Effect of grazing on net primary production of a Mongolian grassland ecosystem

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Introduction

Mongolia is located on northeastern Asia, where ecotone (forest-grassland-desert) is formed because of climatic shift from humid condition to arid condition. An ecotone is a sensitive transitional area between two adjacent ecological communities and generally sensitive to external disturbance (climate change, human activities etc.)

Approximately 75% of Mongolian total area is grassland and shrubland, which has been grazed by domestic livestock all the year around (Maria E. Fernandez-Gimenez, 1999). So grazing is the normal use of these grasslands, as well as main disturbance to the grassland ecosystem. Therefore effect of grazing should be taken into account in order to understand carbon cycle of the Mongolian grassland ecosystem correctly.

Net primary production (NPP) is an important component in terrestrial carbon cycle research. Aboveground net primary production (ANPP) is directly relative to grazing capacity of grassland.

Plant growth and defoliation dynamics are difficult to monitor in grazed rangeland partly because of the large areas and relatively long duration of active interaction between herbivores and vegetation, and partly because of the difficulties encountered in measuring forage consumption of free–ranging animals (White, 1984). In addition, well controlled grazing trials require heavy investment that often makes their implementation impractical. So it is helpful to use simulation models of grazed grassland to clarify the issues that may be involved in grazing experiment, and eventually supply some suggestion for grazing management in rangeland.

The objective of the present study is to study the effect of grazing on aboveground net primary production using a simulation model and to estimate an appropriate stocking rate in KherlenBayaan-Ulaan (KBU) grassland.

Study site

The study site is KherlenBayaan-Ulaan (47º3′N, 108º8′E). Altitude is 1300m above sea level. The mean annual precipitation is 202mm. The mean annual temperature is 1.4℃. Vegetation is semi-arid steppe. Dominant species are *Stipa krylovii, Artemisia frigida* and *Cleistogenes squarrosa*. C4 plant species percent occupy about 10% of total biomass (Mariko *et al*, 2003).

Model description

The basis for the present study is Sim-CYCLE developed by Ito and Oikawa (2002). It was developed on the basis of dry-matter productivity theory. Sim-CYCLE is a compartment model. Terrestrial carbon dynamics is conceptualized as a five-compartment system (Fig.1). Carbon in a given ecosystem (WE) is composed of plant biomass (WP) and soil organic carbon (WS). WP includes three compartments: foliage (F), stem (C), and root (R); WS includes two compartments: litter (L) and humus (H).

$WE=WP+WS$

$WP=WP_F+WP_C+WP_R$

$WS=WS_L+WS_H$

Gross primary production (GPP) is the ultimate origin of all organic carbon, through which atmospheric CO_2 is fixed into dry matter. Instantaneous GPP (GPP_{INS}) is as follow:

$$GPP_{INS} = \int_0^{LAI} PCLAI$$
$$= \frac{PC_{SAT}}{KA}[\ln\{QE + KAPPFD_{TOP}\} - \ln\{QE + KAPPFD_{TOP} * \exp(-KALAI)\}]$$

where PC is single-leaf photosynthetic rate, and

LAI is leaf area index, PC_{SAT} is the single-leaf photosynthetic rate under light-saturation, QE is light-use efficiency, KA is light attenuation coefficient, $PPFD_{TOP}$ is the photosynthetic photon flux density at the canopy top.

Net primary production (NPP) is the difference between GPP and plant autotrophic respiration (AR).

NPP =GPP-AR+Dr

=△W+litterfall+Dr

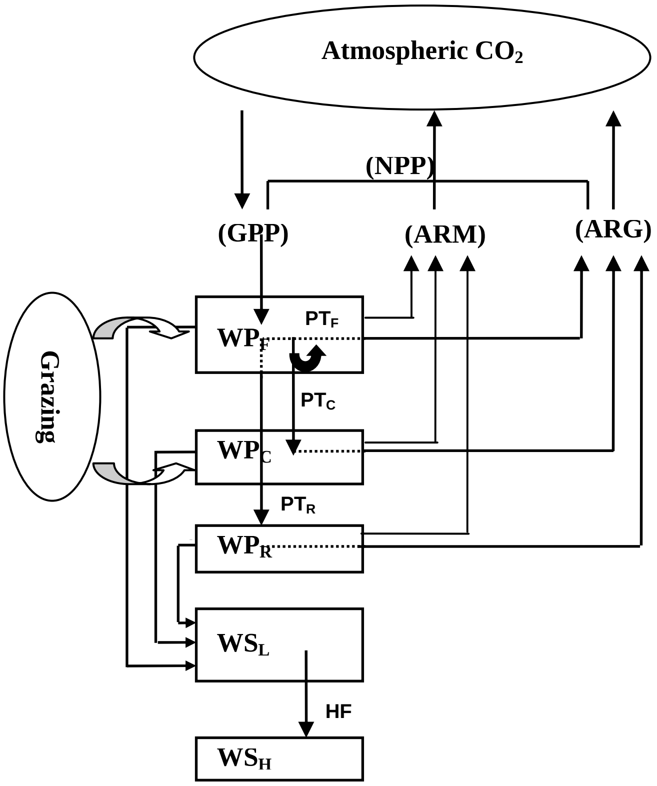

Fig.1 Model structure of Sim-CYCLE (Ito and Oikawa, 2000)

(GPP, Gross primary production; WP_F, foliage; WP_C, stem; WP_R, root; WS_L, litter; WS_H, humus;

ARM, maintenance respiration; ARG, growth respiration)

Sim-CYCLE has been incorporated into a defoliation model in order to simulate effect of grazing on NPP of grassland ecosystem.

Defoliation model (Seligman N.G., 1992) is:

$$D_r = ES_r((WP_F + WP_C) - (WP_F + WP_C)_u)$$

$(0<D_r<S_rD_x)$,

where D_r is defoliation rate (kg ha^{-1} d^{-1}), E is grazing efficiency of livestock (ha d^{-1} per animal), S_r is stocking rate, $(WP_F+WP_C)_u$ is residual biomass unavailable to the livestock (kg ha^{-1} dry matter), D_x is satiation consumption rate of the livestock (=2.4kg d^{-1} per animal).

The grassland was regarded as evenly distributed from top to bottom when the effect of grazing was simulated. It was also regarded as evenly distributed over the site without extreme clumping and without large areas of bare soil; In addition there are many characteristics that are not simulated:

The simulated forage intake is limited to total green leaf and stem. The defoliation routine in this model deals only with green biomass on the assumption that not only is green biomass highly preferred by most livestock but that the amount of green biomass is critical element in the plant system that controls both assimilation and transpiration.

In this study, animals are considered as consumers, i.e. their effect on the grass process only result from "negative" effects.

Plant nutrients are regarded as non-limiting.

The time step is month. Meteorological data and soil data were obtained from the RAISE project.

Results and discussion

Model validation at KBU

Measured data were obtained by clipping experiments at KBU (Urano *et al*, 2004). The simulation results were compared to the measured data in Fig2. The measured data are from enclosure, and then there is no grazing. It is clear that the simulated results show a satisfactory agreement with them. However, it is not always perfect, because the model simplified the real world greatly. It was set up to study potential production as a function of soil water and temperature when soil nutrient did not limit plant growth in the model. All of them could account for the deviation between simulated results and measured data. Despite these deviations, the maximum simulated LAI and ANPP coincided with maximum measured data.

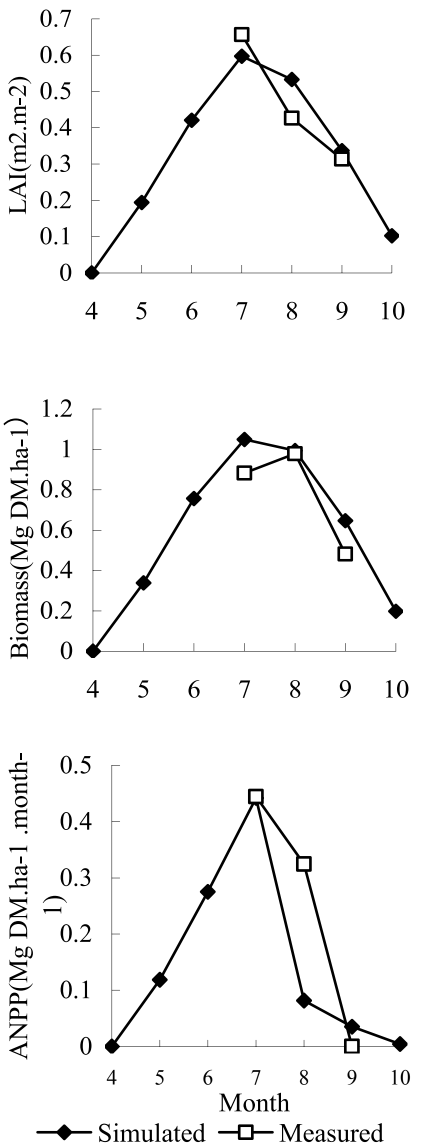

Fig.2 Simulated and measured data at KBU

Aboveground biomass under different stocking rate

Aboveground biomass decreased along an increasing stocking rate (Fig3). The percent of aboveground biomass decrease is different under different stocking rate. In July, aboveground biomass decreased 20% at 1 sheep.ha^{-1} stocking rate. The decrease is 52% at 4 sheep.ha^{-1} stocking rate. Root cease to grow or will die when aboveground biomass was decreased more than 50% (Wang, 2003). Peak aboveground biomass is in July from 1 to 3 sheep ha^{-1} stocking rate. The peak value is in June at 4 sheep ha^{-1} stocking rate. In KBU, precipitation and temperature are optimum for plant growth in July. But peak aboveground biomass under 4 sheep.ha^{-1} stocking rate is not in July. It suggested that the grass cannot grow normally. So the maximum stocking rate should not be higher than 3 sheep.ha^{-1}.

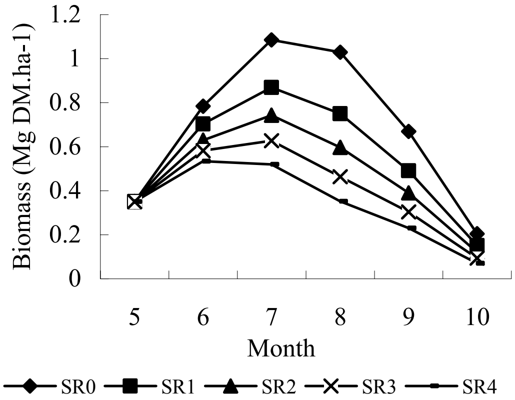

Fig3 Effect of grazing on aboveground biomass

Aboveground net primary production under different stocking rate

Aboveground net primary production also decreased with increasing stocking rate (Fig4). Maximum ANPP is 0.46 Mg dry matter ha^{-1} month^{-1} under no grazing condition. It is 0.40Mg dry matter.ha^{-1} month^{-1} when the stocking rate is 1sheep.ha^{-1}. It is 0.23Mg dry matter ha^{-1} month^{-1} at 4 sheep ha^{-1} stocking rate. LAI will decrease when grass was defoliated by animal. Total intake by animal increased with increasing stocking rate. ANPP decreased due to the above mentioned reasons.

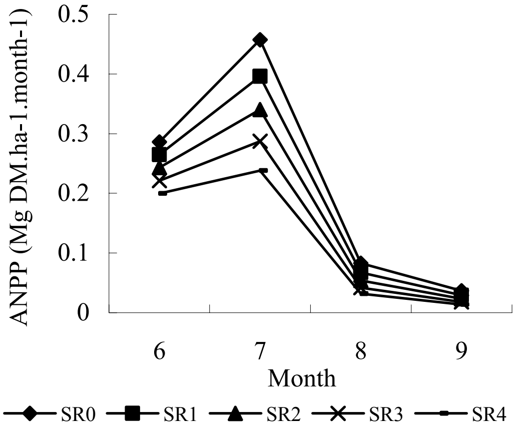

Fig4 Effect of grazing on aboveground net primary production

Conclusion

The following conclusion can be obtained from the present simulation. Aboveground net primary production decreased along an increasing stocking rate. The appropriate stocking rate of KBU grassland is about 3 sheep or sheep equivalent per hectare.

References

Ito Akihiko and Oikawa Takehisa, 2002. A simulation model of carbon cycle in land ecosystems (Sim-CYCLE): a description based on dry-matter production theory and plot-scale validation. Ecological modeling, 151: 143-176.

Maria E. Fernandez-Gimenez, Barbara Allen-Diaz, 1999. Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. Jounal of Applied Ecology, 36, 871-885.

Mariko Shigeru, Urano Tadaaki, Oikawa Takehisa. Biomass and carbon fluxes in a Mongolian grassland. The second workshop on terrestrial change in Mongolia. 2003.

Seligman N.G., Cavagnaro J.B. and Horno M.E., 1992. Simulation of defoliation effects on primary production of warm-season, semiarid perennial-species grassland. Ecological Modelling, 60, 45-61.

Urano Tadaaki, Mariko Shigeru, Kiyokaza Jawada. Japan Earth and Planetary Science Joint Meeting, 2004.

Wang Shiping, Wang Yanfeng, Chen Zuozhong. Grazing ecosystem management. Science Press, China, 26p, 2003.

White, E.G., 1984. A multispecies simulation model of grassland producers and consumers. Ⅰ. Validation. Ecol. Modelling. 24: 137-157.