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Global and Planetary Change 41 (2004) 241–249

GLOBAL AND PLANETARY CHANGE

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Mutual influence between human activities and climate change in the Tibetan Plateau during recent years

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Abstract

It is well known that there is a vast expanse of grassland on the Tibetan Plateau, China. It is suggested that a major climatic factor limiting production of the grassland ecosystem is the low thermo-conditions on the Tibetan Plateau. An increase in temperature may therefore increase the productivity of grasslands on the Plateau. Monthly mean temperature and monthly precipitation data for recent years on the Tibetan Plateau were analyzed. It is clear that the increase in air temperature on the Plateau is greater than that in the whole China and East Asia. On the other hand, statistics show that the production of livestock or meat in the Tibetan Plateau has increased by one to three times since 1978, which means that there should be an equivalent increase in the consumption of plant biomass from the grassland. How is the "increased biomass" related to human activities and climate changes? This paper tries to clarify the relationship between human activities and climate change and to propose a possible answer by laying emphasis on the importance of grassland protection and CO_2 flux monitoring. It is suggested that there is a positive feedback in which degradation of grassland by overgrazing will increase potential evapotranspiration level thereby promoting the climate warming and the degradation process. This feedback should be considered seriously in the future.

Keywords: Biomass; Climate change; Feedback; Grassland; Livestock; Tibetan Plateau

1. Introduction

The Tibetan Plateau (or Qinghai-Xizang Plateau, hereafter TP) with an average elevation of more than 4000 m above sea level (a.s.l.) and area of about 2.3 million km^2 is of immense importance both to climate and to ecosystems of the Asian continent and even the whole world. Although adequate knowledge of climate change over the TP is still insufficient, which is partly due to the lack of sufficient observational data, research on the climate change in the TP has received more and more attention in the literature since mid-1970s (e.g. Lin and Zhao, 1996; Tang et al., 1998; Zheng and Zhu, 2000; Zheng et al., 2000). Many studies show there is strong evidence that the TP exerts profound thermal and dynamical influences on the local weather and climate as well as on atmospheric circulation (e.g. Manabe and Terpstra, 1974;

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doi:10.1016/j.gloplacha.2004.01.010

Yeh and Gao, 1979; Yanai et al., 1992) and some studies suggest that the TP is one of the most sensitive areas to respond to global climate change (e.g. Zhang et al., 1996; Liu and Chen, 2000). Recent work by analyzing the temperature series of 97 stations carried out by Liu and Chen (2000) showed that the main portion of the TP has experienced statistically significant warming since the mid-1950s, especially in winter. The linear rates of temperature increase over the TP during the period 1955–1996 are about 0.16 °C/decade for the annual mean and 0.32 °C/decade for the winter mean, which exceed those for the Northern Hemisphere and the same latitudinal zone in the same period. However, its cause has not been clarified. There is no work dealing with the possible interaction between climate change in the TP and human activities such as grazing. Most of the work concerning climate change in the TP attempt to link the climate change to atmospheric circulations or global warming related to the atmosphere greenhouse gases (e.g. Lin and Wang, 1994; Yin et al., 2000; Liu and Chen, 2000; Liu and Yin, 2001).

It is well known that there is a vast expanse of grassland on the TP. The complex terrain and variable boundary conditions of the TP create unique weather and climatic characteristics as described in some Chinese and English literatures (e.g., Yeh and Gao, 1979; Gao et al., 1984; Domros and Peng, 1988; Tang et al., 1998; Zheng et al., 2000). Despite its harsh climatic conditions, millions of people make use of this vast area through the management of the rangelands that provide the feed for a variety of livestock on which people depend for their daily survival. Six of the largest rivers of the world originate from the TP and provide the much-needed irrigation water that feed the agricultural fields of hundreds of millions of farmers in the downstream regions. Climate impact on human activities and human impact on climate change in the TP have great importance not only to the local area but also to the whole Asian continent and even to the whole world. Some recent biome simulation work on the TP and their responses to global climate change has suggested that there would be a great change in vegetation and permafrost distribution and a significant increase in net primary production on the TP under changed climate with a CO_2 concentration increasing (Zhang et al., 1996; Ni, 2000).

The purpose of this study is to examine the relationship between human activities and climate change in the TP in recent years.

2. Data and methods

Due to the unique environment and social economic development situation, agricultural land (total of grazing land, farmland, forestry and orchard) is about 62% of the total TP and undeveloped land is 34%. Of the agriculture land, grazing land occupies about 80% and forestry about 19% (Wu and Yang, 2000). The annual statistic livestock production and meat production were therefore used for indicating the human activities. Monthly mean surface air temperature and precipitation data from most meteorological stations on the TP are used in this study. Since the statistic livestock production data is available only for administrative districts such as Xizang, the Tibet Autonomous Region (hereafter Tibet), Qinghai Province and the other regions of TP (some parts of Sichuan Province), meteorological stations on TP were also divided into two groups as Tibet (26 stations) and other places on the TP (60 stations) as shown in Fig. 1. Most of the meteorological stations of the TP are situated in its eastern region as shown in Fig. 1. The main region of grassland is also in the east part of the TP. The spatial distribution of these stations is almost overlapped by the area of grasslands on the TP.

Livestock production data is available only from 1978, all the data for livestock were normalized as follows:

$$D_i = (d_i - d_{1978})/d_{1978} \times 100\% \quad (1)$$

where D_i is normalized data of the year i and d_i is the original data of livestock; d_{1978} is the data in 1978.

For air temperature and precipitation anomaly, we have:

$$\text{Anomaly} = P_i - P_{1978} \quad (2)$$

where P_i is the monthly mean air temperature or precipitation, P_{1978} is the original data of monthly mean for 1978.

In order to evaluate the importance of air temperature variation to the grasslands in the region, 30 years

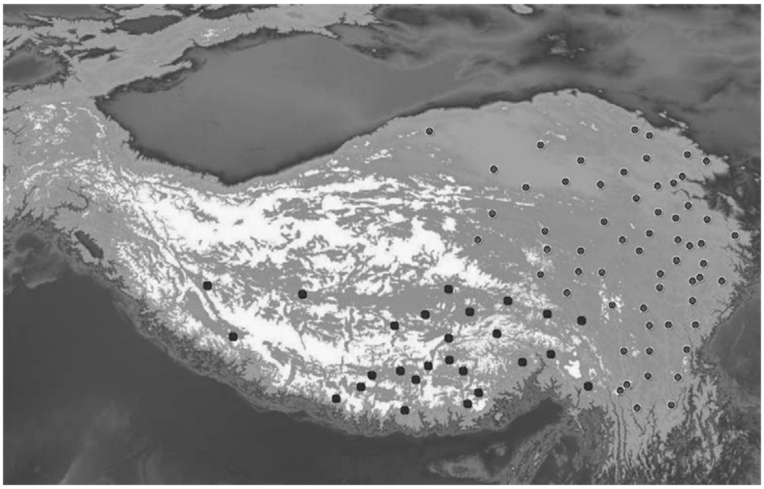

Fig. 1. Location of the meteorological stations used. The black points and circles represent stations in Xizang, the Tibet Autonomous Region and the other regions of Tibet Plateau (include Qinghai Province, parts of Sichuan Province), respectively.

(1960–1990) mean air temperature, precipitating, pan evaporation from 132 stations in the total Chinese grassland were also analyzed. And Martonne's arid index (AI) were calculated as follows:

$$AI = P/(T + \alpha) \quad (3)$$

where P is precipitation, T is air temperature and α is Martonne's constant, we take α=10.

3. Results

3.1. Increase in livestock and meat production

Fig. 2 shows the annual variation of production numbers of livestock in Tibet and Fig. 3 shows the meat production variation in Tibet from 1978 to 1999. It can be seen that the production of sheep in Tibet has increased 106% and that of cattle 249% since 1978.

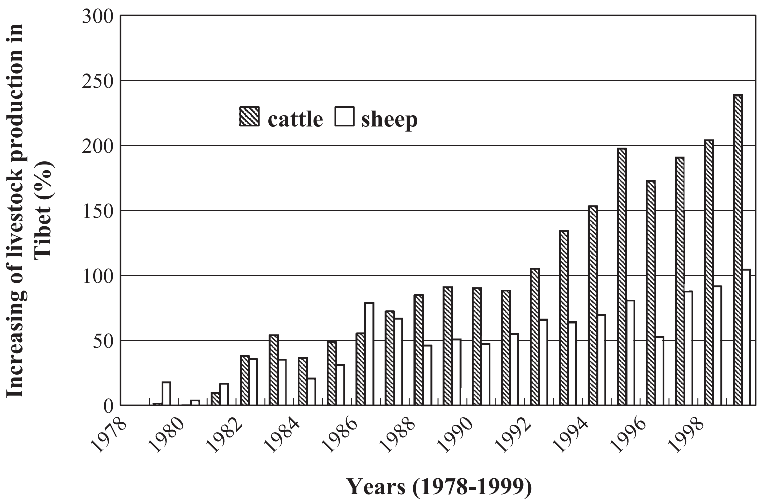

Fig. 2. Increase in livestock (cattle and sheep) productions in Tibet from 1978 to 1999 (%, base is 1978).

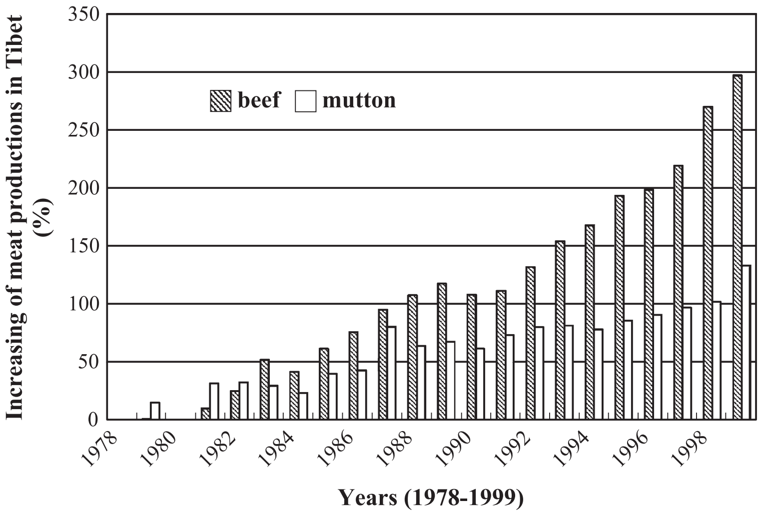

Fig. 3. Increase in meat (beef and mutton) productions in Tibet from 1978 to 1999 (%, base is 1978).

Increases in beef and mutton production in Tibet are about 297% and 133%, respectively. Total meat production (beef, mutton and pork) has increased 212%. For other region of the TP, meat production has increased about 220% and number of cattle and sheep has increased about 180% and 160%, respectively, since 1978. The increase in production of livestock means that there should be an equivalent increase in the consumption of plant biomass from the grassland on the TP since there is no feed import to the TP.

3.2. Increase in air temperature and variation in precipitation

As mentioned above, the main portion of the TP has experienced statistically significant warming (e.g. Tang et al., 1998; Liu and Chen, 2000) during the last 40 or 100 years. To compare the variation of livestock production from 1978 to 1999 with climate, we analyzed air temperature and precipitation variation in the most recent 18 years of record between 1978 and 1995

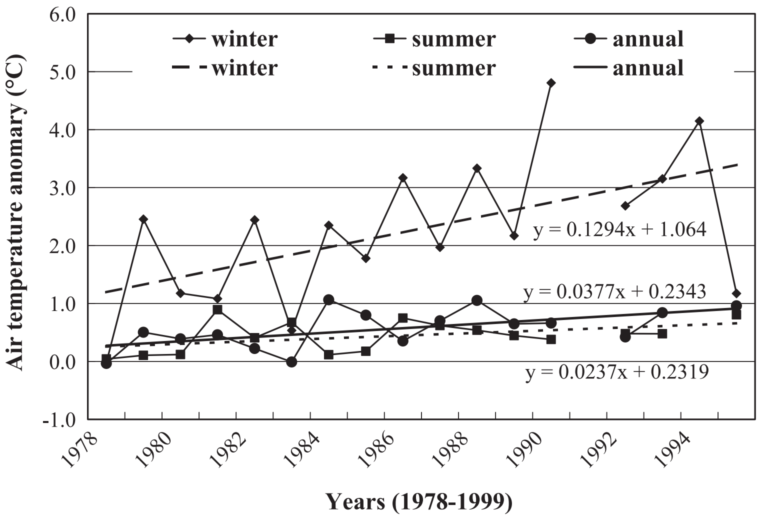

Fig. 4. Winter (Dec. to Feb.), summer (Jun. to Aug.) and annual mean air temperature anomalies (°C) in Tibet from 1978 to 1995.

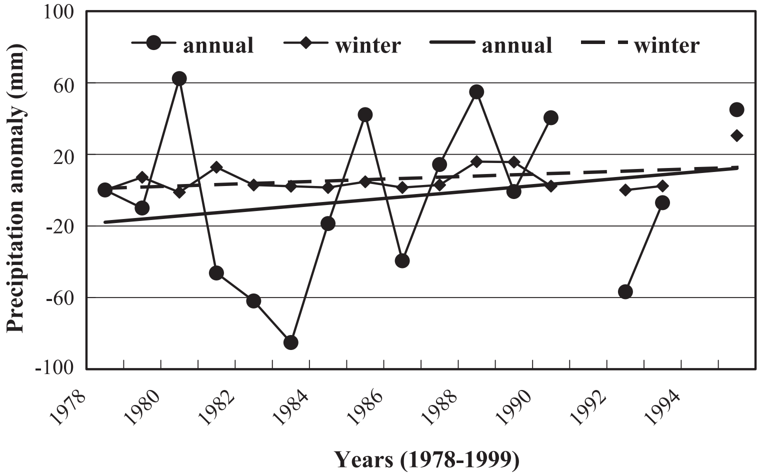

Fig. 5. Winter (Dec. to Feb.) and annual mean precipitation anomalies (mm) in Tibet from 1978 to 1995.

(unfortunately we did not have the 1996–1999 data and data for some stations was missing in 1991, 1994 and 1995). Fig. 4 shows the variation of air temperature anomalies of winter (from December to February), summer (from May to July) and annual mean from 1978 to 1995. Note here that 1978 is used as the reference year. There are marked warming trends (0.13 °C/year in winter, 0.02 °C/year in summer and 0.04 °C/year in annual mean) during the 18 years similar to the result of Liu and Chen (2000). This warming trend is greater than that of the whole China and East Asia (Hulme et al., 1994; Lin and Zhao, 1998).

Fig. 5 shows the variation of precipitation anomalies of winter and annual mean from 1978 to 1995. It can be seen that precipitation on the TP increased slightly and exhibited no statistically significant trends during the period.

3.3. Relationship between climate change and livestock change

As discussed below, climate warming may promote vegetation growth on the TP. However, there is no independent grassland production data. We presume

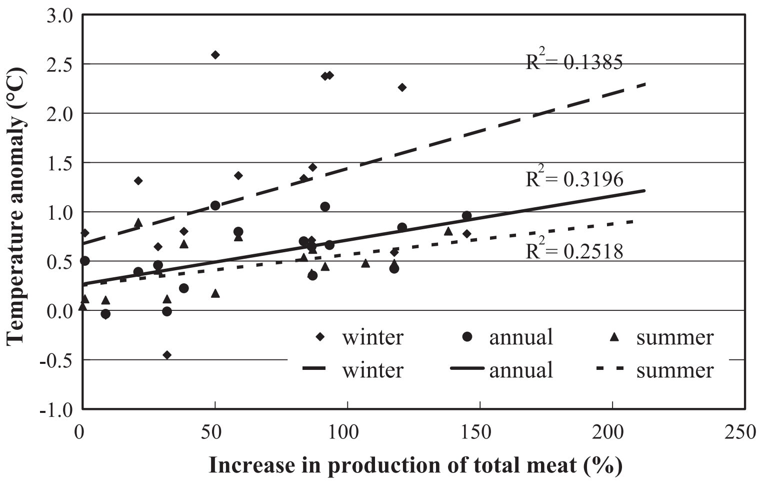

Fig. 6. Relationship between air temperature anomaly (°C) and increase in production of total meat (%) in Tibet.

that the increased amount in livestock production results from the increased consumption of feed or grass biomass on the TP, and we analyzed the relationship between air temperature anomalies and production variation of meat. There is a good statistical significant relationship (at the 95% level) between livestock production and the climate warming in summer and in the annual mean. As shown in Fig. 6, total meat production increase in Tibet is directly proportional to the climate warming in summer and in the annual mean temperature. But there is no statistical significant relationship between livestock or meat production and temperature change in winter and between livestock or meat and precipitation.

4. Discussion and conclusions

Livestock husbandry in the TP is still performed a primitive natural nomadic manner. There is even no artificial grassland field on the TP and no feed import from outside of TP. Production of livestock largely depends on the natural grass and water condition, and the efficiency of animal husbandry practices. Therefore, increase in production of livestock or meat means increased feed or plant biomass use on the TP. One to three times increase in production of livestock means that there should be an equivalent increase in the consumption of plant biomass from the grassland. How did these increased plant biomasses arise? The presumable causes can be as follows: (a) consumption of new source of plant biomass; (b) increase in production of plant biomass; (c) both (a) and (b) with overgrazing.

Although the TP has its unique weather and climatic characteristics, some literature has classified the climate of the grassland in the Tibetan Plateau as a semi-humid-summer steppe climate with cold and dry winter as for other grasslands in China (refer to Domros and Peng, 1988). Chinese grasslands are mainly distributed in a belt from northeast to southwest regions, mainly in the Inner Mongolia Autonomous Region and the TP. Distribution of annual air temperature and precipitation is almost similar in the whole Chinese grassland. However, as shown in Fig. 7, air temperature in summer is much lower on the TP than that in Inner Mongolia, and thereby the Martonne's arid index (AI) is greater and pan evaporation is lower on the TP in July. AI is inversely proportional to air temperature in July on the TP, while that does not change much with air temperature. It is suggested that the main restrictive climatic element is thermo-condition in the TP, while that in Inner Mongolia is water availability. This means that increase in temperature may therefore increase the productivity of grasslands on the Plateau. This is

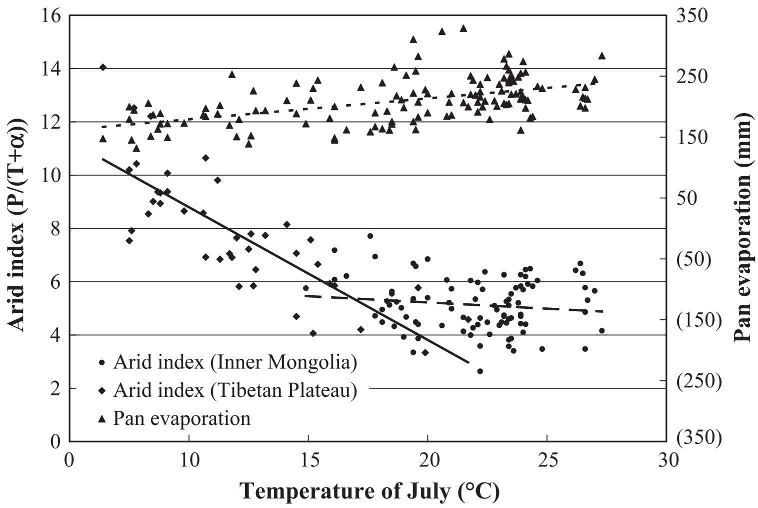

Fig. 7. Relationship between Martonne's arid index and air temperature and between pan evaporation and air temperature in July in Chinese Grasslands (Inna Mongolia and the TP).

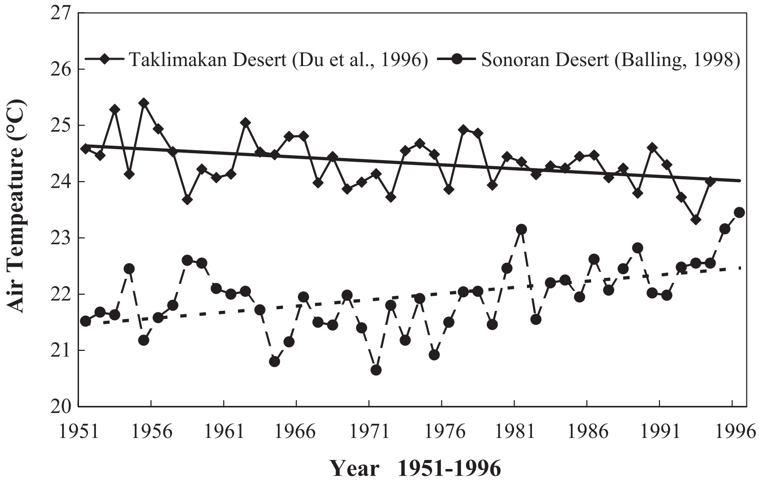

Fig. 8. Examples of impacts of vegetation cover changes on air temperature changes. Summer temperature decrease in Taklimakan Desert due to expansion of oases (redraw from Du et al., 1996) and annual temperature increase in Sonoran Desert due to overgrazing (redraw from Balling et al., 1998).

possibly one reason for supporting the increase in livestock production in recent years. However, it seems difficult to reach the conclusion that one to three times of increase in production of plant biomass is resulted from about 1 °C increase in air temperature. Increasing production of livestock therefore must have used new sources of vegetation suggesting over grazing for some regions. Actually, degradation of grassland due to over grazing on the TP is known to have proposed a problem (Zhu and Li, 2000). One form of the degradation is that it has changed the structure of plant communities and this structure change not only restrained growth of grasses and sedges and contested against livestock for food, but also destroyed plant cover and formed micro landforms, which induced loss of water and soil and essentially degraded the grassland ecosystems.

On the other hand, vegetation variation, especially land degradation by over grazing can affect climate change (e.g. Jackson and Idso, 1975; Courel et al., 1984; Balling, 1988, 1991, 1989; Du, 1996; Du et al., 1996). Many researchers have found that a decrease in vegetation cover reduces evapotranspiration thereby allowing an increase in local temperature levels. As shown in Fig. 8, Balling (1988, 1991, 1989) has revealed that overgrazing and the resultant land degradation in semiarid areas of northern Mexico resulted in significantly higher temperatures. In contrast, Du (1996) and Du et al. (1996) have revealed that due to an expansion of the area of oases, and the increase in windbreak forests have caused an increase in precipitation and decrease in air temperature in summer in the western part of the arid region of China, especially in the Taklimakan Desert. Degradation of grassland on the TP should have been affected the climate change on the TP. This may be one of the reasons why climate warming on the TP is greater than on other places.

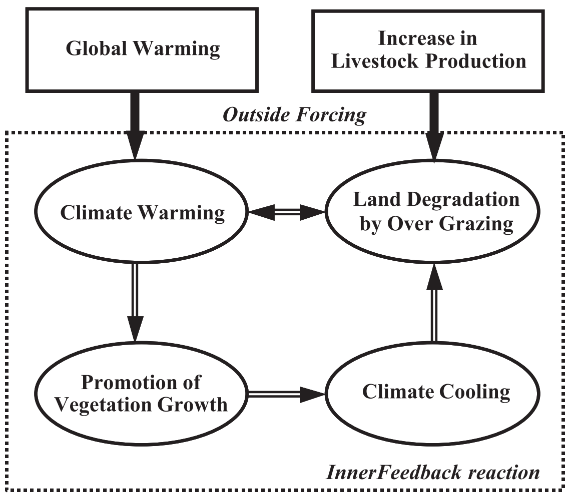

Fig. 9. A simple sketch of relationship between human activities (grazing) and climate change on the TP.

Thus, we can draw a simple sketch as Fig. 9 for considering the relationship between human activities and climate change on the TP. There are two main kinds of forcing functions, the global warming due to greenhouse gas increases and increasing in production of livestock due to population increase and economic development. These dive local climate warming and land degradation by overgrazing. The local climate warming will then promote vegetation growth and accelerate land degradation by effecting water condition (increase in evapotranspiration). Vegetation growth will reduce the warming effect (climate cooling), however climate cooling is not suitable for vegetation growth and thereby will accelerate land degradation processes. Overgrazing will lead to an increase in potential evapotranspiration thereby promoting the local climate warming and further accelerate land degradation processes.

Therefore, the following conclusions can be made. A one-to-three times increase in livestock production in the TP has occurred since 1978. An increase in air temperature on the TP, greater than for whole China and East Asia has occurred within the same period. The increase in livestock production is directly proportional to the degree of climate warming. The temperature rise has resulted in increased potential vegetation growth in the TP. The increase in livestock production reduces biomass and land degradation by overgrazing occurs. This promotes temperature increase and exacerbates land degradation. Protection and increase in vegetation or biomass growth would reduce the temperature-increasing rate in the future.

Grassland occupies about 50% of the TP and may act as a carbon sink nowadays. Climate warming may increase the productivity of the grassland on the Plateau. It may also accelerate carbon releasing at the same time, especially when grassland degradation occurs. At the present time, extensive field observations of energy balance and CO_2 flux has been started recently on the TP at Haibei Alpine Meadow Ecosystem Research Station (37°18′ N, 101°36′ E, 3200 m a.s.l.) under a Japan–China cooperation project. Preliminary analyses of the data suggest that daily net ecosystem exchange of CO_2 in August is much greater than for other grasslands and the air temperature and radiation may play a very important role on the daytime net uptake of CO_2. Future studies should contribute a further understanding of the role of vegetation changes in the relationship between human activities and climate change and in the carbon circulation process.

Acknowledgements

The authors wish to thank Dr. Y. Tang from National Institute for Environmental Studies, Japan for his helpful comments. This study was supported through The Global Environment Research Fund of Ministry of Environment, the Japanese Government.

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