Carbon balance along the Northeast China Transect (NECT-IGBP)

ZHOU Guangsheng (周广胜)[1], WANG Yuhui (王玉辉)[1],
JIANG Yanling (蒋延玲)[1] & XU Zhenzhu (许振柱)[1]

1. Laboratory of Quantitative Vegetation Ecology, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China;
2. Shenyang Institute of Atmospheric Environment, China Meteorological Administration, Shenyang 110016, China
Correspondence should be addressed to Zhou Guangsheng (email: zhougs@public2.bta.net.cn)

Received June 23, 2002

Abstract The Northeast China Transect (NECT) along a precipitation gradient was used to calculate the carbon balance of different vegetation types, land-use practices and temporal scales. NECT consists of mixed coniferous-broadleaved forest ecosystems, meadow steppe ecosystems and typical steppe ecosystems. Analyses of the C budget were carried out with field measurement based on dark enclosed chamber techniques and alkali absorption methods, and the application of the CENTURY model. Results indicated that: (1) soil CO_2 flux had a strong diurnal and seasonal variation influenced by grassland type and land-use practices. However, the seasonal variation on soil CO_2 fluxes did not show obvious changes between non-grazing and grazing *Leymus chinensis* dominated grasslands. (2) Hourly soil CO_2 fluxes mainly depended on temperature, while daily CO_2 fluxes were affected both by temperature and moisture. (3) NPP of the three typical ecosystems showed linear relationships with inter-annual precipitation, but total soil carbon of those ecosystems did not. NPP and total soil carbon values decreased westward with decreasing precipitation. (4) Model simulation of NPP and total soil carbon showed that mean annual precipitation was the major limiting factor for ecosystem productivity along NECT. (5) Mean annual carbon budget is the largest for the mixed coniferous- broadleaved forest ecosystem (503.2 gC m^{-2} a^{-1}), followed by the meadow steppe ecosystem (227.1 gC m^{-2} a^{-1}), and the lowest being the typical steppe ecosystem (175.8 gC m^{-2} a^{-1}). This study shows that concurrent field measurements of terrestrial ecosystems including the soil and plant systems with surface layer measurements along the water-driven IGBP-NECT are valuable in understanding the mechanisms driving the carbon cycle in different vegetation types under different land-use practices. Future transect research should be emphasized.

Keywords: temperate grassland, terrestrial NPP, CENTURY model.

Terrestrial ecosystems play a critical role in modulating the global carbon cycle. Human activities are disrupting terrestrial ecosystems which directly affect ecosystem function. Previous studies have suggested that tropical Asia is an important source of carbon to the atmosphere, ranging from 25%[1] to 31%[2] of the global carbon emissions released from land since the middle of the eighteenth century. Recent estimates have indicated that tropical deforestation in South and Southeast Asia released from one third[3] since the 1980s to more than half[4] of the total carbon lost derived from land-use changes across the globe. However, more recent analyses based on atmospheric transport models and CO_2 observations suggested that the northern portion of monsoon Asia has acted as a carbon sink[5]. The uncertainty in the magnitude of the carbon source or sink strength in monsoon Asia is clearly a key to balancing the global carbon budget. To reduce the uncertainty of the carbon budget in monsoon Asia and to improve our understanding of the carbon cycle at various spatial and temporal scales, the integration of multiple, complementary and independent methods used by the different research communities is required.

Northeast China Transect (NECT) is one of the IGBP (International Geosphere-Biosphere Programme) terrestrial transects, a set of integrated global change studies consisting of distributed observational sites and manipulative experiments coupled with modeling and synthesis activities organized along existing natural environmental gradients, such as temperature, precipitation and land use. The global change and terrestrial ecosystem (GCTE) has used the transects as a major tool in its research programs to (i) determine changes in the terrestrial biogeochemical cycle; (ii) study the effects of global change on ecosystem structure; and (iii) serve as platforms for studying the impacts of global change on terrestrial ecosystems, such as effects on production systems (e.g. managed forests, complex agroecosystems), soil processes and ecological complexity[6]. A general question guiding the NECT is "how does water availability influence the composition of plant functional types, soil organic matter, net primary production, trace gas flux, and land-use distribution?"[6].

The objective of the present research is to elucidate the daily and seasonal variations of CO_2 fluxes as a response to different land use types and environmental factors, and to evaluate the carbon budgets using empirical and modeling approaches along NECT.

1 Materials and methods

1.1 Northeast China Transect (NECT)

NECT is located between 112° and 130°30′E and between 42° and 46°N, and approximately 1600 km in length. The main driving force along NECT is precipitation gradient, and the secondary gradient is land use intensity[7]. Moreover, NECT reflects the comprehensive effects of monsoon climate, drought climate and the Tibetan Plateau.

The vegetation zones or biomes along the NECT consist of temperate mixed evergreen coniferous and broadleaved deciduous forest and temperate steppe, including three subzones, viz. meadow, typical and desert steppes, along an east-westward continuous transitional spatial series, respectively. The mean annual precipitation along the NECT changes from 177 mm to 706 mm from the west to the east[7], with a number of land-use practices such as fenced, mowing, grazing, and reclaiming grasslands. There are three long-term ecosystem research stations from east to west along NECT: Changbai Mountains Forest Ecosystem Research Station, Changling Grassland Station, and Inner Mongolia Grassland Ecosystem Research Station. Therefore, NECT provides an effective research network for investigating how the carbon balance of terrestrial ecosystems responds to precipitation gradient (or precipitation changes in the future) and land use practices.

1.2 Soil CO_2 flux measurements

Soil CO_2 fluxes were measured around the Inner Mongolia Grassland Ecosystem Research Station (43°22′—44°08′N, 116°04′—117°05′E) of the Chinese Academy of Sciences. Measurement sites were selected following annual rainfall gradient variations from southeast to northwest with respect to grassland types and the impacts of human activities. The measurement area had a semi-arid temperate grassland climate with an annual mean temperature of −0.4°C. Cumulative degree days over 10°C reach 1597.9°C during 112 days, including 100 frost-free days. Annual precipitation from southeast to northwest varies from 500 mm to 200 mm with 60% to 80% of annual rainfall concentrating in the July to September period. Altitude of the measurement area ranges from 1400—1500 m in the southeast to 1000—1100 m in the northwest with grassland types varying from meadow steppe, to *Leymus chinensis* grassland, to *Stipa grandis* grassland and to dry steppe.

Soils are chernozem and chestnut soils with sandy loam texture, containing 1.0%—4.1% of organic matter and 0.0735%—0.2182% of total nitrogen at the top 20 cm. Grassland types and 0—20 cm soils of measurement sites are listed in table 1. The *Leymus chinensis* grassland and *Stipa grandis* grassland have been ungrazed for more than ten years, and meadow steppe plots have been lost to cultivation since 1982 with a cropping system of spring wheat once a year[8].

Table 1 Grassland and soils types on experimental sites along NECT[8]

Vegetation type a)	Soil type b)	Organic matter (%)	Total N(%)	pH	Annual rainfall/mm
A	1	4.10	0.2182	6.37	>450
B	1	3.57	0.2023	6.46	>420
C	2	3.18	0.2882	6.92	300—350
D	2	3.00	0.1820	7.92	300—350
E	3	2.76	0.1833	7.64	300—350
F	3	2.69	0.1716	7.63	300—350
G	4	1.03	0.0735	6.76	<200

a) A, Meadow steppe; B, meadow steppe farmland; C, *Leymus chinensis* grassland; D, *Leymus chinensis* grazing; E, *Stipa grandis* grassland; F, *Stipa grandis* grazing; G, dry steppe. b) 1, Chernozem; 2, dark chestnut soil; 3, chestnut soil; 4, light chestnut earth.

1.2.1 Hourly soil CO_2 flux measurements. Hourly soil CO_2 fluxes were measured with an enclosed chamber method from July 17 to 23, 1998[8]. The enclosed chamber was made from 5-mm-thick black acrylic material. The surface area of the chamber was 44 cm × 49 cm. Chambers were 25 cm high except those used in spring wheat fields reclaimed from meadow steppe, which were 65 cm in height. During measurements, chambers were put into the groove (2 cm× 2 cm× 2 cm) outside a stainless steel frame inserted at 5 cm depth into the soil and sealed with distilled water. A black acrylic lid was fitted with an air mixture fan, and temperature sensor and a 3-way sampling stopcock were fitted on the top of the chamber sealed with rubber. CO_2 concentration was directly measured inside the chambers by a CO_2 infrared analyzer (type: LI-COR 6252, Lincoln, NE, USA). Gas samples (three replicates) were supplied to the CO_2 analyzer by a tefloncovered membrane pump and then circulated back to the chamber at a flow rate of 0.5 L/min[8]. Measurements were taken between 09:00 to 12:00, and a 24-hour continuous CO_2 flux measurement of *Leymus chinensis* grassland was done from 09:00, July 22 to 09:00, July 23, 1998. CO_2 fluxes measured is total CO_2 emission from both soil and plant dark respiration.

The gas flux was computed from the concentration change over the measurement period. The positive value denotes the gas emission into the atmosphere from soil and the negative value represents the gas flow from air to soil or soil absorption of this gas from the atmosphere. It can be expressed as follows[8]:

$$F = (\Delta m/\Delta t) \cdot D \cdot (V/A) = h \cdot D \cdot \Delta m/\Delta t,$$

where F refers to gas flux (mg $\cdot$ m^{-2} $\cdot$ h^{-1}), $\Delta m/\Delta t$ denotes linear slope of concentration change with time over measurement period, D is the gas density of the chamber ($D = P/RT$, mol $\cdot$ m^{-3}, P: atmospheric pressure, T: temperature and R: air constant), and h represents the height of the chamber.

1.2.2 Daily soil CO_2 flux measurements. The experimental site and environmental conditions were described in detail by Li et al.[9]. Daily soil CO_2 fluxes were measured at the permanent sampling plot of *Leymus chinensis* grassland with alkali absorption method[10] on the 5th, 15th and 25th of each month from May 31 to September 25, 1998 and on the 10th, 20th and 30th of each month from May 30 to October 15, 1999. Simultaneously, the same type of measurement was made in the grazing grassland located out of the permanent plot of the *Leymus chinensis* grassland. Ten replicate plots were used for non-grazing and grazing *Leymus chinensis* grasslands, whereas three replicate plots were ambient CO_2 concentration in non-grazing and grazing *Leymus chinensis* grasslands. Plots consisted of a cylindrical chamber of zinciferous iron, 25 cm diameter and 40 cm height. A glass containing 20 mL of 1 mol/L NaOH was used as CO_2 absorbent. The solution of NaOH was titrated with 1.0 mol/L HCl using phenolphthalein and methyl orange as indicators.

1.3 CENTURY model

Net primary productivity (NPP) and total soil carbon of three typical ecosystems along the water-driven NECT were analyzed by CENTURY model.

NPP is the amount of carbon fixed by vegetation in an ecosystem from the atmosphere (gross primary productivity) minus the amount of carbon returned to the atmosphere by plants respiration[11]. It represents a major component of Net Ecosystem Production (NEP), which is the net carbon (C) input from the atmosphere into the biosphere, the other component being the release of C through decomposition of organic matter and disturbances[12].

The CENTURY model[13] is a general computer model of terrestrial ecosystems that simulates the carbon (C) dynamics of various plant-soil systems, including grasslands, agricultural land, savannas and forests. CENTURY 4.0 has three major submodels: (1) a biophysical submodel that calculates hydrological and temperature driver variables; (2) a production submodel that simulates above- and belowground vegetation processes; and (3) a soil organic matter submodel that calculates the dynamics of C fluxes from soil and litter pools. The major input variables include: monthly maximum and minimum air temperatures, monthly precipitation, soil texture, atmospheric and soil N inputs, plant lignin content, and initial soil C and nutrient levels. Non-site-specific parameters for three typical ecosystems were left unchanged. Site-specific parameters are given in table 2.

Table 2 Site-specific parameters for CENTURY model

	Inner Mongolia Grassland Ecosystem Research Station	Changling Grassland Station	Changbai Mountains Forest Ecosystem Research Station
Vegetation subzone	typical steppe	meadow steppe	montane mixed coniferous-broadleaved forest
Typical formation	*Stipa grandis, S. krylovii*	*S.baicalensis, Leymus Chinensis*	*Pinus koraiensis, Abies holophylla*
Soil types	chestnut soil	chernozem	montane dark brown forest soil
Precipitation/mm	250—350	340—470	600—800
Monthly mean maximum air temperature/℃	20—23	23—24	20—24
Monthly mean minimum air temperature/℃	−18— −22	−14— −18	−15— −25
Longitude of model site/(°)	117.0	126.67	128.00
Latitude of model site/(°)	44.0	44.67	42.05
Elevation/m	1250	145	736
Fraction of sand in soil (%)	0.49	0.2	0.28
Fraction of silt in soil (%)	0.30	0.45	0.48
Fraction of clay in soil (%)	0.20	0.3	0.24
Bulk density of soil/g • cm^{-3}	1.28	1.54	1.32
Soil pH	7.4	9.0	5.4

2 Results

2.1 Daily soil CO_2 flux variation and the effects of grassland types and land-use practices

2.1.1 Daily soil CO_2 flux of *Leymus chinensis* grassland. Fig. 1 shows the diurnal soil CO_2 flux variations. Diurnal soil CO_2 flux from *Leymus chinensis* grassland indicated a strong diurnal variation with higher emission during daytime than during nighttime hours. The maximum CO_2 efflux was at 12:00, while the minimum at 03:00. Daily average CO_2 emission rate during (1180.4 ± 308.7 (±SE) mg • m^{-2} • h^{-1}) was found very close to those at 09:00 and 19:00. Thus, the soil CO_2 efflux at 09:00 was approximately representative for mean daily value.

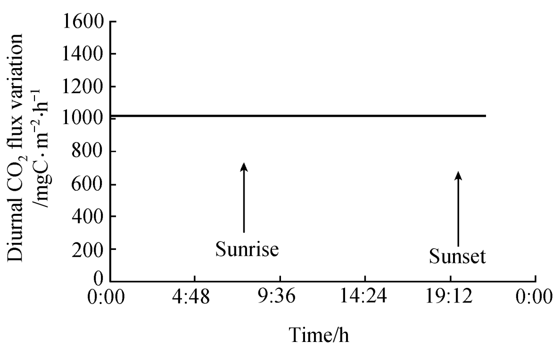

Fig. 1. Variation in diurnal soil CO_2 efflux in *Leymus chinensis* grassland, July 22—23, 1998.

2.1.2 Variation in the soil CO_2 efflux in different grasslands and land-use practices. Fig. 2 shows soil CO_2 effluxes among different grassland types and land-use practices. The soil CO_2 effluxes from grassland types were largest at *Leymus chinensis* grassland (C, 1471.2 mg C m^{-2} h^{-1}), followed by meadow steppe (A, 1304.3 mg C m^{-2} h^{-1}), *Stipa grandis* grassland (E, 895.6 mg C m^{-2} h^{-1}) and the lowest being the Dry steppe (G, 756.0 mg C m^{-2} h^{-1}), while the mean annual precipitation ranged from meadow steppe (A, >450 mm)> *Leymus chinensis* grassland (C, 300—350 mm), *Stipa grandis* grassland (E, 300—350 mm)> Dry steppe (G, <200 mm). It indicated that CO_2 flux depends not only on environmental factors (such as precipitation change) but also on the dominant species.

Human activities also have important effects on soil CO_2 efflux of grasslands. Cultivated meadow steppe resulted in increasing CO_2 efflux (B). However, the function of grazing in typical steppe grassland on CO_2 flux is uncertain (D, F) (fig. 2). Grazing resulted in increased CO_2 efflux from *Stipa grandis* grasslands and in decreased one in *Leymus chinensis* grassland. Changes of land-use practices might not result in increased daily CO_2 flux, and the change of CO_2 flux may be based on the land-use practice types and dominant species.

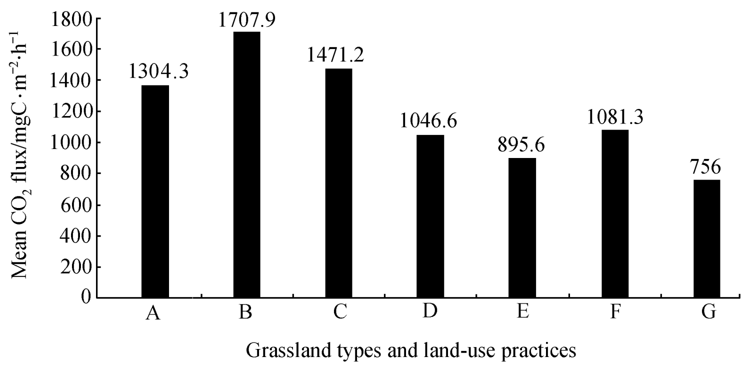

Fig. 2. Soil CO_2 fluxes from different grassland types and land-use practices. A, Meadow steppe; B, meadow steppe farmland; C, *Leymus chinensis* grassland; D, *Leymus chinensis* grazing; E, *Stipa grandis* grassland; F, *Stipa grandis* grazing; G, dry steppe.

2.1.3 Effects of environmental factors on the soil CO_2 flux. The hourly variation of CO_2 flux from *Leymus chinensis* grassland had a close linear correlation with air temperature (fig. 3, R^2 = 0.79, n = 10). However, this linear relationship between variation of CO_2 flux from different grasslands and land-use practices and temperature was lost (fig. 4). These results suggest that temperature is one important factor controlling the hourly variation of CO_2 flux from certain grassland type, and that the relationships between hourly variation of CO_2 flux and air temperature is dependent on grassland type and land-use practices.

2.2 Seasonal soil CO_2 flux and the effects of grazing

The seasonal pattern of soil CO_2 efflux based on continuous measurements at non-grazing and grazing *Leymus chinensis* grasslands from May 31,1998 to October 15, 1999 is shown in fig. 5. Daily soil CO_2 efflux from non-grazing *Leymus chinensis* grassland had a strong seasonal

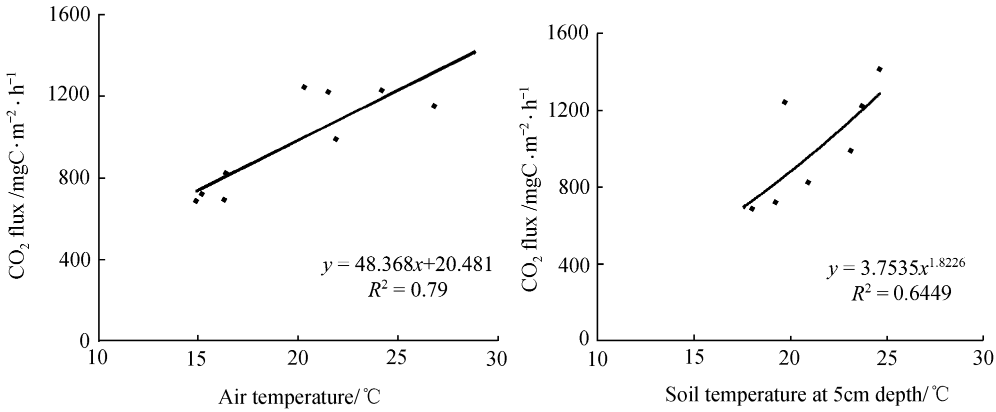

Fig. 3. Relationship between CO_2 fluxes from *Leymus chinensis* grassland and temperature.

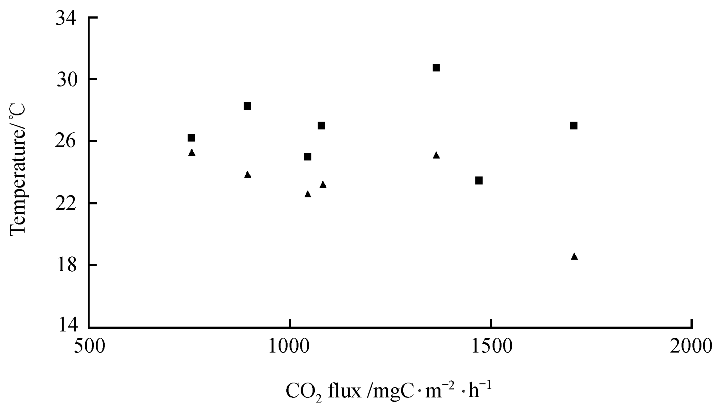

Fig. 4. Relationship between CO_2 fluxes from different grassland types and land-use practices and temperatures. ▲, Air temperature (°C); ■, 5-cm soil temperature (°C).

variation with peak rates during the warmer season and lower emission rates during the colder season. A similar pattern was also found in non-grazing *Stipa grandis* grassland[13], showing peak rates in late July.

Grazing activities did not result in different rates of soil CO_2 effluxes when compared to non-grazing plots in the *Leymus chinensis* grasslands (fig. 5). The average daily soil CO_2 flux on non-grazing and grazing *Leymus chinensis* grasslands were 1752.23±210.83 mg C m^{-2} d^{-1} and 1677.45 ± 229.46 mg C m^{-2} d^{-1} for 1998 and 1353.42 ±183.53 mg C m^{-2} d^{-1} and 1290.71±192.72 mg C m^{-2} d^{-1} for 1999, respectively.

We found that the daily soil CO_2 efflux was affected by the combined effects of air temperature and soil water content at the depth of 0—20 cm. Such correlation could be expressed as[9]

$$\mathrm{Ln(Res)} = 5.8596+0.0125M + 0.0394T + 0.0049MT, \quad R^2 = 0.58,$$

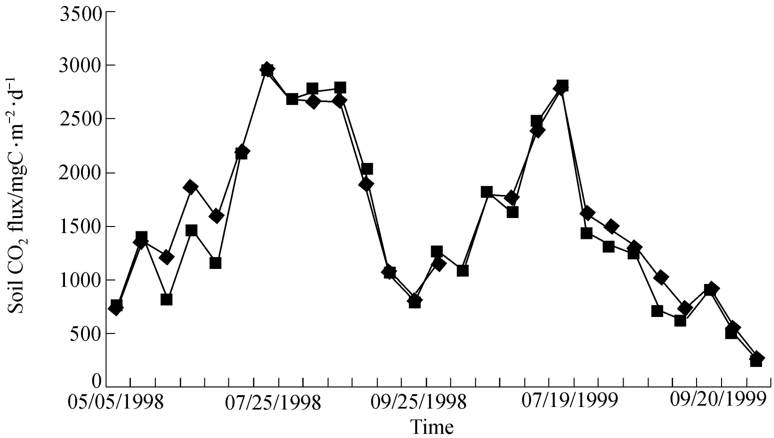

Fig. 5. Seasonal variation in CO_2 fluxes on non-grazing and grazing *Leymus chinensis* grasslands. ◆, Non-grazing plot; ■, grazing plot.

where Res is CO_2 flux (mgC m^{-2} d^{-1}), T is air temperature (℃), and M is soil water content (%). However, Chen et al.[14] found the daily soil CO_2 efflux from non-grazing *Stipa grandis* grassland to be affected by soil water content at the top 20 cm, according to the expression:

$$\text{Res} = 3.469\text{Log}_{10}(M) - 2.053, \quad R^2=0.84.$$

The relationships between daily soil CO_2 flux in non-grazing *Stipa grandis* and *Leymus chinensis* grasslands with environmental factors are different, although they have the same mean annual precipitation. Plant cover, which is very sensitive to water change, may explain the intrinsic responses to temperature and soil water content of soil respiration.

2.3 Carbon budget of typical ecosystems along NECT

CENTURY 4.0 simulations were run for 5000 years to reach equilibrium under natural conditions using repeated mean monthly temperature and CENTURY’s stochastic precipitation generator. Monthly mean maximum and minimum temperature and precipitation values were calculated by CENTURY 4.0 using actual observation data from the three ecosystem research stations. The model validation has been done in Inner Mongolia Grassland[15].

Fig. 6 shows the comparison between observed and simulated aboveground and belowground biomass from January, 1998 to October, 1999 at the Changling Grassland Station (*Leymus chinensis*). Sixty percent of the simulated aboveground biomass had less than 20% error, and eighty percent of the simulated belowground biomass had less than 25% error.

Simulated mean values for NPP of the mixed coniferous-broadleaved forest at Changbai Mountains Forest Ecosystem Research Station was 905.0 g C m^{-2} a^{-1}, and it is very close to the reported NPP value[16], 917.6 g C m^{-2} a^{-1}.

In the absence of disturbance, simulated temporal dynamics of NPP and total soil carbon

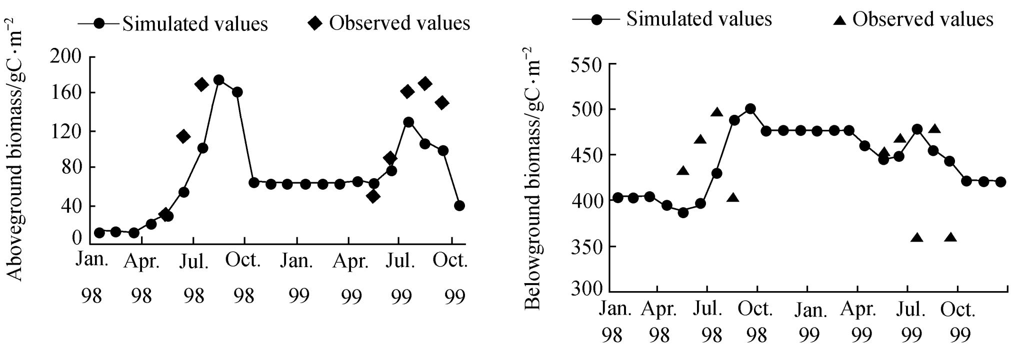

Fig. 6. Comparison of the observed and the simulated aboveground and belowground biomasses of *Leymus chinensis* grassland ecosystem

were different at the three sites along NECT (fig. 7). For each of the sites, inter-annual precipitation had a strong effect on NPP, which declined continuously due to decreased precipitation (fig. 7). The relationship between NPP and precipitation was linear (fig. 8), suggesting that precipitation is a main limiting factor for plant growth along NECT. NPP was highest at the mixed coniferous- broadleaved forest ecosystem and lowest at the typical steppe ecosystem, following the mean annual precipitation gradient along NECT. Moreover, the mean annual carbon budgets also showed the same pattern. The values of carbon budget was largest for the mixed coniferous-broadleaved forest ecosystem (503.2 gC m^{-2} a^{-1}), followed by the meadow steppe ecosystem

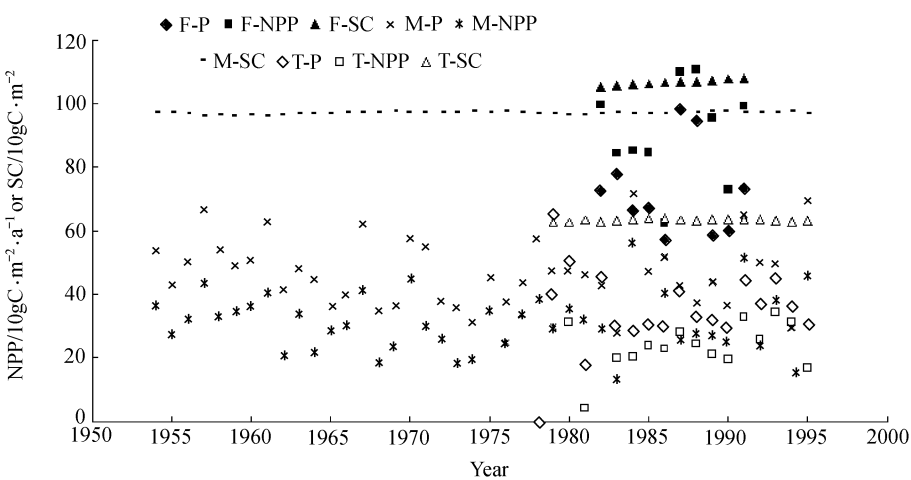

Fig. 7. Simulation of temporal dynamics of NPP and total soil carbon using actual weather records from 1982 to 1991 at Changbai Mountains Forest Ecosystem Research Station, from 1954 to 1995 at Changling Grassland Station, and from 1979 to 1998 at Inner Mongolia Grassland Ecosystem Research Station. F, Changbai Mountains Forest Ecosystem Research Station; M, Changling Grassland Station; T, Inner Mongolia Grassland Ecosystem Research Station; NPP, 10gC • m^{-2} • a^{-1}; SC, total soil carbon (10gC • m^{-2}).

(227.1 gC m^{-2} a^{-1}), and the lowest being the typical steppe ecosystem (175.8 gC m^{-2} a^{-1}). It also indicates that precipitation gradient is a main driving force along NECT.

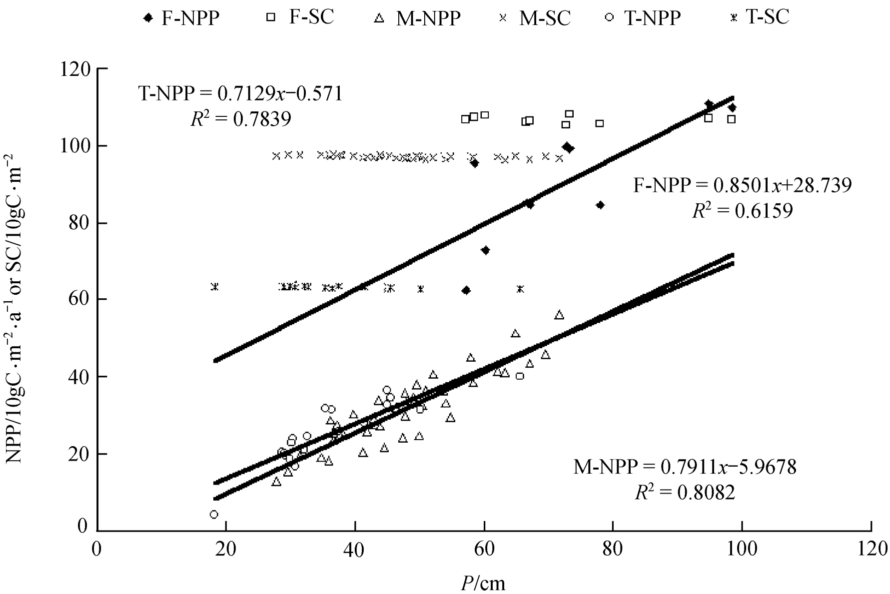

Fig. 8. Effects of precipitation (*P*) on NPP and total soil carbon at three simulated sites. F, Changbai Mountains Forest Ecosystem Research Station; M, Changling Grassland Station; T, Inner Mongolia Grassland Ecosystem Research Station; P, precipitation (cm); NPP, 10 gC • m^{-2} • a^{-1}; SC, total soil carbon (10 gC • m^{-2}).

The simulated temporal dynamics of total soil carbon along NECT was independent of inter-annual precipitation (figs. 7, 8). This might be due to the smaller fluctuation of inter-annual precipitation during the simulation. However, the values of total soil carbon decreased from the mixed coniferous- broadleaved forest ecosystem, through the meadow steppe ecosystem, to the typical ecosystem, following the mean annual precipitation gradient along NECT, suggesting some control of mean annual precipitation on soil carbon along NECT.

3 Discussion

Field measurements in different grassland types, different land-use practices and simulated values along the IGBP-NECT transect at different temporal scales were used to analyze the characteristics of the carbon balance along Northeast China Transect.

Soil CO_2 flux had a strong diurnal and seasonal variation. Daily and seasonal soil CO_2 fluxes were strongly affected by the grassland type and land-use practice. However, the seasonal soil CO_2 fluxes of *Leymus chinensis* grassland were not altered by grazing practices.

The simulated temporal dynamics of NPP, total soil carbon and carbon budget of the three typical ecosystems along NECT (mixed coniferous-deciduous forest ecosystem, meadow steppe ecosystem and typical steppe ecosystem) indicated that inter-annual precipitation had a very strong linear effect on NPP in each site. NPP and carbon budget decreased westward following the decreasing precipitation gradient of the NECT.

The relationship between NPP and precipitation was not showed in the total soil carbon along NECT. Thus, ecosystem NPP was more sensitive to changes in precipitation than total soil carbon, and therefore NPP seems a better indicator of climate change.

The lack of mechanistic understanding of controls of the carbon cycle in ecosystems under different vegetation types and land-use practices limit the development of robust carbon dynamic models. Here we show that the IGBP-NECT transect provides an effective tool for studying carbon cycling of terrestrial ecosystems in China. Grassland desertification, low grassland productivity and grassland conversion to agriculture may lead to a decrease of grassland carbon deposition and accelerate carbon losses from grassland, in addition to sensitivity of soil carbon to decompose under climate change. Similar studies should direct research to understanding the future of Chinese ecosystems under climate and land-use change.

Acknowledgements This work was jointly supported by NKBRSF (Grant No.G1999043407), the National Natural Science Foundation of China (Grant Nos. 30070642, 49905005,30028001), and the Chinese Academy of Sciences (Grant No. KSCX2-1-07, KZCX1-SW-01-12).

References

1. Esser, G., Contribution of Monsoon Asia to the carbon budget of the biosphere, past and future, Vegetatio, 1995, 121: 175—188.
2. Houghton, R. A., Hackler, J. L., Emission of carbon from forestry and land-use change in tropical Asia, Global Change Biology, 1999, 5: 481—492.
3. Fearnside, P. M., Global warming and tropical land-use change: greenhouse gas emission from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation, Climatic Change, 2000, 46: 115—158.
4. Houghton, R. A., The annual net flux of carbon to the atmosphere from changes in land use 1850—1990, Tellus, 1999, 51B: 298—313.
5. Bousquet, P., Ciais, P., Peylin, P. et al., Inverse modeling of annual atmospheric CO_2 sources and sinks: 1.Method and control inversion, J. Geophys. Res., 1999, 104(D21): 26161—26178.
6. Koch, G. W., Scholes, R. J., Steffen, W. L. et al., The IGBP Terrestrial Transects: Science Plan. IGBP Report No.36, Stockholm: IGBP, 1995.
7. Zhang Xinshi, Gao Qiong, Yang Dianan et al., A gradient analysis and prediction on the Northeast China Transect (NECT) for global change study, Acta Botanica Sinica, 1997, 39(9): 785—799.
8. Dong, Y., Zhang, S., Qi, Y. et al., Fluxes of CO_2, N_2O and CH_4 from a typical temperate grassland in Inner Mongolia and its daily variation, Chinese Science Bulletin, 2000, 45(17): 1590—1594.
9. Li Linghao, Wang Qibing, Bai Yongfei et al., Soil respiration of a *Leymus chinensis* grassland stand in the Xilin River Basin as affected by over-grazing and climate, Acta Phytoecologica Sinica, 2000, 24(6): 680—686.
10. Anderson, J. P. E., Soil respiration, in Methods of Soil Analysis, Chemical and Microbiological Properties (ed. Page, A. L.), Part 2, Madison: American Society of Agronomy, 1982, 831—871.
11. McGuire, A. D., Joyce, L. A., Kicklighter, D. W. et al., Productivity response of climax temperature forests to elevated

temperature and carbon dioxide: a North American comparison between two global models, Climate Change, 1993, 24: 287—310.

12. IGBP, Terrestrial Carbon Working Group, The terrestrial carbon cycle: implications for the Kyoto protocol, Science, 1998, 280: 1393—1394.
13. Parton, W. J., Scurlock, J. M., Ojima, D. S. et al., Observations and modeling of biomass and soil organic matter dynamics for the grassland biome worldwide, Global Biogeochemical Cycles, 1993, 7(4): 785—809.
14. Chen Siqing, Cui Xiaoyong, Zhou Guangsheng et al., Study on the CO_2-release rate of soil respiration and litter decomposition in Stipa grandis steppe in Xinlin River Basin, Inner Mongolia, Acta Botanica Sinica, 1999, 41(6): 645—650.
15. Xiao, X. M., Wang, Y. F., Chen, Z. Z., Dynamic of net primary productivity and soil organic carbon of typical steppe ecosystems in Xilin River, Inner Mongolia and its responses to climate change, Acta Botanica Sinica, 1996, 38(1): 45—52.
16. Li, W. H., Study on Biomass of main ecosystems in Changbai mountains, Forest Ecosystem Research (II), 1981, 34—50.