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

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Abstract

The effects of climate change such as dry spells, floods and erosion heavily impact agriculture especially smallholder systems on the Northwestern Loess Plateau of China. Nonetheless agriculture also contributes to global warming through the emission of greenhouse gases such as CO_2, CH_4 and N_2O. Yet this complex conundrum can be alleviated and mitigated through sound soil and water management practices. Despite considerable literature on Conservation Agriculture (CA) as a strategy to improve the resilience and mitigation capacity of agroecosystems, there is still paucity of information on the impacts of CA on crop production and environmental quality on the Plateau. In order to fill this gap this study examined the effects of no-till and straw mulch on crop productivity and greenhouse gas fluxes in agroecosystems on the Plateau where farmers' common practice of conventional tillage (CT) was tested against 3 CA practices: conventional tillage with straw mulch (CTS), no-till (NT) and no-till with straw mulch (NTS). The results indicated that all 3 CA practices (CTS, NT and NTS) markedly increased soil water content (SWC), soil organic carbon (SOC) and soil total nitrogen (STN) but reduced soil temperature (ST). Average grain yields were 854.46±76.51, 699.30±133.52 and 908.18±38.64 kg ha^{-1} respectively under CTS, NT and NTS indicating an increase by approximately 33%, 9% and 41% respectively compared with CT (644.61±76.98 kg ha^{-1}). There were significant ($p < 0.05$) reductions of Net CO_2 emissions under NT (7.37±0.89 tCO2e ha^{-1}y^{-1}) and NTS (6.65±0.73 tCO2e ha^{-1}y^{-1}) compared with CTS (10.65±0.18 tCO2e ha^{-1}y^{-1}) and CT (11.14±0.58 tCO2e ha^{-1}y^{-1}). All the treatments served as sinks of CH_4 but NTS had the highest absorption capacity (-0.27±0.024 tCO2e ha^{-1}y^{-1}) and increased absorption significantly ($p < 0.05$) compared with CT (-0.21±0.017 tCO2e ha^{-1}y^{-1}) however CA did not reduce emissions of N_2O.

40 These had an influence on Global warming potential (GWP) as NT and NTS resulted in
41 significant reduction in net GWP. Grain yield was significantly correlated positively with SOC
42 and STN ($p < 0.05$); ecosystem respiration was also significantly correlated with SWC and ST
43 while CH_4 flux was highly correlated with ST ($p < 0.001$). Crop yield and GHG responses to CA
44 were controlled by soil hydrothermal and nutrient changes, thus improving these conditions
45 through adoption of sustainable soil moisture improvement practices such as no-till, straw mulch,
46 green manuring, contour ploughing and terracing can improve crop resilience to climate change
47 and reduce GHG emissions in arid and semi-arid regions.

48

49 **Keywords:** climate-smart agriculture; sustainability; crop productivity; global warming; carbon
50 dioxide, methane, nitrous oxide.

51

Introduction

53   Agricultural soils are potential sources of carbon dioxide (CO_2), nitrous oxide (N_2O) and
54 methane (CH_4) (Smith et al., 2008). These gases constitute the most important greenhouse gases
55 (GHGs) and their emissions from agriculture and land-use change account for one-third of global
56 warming (Cole et al., 1997). Meanwhile agriculture is also one of the most affected sectors by
57 climate change through several climate induced processes. Changes in hydrological cycle and
58 temperature affects crop cultivation in various ways: higher temperatures may cause shortening
59 of the crop cycle in arid and semi-arid areas, resulting in low yields (IPCC, 2007) while lower
60 precipitation may cause moisture deficit under rainfed cultivation, which could also result in
61 significant yield decline (Calzadilla et al., 2013). In all these complexities, agriculture still holds
62 a potential to adapt to climate change through sound management practices and as well reduce its
63 contribution to global warming through carbon sequestration and less GHG emissions.
64   Wheat is a crop with global importance (Huang et al., 2003) and is central to global food
65 security. Its cultivation in China occupied approximately 24 million hectares (Li et al., 2019). On
66 the Loess Plateau region of Western China wheat accounts for 35% of the region's total
67 production area and 40% of total crop production volumes (An et al., 2014). The Loess Plateau
68 however is a fragile dryland area with abundant smallholder farmers whose activities are
69 threatened by wind and water erosion. Coupled with wide adoption of rainfed agriculture and
70 conventional tillage (CT) practices, the resilience of production systems to climate change is
71 threatened by the intricate interaction of environmental and anthropogenic factors, increasing the
72 risks of farmers to food insecurity and poor livelihood. Innovative soil management practices
73 hold huge potential in alleviating the effect of climate change on production systems and vice
74 versa.
75   Tillage, though an important component of crop cultivation may affect soil carbon (C) cycle.
76 The practice of CT where mechanical means is employed in land preparation causes rapid soil
77 organic matter decomposition and oxidation of soil C to CO_2 (Reicosky, 1997; Six et al., 2000).
78 This may affect changes in soil structure which could influence soil water holding capacity, soil

79 fertility and GHG emissions. Under conservation tillage soil disturbance is minimal which
80 maintains soil physico-chemical and biological properties, thereby improving soil water storage
81 capacity. In addition, the provision of soil cover or amendments increases soil organic matter and
82 nutrient content which may enhance crop yield. Crop yield is dependent on soil suitability and
83 limited by soil physical properties (Indoria et al., 2016), chemical properties (Wang et al., 2008)
84 and biological properties (Woźniak & Gos, 2014). Management practices that would facilitate
85 meeting global food demand and conserving the already stressed environment (Lal, 2005) is key
86 to sustainable crop production. No-till with residue retention is a key conservation agriculture
87 (CA) practice that has been reported to improve soil condition (Li et al., 2014), increased rainfed
88 crop yield (Pittelkow et al. 2015) and increased soil C stocks (Paustian et al., 2006). But these
89 responses to conservation tillage is variable in literature with reports of increased yields (Fabrizzi
90 et al. 2005), reduced yields (Taa et al., 2004) and no effect (Lampurlanés et al., 2002). Different
91 responses are dependent on several factors such as environment, duration of implementation and
92 types of conservation practices adopted (Zheng et al., 2014). It is not clear how the drylands of
93 the Loess plateau will respond to conservation tillage. Furthermore, studies on GHG response to
94 conservation tillage on the Loess Plateau are scarce and much is still unknown. This research is
95 needed in order to provide tailor-made recommendations for sustainable and climate-smart crop
96 production on the plateau.

97   Thus the objective of this study was (1) to examine the influence of no-till and straw
98 mulching soil management practices on crop yield (2) to analyse the dynamics of CO_2, CH_4 and
99 N_2O fluxes as affected by conservation tillage and (3) to identify the mechanisms that control the
100 responses of yield and greenhouse gases to tillage practices in dryland areas.

101

Materials & Methods
Study area

104   This experiment was conducted for two years (2017-2018) in the Anjiapo catchment on the
105 western Loess Plateau in Gansu province at the Soil and Water Conservation Research Institute
106 in Dingxi (35° 34' 53"N, 104° 38' 30"E; 2000 m above sea level). For this study we have
107 continuous data of forty two years (precipitation-385 mm, evaporation-1531 mm, sunshine
108 duration-2448 h, temperature- 7.1 °C, and frost free period-153 days). The soil is formed from
109 Loess with a sandy-loam texture, with average soil bulk density of 1.26 gcm^{-3}. Average soil
110 organic carbon (SOC) was 6.21 gkg^{-1} while total nitrogen content was 0.61 gkg^{-1}. Precipitation,
111 maximum and minimum temperatures for the experimental period are shown in Fig. 1.

112

113 **Fig. 1.**

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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 the plots. Wheat straw (dry weight of 3.75 ton/ha) was spread uniformly on all straw-treated plots immediately after planting. Chemical composition of the wheat straw is shown in Table 1. 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. 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 ºC to constant weight (Alhassan et al. 2018), while grain yields were determined by oven-drying at 105ºC for 45 minutes (Yeboah et al. 2016a).

Table 1

Sampling and Measurements

Soil Properties

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 data was sampled every 2 minutes and subsequently downloaded 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 soil temperature data were taken concurrently with gas sampling.

Soils were sampled at 0-10, 10-20 and 20-40 cm with a soil auger (4 cm diameter) for determination of soil organic carbon (SOC) and soil total nitrogen (STN). SOC was determined by the Walkley-Black dichromate oxidation method (Nelson & Sommers, 1982) while STN was determined by the Kjeldahl digestion and distillation procedure as described by Bremner & Mulvaney (1982).

Gas sampling and Flux measurements

The gas sampling procedure was 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 and released into 100 ml aluminum foil sampling bags (Shanghai Sunrise Instrument Co. Ltd, Shanghai). Gas samples were then analyzed in the laboratory with a GC system (Echrom GC A90, China) 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°C, 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. CO_2 emissions in terms of ecosystem respiration (R_{eco}), CH_4 and N_2O fluxes were calculated as shown in the supplemental file 1 following equation 1(Wei et al. 2014). Further flux analysis, soil carbon input components, and global warming potential were calculated from equations 2-10 as shown in supplemental file 1 (Bolinder et al., 2007; Zhang et al., 2009; Huang et al., 2007; IPCC, 2013).

Statistical Analysis

The data was 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 parameters crop yields, soil properties 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 (supplemental file 1).

191 **Results**

192 **Soil water content and Soil temperature**

193   Soil water content (SWC) was higher in NTS than all other treatments while CT had the
194 lowest SWC at almost all sampling times (Fig. 2a). Conventional tillage with straw mulch (CTS)
195 however stored more moisture than NT and CT at most sampling times. The highest SWC values
196 were recorded in the growing season between July and September.
197 Soil temperature, as shown in Fig. 2b showed peak temperatures occurring in June-August. The
198 highest temperatures were recorded in CT in most times while NTS and NT had the least
199 temperatures in most instances.
200 **Fig 2.**

201

202

203 **Soil organic carbon (SOC) and Soil Total Nitrogen (STN)**

204   Conservation Agricultural practices increased SOC at all depths (Fig. 3 a, b, c). At the 0-10
205 cm and 10-20 cm depths, SOC was increased significantly ($p < 0.05$) under CTS, NT and NTS.
206 For the 0-10 cm SOC values were 9.98±0.73, 11.97±0.5, 11.81±0.09 and 12.57±0.62 gkg^{-1}
207 respectively for CT, CTS, NT and NTS. Compared with CT, SOC was increased by 19.95%,
208 18.38% and 26.03% respectively under CTS, NT and NTS within the 0-10 cm soil depth. A
209 similar trend was observed within the 10-20 cm profile where SOC was also increased by
210 12.51%, 10.76% and 14.26% respectively under CTS, NT and NTS. However in the 20-40 cm
211 depth there was a little deviation where SOC in NTS and CTS were significantly greater than CT
212 but NT showed no significant difference. Meanwhile SOC decreased along soil depth
213 irrespective of treatment.
214   There was also significance ($p < 0.05$) in STN variations among treatments in the 0-10 cm
215 and the 10-20 cm depths (Fig 3 d, e, f). At the 0-10 cm depth STN values were 0.29±0.04,
216 0.36±0.03, 0.42±0.01 and 0.49±0.03 gkg^{-1} in CT, CTS, NT and NTS respectively. Compared
217 with the control (CT), STN was increased significantly ($p<0.05$) by 21.59%, 43.75% and 65.91%
218 respectively in CTS, NT and NTS. Similarly, within the 10-20 cm depth, STN was significantly
219 ($p<0.05$) increased under CTS (0.20±0.07 gkg^{-1}), NT (0.24±0.10 gkg^{-1}) and NTS (0.31±0.01 gkg^{-1}
220 ^{1}) compared with CT (0.17±0.01 gkg^{-1}). Nonetheless there were no significant differences ($p >$
221 0.05) in STN within the 20-40 cm depth. However there were observed reductions of STN along
222 soil depth in all treatments.

223

224 **Fig 3.**

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Grain Yield

230   Tillage and straw treatments influenced grain yield in both years (Table 2). Average grain
231 yields (2017-2018) were 644.61±116.40, 854.46±76.51, 699.30±133.52 and 908.18±38.64 kg ha-
232 1 respectively for CT, CTS, NT ad NTS. This means grain yield was increased by 32.55%, 8.48%
233 and 40.89% respectively under CTS, NT and NTS compared with CT. CTS and NTS increased
234 grain yield significantly ($p < 0.05$) for the period (2017-2018) but grain yield was not
235 significantly increased under NT. There were however slight interannual variations in yield
236 response to treatments. Grain yields were generally higher in 2018 than in 2017. Also in 2017
237 NTS showed the highest grain yield but in 2018 CTS showed the highest grain yield. While only
238 NTS significantly increased grain yield in 2017, in 2018 both NTS and CTS significantly
239 improved grain yield.

240
241 **Table 2.**
242
Average greenhouse gas emissions

244   Ecosystem Respiration for all treatments are shown in figures 4a and 4b respectively. Tilled
245 soils emitted significantly more CO_2 than non-tilled soils. In the growing season, average CO_2
246 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}
247 in CT, CTS, NT, and NTS respectively, resulting in emission reduction in CTS, NT, and NTS by
248 2.81%, 32.03% and 29.48% respectively. In the non-growing season, emissions were relatively
249 lower at rates of 30.55±1.71, 45.51±3.88, 31.74±1.35 and 34.15 ± 5.71 mg C m^{-2} h^{-1} respectively
250 in CT, CTS, NT, and NTS.

251   All the treatments served as minor sinks of CH_4 (Fig. 4c,d). The respective absorption rates
252 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,
253 NT and NTS in the growing season while in the non-growing season the values were -
254 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,
255 there were variations in their sink capacities. NTS was the largest sink in the growing season
256 while CT was the largest sink in the non-growing season. Generally, average absorption rates
257 were higher in the growing season than in the non-growing season in all treatments except CT.
258   Averagely across seasons, all treatments served as emitters of N_2O, but flux values were
259 statistically similar under all treatments in both seasons. Also, there were higher emissions in the
260 growing season than the non-growing season (Fig. 4 e, f). In the growing season, CTS had the
261 highest emission of N_2O. The fluxes in the growing season were 3.09±1.96, 14.88±0.42,
262 11.39±6.80 and 12.61±2.76 µg N m^{-2} h^{-1} for CT, CTS, NT and NTS respectively while in the
263 non-growing season, values of N_2O fluxes ranged between 0.21 and 2.69 µg N m^{-2} h^{-1}.

264
265 **Fig. 4**

266 **Net GHG fluxes, Global warming potential (GWP) and Greenhouse**
267 **Gas Intensity (GHGI)**

268   The Net CO_2-flux, CO_2 equivalents (CO_2e) of CH_4 and N_2O, GWP and GHGI of all
269 treatments are shown in Table 3. Grain Yield (Table 1) and Harvest index were used to estimate
270 the carbon components of harvest i.e. grain and straw in order to obtain Gross Primary
271 production (GPP) and Net Primary Production (NPP). Harvest index, carbon in grain and straw,
272 GPP and NPP are shown in supplemental file 2.

273   Net CO_2 fluxes in NTS and NT (6.65 ± 0.73 and 7.37 ± 0.89 tCO_2e $ha^{-1}y^{-1}$ respectively) were
274 significantly lower than those in CT and CTS (11.14 ± 0.58 and 10.65 ± 0.18 tCO_2e $ha^{-1}y^{-1}$
275 respectively), showing reduced net carbon exchange into the atmosphere under NTS and NT.
276 Similarly, GWP was greater in CT than all other treatments with significant reductions in NT and
277 NTS ($p < 0.05$). Compared with CT, the reduction in GWP was 2.83%, 33.40%, and 40.35%
278 under CTS, NT and NTS respectively. The GHGI is a yield-scale quantification of GWP, thus is
279 a factor of GWP and Grain yield. It shows the contribution of the cropping system to global
280 warming per unit grain yield. Our results showed that CT was the highest contributor of global
281 warming per unit grain produced compared with other treatments. Significant reductions of
282 GHGI were found in NTS and NT ($p < 0.05$).
283
284 **Table 3**
285

286 **Correlations between Soil parameters and Grain Yield**

287   Grain yields were highly influenced by soil nutrients. There were significant positive
288 correlations ($p <0.05$) of grain yield and SOC and STN (Table 4) at the 0-10 cm and 10- 20 cm
289 depths respectively (Table 4). However at deeper depths (20-40 cm), there were no significant
290 correlations observed.
291
292 **Table 4**
293

294 **Correlations between ST, SWC and Greenhouse gases**

295   Greenhouse gas fluxes were generally influenced by ST and SWC as shown in Table 5. CO_2
296 emission in the form of ecosystem respiration (R_{eco}) increased exponentially as ST increased;
297 ST-R_{eco} relationship followed an exponential function and was highly significant ($p < 0.001$) and
298 positive with R^2 values of 0.68, 0.63, 0.80 and 0.80 respectively in CT, CTS, NT and NTS while
299 SWC-R_{eco} relationship was best described by a power function and also showed highly
300 significant ($p < 0.001$) positive correlations with R^2 values of 0.06, 0.10, 0.14 and 0.07
301 respectively in CT, CTS, NT and NTS. Similarly, for CH_4 fluxes, ST-CH_4 relationship was an
302 exponential function and highly significant as well ($p < 0.001$) while SWC-CH_4 relationship was

303 best described by a linear function, albeit not significant. Meanwhile ST and SWC did not seem
304 to explain variations of N_2O as the correlations were not significant except in ST-N_2O
305 relationship under CTS.
306
307 **Table 5**
308

309 ## Discussion

310   Increased SWC and ST reduction in NTS (Fig 2) is in line with other studies where
311 conservation tillage improved SWC and soil water storage (Lal et al., 2012; Li et al., 2014). This
312 could be attributed to the effect of straw (He et al., 2011; Lal et al., 2012). Straw reduced
313 evaporation (Kang et al. 2004) leading to improvement in water retention (Hill et al., 1985) and
314 infiltration (Li et al 2011b). Straw mulch may also insulate the soil from direct impact of solar
315 heat leading to decline of temperature.
316 Other studies have also reported increased SOC stocks after adoption of conservation tillage
317 practices (Ogle et al., 2005; Paustian et al., 2006) which is similar to the findings of this study.
318 Increased SOC and STN in CA plots could be attributed to less disturbance of soil which might
319 reduce the risk of exposure of soil organic matter to decomposition process, thereby increasing
320 SOC storage (Lal, 2015; Reicosky, 1997; Six et al., 2000). Also, favorable moisture content in
321 CA plots (fig. 2) may foster water and nutrient uptake by plant roots and also induce substrate
322 movement for C fixation which may result in higher photosynthetic C input, leading to net C
323 sequestration. Soil moisture and residue retention in CA plots may reduce wind and water
324 erosion which could improve soil water storage and reduce leaching of soil nitrogen (Allmaras
325 and Dowdy, 1985; Lamb et al., 1985).
326   Higher grain yield under CA practices (Table 1) is in tandem with other studies where
327 conservation tillage increased grain yields (Bordovsky et al., 1998; Halvorson et al., 2000; Li et
328 al., 2014; Zheng et al. 2014; Yeboah et al., 2016 a,b). This could be attributed to improved soil
329 properties under these treatments. Higher SWC (Fig. 2) facilitated movement and uptake of
330 available nutrients, as shown by higher SOC and STN stocks in NTS, NT and CTS (Fig 3)
331 thereby leading to higher grain yields. This plausibility is increased as Pearson correlation
332 showed significant positive correlations between grain yield and these soil properties (Table 3).
333   Significant lower rates of ecosystem respiration ($p < 0.05$) in NT and NTS compared with the
334 tilled soils (Fig. 4) was consistent with other studies (Chaplot et al., 2012; Yeboah et al., 2016b)
335 where conservation tillage significantly reduced soil respiration. CO_2 emission rates is often
336 controlled by a number of factors including: gradient of concentration of CO_2 between the
337 atmosphere and the soil medium, soil water, soil temperature, wind speed and soil physical and
338 chemical properties (Raich & Schlensinger, 1992). Tillage influences these factors directly and
339 or indirectly which resultantly influences CO_2 emissions as well. Soil disturbance under
340 conventional tillage, may trigger microbial activities and increase decomposition rates (Alkaisi &
341 Yin, 2005), leading to higher CO_2 emissions. Soil disturbance may also increase soil aeration,
342 resulting in higher oxidation of carbon into CO_2 (Jackson et al., 2003). On the contrary, under

343 no-till, decomposition is slower due to less soil disturbance (Curtin et al., 2000). Higher soil
344 temperature under CT (Fig 2) may exponentially increase microbial activities (Meixner, 2006)
345 while lower soil temperature may reduce microbial activity, hence reduce emissions in the
346 conservation tillage plots (Carbonell-Bojollo et al., 2012). This corroborates with the significant
347 positive relationship between soil temperature and ecosystem respiration found in this study
348 (Table 4).

349 All four tillage methods resulted in uptake of CH_4 in both growing and non-growing seasons.
350 Other studies on the Loess Plateau obtained similar results (Wan et al., 2009; Yeboah et al.,
351 2016b). Shen et al. (2018) indicated that agroecosystems in dry regions with minimal irrigation
352 often act as CH_4 sinks due to aerobic soil conditions. This is due to oxidation of CH_4 under
353 aerobic conditions (Matson et al., 2009; Schaufler et al., 2010). Lower temperatures under NTS
354 may have played significant role in high uptake of CH_4 in NTS. The dominant methanogen
355 during high temperatures (Methanosarcinaceae) utilizes H_2/CO_2 and acetate as methane
356 producing precursors, and produces far higher methane than the methanogen at lower
357 temperatures (Methanosaetaceae), which uses only acetate as methane producing precursor
358 (Ding & Cai, 2003).

359 Average N_2O fluxes found in this study were in the range of fluxes reported by Ma et al.
360 (2013) in their study of GHGs in a rice-wheat rotation under integrated crop management
361 systems. Averagely, all treatments served as slight emitters of N_2O (Fig. 4). This is also
362 consistent with the study of Yeboah et al. (2016b) on the Loess Plateau. There was significant
363 positive correlation between soil temperature and N_2O emission in CTS. Higher temperatures
364 and soil water content in the growing season where 70-80% of rainfall occurs (Fig 1) may have
365 triggered nitrification and denitrification processes (Davidson & Swank, 1986), leading to higher
366 N_2O emissions in this season. High rainfall may increase water filled pore space, which
367 influences N_2O emissions in agricultural soils (Dobbie & Smith, 2003). Trujillo et al. (2008) also
368 reported positive correlation of N_2O with soil temperature and soil water content. Higher
369 emission in the growing season than in the non-growing season could also be related to fertilizer
370 N application in the growing season and its interactive effect with wet conditions within this
371 period on denitrification processes (Cho et al., 1997).

372 The GWPs (Table 2) were in the range as reported by Ma et al. (2013) but greater than those
373 reported by Yeboah et al. (2016b). Furthermore, GHGIs in this study were far higher than those
374 found in other studies (Qin et al., 2010; Ma et al., 2013). Higher GWPs and GHGIs in this study
375 could be attributed to a general lower grain yield (Table 1) which is typically associated with
376 drylands. Lower grain yield may generally result in relatively low carbon input (Supplementary
377 file 2) which may in turn result in relatively higher net GHG emissions. However GWP being
378 lower under NT and NTS than in CT and CTS is attributable to relatively higher carbon input
379 from the above ground plant product coupled with lower ecosystem respiration and higher CH_4
380 uptake in these plots.

381
382

Conclusions

This study hypothesized that no-till and the application of straw improved soil chemical and physical properties, increased crop yield and reduced greenhouse gas emissions by comparing 3 conservation practices [conventional tillage with straw (CTS), No-till (NT) and no-till with straw (NTS)] to conventional tillage (CT). Our study showed that conservation tillage practices especially NTS improved soil water content and reduced soil temperature. Soil organic carbon and total nitrogen were also significantly improved under conservation practices especially within the top soil layer (0-20 cm). There was also significant improvement in average grain yield under NTS and CTS. Conservation tillage further reduced net CO_2 flux; increased CH_4 absorption but only slightly influenced N_2O emissions in the dryland ecosystem. NTS and NT significantly reduced GWP and yield-scale GWP. For sustainability of arid and semi-arid cropping systems and for environmental quality we recommend the adoption of conservation agricultural practices such as no-till, straw mulch, green manuring, contour ploughing and terracing on the Loess Plateau. Furthermore crop genetic and breeding techniques such as the use of drought resistant crop varieties should also be explored in order to enhance climate change resilience of crop production in dryland areas and reduce climate footprint of these areas.

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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

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

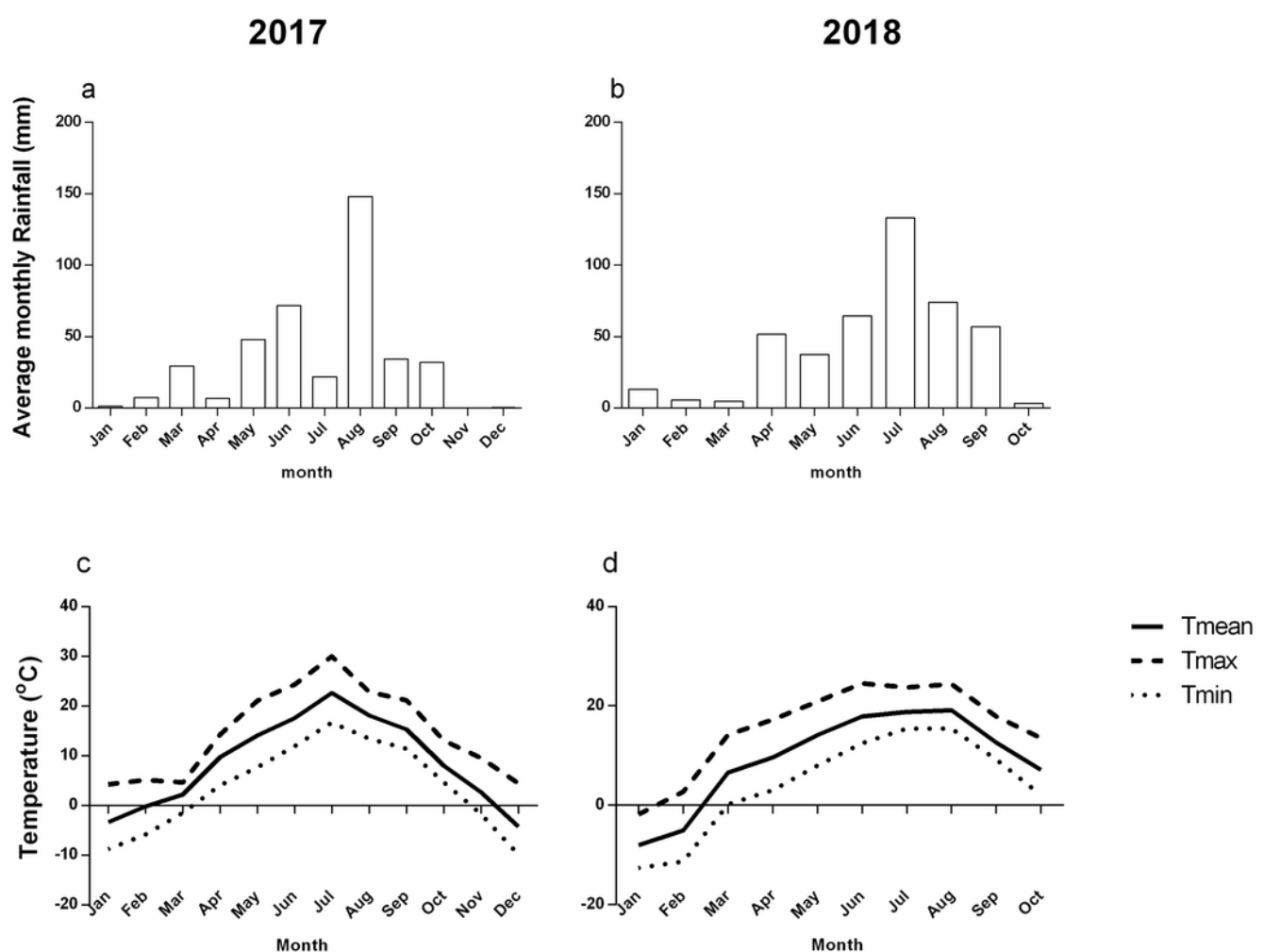



Figure 2

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

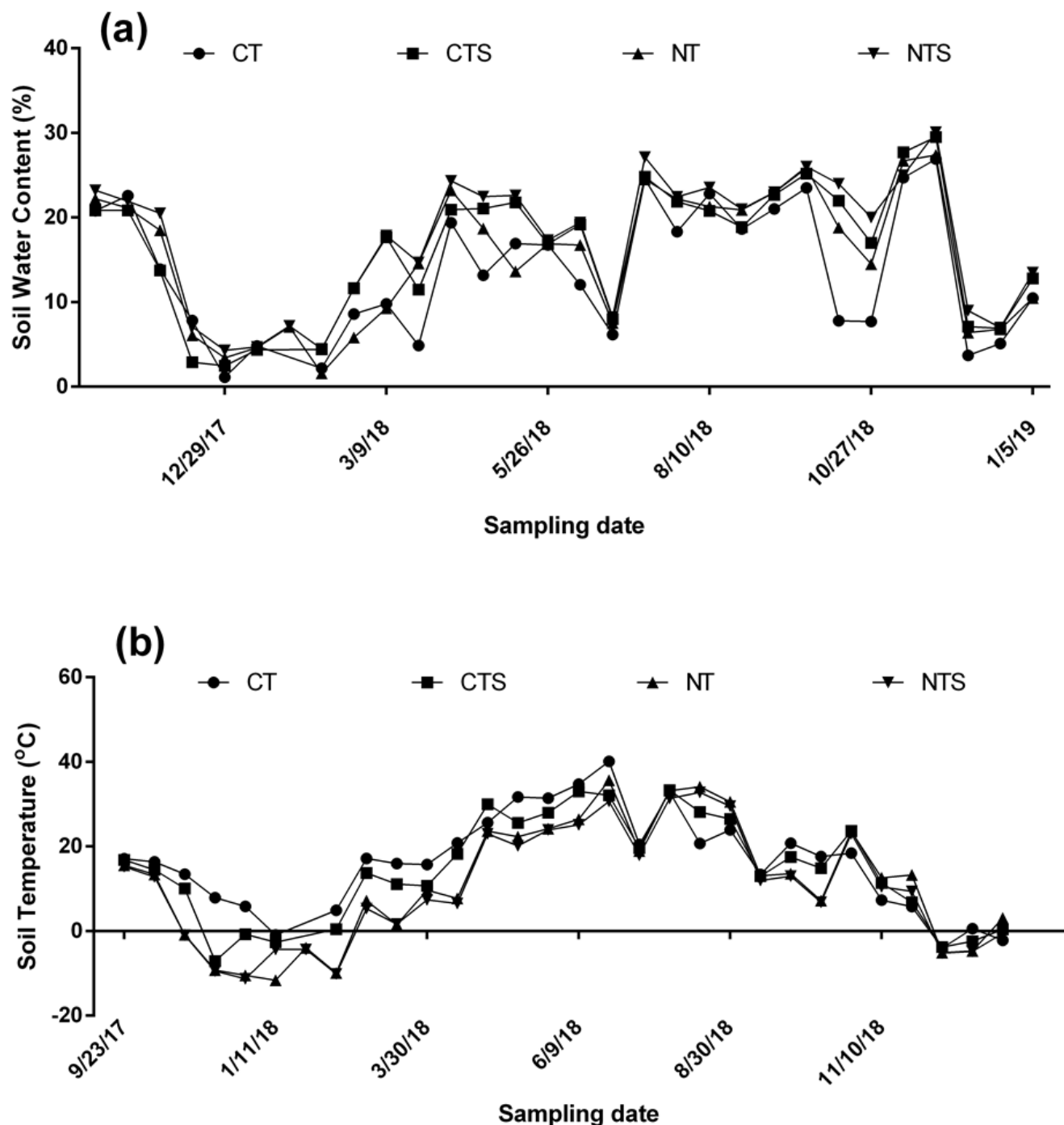



Figure 3

Soil organic carbon (SOC) and soil total nitrogen (STN) among tillage treatments within different depths.

Treatments with common letters within a depth are not statistically different at p ≤ 0.05

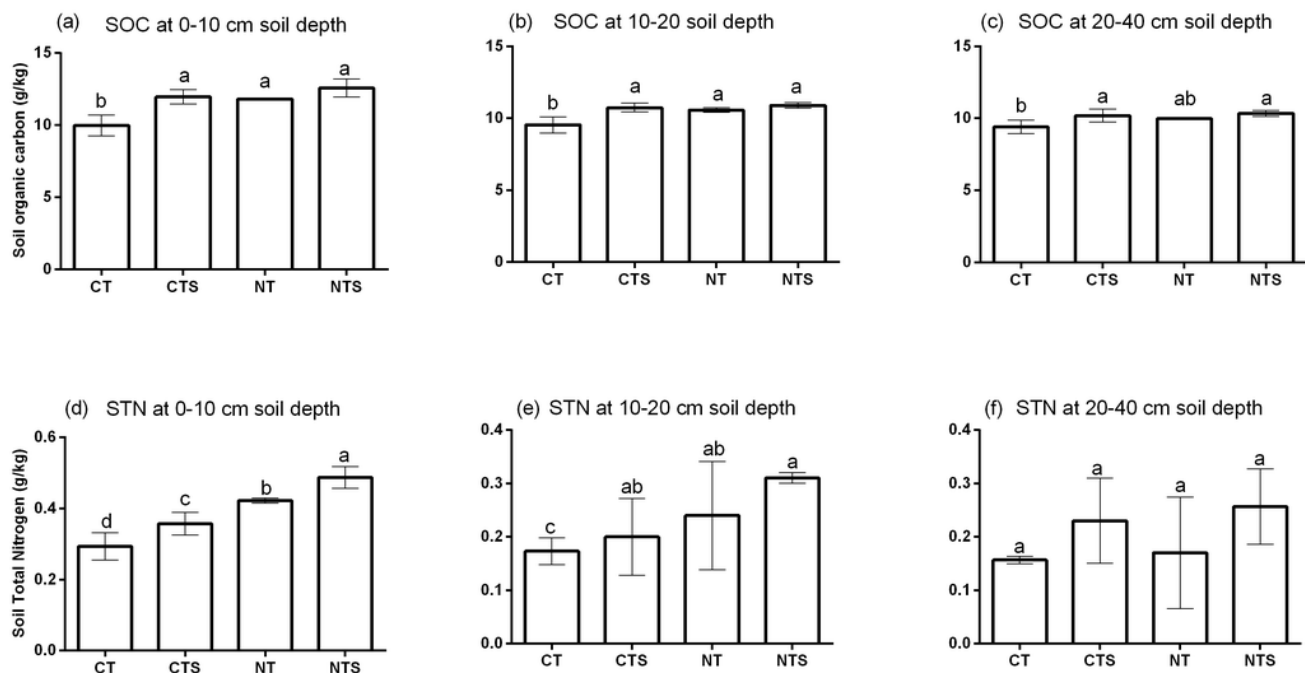
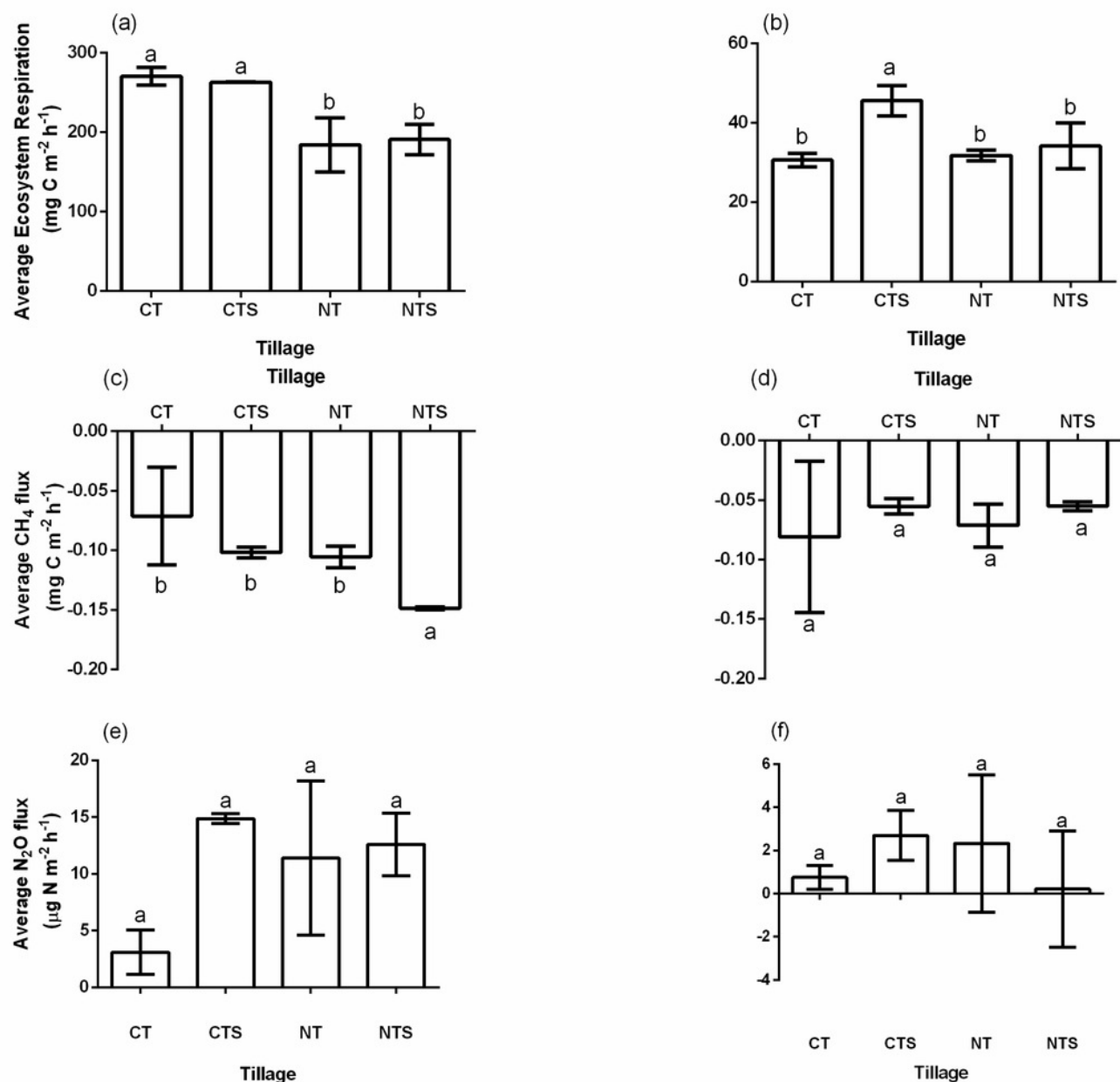



Figure 4

Average ecosystem respiration, CH4 and N2O 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 PeerJ reviewing PDF | (2019:10:42209:0:1:NEW 18 Oct 2019) Manuscript to be reviewed

Properties of wheat Straw mulch

1   **Table 1 Properties of wheat Straw mulch**

Parameter	Content (%)
Potassium	0.54±0.05
Carbon	40.19±3.2
Nitrogen	0.81±0.1
Phosphorus	0.09±0.01

Wheat grain yield response to different tillage treatments

1   **Table 2 Wheat grain yield response to different tillage treatments**

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]

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.**

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).

1 **Table 4 Correlation between Grain Yield and soil chemical properties**

Soil chemical property	Grain Yield
Soil Organic Carbon (SOC)	
Soil organic carbon at 10 cm	0.642*
Soil organic carbon at 20 cm	0.614*
Soil organic carbon at 40 cm	0.487
Total Nitrogen (TN)	
Total nitrogen at 10 cm	0.672*
Total nitrogen at 20 cm	0.609*
Total nitrogen at 40 cm	0.260

2 ****Correlation is significant at the 0.01 level (2-tailed).**
3 ***Correlation is significant at the 0.05 level (2-tailed).**
4

Correlation between greenhouse gases, soil temperature and soil water content

1 **Table 5. Correlation between greenhouse gases, soil temperature and soil water content**

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$_2$O 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	$= 0.067$