Greenhouse Gas Fluxes and Soil Carbon and Nitrogen Following Single Summer Tillage Event

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Authors’ contributions

This research was carried out in collaboration between authors. All authors designed the study. Authors PB and RG conducted the field experiment and laboratory analyses, and performed statistical analyses. Authors UN and JBN provided initial outline for the paper. All authors contributed to manuscript writing and formatting. Author UN was the principal investigator of the project that funded this experiment. All authors read and approved the final manuscript.

ABSTRACT

No-till farming results in gradual buildup of soil organic matter (SOM) and re-introduction of tillage can often reverse it. However, tillage in low precipitation regions may be needed to manage weeds and disperse accumulation of immobile soil nutrients. The main objective of this study was to assess the effects of a single summer tillage on carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), soil water filled pore space (WFPS), dissolved organic carbon (DOC) and nitrate (NO₃) in winter wheat - summer fallow systems that were either tilled for the first time after nine years of no-till (NTT), not-tilled (no-till, NT) or were frequently tilled (conventional, CT; and organic, CF). The study was established in the US Central High Plains region where annual precipitation averaged 332±39 mm. Soil and gas samples were collected before the tillage event (time zero) and at 1hr, 5 hrs, 25 hrs and 50 hrs after. Immediate increases in CO₂ and N₂O fluxes were observed in all tilled treatments within the first 1 to 5 hours but 50-hr cumulative N₂O and CO₂ in NTT did not differ from...
1. INTRODUCTION

Tillage during the fallow phase is a common practice in dry land winter wheat (Triticum aestivum L.) production in the US Central High Plains. Repeated tillage of marginally productive soils in this low precipitation region (annual precipitation ranging between 300 to 400 mm yr⁻¹) [1] has however, resulted in loss of soil organic matter (SOM) and decline in soil nutrient availability [2]. Conversely, long-term no-till management has helped accrue multiple agroecosystem benefits [2,3], which include increase in SOM, reduced soil erosion and improved soil profile water storage [4,5]. While producers who practice no-till in semi-arid regions are typically committed to this form of management, there are several reasons why occasional summer tillage may prove beneficial and offer solutions to some no-till related problems. For example, tillage can temporarily improve soil aeration [6], help incorporate crop residues, disperse near-soil-surface-accumulated low-mobility phosphorous (P) [7]; reduce soil compaction [8], control weeds [9] and reduce stratification of SOM [10].

Tilling of the dry soil however, can trigger microbial processes leading to SOM mineralization and greenhouse gas (GHG) emissions [11,12]. The mechanism of SOM decomposition starts with the release of newly formed or previously aggregate-protected labile organic substrates that are subsequently made available to soil microbes. This results in immediate production of carbon dioxide (CO₂) and nitrous oxide (N₂O), and increased assimilation of methane (CH₄). These rapid changes are important indices demonstrating early soil response to disturbance. In addition, these three gases are of particular interest as they affect soil carbon (C) and nitrogen (N) exchanges with the atmosphere [13] and are important players in the global C cycle [14]. Factors affecting SOM decomposition following disturbance include temperature, water, aeration, pH, and mineral nutrients, plant residue quality and soil structure [15]. For example, frequently tilled soils in semi-arid regions generate twice as much CO₂ compared with long-term not tilled soils over a period of the growing season [16].

CO₂, N₂O and CH₄ are of particular importance as potent GHG species. N₂O is produced primarily during the process of denitrification and carried out by anaerobic microorganisms ubiquitous in soils experiencing periodic water saturation [17]. The process of N₂O production however, is not limited to water-saturated soils, but also takes place in any soil where anoxic microsites exist [18]. In addition, N₂O is produced during aerobic nitrification in well-aerated soils [19]. A single rainfall event after prolonged periods of drought can trigger immediate N₂O pulses that can equal 80-90% of total annual N₂O emissions in semiarid native rangelands [20,21]. Similar water pulses can result in temporary increase in methanogenesis [14]. On the other hand, tillage can trigger CH₄ assimilation driven by methanotrophic microorganisms [14]. It is known that well drained soils effectively assimilate CH₄ and in general, dry soils are important sinks for atmospheric C [22].

The main objective of this study was to quantify GHG emissions and soil C and N after a single summer tillage event performed on a series of winter wheat fallows that have been tilled for the first time after nine years of no-till or are frequently tilled. Such information can help understand the SOM mineralization triggered by a tillage disturbance and demonstrate whether an occasional tillage jeopardizes long-accrued benefits of a no-till practice.
2. MATERIALS AND METHODS

2.1 Study Site

The experiment was conducted in July 2011 at the University of Wyoming Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, WY (42° 5’ N, 104° 23’ W and 1314 meters elevation). Soils at the location are classified as loamy, mixed, active, mesic Ustic Torriorthents, with less than one percent SOM and slightly alkaline soil pH. Climate is semi-arid with approximately 125 frost-free days, average maximum and minimum temperatures of 17.9°C and 0.2°C, respectively, and average annual precipitation of 332±39 mm [1]. Two-week antecedent precipitation before the start of experiment amounted to 28 mm and no precipitation occurred during the five-day period prior to the experiment.

2.2 Experimental Design and Treatments

The experiment was established in a series of 5-ha fields under different long-term tillage treatments that were first applied in 2002. Fields were located adjacent to each other and positioned on a similar landscape. Treatments consisted of: first-time tillage after nine years of a no-till (NTT); no-till managed exclusively with chemicals for weed control (NT), a combination of tillage and chemical weed control also referred to as “conventional” (CT), and chemical-free frequently tilled organic system (CF) (Table 1). The CF treatment involved a maximum of six tillage operations per year and tillage was the only form of soil management and weed control. The CF treatment was designed to reflect organically certified wheat production in eastern Wyoming. This system relies on no external (fertilizer and herbicides) inputs and tillage frequency is determined based on need for weed control. The CT treatment involved a maximum of four tillage operations per year. Due to reoccurring plant-available water shortages, low fertility soils and low overall crop yields, no fertilizer was used in any of the systems. Spring and early summer tillage is replaced with herbicide applications. Early summer tillage operations to a depth of 15 cm in CF were performed using Krause tandem disk (Khun Krause Inc., Hutchinson, KS). Subsequent summer tillage operations to a depth of 10 cm were performed using a Sunflower Fallow-King® (Sunflower Manufacturing, Beloit, KS). Fertilizers have not been applied in any of the treatments since 2002.

Five 10 m × 10 m plots were established at randomly selected locations in NT, CT and CF treatments in fallow strips that were 60 meters long. The NTT plots were also established within the same fallow strips as NT plots. Constraining NTT plots to the same filed as NT treatment plots was intended to assure that concurrent GHG and soil measurements were performed within a

Table 1. Field operations for no-till (NT), first time tillage of no-till (NTT), conventional tillage (CT), and chemical-free (CF) systems in dryland wheat-fallow cropping system until the start of experiment

| Operation                      | NT   | NTT | CT              | CF              |
|--------------------------------|------|-----|-----------------|-----------------|
| Tillage operations per year    | -    | -   | up to 4 times   | up to 6 times   |
| Tillage equipment              | -    | Sunflower Fallow-King® | Krause Tandem Disk; Sunflower Fallow-King® | Krause Tandem Disk; Sunflower Fallow-King® |
| Herbicides per year            | as needed | as needed | 1 time         | -               |
| Type of herbicides             | 2,4-D; Thifensulfuron-methyl and Tribenuron-methyl; Glyphosate | 2,4-D; Thifensulfuron-methyl and Tribenuron-methyl; Glyphosate | 2,4-D; Thifensulfuron-methyl and Tribenuron-methyl; Glyphosate | - |
| Surface residue                | >35% | <30% | <15%            | <10%            |
2.3 Soil and Air Sampling

Concurrently with gas sampling, soil samples underlying a interpolating hourly emissions and integrating the over 50 time. Cumulative fluxes of individual gas species concentrations in the chamber headspace over were calculated from the change in GHG capture CO$_2$, CH$_4$ and N$_2$O, respectively. Fluxes were calculated from the change in GHG concentrations in the chamber headspace over time. Cumulative fluxes of individual gas species over 50-h period were determined by linearly interpolating hourly emissions and integrating the underlying area as described in Hutchinson and Mosier [25].

Concurrently with gas sampling, soil samples (0-10 cm) were collected from three random plot locations within a minimum distance of 0.5 meter away from GHG chamber bases. Three soil cores were homogenized, coarse fragments removed, and a single 5 g subsample was immediately field extracted with 50 ml of 2 molar potassium chloride (2M KCl). The remaining soil was bagged, stored in a cooler and transported to the lab for further analyses.

2.4 Laboratory Analyses

Soil water content was determined by the gravimetric technique [26], dissolved organic carbon (DOC) was quantified using a Shimadzu TOC Analyzer (TOC-VCPH, Shimadzu, Kyoto, Japan) and soil nitrate (NO$_3$) concentration was determined using a micro plate spectrophotometer (Biotek Inc.) [27].

A sub-set of soil samples collected at the beginning of the study was analyzed for particle-size distribution using the hydrometer method [28], bulk density by the core method [29], and pH and electrical conductivity by electrode [30]. Total C and total N (Total N) contents were determined by dry combustion using a NC-2100 elemental analyzer (Carlo Erba Instruments, Milan, Italy). Inorganic C was determined using the modified pressure-calcimeter method [31]. Soil organic C (SOC) was determined by subtracting inorganic C from total C. Water filled pore space (WFPS) was calculated from soil bulk density and gravimetric water content [32]. Particle density of 2.65 g m$^{-3}$ was used in WFPS calculation.

2.5 Statistical Analyses

Data were analyzed using PROC MIXED in the Statistical Analysis System (SAS ver. 9.3, SAS Institute, Cary, NC) [33]. Plots within each treatment though spatially explicit and well replicated, were considered as pseudo-replicates. The statistical analysis considered treatment as a fixed term, time of sampling as a repeated measure, and replications as random terms in the statistical model. The cumulative CO$_2$, CH$_4$, and N$_2$O fluxes were analyzed using one-way ANOVA. Means were separated using PDIFF test in the LSMEANS procedures. Treatment effects were considered significant at \( P \leq 0.05 \). Change in WFPS over time was analyzed using (PROC REG) in SAS. Regression analyses were performed to compare slopes representing change in WFPS over time.
3. RESULTS

3.1 Baseline Soil Properties

Soils at the location were comparable among the treatments and classified as sandy loams. Soils had BD 1.37 g cm$^{-3}$, EC 0.97 ds cm$^{-1}$, pH 8.64, and IC 2.70 g kg$^{-1}$. Soil in NT and NTT had comparable Total N, which was 36% and 34% higher than in CT and CF, respectively (Table 2). In addition, NT and NTT had 17% and 12% higher SOC content than CT and CF. Soil and air temperatures during the experiment were high and ranged between 27°C and 40°C.

3.2 Water Filled Pore Space

Soil WFPS showed significant effects of tillage (P$\leq$ 0.02) and time (P$<$0.001) but no tillage x time interaction. The highest WFPS was reported in NT and the lowest in CF soils. There were however, differences between regression slopes representing WFPS response to tillage treatments in time (Fig. 1). While NT soil was losing soil water at a rate of 0.09% per hr, water loss in NTT soils was only 0.03% higher, while loss in most frequently tilled CF soils were the highest and amounted to 0.20% per hr, respectively.

3.3 Carbon Dioxide

Carbon dioxide showed significant treatment x time interaction (P$\leq$0.001). Before tillage, CO$_2$ fluxes in NTT did not differ from fluxes in NT and CT but were significantly (33%) smaller than in CF (Fig. 2a). Within the first hour, CO$_2$ in NTT increased from 10.7 mg C m$^{-2}$ hr$^{-1}$ to 25.6 mg C m$^{-2}$ hr$^{-1}$ which was 68% more than CO$_2$ flux in NT at T1. CO$_2$ flux in NTT was comparable with CF and 22% lower than in NT. The CO$_2$ flux in NTT was, however, short-lived and became comparable with flux observed at T0 within five hrs. In contrast, CO$_2$ in CT and CF at T1 and T5 were 25% and 67% greater compared with T0. These two fluxes declined to levels comparable with T0 after 25 hrs. The 50-hr cumulative CO$_2$ in NTT averaged 591 mg C m$^{-2}$ and was not significantly different than cumulative CO$_2$ in NT (555 mg C m$^{-2}$). It was however; significantly lower than CO$_2$ in CF (983 mg C m$^{-2}$) and CT (921 mg C m$^{-2}$).

3.4 Methane

Methane also showed significant treatment x time interaction (P$\leq$0.001). All treatments had comparable CH$_4$ assimilation at T0 that averaged 7.0 µg C m$^{-2}$ hr$^{-1}$ (Fig. 2b). At T1, the CH$_4$ assimilation in NTT doubled compared with T0, and it was significantly greater than NT and CF but similar to CH$_4$ assimilation in CT. This increase in NTT was, however, short-lived and the CH$_4$ assimilation became comparable with T0 in NT after five hrs. The 50-hr cumulative CH$_4$ assimilation in NTT (540 µg C m$^{-2}$) was 28% greater than in NT, 22% greater than in CF but 16% lower than CH$_4$ in CT.

3.5 Nitrous Oxide

Nitrous oxide also showed significant treatment x time interaction (P$\leq$0.001). All treatments had comparable N$_2$O fluxes at T0 (Fig. 2c). Tillage did not generate an initial N$_2$O pulse in NTT at T1 unlike in CF and CT when N$_2$O increased by 122% and 65%, respectively. On contrary, the N$_2$O flux in NTT was significantly reduced (20%) in T1 compared with T0 (37.2 µg N m$^{-2}$ hr$^{-1}$).

3.6 Soil Dissolved Organic Carbon

Soil DOC also demonstrated significant treatment x time interactions (P$\leq$0.05). Before tillage, all treatments had comparable DOC (Table 3). At T1, DOC in CT and CF was significantly greater compared with values in NTT and NT. At T25 however, DOC in NTT became significantly greater than in NT and CT but comparable with CF. Twenty five hrs later at T50, DOC became significantly lower in CT and CF compared with NT and NTT. Soil DOC in NTT and NT did not change following tillage except for T25 when DOC in NT was significantly lower than at T0.

3.7 Soil Nitrate

Soil NO$_3$ at T0 was comparable among NTT, CF, and NT, and they were significantly lower than in CT (Table 3). Tillage did not increase NO$_3$ in NTT at T1 or thereafter, unlike in CT and CF where it increased by 4.04 and 4.92 mg kg$^{-1}$ to values that were significantly greater than in NT and NTT. Nitrate remained elevated in CT and CF until T50. Nitrate in NT at T50 was significantly greater compared with T0, but the values were lower than NO$_3$ in CT and CF and comparable with NTT.
Table 2. Soil (0-10 cm depth) total carbon (TC), pH, electrical conductivity (EC), bulk density (BD) and texture in no-till (NT), no-till tilled for the first time (NTT), conventional tillage (CT) and chemical-free (CF) dry land winter wheat-fallow systems. Values in parentheses indicate standard errors (n = 5). Same letters within each row indicate no significant difference among management practices (at minimum P<0.05)

| Parameters          | Management practices |
|---------------------|----------------------|
|                     | NT       | NTT      | CT       | CF       |
| Total N (g kg⁻¹)    | 0.81(0.20)a| 0.88(0.13)a| 0.54(0.05)b| 0.56(0.22)b|
| SOC (g kg⁻¹)        | 5.08(0.21)a| 5.22(0.62)a| 4.27(0.35)b| 4.56(0.39)b|
| IC (g kg⁻¹)         | 2.85(0.27) | 2.68(0.27) | 2.90(0.31) | 2.35(0.10) |
| pH                  | 8.70 (0.05)| 8.70(0.07) | 8.62(0.03) | 8.60(0.03) |
| EC (ds cm⁻¹)        | 0.97(0.03) | 0.97(0.02) | 0.97(0.02) | 0.96(0.01) |
| BD (g cm⁻³)         | 1.38(0.02) | 1.37(0.02) | 1.36(0.02) | 1.37(0.02) |
| Sand (%)            | 62.4(1.03) | 61.2(1.39) | 61.2(0.58) | 60.0(1.22) |
| Silt (%)            | 30.2(0.49) | 31.0(1.52) | 32.2(0.37) | 32.6(0.93) |
| Clay (%)            | 7.40(1.03) | 7.80(0.20) | 6.60(0.24) | 7.40(0.60) |
| Soil Texture        | Sandy loam| Sandy loam| Sandy loam| Sandy Loam|

Fig. 1. Water filled pore space (%) in no-till (NT), no-till tilled for the first time (NTT), conventional (CT), and chemical-free (CF) systems at times zero (T0), one (T1), five (T5), 25 (T25) and 50 (T50) hours after tillage. Bars indicate mean standard errors (n = 5). Lines indicate regression lines for individual treatments.
Fig. 2. Carbon dioxide ($CO_2$) (a), methane ($CH_4$) (b) and nitrous oxide ($N_2O$) (c) fluxes from no-till (NT), no-till tilled for the first time (NTT), conventional (CT), and chemical-free (CF) systems times zero (T0), one (T1), five (T5), 25 (T25) and 50 (T50) hours after tillage. Bars indicate standard errors ($n = 5$). Lower case letters indicate significant treatment differences in each time ($P \leq 0.05$). Asterisk (*) indicates significant differences in time within each treatment.
4. DISCUSSION

Results from this experiment suggest that a single tillage performed during warm summer on previously not tilled dry soils had an insignificant impact on soil C and N as demonstrated by the lack of difference in cumulative CO$_2$ and N$_2$O fluxes between NTT and NT. These fluxes were also significantly lower than CT and CF despite higher overall soil Total N and SOC contents. Tillage however, did result in an immediate but short-lived CO$_2$ pulse in all tilled treatments including NTT, but the magnitude of initial CO$_2$ flux in NTT was only one-third of that from CT and CF. Elevated GHg fluxes from frequently tilled CT and CF soils further confirmed that repetitive tillage contributes to SOM mineralization [16,34]. It is likely that the initial CO$_2$ pulse in NTT was attributed more to the release of CO$_2$ trapped in soil pores under non-tilled soil surface as proposed by Kessavalou et al. [35].

Greater WFPS loss in CT and CF than in NT and NTT over time indicated greater soil water retention under the long-term no-till system, which was conserved even after a single tillage. One-time tillage in NTT also had no significant impact on soil DOC. Unlike CT and CF, where concentrations were initially greater but then significantly declined between 25 and 50 hrs to below NT and NTT levels. Al-Kaisi et al. [36] and Reicosky et al. [37] attributed these changes to soil aggregate disruption and exposure of aggregate-protected C to microbial activity. This newly released C was likely utilized as a microbial substrate during respiration or in support of microbial biomass as proposed by Norton et al. [21] and Ghimire et al. [38] and not measured in this study.

Interestingly, tillage resulted in an initial decline in N$_2$O fluxes within 1 hr after the event in NTT only. This observation agreed in part with the findings by Kessavalou et al. [35] who reported flux declines in frequently tilled soils as well. Moreover, the magnitude of the decline in NTT was much lower compared to the other study in which 83% reduction in N$_2$O for the period of two hours after tillage was observed in spring and 64% reduction for the period of 0.5 hr was observed in summer.

Less NO$_3$ in NTT compared with CT and CF suggested that a single tillage did not trigger anticipated N mineralization as often observed in less water limited agroecosystems [34]. In addition, nitrification was likely the process of N$_2$O production in the studied soils as previously proposed by Grandy and Robertson [39]. This was demonstrated by the synchrony between N$_2$O fluxes and soil NO$_3$ concentrations in CT and CF soils.

However, one-time tillage of a no-till increased soil aeration and allowed for a very short-lived (observed at T1 only) increase in CH$_4$ assimilation. Similar increases in assimilation were also observed as early as 30 min after tillage in wheat-fallow systems in the same region [35]. Such response suggested greater gas exchange between soil and atmospheric air.
and enhanced activity of methanotrophic microorganisms living in a soil layer below top 0-10 cm [40].

5. CONCLUSION

Our study suggested that single summer tillage performed for the first time in nine years in the dry and cold agroecosystem of the central High Plains did not negate the benefits of long-term no-till. Therefore, a summer tillage performed as needed, every several years can be a useful management tool for no-till dry land farmers. However, as soil moisture retention is very critical for dry land production, caution should be applied on how to schedule the timing of such operation. Even small water loss can have long-lasting consequences affecting crop yield in low precipitation regions. Additional research is needed to determine best tillage strategies (depth, intensity, spatial extent and the level of disturbance) to help advance our understanding of the effects of periodic tillage on soil properties and agroecosystem sustainability.

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COMPETING INTERESTS

Authors would like to declare that there were no competing interests of any nature in this research article and that each author played the stipulated roles in the process towards the success of this manuscript.

REFERENCES

1. Western Regional Climate Center. Historical Climate Information. Desert Research Institute, Reno, NV; 2014. Accessed 28 May 2014. Available: http://www.wrcc.dri.edu/narratives/WYOMING.htm

2. Norton JB, Mukhwana EJ, Norton U. Loss and recovery of soil organic carbon and nitrogen in a semiarid agroecosystem. Soil Sci. Soc. Am. J. 2012;76:505-514. DOI:10.2136/sssaj2011.0284

3. Ghimire R, Norton J, Pendall E. Alalfa-grass biomass, soil organic carbon, and total nitrogen under different management systems in an irrigated agroecosystem. Plant Soil. 2014;374:173–184. DOI:10.1007/s11104-013-1854-2.

4. Varvel GE, Whelam WW. No-tillage increases soil profile carbon and nitrogen under long-term rainfed cropping systems. Soil Tillage Res. 2011;87:19-27. DOI:10.1016/j.still.2011.03.005.

5. Feng G, Sharratt B, Young F. Soil properties governing soil erosion affected by cropping systems in the U.S. Pacific Northwest. Soil Till Res. 2011;111:168-174. DOI: 10.1016/j.still.2010.09.008.

6. Tian S, Wang Y, Ning T, Zhao H, Wang B, Li N, Li Z, Chi S. Greenhouse gas flux and crop productivity after 10 years of reduced and no tillage in a wheat-maize cropping system. PLoS One. 2013;8(9):e73550. DOI: 10.1371/journal.pone.0073450.

7. Messiga AJ, Ziadi N, Belanger G, Morel C. Soil nutrients and other major properties in grassland fertilized with nitrogen and phosphorus. Soil Sci. Soc. Am. J. 2013;77:643-652. DOI:10.2136/sssaj2012.0178.

8. Cassel DK, Raczkowski CW, Denton HP. Tillage effects on corn production and soil physical conditions. Soil Sci. Soc. Am. J. 1995;59:1436-1443. DOI:10.2136/sssaj1995.03615995005900050033.

9. Kettler TA, Lyon DJ, Doran JW, Powers WL, Stroup WW. Soil quality assessment after weed-control tillage in a no-till wheat-fallow cropping system. Soil Sci. Soc. Am. J. 2000;64:399-346. DOI:10.2136/sssaj2000.641339.

10. Causarano HJ, Franzluebbers AJ, Shaw JN, Reeves DW, Raper RL, Wood, C. Soil organic carbon fractions and aggregation in the southern piedmont and coastal plain. Soil Sci. Soc. Am. J. 2008;72:221-230. DOI:10.2136/sssaj2006.0274.

11. Reeder JD, Schuman GE, Bowman RA. Soil C and N changes on conservation reserve program lands in the Central Great Plains. Soil Tillage Res. 1998;47:339-349. DOI:10.1016/s0167-1987(98)00122-6.

12. Bruce JP, Frome M, Haites E, Janzen H, Lal R, Paustian K. Carbon sequestration in soils. J. Soil Water Conserv. 1999;54:382-389.
13. Holland EA, Robertson GP, Greenberg J, Groffman PM, Boone RD, Gosz JR. Soil CO₂, N₂O, and CH₄ exchange. In Roberston, G. P., C.S. Bledsoe, D.C. Coleman, and P. Sollins. (eds.) Standard Soil Methods for Long-Term Ecological Research. Oxford Uni. Press. 1999:185-201.

14. Schlesinger WH, Bernhard ES. Biogeochemistry: An analysis of global change. 3rd edition. Academic Press, Inc. San Diego, California, USA; 2012.

15. Paustian K, Babcock BA, Hatfield J, Kling CL, Lal R, McCarl BA, McLaughlin S, Mosier AR, Post WM, Rice CW, Robertson GP, Rosenberg NJ, Rosenzweig C, Schlesinger WH, Zilberman, D. Climate change and greenhouse gas mitigation: Challenges and opportunities for agriculture. Task Force Report No. 141. Council for Agricultural Science and Technology; 2004.

16. Sainju UM, Jabro JD, Stevens WB. Soil carbon dioxide emission and carbon content as affected by irrigation, tillage, cropping system, and nitrogen fertilization. J. Environ. Qual. 2008;37:98-106. DOI:10.2134/jeq2008.0392.

17. Myrold DD. Transformation of nitrogen. pp. 333-372. In Silvia DM, Fuhrmann JJ, Hartel PG, Zuberer DA. (eds.) Principles and applications of soil microbiology. Pearson Education Inc., Upper Saddle River, New Jersey; 2005.

18. Sextone AJ, Parkin TB, Tiedje JM. Temporal response of soil denitrification rates to rainfall and irrigation. Soil Sci. Soc. Am. J. 1985;49:99-103.

19. Firestone MK, Davidson EA. Microbiological basis of NO and N₂O production and consumption in soil. In Andreade MO, Schimel DS (eds.). Exchange of trace gases between terrestrial ecosystems and the atmosphere. John Wiley and Sons, New York; 1989.

20. Mummeey DL, Smith JL, Bolton H. Nitrous-oxide flux from a shrub-steppe ecosystem-sources and regulation. Soil Biol. Biochem. 1994;26:279-286. DOI:10.1016/0038-0717(94)90168-6.

21. Norton U, Mosier AR, Morgan JA, Derner JD, Ingram LJ, Stahl PD. Moisture pulses, trace gas emissions and soil C and N in cheat grass and native grass-dominated sagebrush-steppe in Wyoming, USA. Soil Biol. Biochem. 2008;40:1421-1431. DOI:10.1016/j.soilbio.2007.12.021.

22. Mosier AR, Schimel D, Valentine D, Bronson K, Porton W. Methane and nitrous-oxide fluxes in native, fertilized and cultivated grasslands. Nature. 1991;350: 330-332. DOI:10.1038/350330a0

23. Mosier AR, Mack L. Gas-chromatographic system for precise, rapid analysis of nitrous-oxide. Soil Sci. Soc. Am. J. 1980;44:1121-1123. DOI:10.2136/sssaj1980.03615995004400050048x.

24. Hutchinson GL, Mosier AR. Improved soil cover method for field measurement of nitrous oxide fluxes. Soil Sci Soc Am J. 1981;45:311–316. DOI:10.2136/sssaj1981.0361599500450002017x.

25. Liebig MA, Kronberg SL, Hendrickson JR, Dong X, Gross JR. Carbon dioxide efflux from long-term grazing management systems in a semiarid region. Agric. Ecosyst. Environ. 2013;164:137-144. DOI:10.1016/j.agee.2012.09.015.

26. Gardner WH. Water content. In: Methods of soil analysis: Part 1-Physical and mineralogical methods. Klute A editor 503–507. Soil Sci Soc Am J Madison, WI; 1986.

27. Doane TA, Horwath WR. Spectrophotometric determination of nitrate with a single reagent. Analytical Letters. 2003;36:2713-2722. DOI:10.1081/AL-120024647.

28. Gee GW, Bauder JW. Particle-size analysis. In: Klute A (ed) Methods of soil analysis part 1: physical and mineralogical methods. 2nd ed. Agronomy monograph 9. American Society of Agronomy and Soil Science Society of America, Madison. 1981:45-450. DOI:10.1016/j.agee.2012.09.015.

29. Blake GR, Hartge KH. Bulk density. In: Klute A (ed) Methods of soil analysis, part 1: physical and mineralogical methods, 2nd ed. American Society of Agronomy and Soil Science Society of America, Madison. 1986;383–411.

30. Thomas GW. Soil pH and soil acidity. In: Sparks DL (ed) methods of soil analysis, part 3: chemical methods, ed. Agronomy monograph 9. American Society of Agronomy and Soil Science Society of America, Madison. 1996;475–490.

31. Sherrod LA, Dunn G, Peterson GA, Kolberg RL. Inorganic carbon analysis by
modified pressure-calcimeter method. Soil Sci Soc Am J. 2002;66:299–305.

32. Linn DM, Doran JW. Effect of water-filled pore-space on carbon dioxide and nitrous-oxide production in tilled and non-tilled soils. Soil Sci. Soc. Am. J. 1984;42:1267-1272.

33. Littell RC, Stroup WW, Freund RJ. SAS for linear models, 4th ed. SAS Inst., Cary, N.C; 2002.

34. Ruan L, Robertson GP. Initial nitrous oxide, carbon dioxide, and methane costs of converting conservation reserve program grassland to row crops under no-till vs. conventional tillage. Glob. Change Bio. 2013;19:2478-2489.

35. Kessavalou A, Doran JW, Mosier AR, Drijber RA. Greenhouse gas fluxes following tillage and wetting in a wheat-fallow cropping system. J. Environ. Qual. 1998;27:1105-1116. DOI:10.2134/jeq1998.00472425002700050016.

36. Al-Kaisi MM, Yin, XH. Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations. J. Environ. Qual. 2005;34:437-445. DOI:10.2134/jeq2005.0437.

37. Reicosky DC, Evans SD, Cambardela CA, Armaras RR, Wilts AR, Huggins DR. Continuous corn with moldboard tillage: Residue and fertility effects on soil carbon. J. Soil Water Conserv. 2002;57:277-284

38. Ghimire R, Norton JB, Stahl PD, Norton U. Soil microbial substrate properties and microbial community responses under irrigated organic and reduced-tillage crop and forage production systems. PLOS ONE 2014;9(8):e103901.

39. Grandy AS, Robertson GP. Initial cultivation of a temperate-region soil immediately accelerates aggregate turnover and CO₂ and N₂O fluxes. Global Change Biol. 2006;12:1507-1520.

40. Omonode RA, Vyn TJ, Smith DR, Hegymegi P, Gal A. Soil carbon dioxide and methane fluxes from long-term tillage systems in continuous corn and corn-soybean rotations. Soil Tillage Res. 2007;95:182-195.

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