate oxidation method (Nelson & Sommers, 1982). About 0.1 g of air dried soil sample was treated with 8.0 ml of 0.4 M of $K_2Cr_2O_7$ and 8.0 ml of concentrated H_2SO_4 at 170-180°C for 30 min. After the solution was cooled, 2-3 drops of Ortho-phenanthroline was added to the solution which was back titrated using 0.4N Ferrous Sulphate solution.

Measurement of soil total nitrogen

Total nitrogen content (TN) in the soil samples were determined by the Kjeldahl digestion and distillation procedure as described by Bremner & Mulvaney (1982). A weighed sample of soil (about 1.0g) was put into a Kjeldahl digestion flask, and distilled water was added. Thereafter, the sample solution was digested for 3 hours to a colorless solution. The solution was then diluted further with distilled water of 100 ml of volume. A 5 ml NAOH solution was added to an aliquot (10ml) of the sample solution and put into a reaction chamber, which was then distilled. The distillate was then collected in boric acid and titrated. Titration was done with H_2SO_4 solution. Distillation and titration was also done for a blank solution.

Gas sampling and Flux measurements

Gas samples were conducted between September 2017 and January 2019. The static dark chamber and Gas chromatography (GC) method as described by Wang and Wang (2003) were used for gas sampling and flux measurements. In each plot (a total of 12 plots), a stainless steel base with a collar (50 x 50 x 10 cm) was installed to support placement of the sampling chamber (50 x 50 x 50 cm) for gas sampling. Air samples were drawn from the chambers concurrently for the 3 replicates of each treatment. Samples were drawn at 5 different times at 0, 9, 18, 27, and 36 minutes respectively using 150 ml gas-tight polypropylene syringes. The withdrawn gas were released into 100 ml aluminum foil sampling bags (Shanghai Sunrise Instrument Co. Ltd, Shanghai) connected to the syringes. Gas samples were then analyzed in the laboratory with a GC system (Echrom GC A90, China). The Echrom GC system is equipped with a flame ionization detector (FID) for CH_4 and CO_2 analysis and Electron capture detector (ECD) for N_2O analysis. The FID operates at a temperature of 250^oC, and H_2 flow rate of 35 cm^3 min^{-1}. Peak areas of CO_2, CH_4 and N_2O were analyzed in Echrom-ChemLab software. Before the analyses of sample gases, calibrations were done with standard gas obtained from Shanghai Jiliang Standard Reference Gases Co., Ltd, China. Concentrations of the standard gases were 456.00 ppmv for CO_2, 2.00 ppmv for CH_4 and 0.355 ppmv for N_2O. The sample gas concentrations obtained for the five sampling times were plotted against time in order to obtain the change in concentration over the sampling time (dC/dt). Following equation 1, R_{eco}, CH_4 and N_2O fluxes were calculated (Wei et al. 2014).

$$F = \frac{dC}{dt} \cdot \frac{M}{V_0} \cdot \frac{P}{P_0} \cdot \frac{T_0}{T} \cdot H \qquad (1)$$

where dC/dt is the rate of change of gas concentration; M is the molar mass of Carbon or Nitrogen (12 for CO_2 and CH_4 and 28 for N_2O); V_o is standard molar volume of air (22.41 mol^{-1}), P is the air pressure of the sampling site; P_o is the standard air pressure, T is the air temperature in the chamber at the sampling time, T_o is the standard air temperature; and H is the chamber height.

Cumulative Flux was estimated using the formula below.

$$\text{Cumulative Flux} = \sum_{i=1}^{n} \left(\frac{F_i + F_{i+1}}{2}\right) \times 24 \times \left(D_{i+1} - D_i\right) x\ 10^{-2} \ \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

F_i and F_{i+1} denote ecosystem respiration, N_2O and CH_4 fluxes for previous and current day (in mg m^{-2} h^{-1}) respectively; D_i and D_{i+1} are previous and current sampling days, respectively.

Calculation of Carbon flux components

Net primary productivity (NPP) was estimated as described in equation 3-7 by Bolinder et al (2007), while Gross primary production (GPP) was estimated from NPP using a factor of 0.54 as the ratio of NPP:GPP in cultivated and managed lands (Zhang et al. 2009). Grain yield and harvest index (HI) were used for calculation of NPP and GPP. It is worth noting that the CO_2 measured by the opaque chamber is ecosystem respiration since plant community was not exposed to light and also undisturbed. From this, net CO_2-C flux was calculated by equation 2.15.

$$NPP = C_P + C_S + C_R + C_E \text{......(3)}$$

$$C_P = Y_P \times 0.45 \text{......(4)}$$

$$C_s = \frac{Y_P\,(1-HI)}{HI} \times 0.45 \text{......(5)}$$

$$C_R = \frac{Y_P}{S{:}R \times HI} \times 0.45 \text{......(6)}$$

$$C_E = C_R \times 0.65 \text{......(7)}$$

Where

C_P is the carbon in the harvested product (grain)

C_s is the carbon in straw

C_R is the carbon in root tissues

C_E is the carbon in extra root materials such as root exudate

Y_P is the grain yield, S:R is the shoot – root ratio

As indicated by Bolinder et al. (2007), we assumed carbon concentration in all plant parts of 0.45 $kgkg^{-1}$ while using actual harvest indexes in our study to calculate allocations in straw and root. S:R of 9 for spring wheat was used in this study following Huang et al. (2007).

$$\text{Net } CO_2 \text{ flux} = -GPP + R_{eco} + C_{harvested\ crop} \text{......(8)}$$

GPP- gross primary production, R_{eco}- cumulative ecosystem respiration, $C_{harvested\ crop}$- Carbon contents in harvested crops (straw and grain).

Note: The sign convention adopted is positive (+) means emission whilst negative (-) means absorption.

Calculation of Global warming potential (GWP) and Greenhouse Gas Intensity (GHGI)

Net Global warming potential (GWP) in t CO_2 eq ha^{-1} was determined using equation 9 and Greenhouse gas intensity (GHGI) was determined following equation 10. The IPCC (2013) emission factors of 1, 34 and 298 for CO_2, CH_4 and N_2O respectively were used to convert all gases to CO_2 equivalents (CO_2eq).

$$Net\ GWP = \mathrm{CH_4} flux \times 34 + \mathrm{N_2O\ flux} \times 298 + Net\ CO_2\ flux \quad (9)$$

$$GHGI = \frac{GWP}{Grain\ yield} \quad (10)$$

The sign convention adopted is positive (+) means emission whilst negative (-) means absorption.

Statistical Analysis

Analysis of gas fluxes were done in Excel spread sheet in Microsoft office (2010). The data was statistically analyzed in SPSS, version 22 (IBM Corporation, Chicago, USA). One-way Anova was conducted and treatment means were separated using the Duncan's multiple range tests (DMRT) at $p < 0.05$. Linear and non-linear regressions were used to examine the relationships between crop yields and soil properties as well as between soil variables and greenhouse gas fluxes. The exponential and power equations were used to describe the relationship between ecosystem respiration, soil temperature and soil water content as shown in equations 11 and 12 respectively whilst the Q10 function which was used to estimate the change in ecosystem respiration for every 10 °C change in temperature is shown in equation 13.

$$R = \alpha \times e^{\beta T} \quad (11)$$

$$R = \alpha \times W^{\beta} \quad (12)$$

$$Q_{10} = e^{10\beta} \quad (13)$$

Results

Soil properties

Soil moisture and Soil temperature

Soil water content increased in NTS than other treatments at almost all sampling times (Fig. 2a). CTS also stored more moisture than NT and CT at most sampling times in 2018. CT had the least water contents at most sampling times. SWC ranged between 1.12 % on December 29, 2017 in CT to 30.10% on November 24, 2018 in NTS. Average monthly values showed that soil moisture was higher in July, August and September than the other months under all treatments. Soil temperature, as shown in Fig. 2b showed peak temperatures occurring in June, July and August. The highest temperatures were recorded in CT in most times while NTS and NT had the least temperatures except in August, September and November, 2018.

Soil organic carbon (SOC)

Conservation tillage increased SOC at all depths in the 2nd year of this study (Fig. 3), but in the first year there were no significant changes. Meanwhile SOC decreased along soil depth irrespective of treatment. After harvest in 2018, there were significant differences among treatments in SOC levels where within the 10 cm depth NTS, NT and CTS were all significantly different from the control (CT) and increased SOC by 26.03, 18.38 and 19.95% respectively. Within the 10-20 cm profile, there was increase in SOC by 14.26, 10.76 and 12.51% in NTS, NT and CTS respectively, compared with CT while in the 20-40 cm depth, SOC in NTS and CTS were significantly greater than CT.

Total Nitrogen (TN)

Similar to SOC, there was no difference in TN in 2017 but in 2018, there were significant differences ($p < 0.05$) among treatments in the 0-10 cm and the 10-20 cm depths (Fig 3). Total nitrogen levels at the 0-10 cm depth followed the order NTS > NT > CTS > CT. Compared with CT, TN increased by 65.91, 43.75 and 21.59% respectively in NTS, NT and CTS. In 2018, there was obvious reduction of TN levels along soil depth in all treatments.

Fig 2. Soil water content (a) and soil temperature (b) at various sampling times (10 cm depth)

Fig 3. Distribution of soil organic carbon (SOC) in 2017 (a) and 2018 (b) and total nitrogen (TN) in 2017 (c) and 2018 (d) among tillage treatments within different depths. Treatments with common letters within a depth are not statistically different at $p \leq 0.05$.

Grain Yield

Tillage influenced grain yield in this study in both years (Table 1). Comparing all treatments, NTS had the greatest yield in 2017 while CTS showed the greatest yield in 2018 (Fig. 4b). These were both significantly different from yield under CT ($p < 0.05$). In 2017, grain yields under NTS, NT and CTS were all higher than CT but only NTS showed significant difference. Average yield for the 2 years showed that NTS gave the highest yield following the order: NTS > CTS > NT > CT. In two years, average grain yield were 644.61 ± 116.40, 854.46 ± 76.51, 699.30 ± 133.52 and 908.18±38.64 kg ha^{-1} respectively for CT, CTS, NT ad NTS. Compared with CT using the 2–year average yields, NTS, CTS and NT increased yield by 40.89, 32.55, and 8.48% respectively. Yields were generally higher in 2018 than in 2017.

Table 1. Wheat grain yield under different tillage treatments in (a) 2017 (b) 2018 (c) 2017-2018.

Average emission of greenhouse gases across treatments and seasons

Ecosystem respiration for growing and non-growing seasons for all treatments are shown in figures 4a and 4b respectively. Tilled soils emitted significantly more CO_2 than no-tilled soils. In the growing season, average CO_2 emission rates were 270.475 ± 11.03, 262.88 ± 0.20, 183.83 ± 34.05 and 190.72 ± 19.20 mg C m^{-2} h^{-1} in CT, CTS, NT, and NTS respectively. In the non-growing season, the emission rates were 30.55 ± 1.71, 45.51 ± 3.88, 31.74 ± 1.35 and 34.15 ± 5.71 mg C m^{-2} h^{-1} respectively in CT, CTS, NT, and NTS. Emission in CTS was significantly greater than the other three treatments in the non-growing season. In the growing season, CTS, NT, and NTS reduced emission by 2.81, 32.03 and 29.48% respectively, however in the non-growing season, emission from CT was the least.

Both in the growing and non-growing seasons, the spring wheat ecosystems served as minor sinks of CH_4 irrespective of tillage systems applied (Fig. 4c,d). The respective absorption rates were -0.071 ± 0.041, -0.102 ± 0.005, -0.106 ± 0.009 and -0.149 ± 0.001 mg C m^{-2} h^{-1} for CT, CTS, NT and NTS in the growing season while in the non-growing season the values were -0.081±0.064, -0.055 ± 0.006, -0.071 ± 0.018 and -0.055 ± 0.004 mg C m^{-2} h^{-1} respectively. However, there were variations in their sink capacities. NTS was the largest sink in the growing season while CT was the largest sink in the non-growing season. Generally, average absorption rates were higher in the growing season than the non-growing season for all treatments except in CT.

Averagely across seasons, all treatments served as emitters of N_2O in both the growing and non-growing seasons, however there was higher emission in the growing season than the non-growing season (Fig. 4 e, f). In the growing season, CTS had the highest emission of N_2O but it was not significantly different from the other treatments. Similarly, there was no significant difference in N_2O flux in the non-growing season among treatments. The fluxes in the growing season were 3.09 ± 1.96, 14.88 ± 0.42, 11.39 ± 6.80, 12.61 ± 2.76 μg N m^{-2} h^{-1} for CT, CTS, NT and NTS respectively while in the non-growing season, values of N2O fluxes ranged between 0.21 and 2.69 μg N m^{-2} h^{-1}.

Fig. 4 Average ecosystem respiration, CH_4 and N_2O fluxes across treatments in growing season (a), (c) and (e) and non-growing season (b), (d) and (f). Error bars are standard errors, n=3.

Average cumulative GHG fluxes

Annually, cumulative ecosystem respiration followed the order: CTS > CT > NT > NTS (Table 2). Ecosystem respiration in NTS was 8709.99 ± 1590.95 kg C $ha^{-1}y^{-1}$ as compared with 13320.84 ± 87.71 kg C $ha^{-1}y^{-1}$ under CTS. Compared with CT, cumulative R_{eco} rates decreased by 28.25 and 32.94% under NT and NTS respectively. The contribution of non-growing season emissions to total R_{eco} were 10.71, 15.56, 15.06 and 16.90% in CT, CTS, NT and NTS respectively.

Annually, cumulative uptake of CH_4 occurred in all treatments with the greatest uptake occurring in NTS while the least occurred in CT (Table 2). However, CT was the highest absorber of CH_4 in the non-growing season. Compared with CT, there was increase in annual uptake of CH_4 by 6.07, 15.18 and 27.47% in CTS, NT and NTS respectively. Uptake of CH_4 in NTS was significantly greater than in CT.

All treatments acted as net emitters of N_2O in both seasons. However, emissions in the growing season were extremely higher than in the non-growing season. The highest emission was from CTS in the growing season but NT emitted slightly more in the non-growing season. CT was the least emitter of N_2O. Emission in CTS was significantly higher than that of CT in the growing season while annual emissions of N_2O were significantly higher in CTS, NT and NTS than in CT ($p < 0.05$).

Table 2. Cumulative ecosystem respiration, CH_4 and N_2O fluxes across different tillage treatments and seasons

Monthly variations of GHG emissions

There were obvious variations of ecosystem respiration within the seasons (Fig. 5). The highest emissions occurred within May-August with the peak occurring in CTS on May, 27, 2018 (Fig. 5 a,b). CTS had the highest respiration rates in most months including the peak emission of 556.18 ± 243.21 mg C m^{-2} h^{-1} in May while in June and July, CT had the highest average emission rates (Fig. 5b).

The fluxes of CH_4 were very low at all sampling points and in almost all months, all the treatments acted as CH_4 sinks (Fig. 5c,d). Peak absorption occurred in May under NTS (-0.26 ± 0.14 mg C m^{-2} h^{-1}). Seasonal differences were observed in the sink capacities of various treatments. In the months of March, April, May and August, NTS was the highest sink while in February, September and November, CT was the highest sink.

Peak emission of N_2O flux occurred on May, 11, 2018 under CTS (Fig. 5 e,f). Fluxes of N_2O were greater between March and August than between September and February (Fig. 5 e,f). CTS had higher emissions at most sampling times. At most sampling times and months, CTS served as slight emitters, but was higher than all other treatments in February, May, June, September and October.

Fig. 5 Average ecosystem respiration, CH_4 and N_2O fluxes across treatments at various times and months

Global warming potential (GWP) and Greenhouse Gas Intensity (GHGI)

The Net CO_2-flux, CO_2 equivalents (CO_2e) of CH_4 and N_2O, GWP and GHGI of all treatments are shown in Table 3. Grain Yield (Table 1) and Harvest index (Appendix A1) were used to estimate the carbon components of harvest i.e. grain and straw (Appendix A2, A3) in order to obtain Gross Primary production (GPP) and Net Primary Production (NPP) as shown in Appendix (Appendix A4, A5). Net CO_2 fluxes (Table 3) were estimated by subtracting ecosystem respiration from GPP. GWP was greater in CT than all other treatments. Significant reductions of GWP were observed in NTS and NT ($p < 0.05$). Compared with CT, there was reduction in GWP of 2.83, 33.40, and 40.35% under CTS, NT and NTS respectively. The GHGI was also higher in CT compared with other treatments with significant reductions in NTS and NT. NTS had the lowest GWP and GHGI. No-tillage and straw retention reduced global warming potential and greenhouse gas intensity of agroecosystems. Greenhouse gas intensity in CT was significantly greater than that of NT and NTS.

Temperature sensitivity of ecosystem respiration

Temperature sensitivity of ecosystem respiration was estimated by the Q_{10} value, which shows the relative change in respiration to every 10 ^{o}C increase in temperature. The Q_{10} values are shown in Fig. 6. CT was the most sensitive to temperature changes. The Q_{10} values ranged between 2.31 and 2.85. The following order was established according to the values of Q_{10}: CT > CTS > NT > NTS. Q_{10} in CT was significantly higher than in NTS.

Fig 6 Q_{10} values as affected by tillage treatments

Discussion

Effect of tillage and season on soil properties

Soil water content was higher in NTS and CTS than in CT. This is in line with other studies where conservation tillage improved soil water content and storage (Lal et al., 2012; Li et al., 2014). This could be attributed to the effect of straw (He et al., 2011; Lal et al., 2012) and no-tillage. Straw mulch may reduce evaporation, while pore distribution may also improve due to little soil disturbance –leading to improved water retention (Hill et al., 1985). Improved infiltration may also result in high water retention. Li et al. (2011b) indicated that reduction in evaporation and runoff may enhance infiltration. Kang et al. (2004), also intimated that mulching may retard soil surface air convection, hence resulting in decreased evaporation of soil water, thus maintain available water for a longer time. There was slight decline of temperature under NTS and NT compared with CT. Conservation tillage influenced soil physical and chemical properties (Ram et al., 2012) which in turn influenced soil thermal properties (Van Wie et al., 2013).

Soil organic carbon (SOC) was greater in CTS, NT and NTS compared with CT. Total nitrogen (TN) followed a similar trend where conservation tillage treatments showed higher TN than CT (Fig. 3). However, significant differences were observed only in the second year of the experiment (Fig. 3 b, d). Many studies have reported increased SOC stocks after adoption of NT or reduced tillage practices (Ogle et al., 2005; Paustian et al., 2006). Increased SOC could be attributed to less disturbance of soil during cultivation which might reduce the risk of exposure of soil organic matter to decomposition process, thereby increasing SOC storage (Reicosky, 1997; Six et al., 2000). Favorable moisture content may result in net C sequestration due to higher photosynthetic C input. As shown in fig. 2, soil moisture was improved in NTS and in CTS which may have resulted in high C stocks in these treatments (Fig. 3). Furthermore, soil disturbance through tillage reduces significant quantities of carbon stocks in agroecosystems (Lal, 2015) which may be a contributing factor for lower SOC quantities in the CT plots than other treatments. Moreso, higher crop productivity in conservation tillage plots (Table 1) may have resulted in higher C and N inputs as there was positive correlation between SOC and grain yield, and between TN and grain yield (Table 4).

Table 4. Correlation between Grain Yield and soil chemical properties

Effect of tillage on crop productivity

NTS, NT and CTS showed significantly greater grain yields compared with CT in 2017 while in 2018, they still showed greater yield than CT but only CTS was significantly different (Table 1). Higher grain yield in CA practices in this study is in tandem with other studies where conservation tillage increased grain yields (Bordovsky et al., 1998; Halvorson et al., 2000; Li et al., 2014; Zheng et al. 2014; Yeboah et al., 2016 a,b).

High grain yields under conservation tillage could be attributed to improved soil properties under these treatments. High soil water content may facilitate nutrient movement and uptake. High SOC and TN stocks may also increase grain yields under conservation tillage treatments. In 2018, SOC in NTS, NT and CTS in the 0-10 and 10-20 cm depths were significantly higher than that in CT (Fig. 3 b, d) and may have impacted crop yields. Pearson correlation of SOC and TN at 0-10 cm depth against average grain yield showed significant positive correlations (Table 4). Grain yields were generally higher in 2018 than in 2017 in all treatments (Table 1), which could be attributed to higher rainfall in the growing season of 2018 than in 2017 (Fig. 1 a,b). In 2018, rainfall in the growing season (March-August) amounted to 365.6 mm while in 2017 it was 325.9 mm. Zhang et al. (2013), indicated that the western loess plateau is characterized by low rainfall which negatively influenced crop productivity.

Effect of tillage and season on ecosystem respiration and Net C-flux

In the growing season there were significant lower rates of ecosystem respiration ($p < 0.05$) in NT and NTS compared with the tilled soils (Fig. 4 and Table 2). This is consistent with other studies (Chaplot et al., 2012; Yeboah et al., 2016b) where conservation tillage significantly reduced soil respiration in the growing season. Comparing CO_2 emissions between conventional and conservation tillage treatments, Alkaisi & Yin (2005) reported a whopping 79% reduction in CO_2 emission under minimum and no-tillage immediately after tillage and 19 and 41% reduction under minimum tillage and no-tillage respectively in a 20-day period cumulative emission analyses. CO_2 emission rates is often controlled by a number of factors including: gradient of concentration of CO_2 between the atmosphere and the soil medium, soil water, soil temperature, wind speed and soil physical and chemical properties (Raich & Schlensinger, 1992). The influence of tillage on these parameters would affect CO_2 emissions as well. Conventional tillage in itself causes soil disturbance which increases decomposition rates due to increased microbial activities (Alkaisi & Yin, 2005), leading to higher CO_2 emissions. Soil disturbance may also increase soil aeration, resulting in higher emissions (Jackson et al., 2003). On the contrary, under conservation tillage, decomposition is slower due to absence of soil disturbance (Curtin et al., 2000). Conservation tillage may also improve soil properties which in turn could reduce emissions. Lower soil temperature may also explain the reduced emissions in the conservation tillage plots. Regression analysis showed significant positive relationship between soil temperature and ecosystem respiration in this study (Table 5). When considered separately, soil temperature explained approximately 63-80% of variability of ecosystem respiration while soil water content showed a moderate control over ecosystem respiration, explaining only 5.6 -13.8% of the variations. Relatively higher soil water content in CTS, coupled with higher soil temperatures (Fig. 2) caused higher cumulative emissions in that treatment (Table 2). Soil temperature and soil water content often exert an interactive influence on GHG emissions (Bond-Lamberty et al., 2016). Microbial activities may increase in warm and wet conditions, resulting in higher decomposition rates, thus resulting in higher CO_2 emissions (Carbonell-Bojollo et al., 2012). Substrate supply for microbial activities is influenced by soil water content. Therefore without substrate limitation under moist conditions, temperature may exponentially increase microbial activities (Meixner, 2006).

Table 5. Relationship between Soil temperature, soil water content and greenhouse gases

In the non-growing season, all treatments emitted lower CO_2 compared with the growing season. CT emitted less CO_2 in the non-growing season compared with the other treatments. This may be due to extreme soil dryness, limiting substrate supply for decomposition. Moisture content in CT on December 29, 2017, was as low as 1.12% (volumetric soil water content), which indicates severe dryness. Furthermore, such extreme dry conditions, coupled with relatively low temperatures, will significantly reduce decomposition and GPP. Xu et al. (2004), reported increase of about 2.5 times CO_2 emissions in soil of gravimetric soil moisture of 30% compared with soil of 10% moisture. Ecosystem respiration in non-growing season in CTS had a significant contribution to its total respiration, resulting in very high cumulative annual respiration, surpassing that of CT. Fluxes in the non-growing period contributed between 10.71% and 16.9% of total annual respiration. This implied that fluxes in the non-growing season are important when analyzing total GHG fluxes from ecosystems. More importantly, variations that occur within this period may lead to under or overestimation of annual fluxes if fluxes in this period are left unaccounted.

Gross and net primary productivity (Appendix A4, A5) were greater in NTS and CTS than in NT and CT due to higher crop yield. High crop productivity often results in high carbon input (Ma et. al., 2018). Though all the plots were net C-emitters, NTS and NT significantly reduced net emissions of CO_2 relative to CT (Table 2). Net CO_2 flux is a balance between carbon input through primary production and output through respiration. High crop productivity may therefore lead to low net emission. As shown in this study, grain yield correlated negatively with net CO_2 emission and cumulative ecosystem respiration (Fig. 7). Lower ecosystem respiration in NTS and NT also contributed to the significant reduction in net CO_2 emission. However, yields in this study area are generally low due to poor rainfall and poor soil fertility (Zhang et al., 2013). Improving yield in this area by integrating nutrient management with conservation tillage may result in high net carbon sequestration. A further study may be needed to ascertain impact of interaction between nitrogen levels and conservation tillage on crop yield, soil quality and GHG fluxes in this area.

Fig. 7 Linear regression between 2-year average grain yield and (a) Cumulative net CO_2 emission (b) Ecosystem respiration (c) CH_4 flux and (d) N_2O flux

Soil organic carbon and TN also influenced CO_2 efflux. SOC and TN correlated negatively with net CO_2 flux and ecosystem respiration (Fig. 8). This means high C emission may reduce carbon stocks which may have long term effect on soil fertility. Therefore, reduced C emission in conservation tillage practices not only reduces impact of agriculture on the climate but may have a direct effect on soil fertility.

Fig. 8. Linear regression between average SOC and (a) Cumulative net CO_2 emission (b) Ecosystem respiration (c) CH_4 flux and (d) N_2O flux and between TN and (e) Cumulative net CO_2 emission (f) Ecosystem respiration (g) CH_4 flux and (h) N_2O flux

Note: SOC and TN values are 2-year averages.

Effect of tillage and season on CH_4-flux

All four tillage methods resulted in uptake of CH_4 in both growing and non-growing seasons. Other studies on the Loess Plateau obtained similar results (Wan et al., 2009; Yeboah et al., 2017b). Shen et al. (2018) indicated that agroecosystems in dry regions with minimal irrigation often act as CH_4 sinks due to aerobic soil conditions. This is due to oxidation of CH_4 under aerobic conditions (Matson et al., 2009; Schaufler et al., 2010). The greatest uptake of CH_4 was found in NTS. This was due to high uptake of CH_4 in the growing season. Lower temperatures under NTS may have played significant role in high uptake of CH_4 in NTS. The dominant methanogen during high temperatures (Methanosarcinaceae) utilizes H_2/CO_2 and acetate as methane producing precursors, and produces far higher methane than the methanogen at lower temperatures (Methanosaetaceae), which uses only acetate as methane producing precursor (Ding & Cai, 2003). However, in this study there was significant negative correlation between soil temperature and CH_4 emission, though the relationship was nonlinear (Fig. 8). This might be attributed to lower moisture levels in this water limited area. Lower moisture affects the sensitivity of soil to temperature, which affects the decomposition of organic matter and slows CH_4 production (Craine & Gelderman, 2011). Linear regression analysis did not show significant relationship between CH_4 emission and soil water content (Table 5). This is contrary to other studies where soil water content positively correlates with CH_4 emissions (e.g. Smith et al., 2003). However, other studies also reported negative correlation of CH_4 and soil water content at matrix potential of 0 ($\Psi m = 0$), but was not significantly correlated at other matrix potentials (Panday & Nkongolo, 2015). Unsaturated conditions in our study area may have caused non-significant correlation of CH_4 fluxes with soil moisture in all treatments. Soil organic carbon and total nitrogen also significantly correlated negatively with CH_4 flux. This implied that increased CH_4 emission reduced carbon levels in the soil.

Effect of tillage and season on N_2O-flux

Cumulative N_2O fluxes found in this study were in the range of fluxes reported by Ma et al. (2013) in their study of GHGs in a rice-wheat rotation under integrated crop management systems. Averagely, all treatments served as slight emitters of N_2O (Fig. 4). Net cumulative emissions of N_2O occurred in all treatments and in both seasons but were higher in growing season than the non-growing season. This is also consistent with the study of Yeboah et al. (2016b) on the Loess Plateau. There was significant positive correlation between soil temperature and N_2O emission in CTS. Higher temperatures and soil water content in the growing season where 70-80% of rainfall occurs may have triggered nitrification and denitrification processes (Davidson & Swank, 1986), leading to higher N_2O emissions. High rainfall may increase water filled pore space, which influences N_2O emissions in agricultural soils (Dobbie & Smith, 2003). Trujillo et al. (2008) also reported positive correlation of N_2O with soil temperature and soil water content. Higher emission in the growing season than the non-growing season could also be related to fertilizer application in the growing season and its interactive effect with wet conditions within this period on denitrification processes (Cho et al., 1997). There was no significant difference in cumulative N_2O emissions among treatments but CTS emitted the greatest. It is possible that denitrification conditions were not significantly different among treatments since there were only slight differences in hydrothermal conditions among the treatments. Crop yield, soil organic carbon and total nitrogen correlated positively with N_2O emission. Li et al. (2005) reported that increased production of N_2O may be as a result of increased TN and microbial activities; meanwhile microbial activities are controlled by SOC. This implied that SOC enhances the activities of N_2O-producing microbes. This also corroborates the findings of Bouwman (2006) who indicated that high SOC generally increases N_2O emission. Crop yield significantly correlated positively with SOC and TN in this study (Table 4) implying that higher crop yield resulted in higher SOC and TN. By inference, high crop yield may therefore have impacted higher cumulative N_2O emissions in CTS, NTS and NT compared with CT.

Effect of tillage on GWP and GHGI

The GWPs found in our study ranged between 6.5 and 10.96 $tCO_2e\ ha^{-1}y^{-1}$ which is in the range of those reported by Ma et al. (2013) but greater than those reported by Yeboah et al. (2016b). Furthermore, GHGIs in this study were far higher than those found in other studies (Qin et al., 2010; Ma et al., 2013). Higher GWPs and GHGIs in our study could be attributed to a general lower biomass and grain yield in our study area. Lower grain yield in our study area resulted in relatively low carbon input (Table 1, Appendix A-2, A-5), hence low sequestration across all sites. Since GHGI is a function of crop yield, low grain yield has direct effect on it. No-till (NT) and No-till with straw retention (NTS) reduced global warming potential and greenhouse gas intensity of agroecosystems significantly. Much of the contribution came from lower net CO_2-C emission (Table 3) as a result of higher carbon input from the above ground plant product (Appendix A2), lower ecosystem respiration and higher CH_4 uptake (Table 2). In this study, correlation analysis of net CO_2-C flux against GWP and GHGI showed highly significant negative correlation (Table 6).

Table 6. Pearson correlations among Net CO_2 flux, CH_4-CO_2e and N_2O-CO_2e, GWP and GHGI

Conclusions

This study hypothesized that, no-till and the application of straw may increase crop yield, improve soil chemical and physical properties, and reduce greenhouse gas emissions. Soil water content was higher under NTS than all treatments at most sampling times while CTS also showed higher SWC than CT and NT at most sampling times. Soil organic carbon and total nitrogen showed significant changes in the second year of the experiment with all conservation tillage treatments being greater than CT, especially within the 0-10 cm and 10-20 cm where root activity is high. Changes in soil physical and chemical properties under no-till and straw mulching also influenced wheat grain yield. Two-year average grain yield followed the ranking: no-till with straw mulch (NTS) > conventional tillage with straw mulch (CTS) > no-till (NT) > conventional tillage (CT). No-till and no-till with straw mulching reduced ecosystem respiration and net CO_2 emission but slightly increased N_2O emissions. Irrespective of tillage system, the spring wheat systems in the dryland region cumulatively served as absorbers of atmospheric CH_4 but with varying rates. No-tillage with straw mulch had the least GWP and GHGI. Conservation tillage practices especially the combination of no-till with straw mulching increased soil water availability, increased soil chemical properties, and enhanced crop productivity. Significant reduction in GHG emissions in the dryland area also occurred under NT and NTS. For sustainability of arid and semi-arid land cropping systems, the adoption of no-till, especially with straw retention is recommended.

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Figure 1

Rainfall amounts for 2017 (a), 2018 (b) and Mean, maximum and minimum temperatures for 2017 (c) and 2018 (d) in the Anjiapo catchment in Dingxi

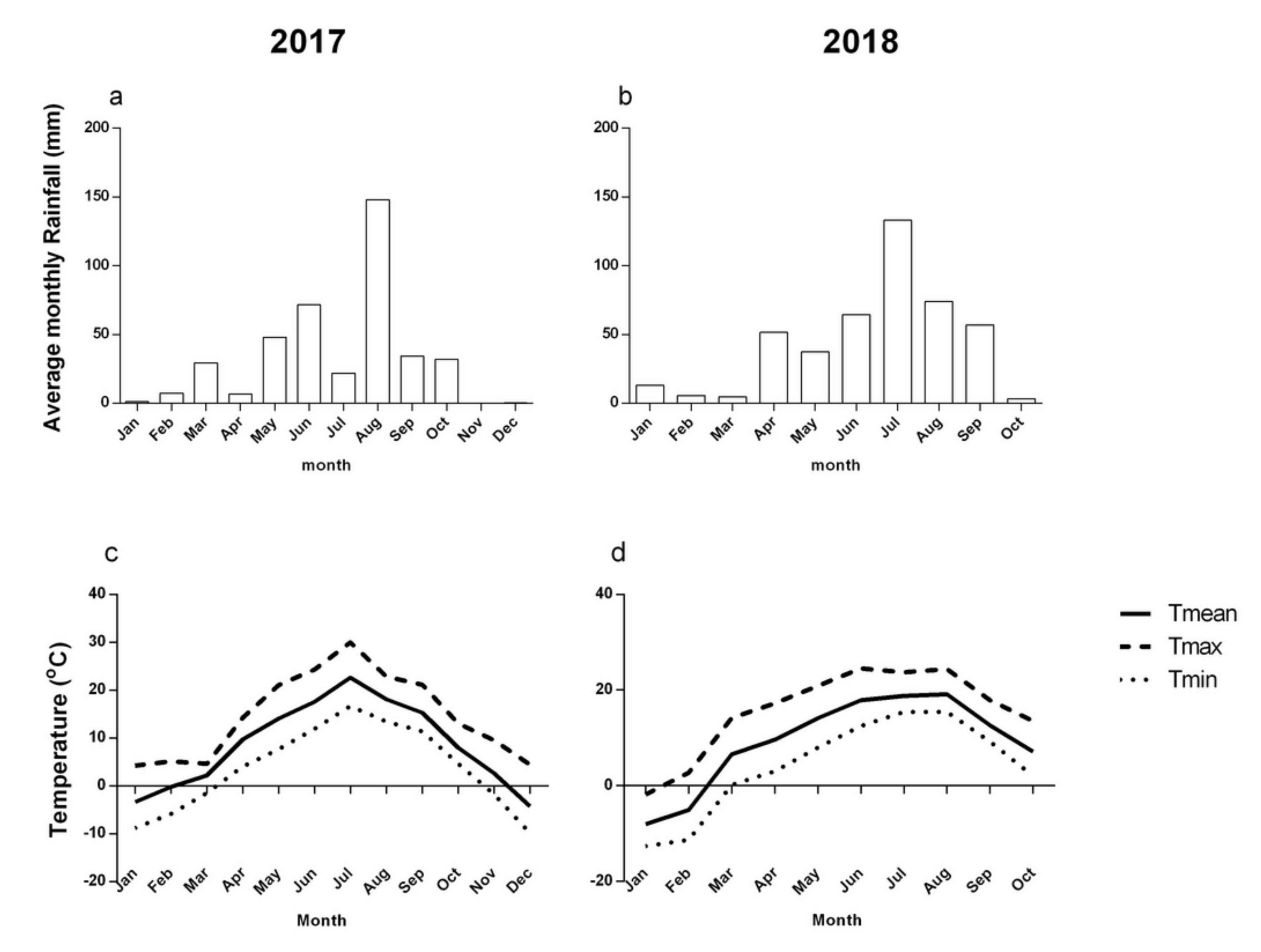


Figure 2

Soil water content (a) and soil temperature (b) at various sampling times (10 cm depth)

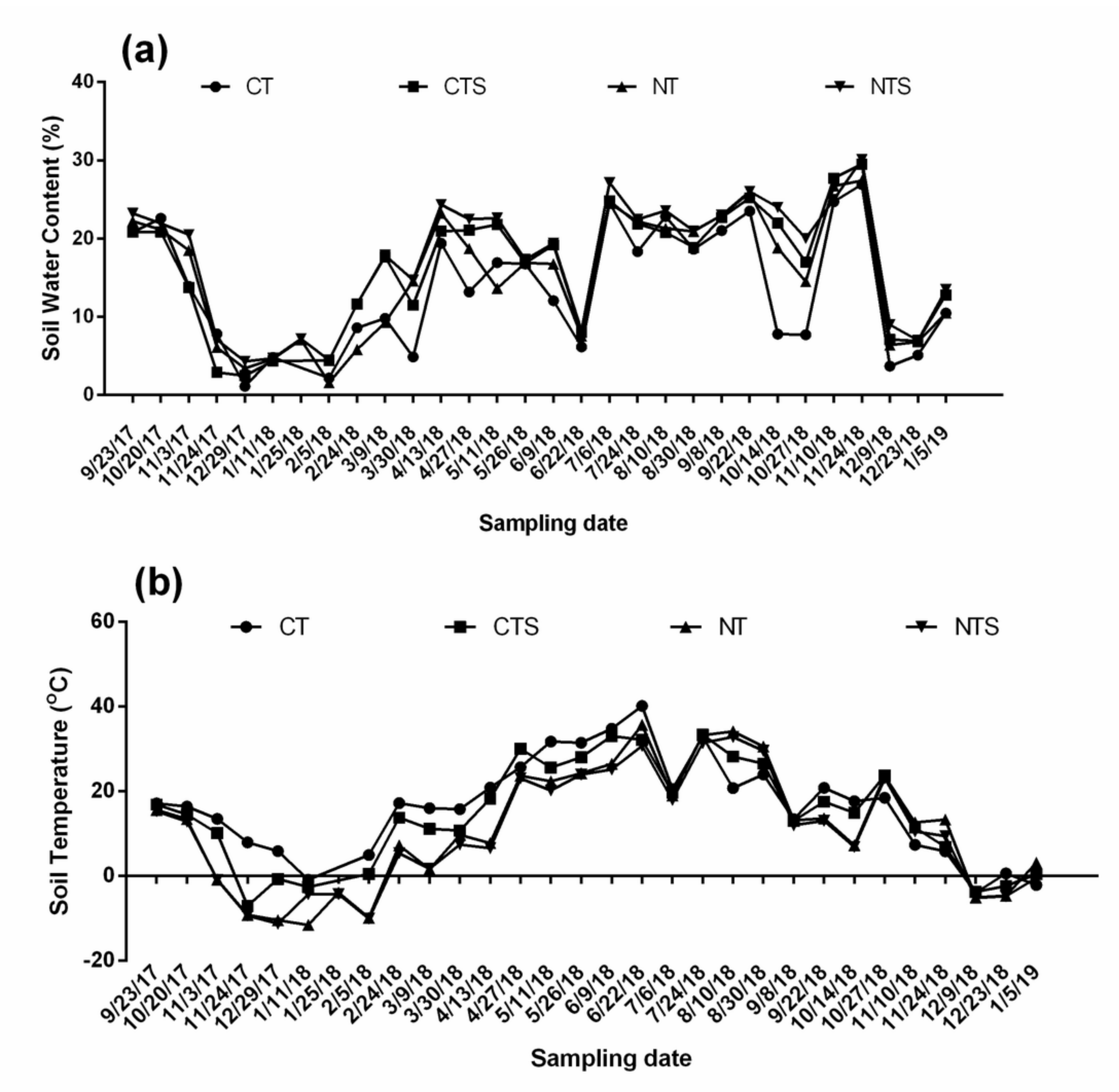


Figure 3

Distribution of soil organic carbon (SOC) in 2017 (a) and 2018 (b) and total nitrogen (TN) in 2017 (c) and 2018 (d) among tillage treatments within different depths. Treatments with common letters within a depth are not statistically different at $p \leq 0.05$

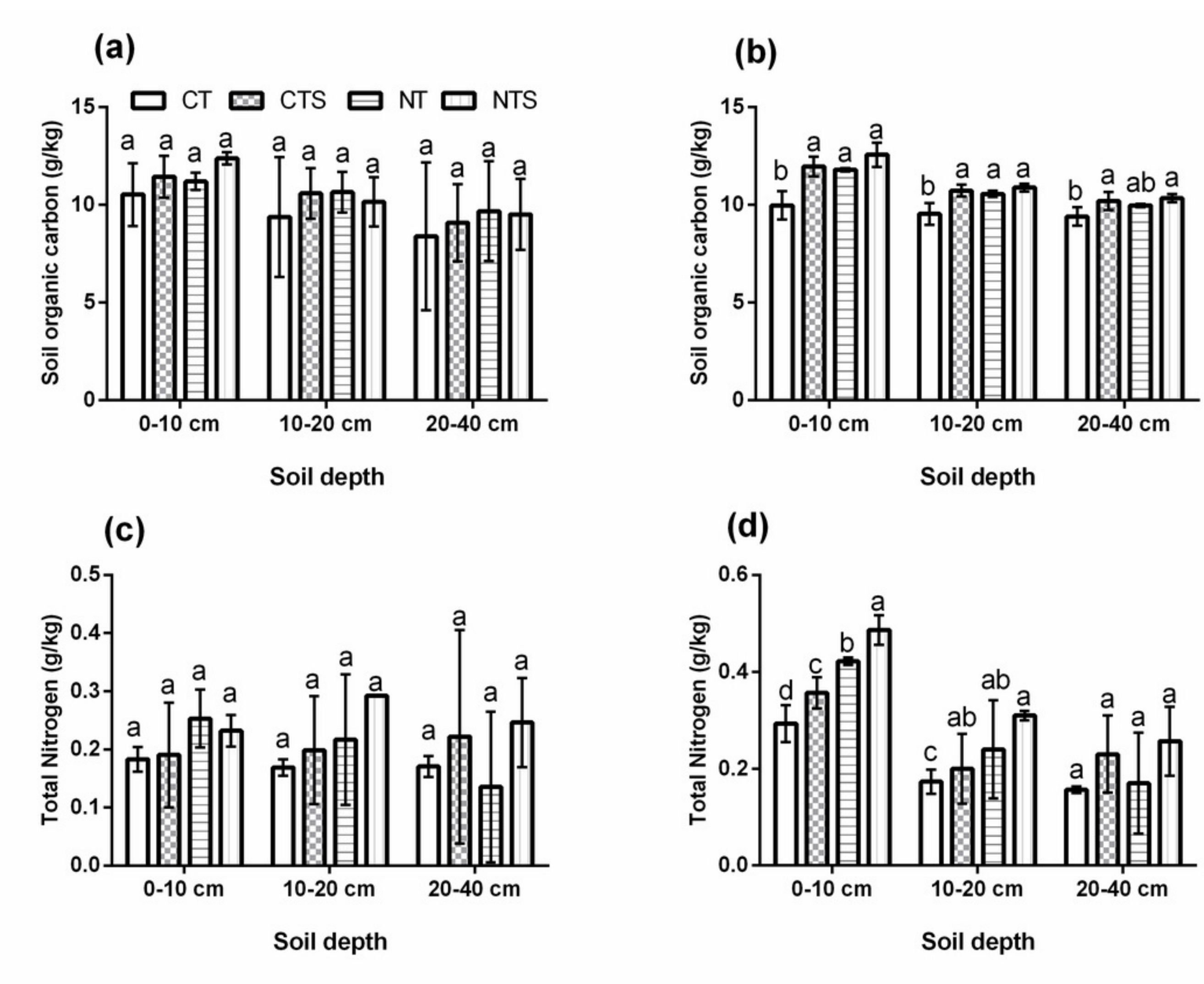


Figure 4

Average ecosystem respiration, CH_4 and N_2O fluxes across treatments in growing season (a), (c) and (e) and non-growing season (b), (d) and (f). Error bars are standard errors, n=3

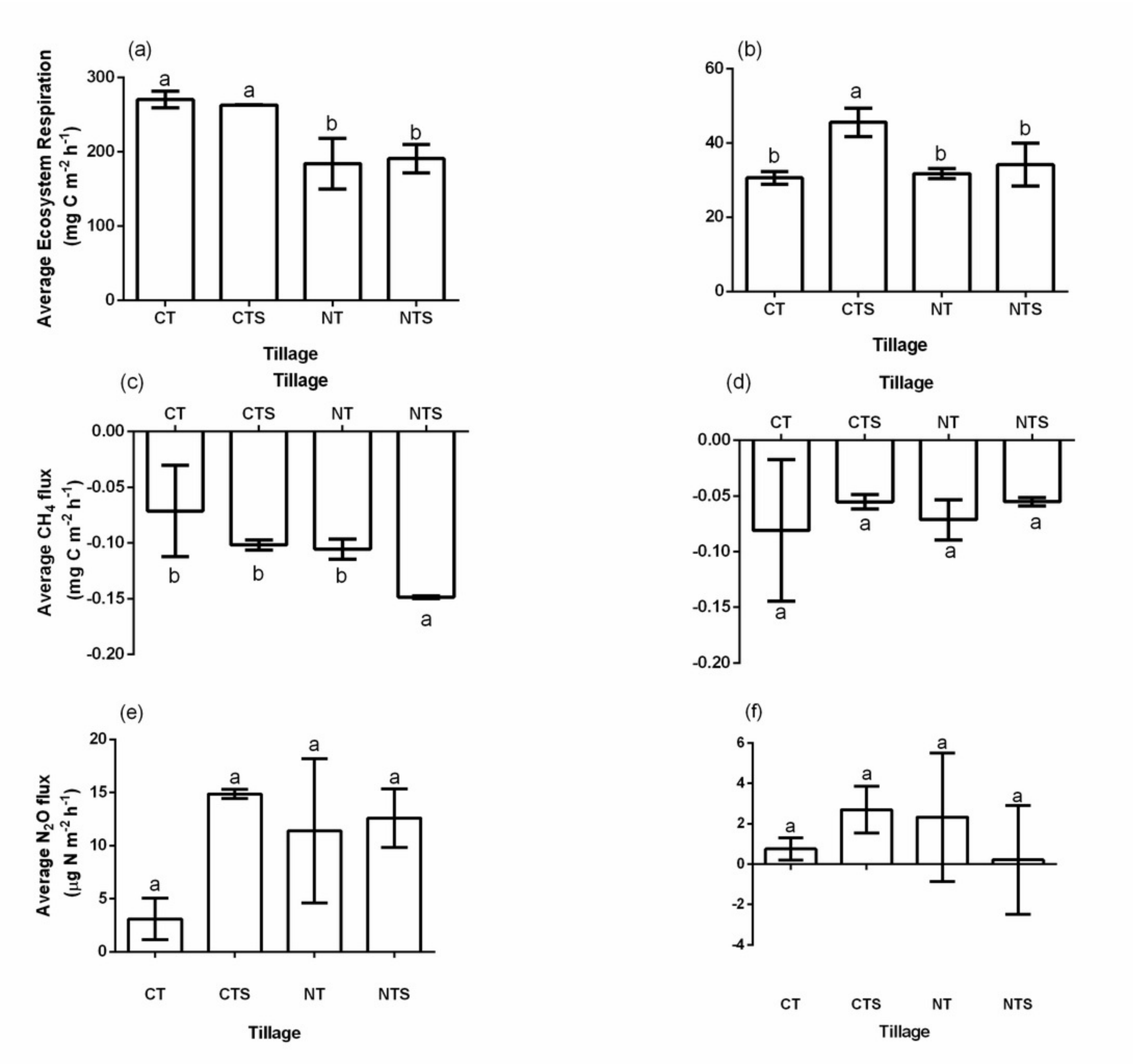


Figure 5

Average ecosystem respiration, CH_4 and N_2O fluxes across treatments at various times and months

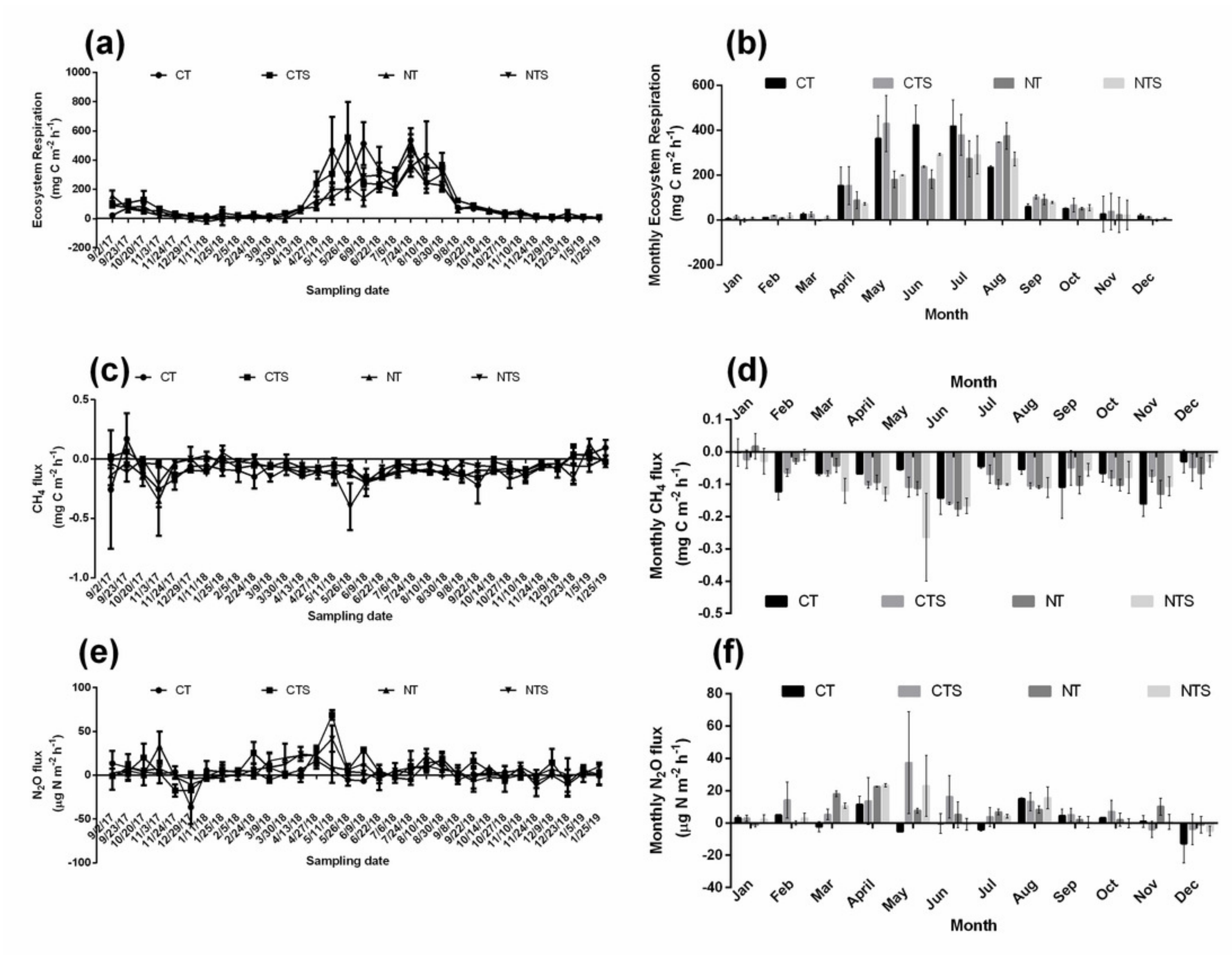


Figure 6

Q_{10} values as affected by tillage treatments

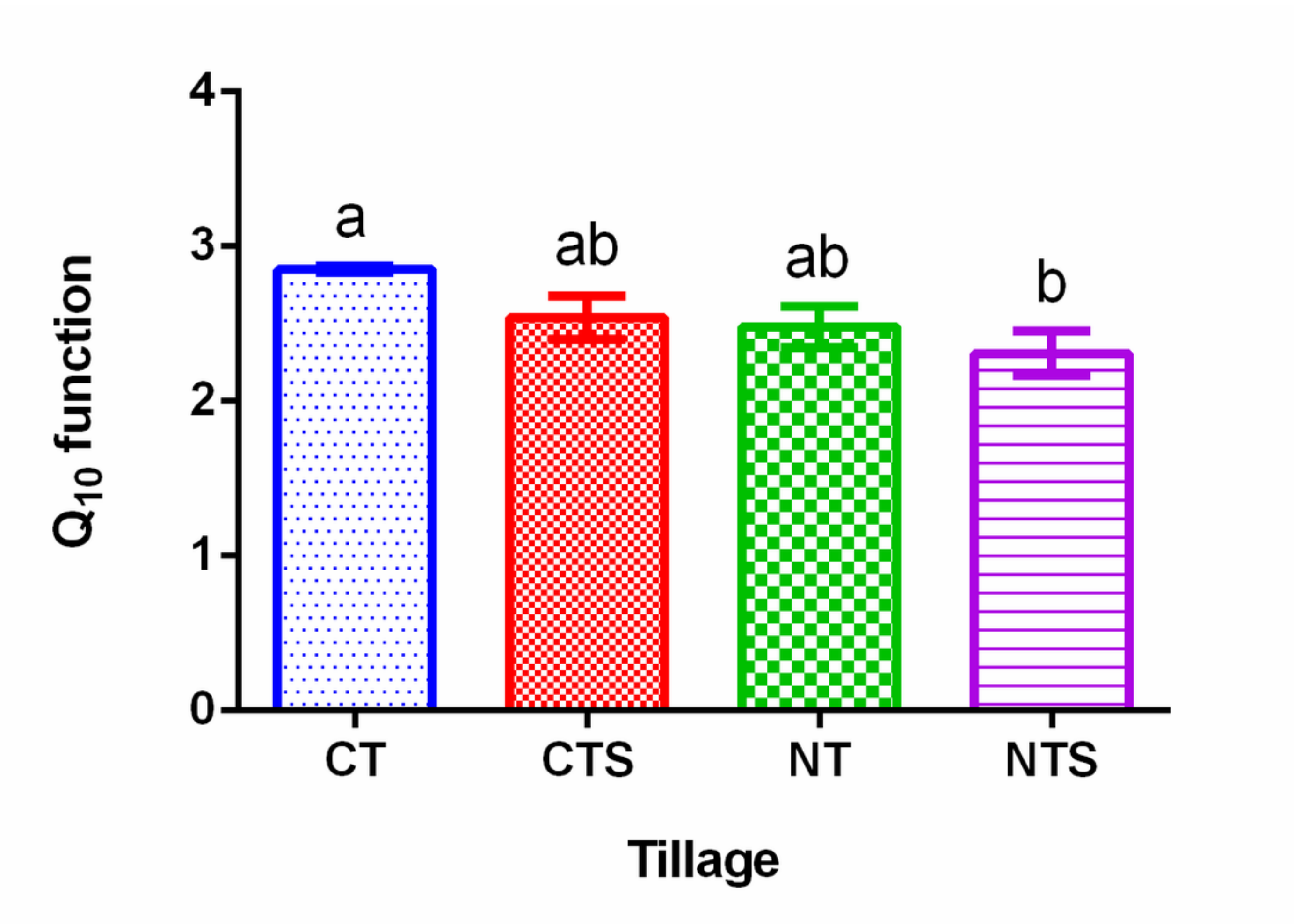


Figure 7

Linear regression between 2-year average grain yield and (a) Cumulative net CO_2 emission (b) Ecosystem respiration (c) CH_4 flux and (d) N_2O flux

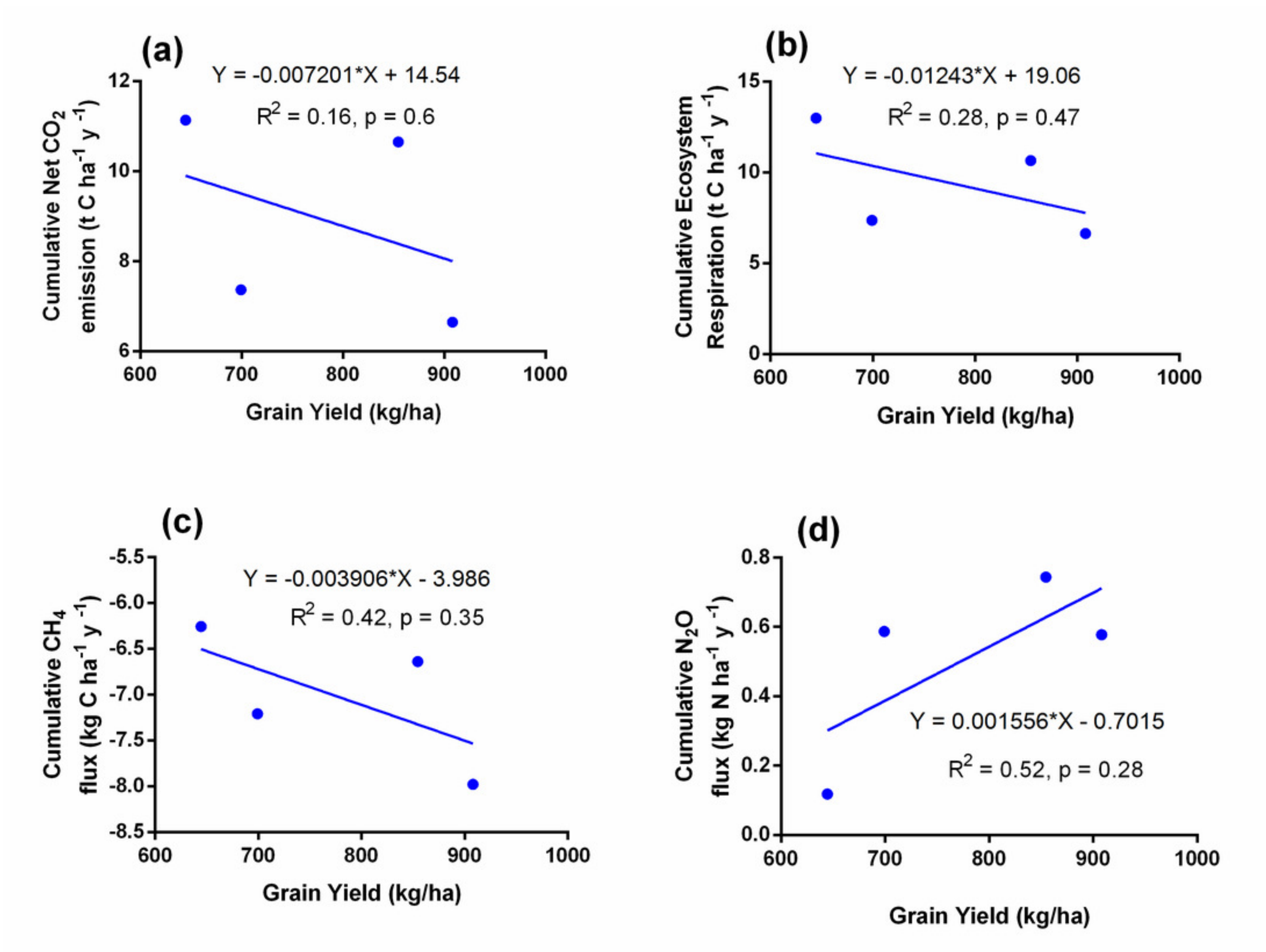
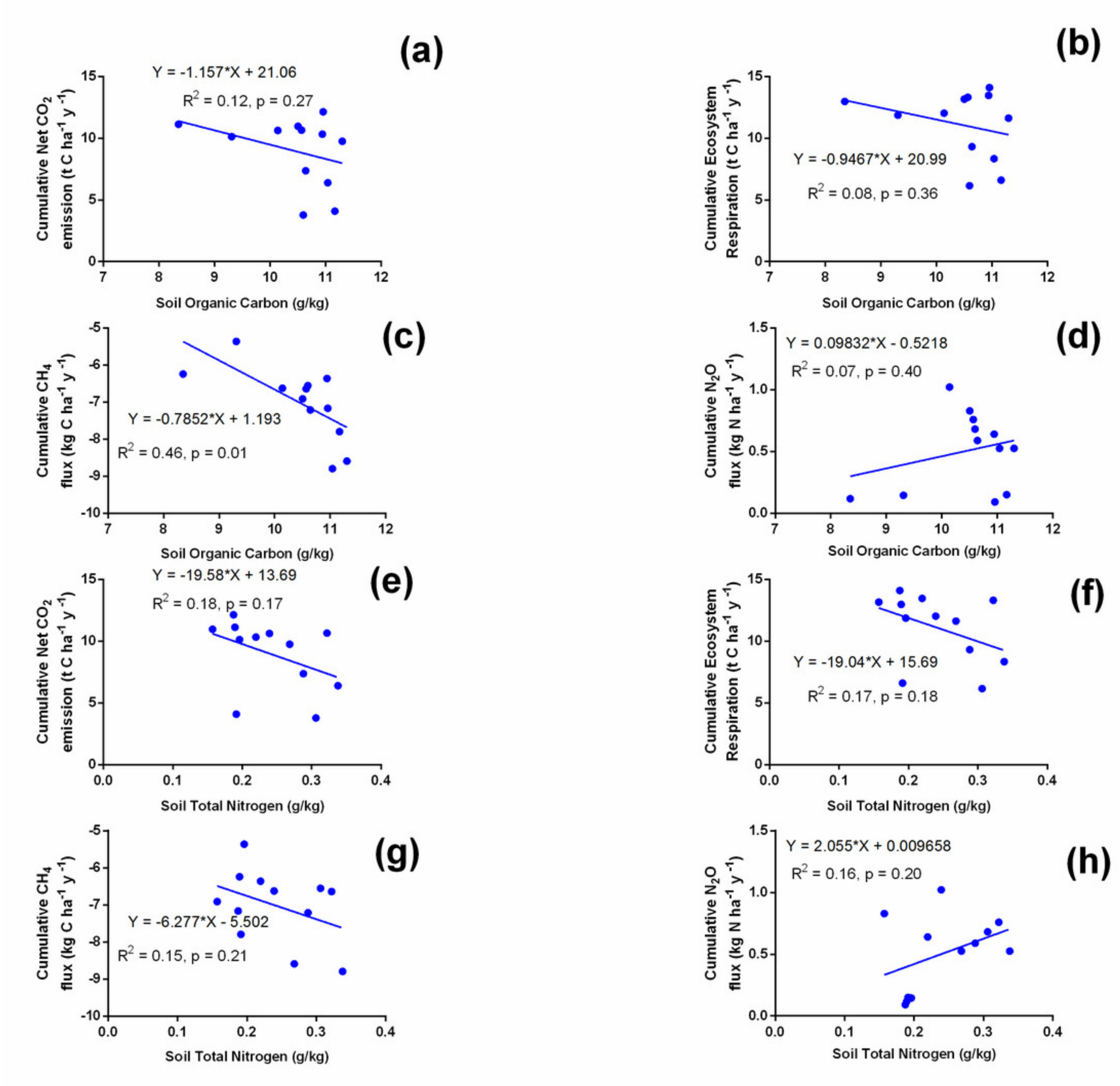


Figure 8

Linear regression between average SOC and (a) Cumulative net CO_2 emission (b) Ecosystem respiration (c) CH_4 flux and (d) N_2O flux and between TN and (e) Cumulative net CO_2 emission (f) Ecosystem respiration (g) CH[s

SOC and TN values are 2-year averages



(a)
Y = -1.157*X + 21.06
R2 = 0.12, p = 0.27
Cumulative Net CO2 emission (t C ha-1 y-1)
Soil Organic Carbon (g/kg)
(b)
Y = -0.9467*X + 20.99
R2 = 0.08, p = 0.36
Cumulative Ecosystem Respiration (t C ha-1 y-1)
Soil Organic Carbon (g/kg)
(c)
Y = -0.7852*X + 1.193
R2 = 0.46, p = 0.01
Cumulative CH4 flux (kg C ha-1 y-1)
Soil Organic Carbon (g/kg)
(d)
Y = 0.09832*X - 0.5218
R2 = 0.07, p = 0.40
Cumulative N2O flux (kg N ha-1 y-1)
Soil Organic Carbon (g/kg)
(e)
Y = -19.58*X + 13.69
R2 = 0.18, p = 0.17
Cumulative Net CO2 emission (t C ha-1 y-1)
Soil Total Nitrogen (g/kg)
(f)
Y = -19.04*X + 15.69
R2 = 0.17, p = 0.18
Cumulative Ecosystem Respiration (t C ha-1 y-1)
Soil Total Nitrogen (g/kg)
(g)
Y = -6.277*X - 5.502
R2 = 0.15, p = 0.21
Cumulative CH4 flux (kg C ha-1 y-1)
Soil Total Nitrogen (g/kg)
(h)
Y = 2.055*X + 0.009658
R2 = 0.16, p = 0.20
Cumulative N2O flux (kg N ha-1 y-1)
Soil Total Nitrogen (g/kg)

Table 1(on next page)

Grain Yield among tillage treatments from 2017-2018

Table 1 Grain Yield among tillage treatments from 2017-2018

Treatment	**2017**	**2018**	**2017-2018**
	Grain yield		
CT	581.45±73.89^{b}	707.78±96.49^{b}	644.61±76.98^{c}
CTS	587.69±35.96^{b}	1121.23±54.19^{a}	854.46±59.02^{ab}
NT	653.36±27.25^{b}	745.23±134.42^{b}	699.30±64.88^{bc}
NTS	854.46±25.33^{a}	961.90±21.61^{ab}	908.18±22.31^{a}

Table 2 (on next page)

(on next page)

Cumulative ecosystem respiration, CH_4 and N_2O fluxes across different tillage treatments Table 1 and seasons

Table 2 Cumulative ecosystem respiration, CH_4 and N_2O fluxes across different tillage treatments Table 1 and seasons

Season	Cumulative ecosystem respiration (kg C $ha^{-1}y^{-1}$)			
	CT	**CTS**	**NT**	**NTS**
Growing Season	11596.19±554.70[a]	11248.46±93.78[ab]	7915.07±1484.74[bc]	7237.76±1402.96[c]
Non-growing Season	1391.59±88.20[b]	2072.38±181.49[a]	1403.29±82.25[b]	1472.23±244.27[b]
Average Annual	12987.52±642.90[ab]	13320.56±87.71[a]	9317.90±1566.99[bc]	8709.99±1590.95[c]
	Cumulative CH_4 flux (kg C $ha^{-1}y^{-1}$)			
Growing Season	-3.21±0.91[b]	-4.39±0.07[ab]	-4.47±0.19[ab]	-5.99±0.56[a]
Non-growing Season	-3.06±1.43[a]	-2.24±0.09[a]	-2.73±0.53[a]	-1.99 ±0.20[a]
Average Annual (2017-2018)	-6.26±0.52[b]	-6.64±0.16[ab]	-7.21±0.34[ab]	-7.98±0.71[a]
Season	**Cumulative N_2O flux (kg N $ha^{-1}y^{-1}$)**			
Growing Season	0.11±0.04[b]	0.66±0.03[a]	0.50±0.17[ab]	0.56 ±0.08[ab]
Non-growing Season	0.01±0.02[a]	0.07±0.02[a]	0.09±0.09[a]	0.02±0.07[a]
Average Annual	0.12±0.02[b]	0.74±0.06[a]	0.59±0.25[a]	0.58±0.05[a]

Table 3 (on next page)

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Net GHG fluxes, Global warming potential and Greenhouse gas intensity among tillage treatments

1 **Table 3 Net GHG fluxes, Global warming potential and Greenhouse gas intensity among tillage**
2 **treatments**

	Net CO_2-flux ($tCO_2e\ ha^{-1}y^{-1}$)	CH_4 –CO_2e ($tCO_2e\ ha^{-1}y^{-1}$)	N_2O-CO_2e ($t\ CO_2e\ ha^{-1}y^{-1}$)	Net GWP ($tCO_2e\ ha^{-1}y^{-1}$)	GHGI ($tCO_2e\ t^{-1}$ grain)
CT	11.14±0.58[a]	-0.21±0.017[b]	0.035±0.004[b]	10.96±0.56[a]	17.21±1.18[a]
CTS	10.65±0.18[a]	-0.23±0.005[ab]	0.22±0.016[a]	10.65±0.19[a]	12.56±0.9[ab]
NT	7.37±0.89[b]	-0.25±0.011[ab]	0.18±0.075[a]	7.30±0.97[b]	10.37±2.34[b]
NTS	6.65±0.73[b]	-0.27±0.024[a]	0.17±0.016[a]	6.55±0.70[b]	7.18±1.77[b]

3 **Note: The sign convention adopted is positive (+) means emission whilst negative (-) means**
4 **absorption.**

5

Table 4 (on next page)

Correlation between Grain Yield and soil chemical properties

****Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).**

Table 4 Correlation between Grain Yield and soil chemical properties

Soil chemical property	Grain Yield (2017)	Grain Yield (2018)
Soil organic carbon at 10 cm (2017)	0.778**	0.332
Soil organic carbon at 20 cm (2017)	-0.101	0.218
Soil organic carbon at 40 cm (2017)	0.290	0.230
Soil organic carbon at 10 cm (2018)	0.642*	0.491
Soil organic carbon at 20 cm (2018)	0.614*	0.575
Soil organic carbon at 40 cm (2018)	0.487	0.637*
Total nitrogen at 10 cm (2017)	0.319	-0.177
Total nitrogen at 20 cm (2017)	0.566	0.361
Total nitrogen at 40 cm (2017)	0.238	0.168
Total nitrogen at 10 cm (2018)	0.672*	0.155
Total nitrogen at 20 cm (2018)	0.609*	0.278
Total nitrogen at 40 cm (2018)	0.260	0.228

****Correlation is significant at the 0.01 level (2-tailed).**

***Correlation is significant at the 0.05 level (2-tailed).**

Table 5(on next page)

Relationship between Soil temperature, soil water content and greenhouse gases

Table 5. Relationship between Soil temperature, soil water content and greenhouse gases

Treatment	Soil temperature			Soil water content		
			Ecosystem respiration			
	Equation	R^2	*p*-value	Equation	R^2	*p*-value
CT	$y=33.04e^{0.07x}$	0.68	<0.001	$y=363.57x^{0.48}$	0.056	<0.01
CTS	$y=32.55e^{0.075}$	0.63	<0.001	$y=474.18x^{0.67}$	0.095	<0.001
NT	$y=21.58e^{0.08x}$	0.80	<0.001	$y=483.20x^{0.88}$	0.138	<0.001
NTS	$y=27.79e^{0.077x}$	0.80	<0.001	$y=317.12x^{0.67}$	0.07	<0.001
			CH_4 flux			
CT	$y=-0.063e^{0.012x}$	0.019	=0.001	y=-0.07-0.05x	0.03	=0.79
CTS	$y=-0.052e^{0.026x}$	0.135	<0.001	y=-0.08-0.02x	0.04	=0.87
NT	$y=-0.062e^{0.022x}$	0.085	<0.001	y=0.12-0.35x	0.1	=0.05
NTS	$y=-0.068e^{0.028x}$	0.174	<0.001	y=-0.04-0.31x	0.04	=0.137
			N_2O flux			
CT	y=-0.84+0.12x	0.016	=0.456	y=-2.45+26.62x	0.01	=0.269
CTS	y=-1.77+0.66x	0.209	<0.01	y=-3.87+71.36x	0.08	=0.075
NT	y=4.64+0.12x	0.003	=0.65	y=-0.68+43.45x	0.09	=0.055
NTS	y=2.05+0.28x	0.08	=0.07	y=-3.6+48.92x	0.08	=0.067

Table 6(on next page)

Pearson correlations among Net CO_2 FLUX, CH_4-CO_2e and N_2O-CO_2e, GWP and GHGI

****Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).**

Table 6. Pearson correlations among Net CO_2 FLUX, CH_4-CO_2e and N_2O-CO_2e, GWP and GHGI

	Net CO_2 flux	CH_4 -CO_2e	N_2O-CO_2e	GWP	GHGI
Net CO_2 flux	1	-0.346	-0.020	-0.999**	-0.845**
CH_4-CO_2e	-0.346	1	-0.041	0.354	0.531
N_2O-CO_2e	-0.020	-0.041	1	0.052	-0.269
GWP	-0.999**	0.354	0.052	1	0.838**
GHGI	-0.845**	0.531	-0.269	0.838**	1

****Correlation is significant at the 0.01 level (2-tailed).**

***Correlation is significant at the 0.05 level (2-tailed).**