Range Mgmt. & Agroforestry 38 (2) : 165-170, 2017
ISSN 0971-2070

Soil respiration as affected by long-term fencing in a mountain meadow steppe of Central Asia

Han Dongliang, Hu Yi, Zhu Xinping and Jia Hongtao*
College of Grassland and Environmental Sciences, Xinjiang Agricultural University, Urumqi-830052, China
*Corresponding author e-mail: jiahongtao2015@126.com
Received: 1st January, 2017 Accepted: 28th October, 2017

Abstract
A better understanding of the responses of various soil respirations to land management is vital for restoring degraded grasslands and mitigating global warming. We used an automated soil respiration system (LI-8100, LI-COR, USA) in 2013 from March to October to assess the effect of fenced and grazed meadows to soil respiration rate. Results showed that the soil respiration rate (SRR) significantly (*P*<0.01) increased by the fenced management during the growing season (March-October), which ranged from 0.45 μmol·m^{-2}·s^{-1} in October of grazed meadow to 4.01 μmol·m^{-2}·s^{-1} in June of fenced meadow. Compared with grazed meadow, fenced meadow changed the percentages of aboveground biomass, soil temperature and soil water content by 39.55%, -11.03% and 8.42%, respectively. These findings suggested that variation of SRR as affected by aboveground biomass was stronger than soil temperature and soil water content. In addition, the scientific and standardized workflows showed that through the field investigation and long-term trials the effectiveness of grazing exclusion, compensatory payments and management in meadow steppe can be assessed in the future.

Keywords: Biotic-abiotic factors, Climate change, Compensatory payment, Fenced meadow, Soil respiration rate

Abbreviations: AB: Aboveground biomass; **SOC:** Soil organic carbon; **SRR:** Soil respiration rate; **ST:** Soil temperature; **SW:** Soil water content

Introduction

The meadow steppe ecosystems are either important carbon-source or sink and soils are the source of uncertainty in the meadow steppe ecosystems carbon balance (Piao *et al.,* 2009). Soil respiration is a major component of carbon exchange between soil and the atmosphere (Zhao *et al.,* 2013). The unprecedented global warming (Xia *et al.,* 2009) and human activities (Lang *et al.,* 2011) can profoundly impact terrestrial carbon cycling and budgets, with consequent feed back to climatic change (Cox *et al.,* 2000; Ghosh and Mahanta, 2014; Sarkar *et al.,* 2017). Fencing meadow is such an activity which plays an important role on carbon pools in the meadow steppe ecosystems.

To conserve the meadow steppe, the central government of China was started to implement the degraded meadow steppe recovery project and increased forage production since 2000. Meanwhile, a new compensatory payment policy was launched in 2011, which allocate funds annually 13.4 billion CNY for grassland (e.g. meadow steppe) ecological and environmental protection including Xinjiang province (Hai, 2014). According to this policy, local herdsman families (major is Kazak in Xinjiang) are allowanced by approximately 80 CNY (100 CNY=13.76 EUR, =11.71 GBP, = 14.40 USD, and 1689.56 JPY) per hectare annually (Hai, 2014) if their degraded meadows are fenced or protected from domestic animals (Yu *et al.,* 2016). However, Yu *et al*. (2016) reported that the extent of the ecological and environmental benefits potentially resulting from fenced meadow and compensatory payments are not seriously considered and assessed, since it is still a big problem to disentangle the relative contributions of different attributes like climate patterns, changes and trends, greenhouse effect (e.g. soil respiration), grazed meadow and economic policies to the degraded grassland recovery.

To our knowledge, a previous study reported that predicting the response of soil respiration to climate change requires a thorough understanding of the dependence of this process on biomass, soil temperature and soil water content (Zhao *et al.,* 2013). However, the effects of biotic-abiotic factors on the ecosystem processes controlling carbon cycling at the fenced and grazed mountain meadows are inconclusive.

Therefore, the objectives of this study were to investigate the dynamics of soil respiration rate under fenced and grazed meadows, evaluate relationships between soil respiration rate and biotic-abiotic factors, and assess the effectiveness of grazing exclusion and compensatory payments in the future.

Materials and Methods

***Study area*:** The mountainous area in Gangou Township of Urumqi County is the mid mountain belt on the northern slope of Tianshan Mountains in Xinjiang, NW China (N 43.54133°, E 87.2145°, 1742 m a. s. l. Fig 1A). The local climate is a typically arid and continental. The grassland types are mountain meadow steppe and mountain meadow. The experimental area is steep in terrain with the gradient of 28°-35°. Local meteorological data (1956-2013) show an average annual precipitation of 308.75 mm, with 90% occurring in the growing season from March to October. The annual average temperature is 4.6°C, with a lowest monthly value of -10.3°C in January and a highest monthly value of 23.5°C in July (Fig 2).

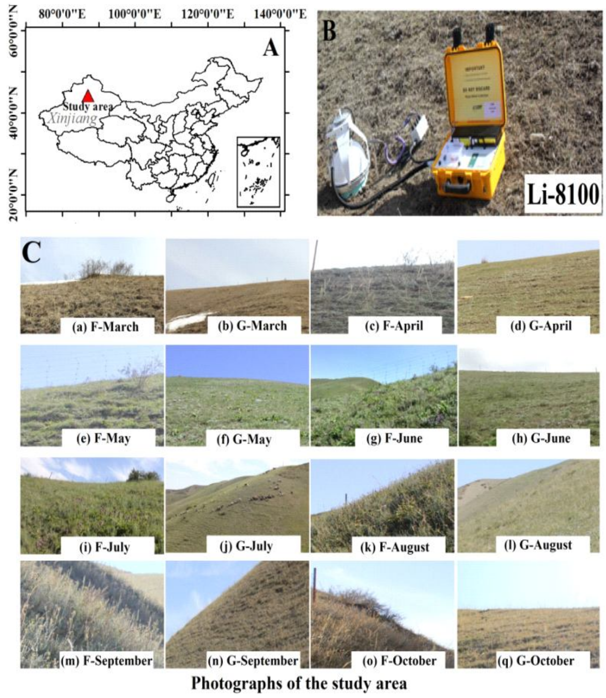

Fig 1. Location of the study area (the red triangle; A), an automated soil respiration system (B) and photographs of the study area (C) from March to October in the fenced (F) meadow and grazed meadow (G), respectively

Grazed meadows had become degraded because they were undergoing nomadic grazing with a grazing intensity of 4.1 sheep ha^{-1}. Meadows were fenced because of the protection of pasture and improvement of pastoralist's managerial skill. The fenced area of meadow is around 400 m^2 and completely excluded livestock grazing from 2005 to till date. In the fenced meadow, the major native vegetations are *Stipa capillata*, *Phlomis umbrosa*, *Artemisia gmelinii*, *Festuca ovina, Leontopodium and Potentilla aiscolor Bunge.* In the grazed meadow, the major native vegetations are *Stipa capillata and Artemisia gmelinii.*

In addition, the soil types of the grasslands are mountainous the chernozem soil, which is being classified according to the FAO Soil Taxonomy. Means of soil bulk density, soil organic carbon content (SOC) and soil organic carbon stock (30 cm-soil depth) were 0.98 ± 0.02 g cm^{-3} and 1.09 ± 0.03 g cm^{-3}, 42.10 ± 1.37 g kg^{-1} and 33.24 ± 2.09 g kg^{-1}, and 1.24 ± 0.06 kg m^{-2} and 1.09 ± 0.05 kg m^{-2} at the fenced and grazed meadows, respectively. Bulk density was measured gravimetrically. Soil organic carbon content under different land management was determined following a modified Mebius method (Yeomans and Bremner, 1988). Soil organic carbon stock calculation is the product of soil organic carbon content × soil bulk density × soil depth (Han *et al*., 2017).

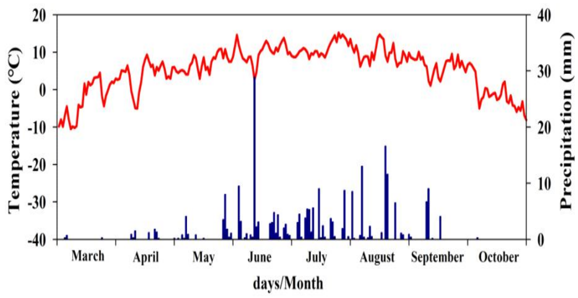

Fig 2. Daily precipitation (bars) and daily mean air temperature (line) in 2013

***Experimental design and sampling*:** We selected 5 blocks (5 m × 5 m) in the fenced meadows and 5 blocks in the grazed meadows for sampling during the plant growth-season from March to October, which was about 10 m away from the block to block. The quadrats (1 m × 1 m) were randomly arranged in every sampling block. Aboveground biomass samples were taken at three-month intervals in 2013 (Fig 1C). The sampling plants were harvested and brought back to laboratory, and oven dried at 65 ^{0}C at least for 48 hours to constant weight. Soil samples were collected to a depth of 30 cm with a 5 cm diameter soil core sampler after removing the aboveground biomass in Mid-August, when biomass had reached its highest. In addition, soil samples were air dried, separated from the visible plant materials, passed through a 0.25-mm sieve for soil organic carbon content.

***Soil respiration*:** Soil respiration rate was measured for 24 h at three-month (same as the aboveground biomass sampling) intervals (collected between 11:00 and the next 11:00 hours on local time, once every three hours on clear days) from March to October, using an automated soil respiration system (Li-8100, Li-COR, USA, Fig 1B) in 2013. PVC collars (diameter, 20 cm; height, 5 cm) were permanently inserted 2-3 cm into the soil to measure soil respiration at each plot. Every plot had 5 PVC collars. In addition, living plants inside the soil collars were removed at the soil surface before we measured the soil respiration to eliminate aboveground plant respiration. Each measurement took approximately three minutes to complete. The soil respiration system (Li-8100) automatically recorded the data at 5-s intervals. At the depths of 10-cm, soil temperature and soil water content was also determined with the soil respiration rate. Soil temperature was calculated automatically with a data-logger (the Soil Temperature Measurement System, HA1001; Handan Electronic Institute, Hebei, China). Soil water content was measured with a soil moisture probe (TY10MST3000; STEPS, Germany).

***Statistical analysis*:** General Linear Model-Repeated Measures Define Factors (SPSS 17.0, SPSS Inc., Chicago, IL, USA) was used to assess the significance of the impacts of treatment (fenced and grazed), sampling day, and their interactions on SRR. To test the correlations among the AB, ST, SW and SRR, respectively, Pearson's correlation and partial correlation analysis were performed. All significances mentioned in the text were at the 0.05 level.

Results and Discussion

***Effect of land management on SRR*:** Different land management (fenced and grazed) had a significant (P<0.01) effect on SRR. The SRR was increased from the grazed meadow to the fenced meadow over the growing season (March-October), which ranged from 0.45 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in October of grazed meadow to 4.01 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in June of fenced meadow (Fig 3). In addition, the effect of fenced meadow on aboveground biomass differed among the months. Compared with grazed meadow, the treatment of fenced meadow increased the percentage of aboveground biomass by 15.99% in March, 37.72% in April, 38.21% in May, 44.66% in June, 37.59% in July, 46.98% in August, 48.37% in September and 38.31% in October, respectively (Table 1). The average soil temperatures and soil water content at 10 cm depth were 10.96 and 22.08% at fenced meadow, with 12.17 and 20.22% at grazed meadow over the entire growing season from March to October, respectively (Table 1).

***Relationships between SRR and biotic-abiotic factors*:** The fenced meadow was a relatively strong source of CO_2 during the growing season from March to October, probably because of CO_2 derived from soil microbial stimulation (Bol *et al.,* 2003), and there was increase in aboveground biomass (Ma *et al.,* 2006), which directly increases the amount of carbon incorporated into the soil (Davidson *et al.,* 1998) and also caused higher source of soil organic carbon content, which was decomposed by soil microbials. Simple linear regression analyses showed significant linear relationships between SRR and aboveground biomass (all P<0.05), which aboveground biomass explained 56% and 59% of SRR variation fitted with a linear regression model at grazed meadow and fenced meadow, respectively.

In addition, a linear model based on soil temperature explained 42 to 50% of the variation on SRR for all treatments. The findings were in line with previous studies which stated that soil CO_2 emission rates can be controlled by temperature (Lin *et al.,* 2009), this is partly because soil temperature can directly influence roots and microbial activities and respiration (Hirota *et al.,* 2004), and/or indirectly via altering plant growth and belowground carbon allocation as well as litter decomposition (Wan *et al.,* 2007), which determine the availability of carbon substrate for plant roots and soil microorganisms.

Soil water content was the primary limiting factor for SRR (Chen *et al.,* 2009) and microbial activity (Liu *et al.,* 2007). Results showed that soil water content explained 19% and 21% of SRR variation fitted with a quadratic function regression model at grazed meadow and fenced meadow, respectively. Zhao *et al.* (2013) showed that SRR decreased with increase in soil water content in the 0-10 cm layer, when soil water content was below 27%, SRR was larger than 1 ìmol$\cdot m^{-2} \cdot s^{-1}$ and when soil water content was higher than 27%, SRR was less than 1 ìmol$\cdot m^{-2} \cdot s^{-1}$. However, our results showed that when soil water content was below 14.4%, SRR was larger than 1.48 ìmol$\cdot m^{-2} \cdot s^{-1}$ and when soil water content was higher than 14.4%, SRR was less than 1.48 ìmol$\cdot m^{-2} \cdot s^{-1}$, probably because land management is a major factor that influences the SOC between inputs and losses of organic carbon in soils and hence leads to sequestration or emission of SRR (Yu *et al.,* 2013).

Table 1. The mean (± SE) values of aboveground biomass (AB), soil temperature (ST) and soil water content (SW at fenced and grazed meadows, respectively

Months	Fenced meadow			Grazed meadow			Change (%)		
	AB (g m^{-2})	ST (°C)	SW(%)	AB (g m^{-2})	ST (°C)	SW(%)	a	b	c
March	75.40	**5.20**	29.37	63.34	**5.55**	27.28	15.99	**-6.73**	7.11
	(23.11)	**(1.01)**	(8.92)	(14.58)	**(2.37)**	(4.44)			
April	80.87	**6.56**	30.64	50.36	**7.64**	29.27	37.72	**-16.46**	4.47
	(18.91)	**(2.37)**	(5.44)	(20.66)	**(1.88)**	(1.06)			
May	88.02	**12.92**	21.13	54.39	**12.17**	20.01	38.21	**-5.80**	5.30
	(20.39)	**(1.88)**	(3.31)	(17.99)	**(4.67)**	(1.89)			
June	140.30	**16.33**	17.22	77.64	**18.41**	15.93	44.66	**-12.73**	7.49
	(43.12)	**(3.55)**	(2.10)	(21.47)	**(2.69)**	(2.03)			
July	99.86	**15.18**	20.42	62.32	**15.55**	17.01	37.59	**-2.43**	16.69
	(21.31)	**(4.01)**	(6.23)	(19.35)	**(4.36)**	(1.67)			
August	104.45	**18.39**	11.87	55.38	**21.71**	11.04	46.98	**-18.05**	6.99
	(37.86)	**(4.36)**	(1.73)	(21.10)	**(2.42)**	(2.11)			
September	96.82	**9.67**	19.03	49.98	**11.76**	18.42	48.37	**-21.61**	3.21
	(17.53)	**(1.26)**	(8.57)	(10.66)	**(3.19)**	(3.21)			
October	90.28	**3.44**	26.94	55.69	**4.57**	22.78	38.31	**-32.84**	15.44
	(31.69)	**(0.69)**	(2.66)	(14.37)	**(0.58)**	(6.69)			
Mean	97.00	**10.96**	22.08	58.63	**12.17**	20.22	39.55	**-11.03**	8.42

AB is aboveground biomass; ST is soil temperature (10 cm-soil depth); SW is soil water content (10 cm-soil depth); Compared with grazed meadow, fenced meadow increased/decreased the percentage of aboveground biomass (a), soil temperature (b) and soil water content (c), respectively

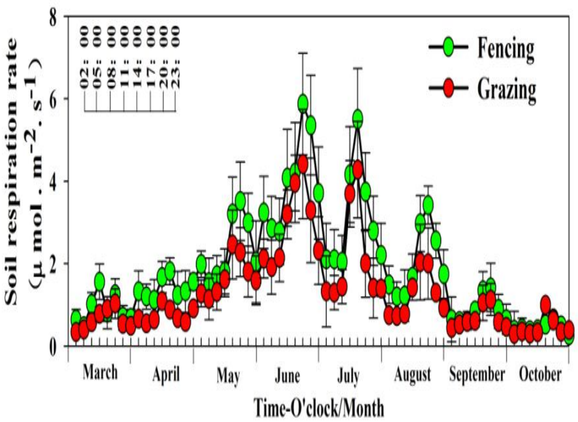

Fig 3. Seasonal dynamics and means (insets means ± SE) of soil respiration rate under fenced and grazed meadows over the growing season in 2013.

***Scientific and standardized workflows recommended*:** To scientifically assess the influences of grazed and fenced meadows on the ecological attributes (e.g. the major factors form AB, ST and SW) and environmental (e.g. SRR) recovery, the followings are recommended.

First of all, AB, ST and SW as affected by climate changes and fenced meadow, and indirectly influence the SRR (Lin *et al.,* 2009; Chen *et al.,* 2009). Yu *et al.* (2016) have shown that the changing climate conditions likely exceed fencing in influencing the recovery process where the degradation (recovery) was primarily caused by warming or drought (Chen *et al.,* 2014; Louhaichi *et al.,* 2017). Secondly, recovery of biodiversity (including plants, animals, and microorganisms) is closely related to recovery of ecological/environmental services (Meli *et al.,* 2014), for example, enhancing primary productivity (Cardinale *et al.,* 2011; Kumar *et al.,* 2017), increasing SOC content (Yu *et al.,* 2013) and soil erosion control (Balvanera *et al.,* 2006). A better understanding of the responses of biodiversity to climate changes is vital for recovery of degraded meadow steppe and mitigating global warming. Lastly, long-term grazing (or overgrazing) can lead to meadow degraded (e.g. biomass reduction), limited oxygen concentrations and soil porosity (e.g. effect on soil temperature), increased soil erosion and reduced soil infiltration rates (e.g. effect on soil water content), which might harm to the local environment and ecological attributes. However, duration and layout of fencing may improve the plant species (e.g. biodiversity), soil properties and nutrient content (e.g. SOC). Our study attempted to enhance the sustainable development between environment and ecological attributes through adaptive strategies and policies. Therefore, a long-term effective observation plan with grazed and fenced meadows paired plots across grazing exclusion and paddocks are necessary to answer how long to fenced meadow. Grazing exclusion and paddocks not only were supporting sustainable intensive sheep farming but also relating to livestock and forage balance. It should be considered when assessing the environmental and ecological influences of fencing on the meadow steppe (Yu *et al.,* 2016).

Conclusion

In general, the variation of SRR as affected by aboveground biomass was stronger than soil temperature and soil water content. Grazing exclusion, compensatory payments and management are necessary to answer how long to be fenced a meadow.

Acknowledgment

This work was supported by Natural Science Foundation of China (31560171 and 31500446) and Strategic Priority Research Program-Climate Change: Carbon Budget and Related Issues of Chinese Academy of Sciences (XDA05050405).

References

Balvanera, P., A. B. Pfisterer., N. Buchmann., J. He., T. Nakashizuka., D. Raffaelli and B. Schmid. 2006. Review and synthesis: Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters* 9: 1146-1156.

Bol, R., J. Moering., Y. Kuzyakov and W. Amelung. 2003. Quantification of priming and CO_2 respiration sources following slurry-C incorporation into two grassland soils with different C content. *Rapid Communication in Mass Spectrometry* 17: 2585-2590.

Cardinale, B. J., K. L. Matulich., D. U. Hooper., J. E. Byrnes., E. Duffy., L. Gamfeldt., P. Balvanera., M. I. O'Connor and A. Gonzalez. 2011. The functional role of producer diversity in ecosystems. *American Journal of Botany* 98: 572-592.

Chen, B. X., X. Z. Zhang., J. Tao., J. S. Wu., J. S. Wang., P. Shi., Y. J. Zhang and C. Q. Yu. 2014. The impact of climate change and anthropogenic activities on alpine grassland over the qinghai-tibet plateau. *Agricultural and Forest Meteorology* 189: 11-18.

Chen, S. P., G. H. Lin., J. H. Huang and G. D. Jenerette. 2009. Dependence of carbon sequestration on the differential responses of ecosystem photosynthesis and respiration to rain pulses in a semiarid steppe. *Global Change Biology* 15: 2450-2461.

Cox, P. M., R. A. Betts., C. D. Jones., S. A. Spall and I. J. Totterdell. 2000. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature* 408: 184-187.

Davidson, E. A., E. Belk and R. D. Boone. 1998. Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. *Global Change Biology* 4: 217-227.

Ghosh, P.K. and S.K. Mahanta. 2014. Carbon sequestration in grassland systems. *Range Management and Agroforestry* 35: 173-181.

Hai, L. Q. M. 2014. Research on the effect of grazing prohibition policy to herdsmen and its behavioral response in Xinjiang. *PhD Dissertation*. Urumqi: Xinjiang Agriculture University. pp. 1-124 (in Chinese).

Han, D. L., X. P. Zhu., H. T. Jia and P. J. Yu. 2017. Soil Organic Carbon Dynamics Responses to Soil Fertility in the Agricultural Regions of China. *Agricultural Research* 6: 281-295.

Hirota, M., Y. H. Tang., Q. W. Hu., S. Hirata., T. Kato., W. H. Mo., G. M. Cao and S. Mariko. 2004. Methane emissions from different vegetation zones in a Qinghai- Tibetan Plateau wetland. *Soil Biology and Biochemistry* 36: 737-748.

Kumar, S., J. P. Singh., K. Venkatesan., B. K. Mathur and P. K. Bhatt. 2017. Changes in seasonal vegetation and sustenance of tussocky arid rangelands under different grazing pressures. *Range Management and Agroforestry* 38: 35-42.

Lang, M., Z. C. Cai and S. X. Chang. 2011. Effects of land use type and incubation temperature on greenhouse gas emissions from Chinese and Canadian soils. *Journal of Soils and Sediments* 11: 15-24.

Lin, X. W., S. P. Wang., X. Z. Ma., G. P. Xu., C. Y. Luo., Y. N. Li., G. M. Jiang and Z. B. Xie. 2009. Fluxes of CO sub (2, CH) sub (4), and N sub (2O in an alpine meadow affected by yak excreta on the Qinghai-Tibetan plateau during summer grazing periods). *Soil Biology and Biochemistry* 41: 718-725.

Liu, W. X., W. H. Xu., Y. Han., C. H. Wang and S. Q. Wan. 2007. Responses of microbial biomass and respiration of soil to topography, burning, and nitrogen fertilization in a temperate steppe. *Biology and fertility of soils* 44: 259-268.

Louhaichi, M., K. Clifton and S. Hassan. 2017. Direct seeding of Salsola vermiculata for rehabilitation of degraded arid and semi-arid rangelands. *Range Management and Agroforestry* 35: 182-187.

Ma, X. Z., S. P. Wang., Y. F. Wang., G. M. Jiang and P. Nyren. 2006. Short-term effects of sheep excreta on carbon dioxide, nitrous oxide and methane fluxes in typical grassland of Inner Mongolia. *New Zealand Journal of Agricultural Research* 49: 285-297.

Meli, P., J. M. R. Benayas., P. Balvanera and M. M. Ramos. 2014. Restoration enhances wetland biodiversity and ecosystem service supply, but results are context- dependent: A meta-analysis. *PLoS One* 9: e93507.

Piao, S. L., J. Y. Fang., P. Ciais., P. Peylin., Y. Huang., S. Sitch and T. Wang. 2009. The carbon balance of terrestrial ecosystems in China. *Nature* 458: 1009-1013.

Sarkar, S., R. N. Padaria and A. Bhowmik. 2017. Analyzing farmers' vulnerability and adaptation strategy to climate change in arid ecosystem of India. *Range Management and Agroforestry* 38: 127-133.

Wan, S., R. J. Norby., J. Ledford and J. F. Weltzin. 2007. Responses of soil respiration to elevated CO_2, air warming, and changing soil water availability in a model old-field grassland. *Global Change Biology* 13: 2411-2424.

Xia, J., Y. Han., Z. Zhang and S. Wan. 2009. Effects of diurnal warming on soil respiration are not equal to the summed effects of day and night warming in a temperate steppe. *Biogeosciences* 6: 1361-1370.

Yeomans, J. C. and J. M. Bremner. 1998. A rapid and precise method for routine determination of organic carbon in soil. *Communications in soil science and plant analysis* 19: 1467-1476.

Yu, C. Q., X. Z. Zhang., J. Zhang., S. W. Li., C. Q. Song., Y. Z. Fang., S. Wurst and J. S. Wu. 2016. Grazing exclusion to recover degraded alpine pastures needs scientific assessments across the northern Tibetan Plateau. *Sustainability* 8: 1162-1168.

Yu, P. J., H. T. Jia., Q. Li., W. Zheng., F. Li and D. W. Zhou. 2013. Effect of fire, plowing and N addition on soil carbon dynamics in Songnen grassland, Northeast China. *Range Management and Agroforestry* 34: 145-150.

Zhao, Z. M., C. Y. Zhao., Y. Y. Yan., J. Y. Li., J. Li and F. Z. Shi. 2013. Interpreting the dependence of soil respiration on soil temperature and moisture in an oasis cotton field, Central Asia. *Agriculture, Ecosystems and Environment* 168: 46-52.