Range Mgmt. & Agroforestry 34 (2) : 145-150, 2013
ISSN 0971-2070

Effect of fire, plowing and N addition on soil carbon dynamics in Songnen grassland, northeast China

Yu Pujia[1*], Jia Hongtao[2], Li Qiang[1, 3], Zheng Wei[1], Li Fei[1,3], and Zhou Daowei[1*]

[1]Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China.
[2]College of Grassland and Environment Sciences, Xinjiang Agriculture University, Urumqi 830052, China
[3]University of Chinese Academy of Sciences, Beijing 100049, China
[*]Corresponding authors e-mail: yupujia@neigae.ac.cn, zhoudaowei@neigae.ac.cn
Received: 1st March, 2013 Accepted: 1st August, 2013

Abstract

This study measured soil respiration rate and soil organic carbon (SOC) concentration in Songnen grassland for treatment of Fire, Plowing and N addition and discussed the effect of these treatments on soil respiration and soil carbon stocks. Our results showed that the diurnal soil respiration rate has the same change trend. Compared with Native grassland, Plowing and Fire treated grassland increased 25.8% and 9.2% of the soil respiration rate. Over 65% of total soil C stocks was stored in the 0-30 cm soil depth. The treatment of Fire and Plowing decreased 7.97% and 8.58% of SOC stocks related to Native grassland in entire profile. The carbon stock was highest at low N addition level (0 and 5 g/m^2), and was lowest at high N addition level (15 and 25 g/m^2), which indicated that high N addition level may be having a negative effect on SOC stock in Songnen grassland.

Keywords: Alkali-saline soil, Fire and plowing, N addition, Soil organic carbon, Soil respiration

Abbreviation: SOC: Soil Organic Carbon, **SOM:** Soil Organic Matter

Introduction

Concerns about rising atmospheric CO_2 levels have prompted considerable interest in recent years regarding the sink potential of soil organic carbon (SOC) (Baker *et al*., 2007). Soils hold approximately 75% of the carbon stored on land and about twice that stored in the atmosphere (Swift, 2001). So, even a slight change of SOC stock could have a great effect on the global C budget (Johnson *et al*., 2007).

Dynamics of SOC stock are controlled by many ecosystem processes (Ganjegunte *et al*., 2005) and management practices (Frank *et al*., 2006). Fire is one of the most common disturbance factors in grassland and is considered to have an important impact on carbon cycling (He *et al*., 2012). Large inconsistencies in the responses of SOC to fire have been found. For example, fire increased soil respiration by 20-55% in a sub-humid grassland (Knapp *et al*., 1998), but had a positive effect on SOC stock and decreased soil respiration in Siberian Taiga ecosystems (Sawamoto *et al*., 2000).

Plowing practices can alter the vertical distribution and quantity of SOM in soils through several processes. The practice of plowing the soil can make the loss of carbon in lands (Guo and Gifford, 2002). Whitbread *et al*. (1998) reported that a Grey Clay soil that had been plowing for over 40 years lost 51% of its original total C, while an adjacent Grey Clay soil that had tillage for only two years, lost 26% of its total C. N addition can also change the soil respiration and carbon stock in grassland, because the N statues can influence the temperature sensitivity of soil respiration rate (Conant *et al*., 2004) or influence the decomposition of SOC through the decrease of C/N ratio (Zheng *et al*., 2012).

In this study, we measured the soil respiration rate and SOC concentration in grassland for treatment of Fire, Plowing and N addition. The main objectives of this study were to provide a more detailed understanding of the treatment of Fire, Plowing and N addition on soil respiration and carbon stock in Songnen grassland.

Materials and Methods

Study area

The experiment was conducted at Changeling Station of Grassland and Agro ecology, Chinese Academic of Sciences, Songnen grassland (44°33ôN, 123°31ôE), with an area of 300 ha. The study area has a typical temperate, semi-arid continental monsoon climate. Mean annual air temperature was between 4.9 to 6.4ºC Precipitation varied from 300 to 450 mm greatly between years. The soil was alkali-saline, which is classified as Salic Solonetz in WRB soil taxonomic system. Soil pH is between 7.5 and 11. The dominant native plants were *Leymus chinense* in Songnen grassland. The companion species were *Choris virgata, Puccinellia spp, Potentilla spp etc*. The vegetation coverage was 60-90%, with 100-200 g/m^2 dry weight biomass.

The study area had been exposed to long-term heavy grazing before 2009 and degraded as indicated by low vegetation cover (20%-30%). Since early 2009, the grassland was grazing-excluded. Through several years of recovery, the vegetation coverage increased up to 70-80%. Due to degeneration, most of the grassland plants were replaced by annual plant of *Choris virgata* or *Suaeda glauca.* In May 2011, we processed study area with fire, plowing and native as three treatment groups. Then we divided each group into 24 plots (3 m×3 m), and randomly added N in four levels (0, 5, 15, and 25 g/m^2 a). There were six replications at each N addition treatment. All plots shared similar topography and soil type.

Measurement of soil respiration rate

Field measurement of soil respiration was conducted in middle of August 2011, which is the typical period when aboveground biomass attains its peak value. The aboveground biomass was removed before two days of the measurement start. We measured soil respiration rate for 9 days from August 20 to 28, 2011 using the CIRAS-2 with a SRC-1 (PP Systemsôanalyzer, England). One group was measured in each day from 4:00 am to 7:00 pm at intervals of 3 hours. Three days were a turn and each group was measured for three days.

Soil sampling and laboratory analysis

Soil samples were collected to a depth of 50 cm at five intervals of 0-5, 5-10, 10-20, 20-30, 30-50 cm using a soil corer (5 cm diameter) in each plot after the aboveground biomass and litter collected in September 2011. Cores were taken using the direct push method. At each plot, three soil cores were taken and mixed at each soil depth. A total of 360 soil samples were obtained. The soil samples were put in the plastic bags and immediately transported to laboratory for measurement. Soil bulk density (BD) of each depth measured using the core method described by Blake and Hartage (1986). This allowed us to estimate the mass of SOC at each site.

Soil samples were air-dried at room temperatures, removed the visible plant residues and ground through a 2-mm sieve first, then though a 0.149-mm sieve for chemical analysis. SOC concentration was determined using the $K_2Cr_2O_7$-H_2SO_4 oxidation method (Nelson and Sommers, 1982).

Calculations and data analysis.

SOC stock at 0-50 cm soils was obtained by the sum of SOC stock of five depths. For each soil depth interval, SOC stock was calculated as follows:

$$S = BD \times E \times T \times k$$

Where S is the SOC stock (kg C/m^2), BD is the bulk density (g/cm^3), E is the SOC concentration (g C/kg), T is the soil depth (cm), and k is a constant (10^{-2}).

All statistical analyses were carried out with SPSS 13.0 software package (SPSS 13.0 for windows, Release 13.0, USA). Factorial fashion (One-way ANOVA) was used to analyze the data and to test the treatment effects (fire, plowing and N levels) on SOC stock and soil respiration. Treatments mean and standard error for each variable measured was provided.

Results and Discussion

Dynamics of soil respiration rate

Soil respiration is defined as the release of CO_2 from soil to atmosphere, and includes soil microbial respiration, soil fauna respiration, and plant root respiration (Frank *et al*., 2006). So, soils with large amounts of primary and secondary productivity can be expected to have high soil respiration, such as the soils in grassland (Knapp *et al*., 1998). The diurnal soil respiration rate of Native, Fire and Plowing grassland has the same change trend (Figure 1). The flux increased with the time and reached its peak value at 10:00 or 13:00. Then, the flux decreased at 16:00, and had a slight increase at 19:00. The soil respiration was strongly influenced by soil temperature and it always increased when comparing morning measurements with those at noon (Eriksen and Jensen, 2001). Soil moisture and soil temperature are two important factors for soil respiration (Yu *et al*., 2012). The soil temperature has a higher effect on soil respiration when the soil moisture is suitable or unchanges (Borken *et al*., 1999; Yu *et al*., 2012). Our results indicated that the change trend of soil respiration rate corresponded with temperature, which peaked at noon and was lowest at morning and evening. But the peak respiration of Native and Fire grassland was different from the Plowing grassland (Figure 1). These differences may be mainly due to the surface soil temperature and vegetative cover at noon in these grasslands, because the soil moisture is not varying within few hours to have effect on soil respiration.

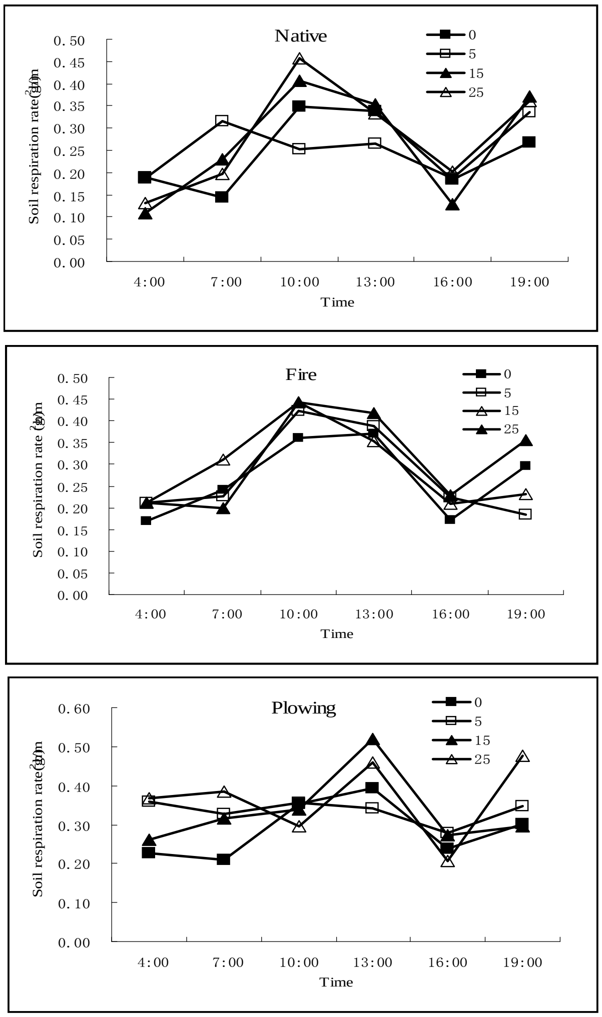

Fig. 1 Diurnal variations of soil respiration for each treatment

When soils are disturbed, the SOC concentration declined, which is seen because the conditions of decomposition are improved, such as the greater rates of soil respiration (Schlesinger and Andrews, 2000). Without regard of N addition, the soil respiration rate of plowing grassland was highest, followed by the Fire grassland and the Native grassland in our study (Figure 2). Compared with the Native grassland, the increase of soil respiration in Fire grassland generally provide some support for the findings of Knapp *et al*. (1998) that spring fire increased estimated annual soil CO_2 flux by 38-51% relative to unburned sites over 2-yr period. But the increase of our mean soil respiration in Fire grassland was lower than the results of Knapp *et al*. (1998), with a value of 9.2% compare with native grassland. The increase of mean soil respiration in Plowing grassland was significantly higher ($P<0.05$) than Native grassland (Figure 2).

The plowing can increase the rates of organic matter decomposition and mineralization by aerating the soil, burying surface residues and breaking soil aggregates, and thereby increasing the soil respiration (Hendrix *et al*., 1988). Large variations of soil respiration responses to N addition have been found on different ecosystems and regions. Yan *et al*. (2010) showed that N addition increased autotrophic soil respiration (SR_A) in 2006 but not in 2007, while it decreased heterotrophic soil respiration (SR_H) in both years, leading to a positive response of total soil respiration (SR_{TOT}) in 2006 but a negative one in 2007. In our results, the soil respiration rate was increasing with the level of N addition in the three grasslands, but there was no significantly difference for the three grasslands (P=0.692 for N=0 level, P=0.138 for N=5 level, P=0.750 for N=15 level, P=0.438 for N=25 level). The clear trend of soil respiration rate may be due to the decrease of C/N values, because the activity of microbial will increase when N is added in soil, especially in the soil with low N concentration (Yu *et al*., 2012). N addition has a complex effect on soil respiration, because N addition can affect the soil water availability, the C/N ration, and other soil characters (Yan *et al*., 2010).

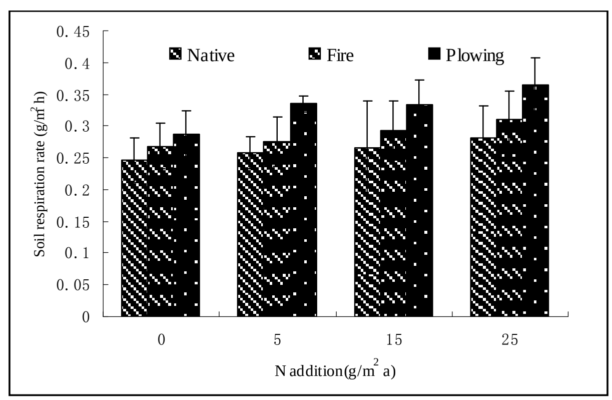

Fig. 2. The average soil respiration for each treatment. The whiskers placed on the bars are the standard error of soil respiration values.

Dynamics of soil carbon concentration and stock

Carbon is sequestered in soil when organic matter accumulates faster than it is respired as CO_2 by soil heterotrophy (Syswerda *et al*., 2011). The SOC concentration of Native, Fire, and Plowing grassland decreased from surface soil to subsoil (Table 1), which was determined by the plant biomass, especially root biomass. From different soil layers, the SOC concentration of top soil (0-5 cm) was significantly higher (P< 0.01) than the subsoil (30-50 cm). The highest variability of SOC concentration with depth was found in Plowing grassland and the lowest variability with depth was found in Native grassland, which indicated that the treatment of Plowing and Fire had great effect on SOC concentration. The average concentration of SOC for Native, Fire, and Plowing grassland was 6.10, 5.80, and 5.90 g C/kg, respectively. These results indicated that treatment of Fire and Plowing reduced carbon concentration in the 0-50 cm soils. The results of lower SOC concentration and higher variability can be explained by the increase of soil respiration rate for the grassland treatment of Fire and Plowing. There is no consistent trend for the changes of SOC concentration under different N addition levels. With the increase of N addition, the SOC concentration of Native grassland was slightly decreased while that of the Plowing grassland was slightly increased. The plowing lead to the increase of soil respiration, which should make the SOC concentration decreased. But the concentration of SOC is a slightly increase, which may be mainly due to the decrease of soil bulk density in our study. The bulk density of 0-20 cm soil in plowing grassland decreased 0.07g/m^3 in comparison to Native grassland (Table 2). N addition had a positive effect on the aboveground biomass after four years addition in mature and degrade grassland, but the response of N addition on aboveground biomass in the first year was little in both mature and degrades grassland (Bai *et al*., 2010). The increase of plant biomass will increase the input of root biomass to the soil, which may be conducive to the soil carbon sequestration in grassland.

The organic carbon stock in grassland can be affected by many factors, such as climate, land use, plant type and soil physical and chemical properties. Fire and Plowing are the most important management practices in grassland. In our study, over 65% of total soil C was stored in the 0-30 cm soil depth. The stock of SOC in surface soil (0-30 cm) ranged from 2.69 kg C/m^2 for Fire grassland to 3.26 kg C/m^2 for Native grassland (Table 3). Compared with the Native grassland, the SOC stock of treatment for Fire and Plowing decreased 7.97% (0.365 kg C/m^2) and 8.58% (0.393 kg C/m^2) in entire profile, respectively. He *et al*. (2012) found that fire and fire regimes decreased the C stock in soil and soil fractions in the longï terms grazing excluded grassland in Inner Mongolia and the effect on the surface soil (0-10 cm) is bigger than the subsoil (10-30 cm). Richter *et al*. (1990) reported that carbon stock in the surface (15 cm) soil was reduced by 24% (687 g C/m^2) over seven years of annual tillage mainly due to the reduction of root biomass. The soil carbon stock varied with the increase of N addition level in Songnen grassland. The total carbon stock under different N addition level was highest at the 0 level for Native and Fire grassland, the 5 level for the Plowing grassland, and was lowest at the 25 level for native grassland, the 15 level for Fire and Plowing grassland (Table 3). That is to say, the high N addition level (15 and 25 level) may be having a negative effect on SOC carbon stock in Songnen grassland. The variability of SOC stock for Native, Fire, and Plowing grassland was 0.44, 0.33, 0.43 kg C/m^2, which indicated that the effect of N addition is larger in Native and Plowing grassland than the Fire grassland. Overall, the treatment of Fire and Plowing in grassland had a great effect on the carbon sequestration dynamics.

Table 1. The concentration of soil organic carbon for each treatment at different depths.

Treatment		**Soil organic carbon concentration at different depth (g C/kg)**				
Groups	N addition (g/m^2 a)	0-5 cm	5-10 cm	10-20 cm	20-30 cm	30-50 cm
Native	0	7.21(0.66)a	6.73(1.34)a	6.51(1.03)a	6.61(1.47)a	4.75(0.82)a
	5	7.31(0.57)a	6.6(1.15)ab	5.59(0.87)ab	5.87(0.70)ab	4.60(0.19)b
	15	6.87(0.70)a	7.99(1.00)ab	6.63(0.52)ab	5.07(0.84)b	4.59(0.83)b
	25	6.66(0.49)a	6.47(0.90)a	5.94(0.67)ab	5.45(0.01)ab	4.47(0.21)b
Fire	0	7.23(1.28)a	7.02(0.95)a	5.92(1.08)a	4.62(0.64)a	4.60(1.16)a
	5	7.73(0.48)a	8.00(0.26)a	6.18(0.72)ab	4.85(0.52)b	3.24(0.74)b
	15	6.43(0.8)a	6.93(1.36)a	5.56(1.17)a	4.43(1.07)a	4.11(1.10)a
	25	6.80(1.47)a	6.67(1.42)a	6.09(1.16)a	5.65(1.43)a	3.99(0.34)a
Plowing	0	7.04(0.83)a	6.90(1.52)a	6.21(0.77)a	5.35(0.85)a	3.94(0.83)a
	5	6.23(1.31)a	7.65(1.29)ab	5.88(0.73)ab	5.44(0.17)ab	4.60(0.31)b
	15	7.35(0.51)a	6.47(1.43)a	7.33(0.62)a	4.64(0.78)a	3.03(0.94)a
	25	7.04(0.33)a	7.68(0.87)a	6.66(1.12)a	5.02(1.10)ab	3.50(0.74)b

Values with different lower case letters within the table are significantly different at P < 0.05 of different soil depths for soil organic carbon concentration. There are no significantly different at P < 0.05 for grassland (Fire, Plowing and Native) and N addition level on soil organic carbon concentration. Results are shown as mean (standard error).

Table 2. The soil bulk density of each treatment at different soil depths

Soil depth (cm)	Bulk density (g/m^3)		
	Native grassland	Fire grassland	Plowing grassland
0-5	1.48	1.47	1.41
5-10	1.67	1.64	1.60
10-20	1.67	1.65	1.60
20-30	1.63	1.63	1.62
30-50	1.64	1.68	1.67

Table 3. The stocks of soil organic carbon for each treatment at different soil depths.

Treatment	Soil organic carbon stocks at different depth (kg C/m^2)			
N addition(g/m^2 a)	Groups	0-30 cm	30-50 cm	0-50 cm
0	Native	3.26(0.35)Ab	1.56(0.21)Ac	4.82(0.42)Aa
	Fire	2.86(0.43)Aab	1.52(0.55)Ab	4.38(0.97)Aa
	Plowing	2.90(0.52) Aab	1.31(0.28)Ab	4.22(0.72)Aa
5	Native	2.98(0.18)Ab	1.51(0.03)Ac	4.49(0.21)Aa
	Fire	3.05(0.10)Ab	1.07(0.25)Ac	4.11(0.33)Aa
	Plowing	2.87(0.28)Ab	1.53(0.10)Ac	4.40(0.28)Aa
15	Native	3.11(0.19)Ab	1.50(0.21)Ac	4.62(0.17)Aa
	Fire	2.69(0.34)Ab	1.36(0.29)Ac	4.05(0.51)ABa
	Plowing	2.96(0.64)Aab	1.01(0.31)Ab	3.97(0.93)Ba
25	Native	2.92(0.13)Ab	1.46(0.05)Ac	4.38(0.15)Aa
	Fire	2.99(0.29)Ab	1.32(0.04)Ac	4.31(0.28)Aa
	Plowing	2.99(0.38)Aa	1.17(0.19)Ab	4.15(0.55)Ba

Values with different capital letters and lower case letters within the table are significantly different at $P < 0.05$ of different treatments (Native, Fire and Plowing, capital letters) and soil depths (0-30, 30-50, and 0-50 cm, lower case letters) for soil organic carbon concentration. There is no significantly different at $P < 0.05$ for grassland N addition level on soil organic carbon stock. Results are shown as mean (standard error).

Conclusion

It is widely believed that soil disturbance was a primary cause of the historical dynamics of soil organic carbon in Songnen grassland, and so substantial SOC sequestration can be accomplished by changing management practices. The treatment of fire, plowing and N addition had a great effect on the soil respiration and soil organic carbon stocks in Songnen grassland. Our results showed that the diurnal soil respiration rate of the fire, plowing and Native grassland increased with the time and reached its peak value at 10:00 or 13:00, and then decreased. On average, the Plowing and Fire grassland increased 25.8% and 9.2% of soil respiration related to Native grassland. The average concentration of SOC for Native, Fire, and Plowing grassland was 6.10, 5.80, and 5.90g C/kg, respectively. The SOC concentration of top soil (0-5 cm) was significantly higher ($P<0.01$) than the subsoil (30-50 cm). Fire and Plowing treatment had a negative effect on the SOC stocks. Compared with the Native grassland, SOC stocks for Fire and Plowing grassland decreased 0.365 and 0.393 kg C/m^2, respectively. High N addition level (15 and 25 g/m^2 a) decreased 0.16 kg C/ m^2 of SOC stocks than the low N addition level (0 and 5 g/m^2 a), which indicate that high N level has a negative effect on SOC stocks in Songnen grassland. These results will provide a scientific basis for implementing management practices in this area to prevent the loss of soil organic carbon storage and concentration.

Acknowledgements

We thank Liu Shiwei, Song Yantao, Shen Xiangjin, Zhang Chunyu and many others at Changling grassland station for their help with fieldwork. This work was supported by the National Basic Research Program of China (2011CB403203), the Strategic Science and Technology Guide Project of CAS (XDA05050401), and National Natural Science Foundation of China (4101534).

References

Bai, Y. F., J. G. Wu, C. M. Clark, S. Naeem, Q. M. Pan, J. H. Huang, L. X. Zhang and X. G. Han. 2010. Trade offs and thresholds in the effects of nitrogen addition on biodiversity and ecosystem functioning: evidence from inner Monglia Grassland. *Global Change Biology* 16:358-372.

Baker, J .M., T. E. Ochsner and R. T. Venterea. 2007. Tillage and soil carbon sequestration-What do we really know? *Agriculture, Ecosystems and Environment* 118: 1-5.

Blake, G. R. and K. H. Hartage. 1986. Bulk density. In: A. Klute (ed.). *Methods of Soil Analysis. Part 1-Physical Mineralogical Methods*, Madison, WI: ASA and SSSA, pp 363-375.

Borken, W., Y. J. Xu and R. Brummer. 1999. A climate change scenario for carbon dioxide and dissolved organic carbon fluxes from a temperature forest soil: drought and rewetting effects. *Soil Sci. Soc. Amer. J.* 63: 1848-1855.

Conant, R. T., P. Dalla-Betta, C. C. Klopatek and J. A. Klopatek. 2004. Controls on soil respiration in semiarid soils. *Soil Biology and Biochemistry* 36: 945ï 951.

Eriksen, J. and L. S. Jensen. 2001. Soil respiration, nitrogen mineralization and uptake in barley following cultivation of grazed grasslands. *Biology and Fertility of Soils* 33:139-145.

Frank, A. B., M. A. Liebig and D. L. Tanaka. 2006. Management effects on soil CO_2 efflux in northern semiarid grassland and cropland. *Soil and Tillage Research* 89:78-85.

Ganjegunte, G. K., G. F. Vance, C. M. Preston, G. E. Schuman, L. J. Ingram, P. D. Stahl and J. M. Welker. 2005. Soil organic carbon composition in a northern mixed-grass prairie: effects of grazing. *Soil Sci. Soc. Amer. J.* 69: 1746ï 1756.

Guo, L. B. and R. M. Gifford. 2002. Soil carbon stocks and land use change: a meta analysis. *Global Change Biology* 8: 345ï 360.

He, N. P., X. G. Han, G. R. Yu and J. Z. Dai. 2012. Effect of prescribed fire on carbon sequestration of long-term grazing-excluded grasslands in Inner Mongolia. *Acta Ecologica Sinica* 32: 4388-4395. (in Chinese)

Hendrix, P. F., C. R. Han and P. M. Groffman. 1988. Soil respiration in conventional and No-tillage agroecosystems under different winter cover crop rotations. *Soil and Tillage Research* 12: 135-148.

Johnson, D. W., D. E. Todd, C. F. Trettin and J. S. Sedinger. 2007. Soil carbon and nitrogen changes in forests of Walker Branch watershed, 1972 to 2004. *Soil Sci. Soc. Amer. J.* 71: 1639ï 1646.

Knapp, A. K., S. L. Conard and J. M. Blair. 1998. Determinants of soil CO_2 flux from a sub-humid grassland: effect of fire and fire history. *Ecological Applications* 59:8-13.

Nelson, D. W. and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. In: A. L. Page, R. H. Miller and D. R. Keeney (eds.). *Methods of soil analysis, agronomy, part 2*. 2nd edition Madison, WI: ASA and SSSA, pp 539-577.

Richter, D. D., L. I. Babbar, M. A. Huston and M. Jaeger. 1990. Effects of annual tillage on organic carbon in a fine-textured udalf: the importance of root dynamics to soil carbon storage. *Soil Science* 149: 78-83.

Sawamoto, T., R. Hatano, T. Yajima, K. Takahashi and A. P. Isaev. 2000. Soil respiration in Siberian Taiga ecosystems with different histories of forest fire. *Soil Sci. Plant Nutr.* 46: 31-42.

Schlesinger, W. H. and J. A. Andrews. 2000. Soil respiration and the global carbon cycle. *Biogeochemistry* 48: 7-20.

Swift, R. S. 2001. Sequestration of carbon by soil. *Soil Science* 166: 835-858.

Syswerda, S. P., A. T. Corbin, D. L. Mokma, A. N. Kravchenko and G. P. Robertson. 2011. Agriculture management and soil carbon storage in surface vs. deep layers. *Soil Sci. Soc. Amer. J.* 75, 92-101.

Whitbread, A. M., R. D. B. Lefroy and G. J. Blair. 1998. A survey of the impact of cropping on soil physical and chemical properties in north-western New South Wales. *Austr. J. Soil Res.* 36: 669ï 682.

Yan, L. M., S. P. Chen, J. H. Huang and G. H. Lin. 2010. Differential responses of auto- and heterotrophic soil respiration to water and nitrogen addition in a semiarid temperate steppe. *Global Change Biology* 16: 2345-2357.

Yu, P. J., H. L. Xu, W. Wang, P. Zhang, X. F. Zhao and J. J. Gong. 2012. Response of soil respiration to artificial rainfall in different parts of sand dunes. *Journal of Desert Research* 32:437-441. (in Chinese)

Zheng, J. J., H. J. Fang, S. L. Cheng, G. R. Yu, P. L. Zhang, M. J. Xu and Y. N. Li. 2012. Effects of N addition on soil organic carbon components in an alpine meadow on the eastern Qinghai-Tibetan Plateau. *Acta Ecological Sinica* 32: 5363-5372. (in Chinese).