Effects of land use and management on ecosystem respiration in alpine meadow on the Tibetan plateau

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ABSTRACT

Land use change and management practices have greatly affected global carbon dynamics, especially the critical process of ecosystem respiration (Re). Our aim was to assess how Re and Re intensity (Re per unit aboveground biomass) are affected by land use (i.e. native alpine meadow with winter grazing (NAM), abandoned cropland/pastureland (APL), perennial *Elymus nutans* (PEN) and annual *Avena sativa* L. pasture (AO)) and management practices (i.e. nitrogen (N) inorganic fertilizer or sheep manure for APL, PEN and AO, tillage and no-tillage for AO) in a Gelic Cambisol soil underlying alpine meadow on the Tibetan plateau from 2008 to 2010. In the present study we hypothesized that (1) the conversion of abandoned cropland/pastureland to pasturelands would increase Re and Re intensity; (2) natural restoration following the abandonment of cropland/pastureland would decrease Re and Re intensity; and (3) management practices mentioned above would reduce the magnitude of the effects of land use change on Re and Re intensity in the alpine meadow ecosystem. Generally, our results did not support our hypotheses. There were no significant differences between annual average Re in NAM and APL, while the annual average Re for native meadows were 2–3 times higher than that of pasturelands in 2008. Re intensities for PEN and AO were 1.7 times lower than NAM and APL, and Re intensity was higher for APL than for NAM in 2010. Management practices did not significantly affect Re and Re intensity for PEN and AO treatments, except for the interaction between tillage and year on the Re of AO in 2010. The results suggest that conversion of abandoned cropland/pastureland to pastureland decreases Re and Re intensity, while natural restoration following the abandonment of cropland/pastureland increased Re intensity. Management practices did not significantly modify the patterns of the effects of land use on Re and Re intensity.

1. Introduction

Land use changes and management practices alter the exchange of carbon (C) between the atmosphere and terrestrial pools of aboveground biomass, underground biomass and soil (IPCC, 2007). Many studies have estimated the influence on the global C cycle of land use change and/or management in different ecosystems (Frank et al., 2006; Bahn et al., 2006; Pendall et al., 2010; Medina-Roldán et al., 2012). Soil organic matter losses due to land use

change through the conversion of native grasslands to cultivation are both extensive and well documented (Conant et al., 2001; Guo and Gifford, 2002; Soussana et al., 2004; Wang et al., 2011). In addition, CO_2 emissions can be reduced by improving or adopting alternative management practices, such as no-tillage or the alteration of fertilization pattern, which may restore part of the native soil C that is lost following the conversion of native systems to cropland (Lal, 2004). However, studies conducted on the effects of land use change and management practices on CO_2 emission have shown inconsistent results (Lal, 2004; Qi et al., 2007). Moreover, data is almost entirely lacking for alpine meadows regions of the Tibetan plateau.

As the largest grassland in Eurasia, due to its high productivity during the growing season and the low rate of decomposition resulting from low temperatures, the Tibetan plateau acts as a sink of CO_2 and plays a potentially significant role in global C

sequestration (Kato et al., 2006). In the Plateau region, land use change is driven by two primary forces: grassland degradation and expansion of forage production. On the one hand, China's central government has promoted the conversion of marginal cropland into grasslands since the early 2000s, which has resulted in abandonment of some croplands after a few years of cultivation. On the other hand, due to the large forage requirement of livestock in the region, a huge area has previously been converted to pastureland from native meadow. Considering the growing consumption demand of China's population, China's government has set a target for reducing greenhouse gases (GHGs) emission intensity (i.e. emissions of GHGs per unit of Gross Domestic Product (GDP)), rather than a target for reduction in the absolute level of emissions. Thus, considering both the need to mitigate climate change and the need to meet consumption demand, there is a need to identify cost-effective ways to avoid an increasing intensity of GHG emissions (Burney et al., 2010). In light of this, understanding the Re intensity (i.e. Re per unit of aboveground biomass) of different land uses and management practices can contribute to identify land uses and management strategies to balance forage production and environmental conservation objectives in the alpine meadows areas of China.

Considering evidence that land use change through conversion of native grasslands to cultivation can lead to soil C losses and CO_2 emissions can be reduced by improving or adopting alternative management practices, in the present study, we hypothesized that the conversion of abandoned cropland/pastureland to pastureland would increase Re and Re intensity, and natural restoration following the abandonment of cropland/pastureland would decrease Re and Re intensity, whereas the adoption of management practices would reduce the magnitude of the effects of land use change on Re and Re intensity in the alpine meadow ecosystem. The specific objectives were to investigate: (1) seasonal and annual changes in Re under different land uses and management practices; (2) effects of different land uses and management practices on Re intensity; (3) the relationships between biotic (plant biomass) and abiotic (soil temperature and soil moisture) factors and Re and Re intensity; and (4) whether natural restoration of abandoned cropland or conversion to pastureland would be a better option from the perspective of Re intensity for balancing socio-economic development and environmental conservation objectives in the Tibetan plateau.

2. Materials and methods

2.1. Study site

This study was conducted in an alpine meadow at Haibei Alpine Meadow Ecosystem Research Station, Northwest Plateau Institute of Biology, Chinese Academy of Sciences (37°36′N, 101°12′E, and 3250 m above sea level) in Qinghai province during the growing seasons of 2008–2010. The mean annual precipitation is 580 mm with the 80% concentrated in the growing season from May to September. Mean annual air temperature is −1.7 °C with monthly mean air temperature ranging from −15 °C in January to 10 °C in July. The native plant community is dominated by Kobresia humilis (C.A. Mey.), Elymus nutans (Griseb.), Stipa aliena (Keng), Gentiana straminea (Maximovicz), Potentilla nivea (L.), and Festuca ovina (L.). The soil is clay-loam textured, with an average depth of 65 cm and is classified as Mat-Gryic Cambisol (Chinese Soil Taxonomy Research Group, 1995), corresponding to Gelic Cambisol (WRB, 1998). Basic soil properties were as follows: total organic carbon (C) 55.8 g kg⁻¹, potassium (K) 13.0 g kg⁻¹, phosphorus (P) 0.70 g kg⁻¹, nitrogen (N) 5.37 g kg⁻¹, a pH of 8.2 was determined in distilled water, and bulk density in the 0–10 cm soil layer was 1.05 g cm⁻³. Mean air temperature and total rainfall during the

growing seasons from 15 May to 30 September in 2008, 2009, and 2010 were 8.3, 8.6, and 9.3 °C, and 324.6, 308.8, 410.8 mm, respectively. The seasonal rainfall distributions and temperatures are shown in Fig. 1.

2.2. Experimental design

An experimental site of 100 m × 100 m was fenced in early May 2007. The site had been planted to barley for about 20-year until the 1980s, and with E. nutans pasture in 1990s, after which it was abandoned and allowed to naturally regenerate with grazing in the winter season only for 8 years until 2007. A completely randomized design was used for four land uses and their fertilizer management practices with three replicate plots (4 m × 4.5 m) for each treatment from 2008 to 2010. The tillage practice was only performed for annual oat in 2009 and 2010 using a split plot design. The details of the experimental design are shown in Table 1. Each plot was separated by a 2 m-wide buffer zone.
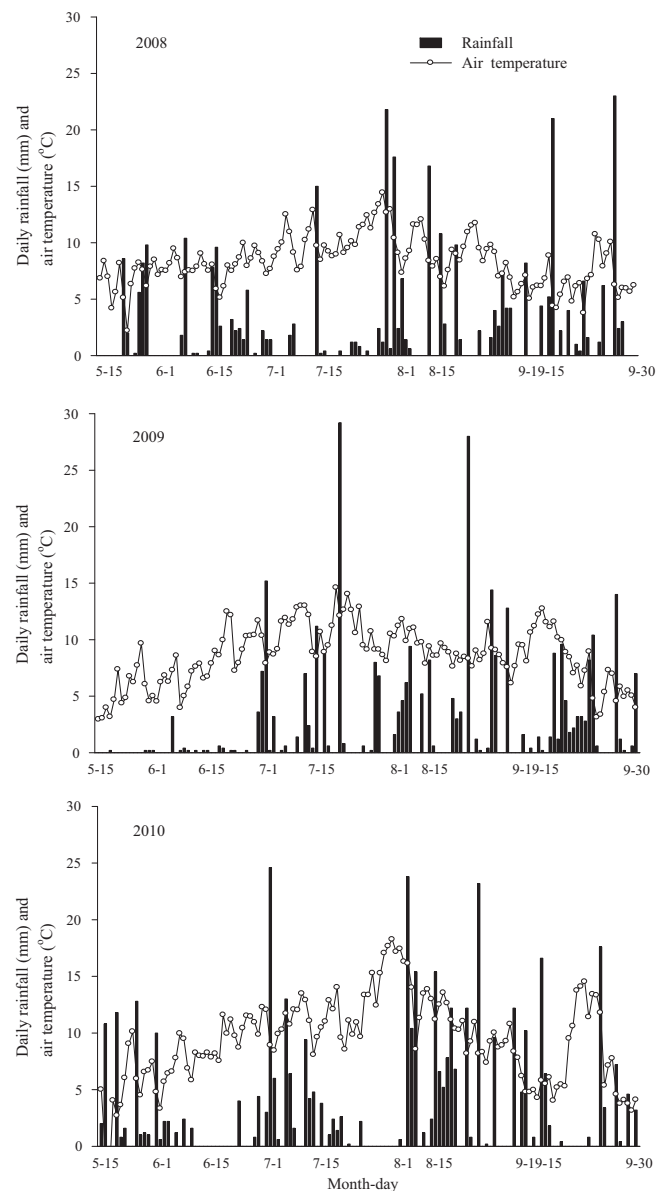

Fig. 1. Daily average temperature and daily rainfall from 15 May to 30 September in 2008, 2009, and 2010.

Table 1
Description of different land use and management practices.

Code	Land use	Description	Management practices
NAM	Native alpine meadow	Outside the fence, with winter grazing	None
APL	Abandoned cropland/pasture	Inside the fence with no grazing, with natural restoration for 8 years	Without and with N inorganic fertilization, 69 kg N ha^{-1} year^{-1} as urea applied in the middle of July
PEN	Perennial *E. nutans* converted from abandoned cropland/pastureland	Inside the fence, cultivated and sown (32 kg seeds ha^{-1}) by the end of May 2008, and harvested by the end of August each year	Without and with N inorganic fertilization, 69 kg N ha^{-1} year^{-1} as urea applied in the middle of July, and with sheep manure (i.e. 1687 kg C ha^{-1}, 93 kg N ha^{-1}, 45 kg P ha^{-1} and 33 kg K ha^{-1}, respectively) applied in early May
AO	Annual oats converted from abandoned cropland/pastureland	Inside the fence, cultivated and sown (600 kg seeds ha^{-1}) every year by the end of May and to be harvested by the end of August each year	Without tillage and without fertilization; without tillage and with N inorganic fertilization, 69 kg N ha^{-1} year^{-1} as urea applied in the middle of July; without tillage and with sheep manure (1687 kg C ha^{-1}, 93 kg N ha^{-1}, 45 kg P ha^{-1} and 33 kg K ha^{-1}, respectively) applied in early May With tillage and without fertilization; with tillage and with N inorganic fertilization, 69 kg N ha^{-1} year^{-1} as urea applied in the middle of July; with tillage and with sheep manure (1687 kg C ha^{-1}, 93 kg N ha^{-1}, 45 kg P ha^{-1} and 33 kg K ha^{-1}, respectively) applied in early May

2.3. Field sampling and measurements

2.3.1. Soil temperature and water content of soil

Soil temperature and soil water content at 5 cm depth were measured simultaneously to the CO_2-C flux measurements at each chamber using a digital temperature sensor (JM624 digital thermometer, Living–Jinming Ltd., China) and a Time Domain Reflectometer (JS-TDR300, Meridian Measurement, USA).

2.3.2. Aboveground and belowground biomass

The peak aboveground biomass was estimated by clipping a 1 m × 1 m quadrat 20 cm away from the plot edge in each plot in late August each year. At the center of each quadrat two soil cores of 0–20 cm depth were collected using an 8 cm diameter soil auger. All samples with three replicates were taken on the same day. Samples of soil cores were washed in the laboratory with tap water to remove the soil so as to estimate belowground biomass. All samples were oven-dried at 65 °C to constant weight.

2.3.3. Re measurement and Re intensity calculation

In May 2008, a stainless steel square box (without a top or bottom, 0.4 m (length) × 0.4 m (width) × 0.08 m (height)) with a water groove to make the chamber airtight was placed 20 cm away from the edge of each plot and inserted into the soil to a depth of 8 cm. Re was measured using static chamber and gas chromatography techniques (Lin et al., 2009). The static chamber was made of stainless-steel (without bottom, 0.4 m (length) × 0.4 m (width) × 0.4 m (height)), and a battery-operated fan was installed on the top wall of each chamber to mix the air when the chamber was closed, and a silica gel pipe were connected to a syringe and a three-way stopcock for gas sampling. During sampling dates, the opaque chamber was sealed on the square box and removed afterwards. Samples were collected from 09:00 a.m. to 11:00 a.m. on the same day as described in previous reports (Lin et al., 2009; Jiang et al., 2010). The gas samples were collected every 7–10 days from May to September during the growing seasons in 2008, 2009, and 2010. Gas samples were collected 4 times at 10 min intervals after the chamber was closed using 100 ml plastic syringes and analyzed for CO_2 within 24 h using a gas chromatograph (HP Series 4890 plus, Hewlett Packard, USA). The gas chromatograph was equipped with a flame ionization detector (FID) for CO_2 analysis. The Re was calculated from the slope of the linear regression between concentration and time using the equation described by Song et al. (2003). Coefficients of determination (R^2) for all linear regressions were required to be >0.98. Average gas fluxes and standard errors were calculated from three replicates for all observations. Annual Re in 2008 was estimated by calculating average fluxes over an experimental period comprising 15 flux observations in 2008. Annual Re in 2009 and 2010 were estimated by calculating average fluxes over an experimental period containing 18 flux observations in 2009 and 2010, respectively. Re intensity was estimated as the ratio of annual average Re to aboveground biomass.

2.4. Statistical analysis

First, General Linear Model (GLM)–Repeated Measures analyses of variance (RMANOVA), with land uses as the main factor (between-subject) and with sampling date as the within-subject factor including interactions, was applied to test the effects of the main factor on monthly soil temperature, monthly water content of soil, aboveground and belowground biomass, daily Re and annual average Re, and Re intensity. Second, the same analysis was performed using different management practices as the main factor under the same land use and with sampling date as the within-subject factor including interactions. Multi-comparison of least standard difference (LSD) was conducted for all measured variables within each sampling date using a one-way ANOVA. Because of the different sampling dates and frequencies for Re in 2008 compared with 2009 and 2010, Re was analysed alone in 2008.

In order to assess how fertilizer (i.e. N fertilizer and sheep manure) affected the magnitude of the effect of land use change on Re and Re intensity, the relative differences (%) in Re and Re intensity were calculated between PEN, APL, AO without or with fertilizer and NAM without fertilizer, and between PEN, AO without or with fertilizer and APL without fertilizer. To assess the effect of tillage, the relative differences in Re and Re intensity were calculated between AO without tillage or with tillage and APL without tillage. Multi-comparison of least standard difference (LSD) was conducted using a one-way ANOVA to assess the relative differences in Re and Re intensity under no-fertilizer and with-fertilizer and under no-tillage and tillage management practices. All statistical analyses were performed with SPSS (SPSS 16.0, SPSS Inc., Chicago, IL, USA) using the GLM procedure and type III sum of squares during the growing season.

Stepwise regression analysis was conducted with Re and Re intensity as the dependent variables, and soil temperature, soil

water content, and/or aboveground biomass and belowground biomass as the independent variables in 2009 and 2010. Differences were considered significant at $P < 0.05$

3. Results

3.1. Soil temperature and soil water content

Generally, the effect of land use on soil temperature and soil water content varied with sampling date and year, and there was a significant interaction between land use and year and sampling date ($P < 0.05$). Average annual soil temperature (Fig. 2A) and soil water content (Fig. 2B) were greater for NAM, but lower for AO. There was no significant difference in annual soil temperature between APL and AO in 2009 or in 2010 (Fig. 2A), but there was a significant difference between PEN and AO temperature in 2009. Annual soil water content of AO was significantly lower than APL in

2009 and in 2010, but only was significantly lower than PEN in 2010 (Fig. 2B). No management practices significantly affected soil temperature or soil water content, except for tillage in 2010. In this case, tillage significantly decreased soil water content at 5 cm by 16% (Fig. 2C).

3.2. Aboveground and belowground biomass

Aboveground and belowground biomass were significantly affected by land use and year (Fig. 3A and B). The interactive effect between land use and year was significant for aboveground biomass but not for belowground biomass. Both PEN and AO significantly increased aboveground biomass except for the first year in 2008 for PEN, and aboveground biomass for PEN and AO were about 2–3 times higher than that of NAM and APL in both 2009 and 2010 (Fig. 3A). Aboveground biomass was higher for NAM than for APL only in 2010, and it was greater for PEN compared with AO in 2010 (Fig. 3A). However, belowground biomass was lower for PEN and AO than for NAM and APL, and it was higher for NAM than for APL. There was no significant difference in belowground biomass between PEN and AO in 2009 and 2010 (Fig. 3B). The belowground biomass for NAM was 2–5 times greater than that of PEN and AO.

Neither N fertilization nor application of sheep manure significantly affected aboveground biomass for APL, PEN and AO (data not shown), although there was a trend in the data that both N fertilization and sheep manure increased aboveground biomass. However, N fertilization and sheep manure significantly increased belowground biomass for PEN in 2009 (Fig. 3C). In the wet year 2010, N fertilization significantly increased belowground biomass for APL (Fig. 3D) and sheep manure enhanced belowground biomass for AO (Fig. 3E). Generally, tillage did not affect the belowground biomass of AO (Fig. 3F), whereas belowground biomass for the no N fertilization with tillage treatment was lower compared with sheep manure with no-tillage ($P < 0.05$).

3.3. Ecosystem respiration (Re)

In 2008, Re was significantly affected by land use, sampling date, and their interaction (Table 2). PEN had the lowest Re during the growing season due to a lower aboveground biomass in the first year of establishment. Similarly, AO had lower Re in 8 out of 12 samples compared with NAM except in August, and there was no significant difference between AO and APL after the middle of August (Fig. 4A). APL had significantly lower Re than NAM only on 24 June and on 2 July and 11 July (Fig. 4A). Annual average Re during the growing season from May to September for NAM (654 mg CO_2 m^{-2} h^{-1}) and APL (523 mg CO_2 m^{-2} h^{-1}) was 2–3 times higher than that of PEN (217 mg CO_2 m^{-2} h^{-1}). There was no significant difference between PEN and AO (349 mg CO_2 m^{-2} h^{-1}) (Fig. 4A).
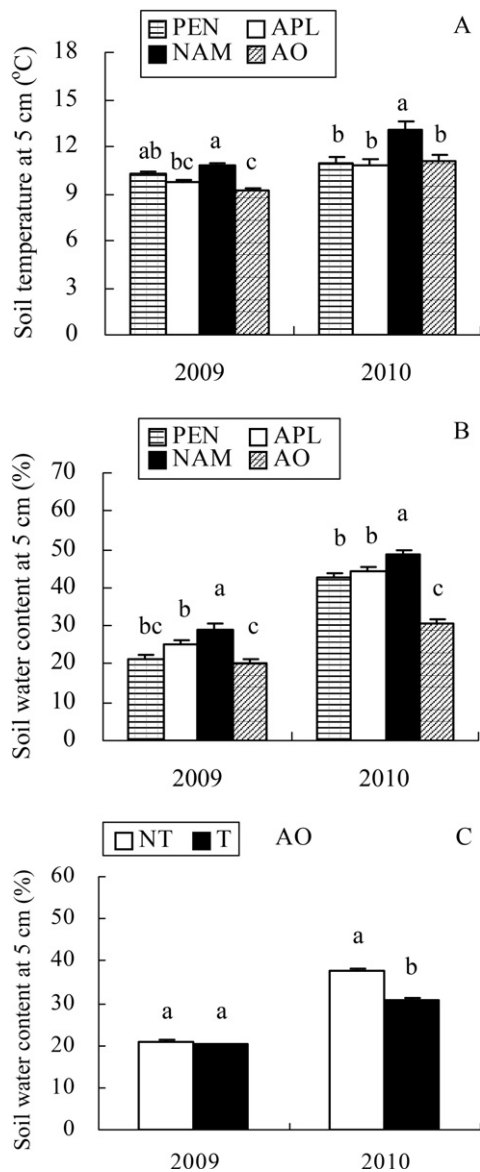

Fig. 2. Annual soil temperature (A) and annual water content of soil (B) at a depth of 5 cm under different land uses and annual soil water content (C) under tillage and no-tillage management from May 2009 to September 2010. PEN: perennial *Elymus nutans* pasture; NAM: native alpine meadow; APL: abandoned cropland/pastureland; AO: annual oat pasture; T: tillage; NT: no-tillage. Bars indicate mean ± 1SE. Different letters indicate significant differences at $P = 0.05$.

Table 2
Summary of repeated-measures ANOVA on the effects of year, sampling date, and land uses on ecosystem respiration.

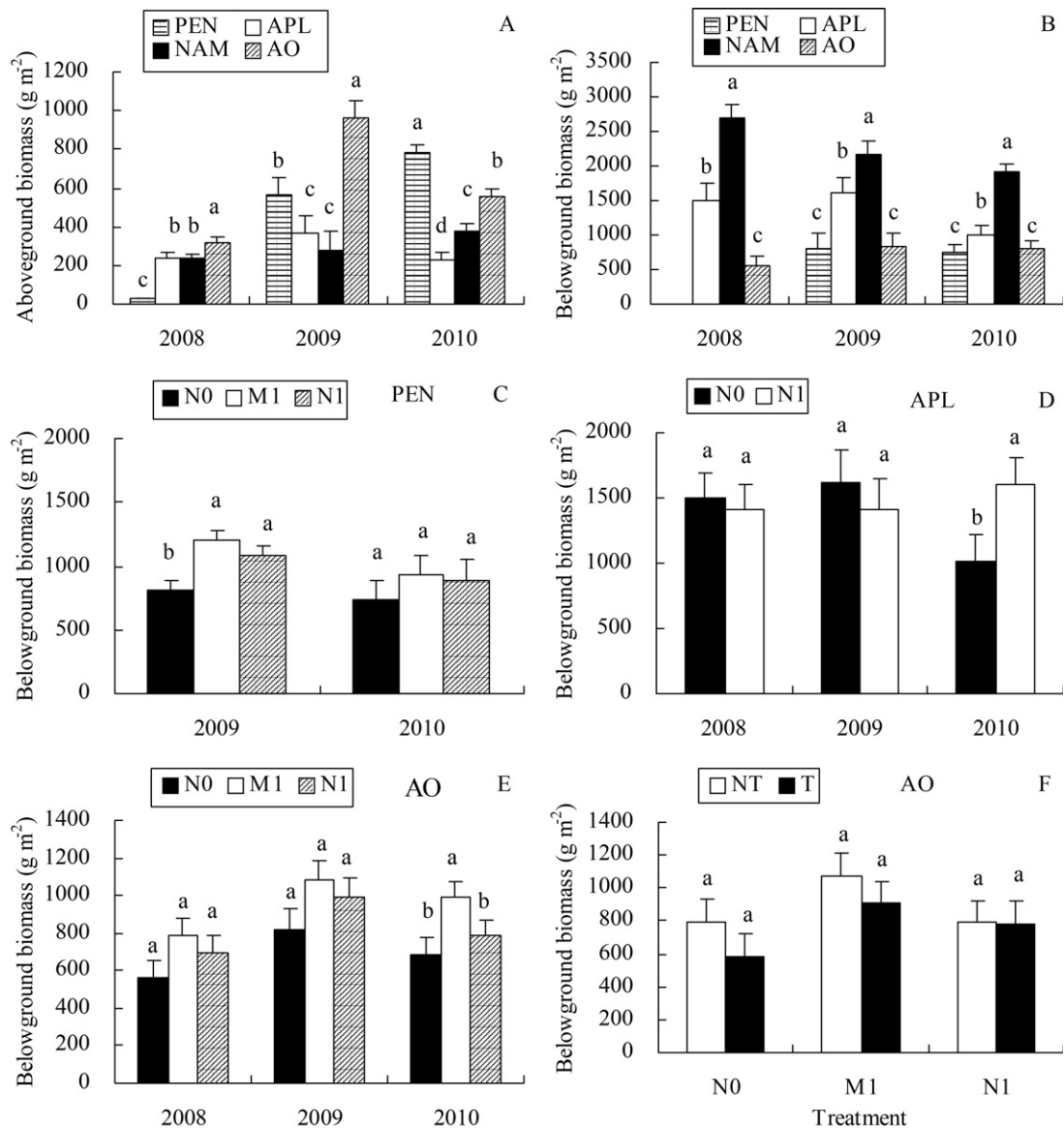| Year	Model	F	P
2008	Land use (L)	12.673	0.002
	Sampling date (D)	34.425	<0.001
	$D \times L$	4.528	<0.001
2009–2010	L	1.701	0.243
	Year (Y)	8.971	0.017
	D	84.165	<0.001
	$L \times Y$	1.997	0.193
	$L \times D$	4.578	<0.001
	$Y \times D$	9.639	<0.001
	$L \times Y \times D$	3.092	<0.001

Fig. 3. Aboveground biomass (A) and belowground biomass (B) under different land uses. Belowground biomass under different fertilization treatments for PEN (C), for APL (D) and for AO (E) and under different tillage practices for AO (F) in 2008, 2009, and 2010. PEN: perennial *Elymus nutans* pasture; NAM: native alpine meadow; APL: abandoned cropland/pastureland; AO: annual oat pasture. Bars indicate mean ± 1SE. Different letters indicate significant differences at $P = 0.05$.

In 2009 and 2010, Re was mainly affected by year, sampling date and the interactive effects between land use, year and/or sampling date (Table 2). There were no significant differences in annual average Re for all land uses in 2009 (Fig. 5B), although the daily Re before August was lower for PEN and AO than for NAM and APL (Fig. 4B). In 2010 Re for AO was lower than for the other three land uses only during June and July (Fig. 4C), and there were no significant differences in the annual average Re of all land uses (Fig. 5C). Annual average Re for all land uses was lowest in 2008. Annual average Re for PEN and AO were significantly higher in 2010 than in 2009, and there were no significant differences for NAM and APL between 2009 and 2010.

Neither N fertilizer nor sheep manure significantly affected annual average Re for PEN ($P = 0.977$), and there were no significant interactive effects between N fertilizer and/or sampling date and/or year (data not shown). Similar results were found for APL (data not shown). N fertilizer alone ($P = 0.342$) and no-tillage alone ($P = 0.893$) did not affect the annual average Re of AO, but there were significant interactive effects between tillage and sampling date ($P = 0.013$) and

between tillage and year ($P = 0.051$). For example, although tillage did not affect annual average Re during the growing seasons in 2009 or 2010, the increase in annual average Re was higher for tillage (36.7%) than for no-tillage (20.7%) when 2009 is compared with 2010 (Fig. 6). In particular, tillage increased Re by 30.1% only on 20 May in 2009 ($P = 0.021$), whereas tillage significantly decreased average Re by 36.0% (range 23.8–51.0%) from 27 June to 27 July in 2010 (Fig. 6).

3.4. Ecosystem respiration (Re) intensity

Land use ($P = 0.002$) and its interaction with year ($P = 0.022$) significantly affected Re intensity. PEN and AO significantly decreased Re intensity by about 170% compared with NAM and APL (Fig. 7A). There was no significant difference between PEN and AO, but NAM significantly decreased Re intensity compared with APL when rainfall was rich in 2010 (Fig. 7A). However, the different management practices studied did not significantly affect Re intensity (data not shown). Re intensities in 2010 were higher than in 2009 for all treatments (Fig. 7B).
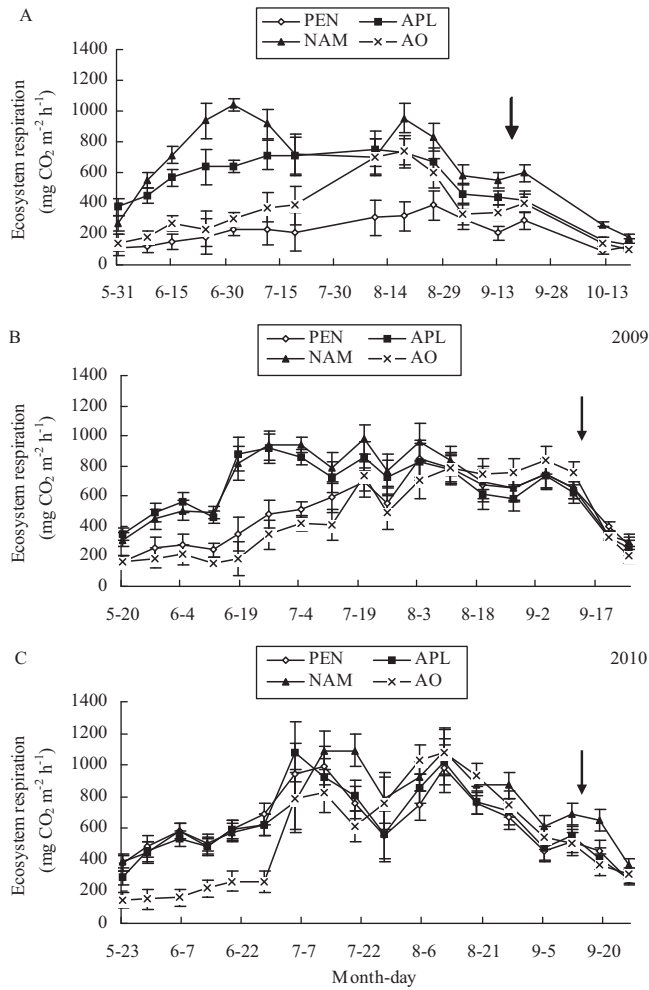
Fig. 4. Daily Re under different land uses in 2008 (A), 2009 (B) and 2010 (C). PEN: perennial *Elymus nutans* pasture; NAM: native alpine meadow; APL: abandoned cropland/pastureland; AO: annual oat pasture. Bars indicate mean ± 1SE. Different letters mean significant differences at $P = 0.05$. → indicates harvest time in the figures.

3.5. Factors affecting Re and Re intensity

Generally, daily Re (Table 3), annual average Re and Re intensity (Table 4) were significantly influenced by soil temperature, soil water content, aboveground and/or belowground biomass and the root to shoot ratio (data not shown), but their influences depended on land uses and management practices (Tables 3 and 4). For example, daily Re was only controlled by soil temperature for PEN with N fertilizer, but it was controlled by soil temperature and soil water content for PEN without N fertilizer and with sheep manure (Table 3). Regardless of N fertilizer, no-tillage significantly increased the dependence of daily Re on soil temperature due to a greater coefficient between Re and soil temperature compared with tillage, whereas under N fertilization the dependence of daily Re on soil temperature was higher for no-tillage than for tillage. Sheep manure did not affect the response of daily Re of AO to soil temperature under the no-tillage treatment, whereas the dependence of the daily Re of AO on soil temperature was higher for no-tillage than for tillage when sheep manure was applied (Table 3).

When all data for all treatments in the study were pooled, annual average Re was controlled by soil water content, root to shoot ratio and soil temperature, and when all data for all land uses without fertilization and sheep manure were pooled, annual average Re was controlled by soil water content and belowground biomass (Table 4). Similarly, when all data for all management
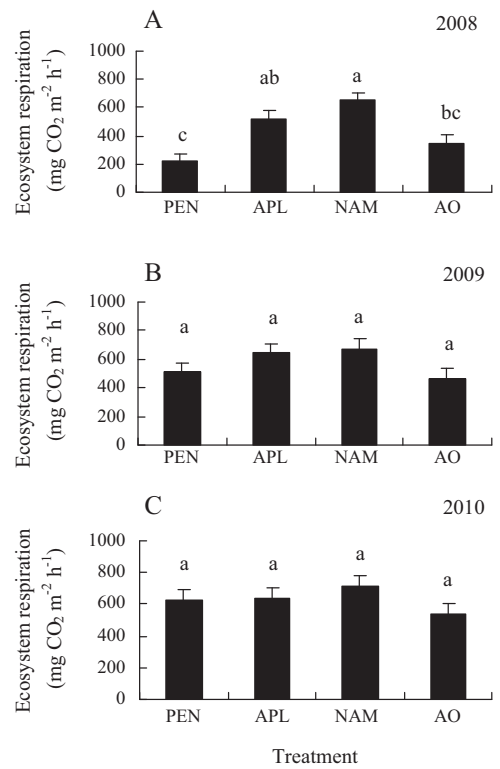

Fig. 5. Average annual Re under different land uses in 2008 (A), 2009 (B) and 2010 (C). PEN: perennial *Elymus nutans* pasture; NAM: native alpine meadow; APL: abandoned cropland/pastureland; AO: annual oat pasture. Bars indicate mean ± 1SE. Different letters indicate significant differences at $P = 0.05$.
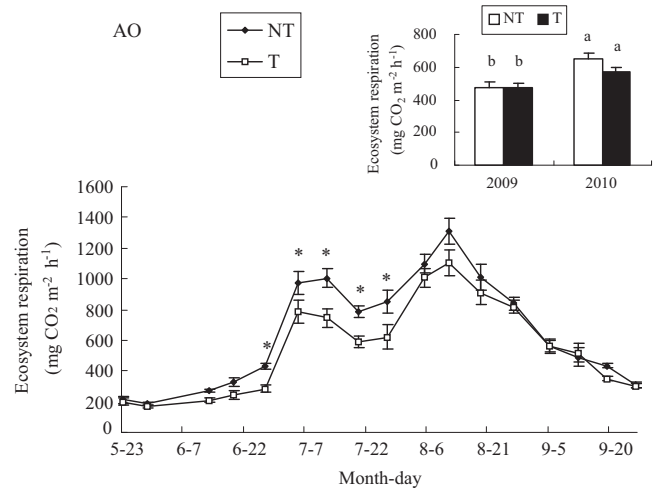

Fig. 6. Daily Re in AO under tillage and no-tillage in 2010. The panel inside is annual average Re. * indicates significant difference between T and NT. T: tillage; NT: no-tillage. Bars indicate mean ± 1SE. Different letters indicate significant differences at $P = 0.05$.

practices with fertilization and no-tillage were pooled, annual average Re was controlled by soil water content and soil temperature (Table 4). PEN decreased the dependence of annual average Re on soil water content compared with AO with no-tillage under all treatments, whereas annual average Re was only controlled by soil temperature for AO with tillage (Table 4). Annual Re intensities for all land use and management practice treatments were mainly controlled by soil water content and soil temperature which explained about 31% of the variation of annual Re intensity ($R^2 = 0.31$) (Table 4). In particular, soil water content
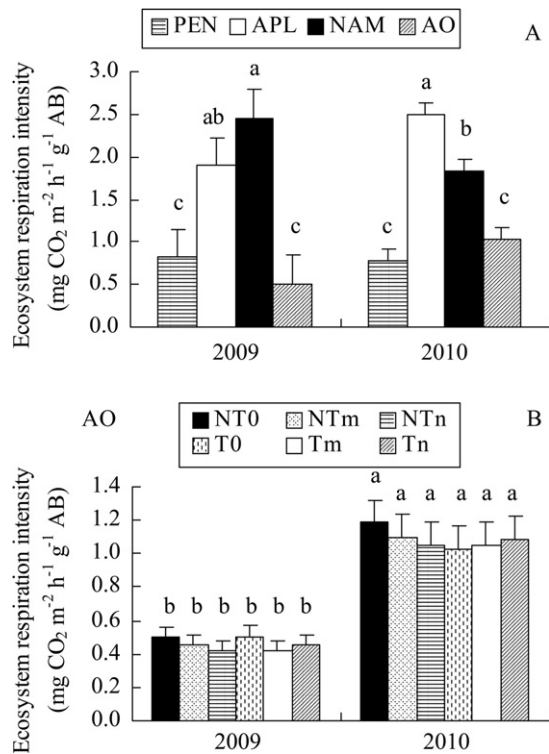
Fig. 7. Annual Re intensity of different land uses (A) and management practices (B) in 2009 and 2010. AO: annual oat pasture; NT0: no-tillage with no fertilizer; NTm: no-tillage with sheep manure; NTn: no-tillage with nitrogen fertilizer; T0: tillage with no fertilizer; Tm: tillage with sheep manure; Tn: tillage with nitrogen fertilizer. Bars indicate mean ± 1SE. Different letters indicate significant differences at $P = 0.05$.

and soil temperature explained about 90% of the variation in annual Re intensity for AO regardless of tillage, whereas annual Re intensity for PEN was not affected by these factors (Table 4).

3.6. Effects of fertilizer on the magnitude of the effect of land use change on Re and Re intensity

Neither N fertilizer nor sheep manure significantly affected the magnitude of the effect of land use on Re and Re intensity for PEN ($P = 0.345$ and 0.343), APL ($P = 0.214$ and 0.910) and AO ($P = 0.821$

and 0.304) when using NAM without fertilizer as the control, and for PEN ($P = 0.363$ and 0.470) and AO ($P = 0.895$ and 0.982) when using APL without fertilizer as the control. Similarly, tillage did not affect the magnitude of the effect of land use on Re and Re intensity for AO ($P = 0.404$ and 0.891) when using APL with no-tillage as the control.

4. Discussion

Although some studies have reported significant effects of different management practices and tillage methods on land use change (Smith et al., 2008), our results indicated that the responses of Re and Re intensity to conversion of alpine meadow to cropland/ pastureland and the abandonment of cropland/pastureland did not vary with N fertilization or tillage practices during the experimental periods. These results imply that Re and Re intensity may be controlled by land use, and N fertilization and no-tillage practices do not change their response patterns to land use change in the region.

4.1. Effects of land use change on Re

Frank et al. (2006) reported that the conversion of grassland to cropland could lead to a decreasing soil CO_2 emission rate, due to the greater root biomass and lack of disturbance which provides rich carbon supply for microbial activity. In our study, although PEN and/or AO significantly decreased soil temperature and soil water content (Fig. 2) and belowground biomass (Fig. 3) compared with NAM and/or APL, there were no significant differences in annual average Re among land uses in 2009 or 2010 (Fig. 5B and C). On the one hand, it is likely that following conversion from natural alpine meadow to pastureland, a decline in soil aggregation resulted in an increase in soil bulk density in the surface layer which indirectly influences the CO_2 flux via change in the carbonate dissolution chemistry and surface adhesion to soil particles (Sánchez et al., 2002; Ball et al., 2009). On the other hand, increased aboveground biomass (Fig. 3) may increase plant respiration for PEN and AO. These effects could offset greater soil respiration due to higher soil temperature and soil water content and higher belowground biomass for NAM and APL (Craine and Wedin, 2002; Almagro et al., 2009). Third, animals grazing during winter deposited much excreta in the NAM plots, which could increase Re (Lin et al., 2009). Annual average Re was significantly higher for NAM compared with PEN and AO (Fig. 5) due to a drought in 2008 which limited forage growth especially for PEN

Table 3

Regression models relating daily ecosystem respiration, soil temperature (ST), and soil water content (SM) under the different land uses and management practices studied.

Activity	Treatment	Linear model	R^2	P
Land use and management	Pooled data	$Y = -86.859 + 36.718ST + 6.696SM$	0.21	<0.001
Land use	Pooled data	$Y = -79.219 + 48.152ST + 5.982SM$	0.31	<0.001
Management	Pooled data	$Y = 299.318 + 8.294SM$	0.35	<0.001
Land use	NAM	$Y = -50.971 + 49.537ST + 3.478SM$	0.34	<0.001
	APL_0	$Y = -181.307 + 62.196ST + 4.459SM$	0.40	<0.001
	PEN_0	$Y = -67.924 + 48.107ST + 4.050SM$	0.27	<0.001
	AO_0-T	$Y = -38.048 + 37.746ST + 5.982SM$	0.19	<0.001
Management	PEN_m	$Y = -23.775 + 48.621ST + 3.784SM$	0.31	<0.001
	PEN_n	$Y = -113.720 + 45.352ST$	0.23	<0.001
	APL_n	$Y = -133.514 + 64.751ST + 3.600SM$	0.49	<0.001
	AO_0-NT	$Y = -190.404 + 55.157ST + 4.887SM$	0.29	<0.001
	AO_m-NT	$Y = -365.893 + 59.351ST + 10.167SM$	0.32	<0.001
	AO_m-T	$Y = -35.576 + 31.501ST + 8.222SM$	0.19	<0.001
	AO_n-NT	$Y = -193.373 + 48.717ST + 7.482SM$	0.24	<0.001
	AO_n-T	$Y = -49.688 + 25.893ST + 7.340SM$	0.14	<0.001

NAM: native alpine meadow with winter grazing; APL_0: abandoned cropland/pastureland without nitrogen fertilizer; PEN_0: perennial *Elymus nutans* pasture without fertilizer; AO_0-T: annual oat pastures without any fertilizer or tillage. PEN_m: PEN with sheep manure; PEN_n: PEN with nitrogen fertilizer; AO_0-NT: AO without nitrogen fertilizer and no-tillage; AO_m-NT: AO with sheep manure and no-tillage; AO_m-T: AO with sheep manure and tillage; AO_n-NT: AO with nitrogen fertilizer and no-tillage; AO_n-T: AO with nitrogen fertilizer and tillage.

Table 4

Regression models relating annual average ecosystem respiration (Y_1), and ecosystem respiration per gram of aboveground biomass (Y_2) to aboveground biomass (AB), belowground biomass (BB), the ratio of BB and AB (BB/AB), soil temperature (ST), and soil water content (SM) under the different land uses and management practices studied.

Activity	Treatment	Linear model	R^2	P
Land use and management	Pooled data	$Y_1 = 41.161 + 6.475SM + 13.979BB/AB + 27.632ST$	0.54	<0.001
		$Y_2 = -2.094 + 0.023SM + 0.231ST$	0.31	<0.001
Land use	Pooled data	$Y_1 = 274.165 + 6.644SM + 0.085BB$	0.56	<0.001
		$Y_2 = 0.382 + 0.034SM$	0.18	<0.001
Management	Pooled data	$Y_1 = -106.132 + 7.759SM + 40.856ST$	0.53	<0.001
		$Y_2 = -1.645 + 0.023SM + 0.178ST$	0.37	<0.001
Management	PEN	$Y_1 = 355.341 + 6.623SM$	0.32	<0.001
	AO-NT	$Y_1 = 169.691 + 12.930SM$	0.65	<0.001
		$Y_2 = -2.169 + 0.025SM + 0.211ST$	0.89	<0.001
	AO-T	$Y_1 = -188.582 + 65.102ST$	0.47	<0.001
		$Y_2 = -1.734 + 0.168ST + 0.029SM$	0.88	<0.001

PEN: perennial *Elymus nutans* pasture with sheep manure or nitrogen fertilizer; AO-NT: annual oat pasture with no-tillage and sheep manure or nitrogen fertilizer; AO-T: annual oat pasture with tillage and sheep manure or nitrogen fertilizer. Y_1: ecosystem respiration (Re); Y_2: ecosystem respiration per gram aboveground biomass (i.e. Re intensity). SM: water content of soil at 5 cm; ST: soil temperature at 5 cm; AB: aboveground biomass; BB: belowground biomass for 0–20 cm.

which was in its first year of establishment. Although Re was not significantly different between NAM and APL (Figs. 4–6), below-ground biomass was higher for NAM than for APL from 2008 to 2010, and even aboveground biomass was higher in 2010 for NAM than for APL. Probably increased Re for APL, due to poorer soil aggregation (Dieckow et al., 2005), may compensate for the increased Re due to a greater belowground biomass for NAM. These results indicate that abandoned land may need a longer time to restore because compared with NAM restoration for 8–10 years from APL still does not achieve the relative maximum potential ecosystem structure and function. During the 3 year experimental period, the conversion of abandoned cropland/pastureland to pastureland decreased Re, which did not support our hypotheses.

Inconsistent results have been observed for the relationships between daily Re and soil water content in the region. For example, similarly to previous reports (Jiang et al., 2010), we found that soil water content significantly affected daily Re but there was a lower coefficient in our study, whereas Lin et al. (2009) reported that soil water content did not significantly affect daily Re due to a lack of significant differences in soil water content between treatments. We also found that there was no significant correlation between annual average Re and soil temperature when data from all land uses without fertilization was pooled (Table 4), indicating that soil water content mainly controlled annual average Re in our study. These results suggest that the factors affecting Re at different temporal scales are different, as annual average Re may be controlled by soil water content and belowground biomass under land use change (Table 4). Therefore, a multi-factor controlled experiment is needed to identify the effects of soil water content, soil temperature and their interactive effects on CO_2 flux in alpine meadows.

4.2. Effects of management on Re

Inconsistent results have been observed in microbial activity and/or CO_2 emission due to N fertilizer application, with decrease (Al-Kaisi et al., 2008) or no change (Zhang et al., 2007) or increase (Kaye et al., 2005) reported in the literature. Organic fertilization presents advantages over inorganic fertilization because it improves soil structure and water retention (Latif et al., 1992) and soil organic matter (Fraser et al., 1988). Organic fertilization applications increase CO_2 loss through stimulating soil respiration but also enhance soil C storage compared with inorganic fertilization (Jones et al., 2006). Although N limits plant primary production in the majority of terrestrial ecosystems (LeBauer and Treseder, 2008), in our study N fertilization and manure had no significant effect on aboveground biomasses and Re, and little effect on the belowground biomass of PEN and AO. The lack of

fertilization effect on Re can be attributed to counteracting plant and soil respiration response patterns. Increased N uptake following fertilization would influence metabolic processes in plants which are expected to induce short-term increases in plant respiration (Jassal et al., 2011), while N fertilization generally decreases soil respiration via decreased microbial biomass and activity (Frey et al., 2004; Mo et al., 2008). There was certainly a trend in our study that fertilization increased aboveground biomass, which is also expected to increase plant respiration. These results suggest that a future increase in N deposition might not have an important effect on Re for PEN and AO which are the main types of pasture in the region.

The effect of soil tillage on soil CO_2 flux (Rs) depends on the duration, season, soil water content and temperature, soil type, the mechanism of soil C stabilization and C stocks (Liu et al., 2006). Inconsistent results have been reported on the effects of tillage regimes on Rs. For example, many studies have found decreased short-term Rs under no-tillage compared with tillage (La Scala et al., 2006; Lal, 2003). In contrast, Franzluebbers et al. (1995) found higher Rs under no-tillage compared with tillage during overnight measurements taken using alkali traps. Aslam et al. (2000) found a lack of statistical difference in Rs between tillage and no-tillage treatments. In our study, we found that no-tillage did not affect Re of AO and there was no interactive effect between fertilization and no-tillage in 2009 or 2010 (Fig. 6). This may be attributed to the fact that tillage significantly decreased soil water content at 5 cm, which limited microbial activity and Re offset the release of CO_2 stored in soil pores and water (Liu et al., 2006).

4.3. Ecosystem respiration (Re) intensity

In our study, we found that the conversion from APL to pastureland significantly decreased Re intensity compared with APL (Fig. 7) due to increasing aboveground biomass and decreasing Re, whereas restoration for 8–10 years from APL had significantly increased Re intensity compared with NAM in 2010. Investment in yield improvements compares favorably with other commonly proposed mitigation strategies (Burney et al., 2010). To mitigate agriculture's future contributions to climate change, continuing improvement in forage yields is paramount. On the one hand, this could reduce grazing pressure on natural alpine meadows, and on the other hand it could enhance the carbon sequestration of degraded meadows in grassland ecosystems (Conant et al., 2001; Wang et al., 2011). Our results suggest that the conversion of historical cropland land into pasturelands is preferable to natural restoration because of the enhanced ability of pasturelands to meet forage requirements in the region. There were no significant effects

of different fertilization and tillage practices on Re intensity. These results suggested that in the short-term the contradiction between the need for increased forage production and environmental objectives could not be resolved by either N inorganic fertilization or organic fertilization in the alpine meadow region. Overall, conversion of abandoned cropland/pastureland to pastureland decreased Re intensity, and natural restoration from the abandonment of cropland/pastureland increased Re intensity. Management practices did not significantly modify the patterns of the effects of land use on Re intensity.

5. Conclusion

Our results did not support the hypotheses that conversion of abandoned croplands/pasturelands to pasturelands would increase Re and Re intensity, and natural restoration from abandoned croplands/pasturelands for 8 years did not decrease Re. Annual average Re was not significantly influenced by N fertilization or sheep manure, but there was an interactive effect between tillage and year on Re. Therefore, based on considerations of biomass production and Re in the region, our results suggest that the conversion of historical cropland into pasturelands, especially into perennial pasture, is preferable to natural restoration of alpine meadow. Annual average Re was mainly controlled by soil water content and belowground biomass under different land uses, but management practices increased the dependency of Re on soil water content. Re intensity was mainly controlled by soil water content and soil temperature under different land uses and management practices except for PEN. Thus, further studies are needed to identify the controlling factors on Re under different land uses in this region.

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