

Full Length Research Paper

Effects of mowing disturbance on the community succession of typical steppe in the Loess Plateau of China

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Research based on *Stipa bungeana* community enclosing typical steppe zone in the Loess Plateau, and through different intensity-mowing disturbance test for 27 years, shows that higher species diversity and productivity are retained for grassland through moderate mowing, promotion of substance balance, starting cycle and providing an important basis for reasonable mowing and using the enclosed grassland. Due to the effects of rainfall and plant growth environment in mowing early days (1982 to 1987a), the species diversity of the grassland showed conk-increasing trend, and the species diversity showed significant changes under different intensity-mowing, and later -mowing (1988 to 2008a). The obtained results are as follows: mowing once every 2 year was 24.1 ± 0.64 (species/m²); mowing once a year was 15.5 ± 0.37 (species/m²), and mowing twice a year was 13.9 ± 0.41 (species/m²). The biomass presented a parabola model in three mowing treatments, and average aboveground biomass in 27 years showed that: mowing once every 2 years was 785.6 ± 111.84 (g/m²), mowing once a year was 630.8 ± 115.1 (g/m²), and mowing twice a year was 501.5 ± 120.53 (g/m²). The succession process of grassland community of three mowing disturbance had five phases: *S. bungeana* community reached the sub-climax at the iv succession phase with the abundant species number of plant community reaching 159; the shrubs and herbages of forest-steppe zone showed that the succession of typical steppe community tended to forest or bush steppe development. For the succession at the v period, *S. bungeana* as constructive species turned to mutation when the individual numbers of the community declined substantially and the clusters appeared to be a serious-death phenomenon. *Stipa grandis* community had the tendency that substituted for *S. bungeana* and became the constructive species. However, tiller capacity of the individual was poor, and the cluster small, and the coverage and biomass were low for *S. grandis*, so whether or not it reached the climax communities, succession growth needs to be observed further. The following results provide more scientific evidence for plant-soil system interactions and grassland management.

Key words: Plant-soil biosystem, typical steppe, *Stipa bungeana* community, mowing frequency, succession process, Loess Plateau.

INTRODUCTION

Owing to the great human impact on grassland ecosystem, the ecological function of mowing disturbance has been researched generally (Liu et al., 2002a, b; Wang, 1996). Temperate grassland takes up about one-

fourth of the territory in China, and has many unique species of genetics and ecology. However, grassland has

been disturbed and destroyed seriously by human activities (Liu et al., 2008). Disturbance is an important reason for grassland degradation, desertification, salinization-alkalization, as well as a dominant factor for species diversity for grassland ecosystem (Sprugel and Bormann, 1981; Li and Zhang, 1998). Grassland ecosystem environment and biology resource quality shows that occupied space, scale, modality and distribution have been affected by longer terms of unreasonable mowing disturbance (Ding et al., 1993; Zhang, 1993). Meanwhile, as the account of species diversity changed, grassland area became shortened and its biomass declined gradually. Therefore, study on mowing disturbance has a profound significance on preserving stability and sustainable development for grassland ecosystem (Wang, 1998).

Mowing is primary used for grasslands, and mowing experiment is the most commonly used method for grassland research. Many researches about effects of grassland by mowing had been done for many years, and already produced several achievements (Cheng, 1991; Li et al., 2000). Some previous researcher have paid more attention to *Aneurolepidium chinense* Grassland in the Shong-Nen Plain, which included mowing time, effects of mowing on grassland productivity, accumulation of stick and deciduous leaf, soil salinization (Zhong et al., 1991; Hofmann and Karn, 1981). It is widely acknowledged that mowing intensity is a crux to ascertain grassland degradation and sustainable use (Leyshon and Campbell, 1992; Zhou and Liu, 1994; Mullahey et al., 1991; Mcnaughton and Wallace, 1983; Thornton and Millard, 1996; Scott et al., 1998). Nevertheless, due to unsuitable grassland management measures and excessive feed and mowing activities, serious degeneration and declining productivity have taken place in typical steppe of loess plateau. Unfortunately, there are little articles written about mowing activities of typical steppe in loess plateau.

Therefore, a location experiment of different intensity mowing was developed for the typical steppe in loess plateau to prove the effects that species diversity and productivity and succession process as a result of mowing in typical steppe, and provide theory basis for reasonable use and building close grassland process.

MATERIALS AND METHODS

Study area

The study area is located on the upper reaches of RuHe River of the second tributary of the Yellow River in the south of Ningxia province, the study site (106°24'E, 36°13'N) is located at elevation of 1 800 to 2140 m on a gradient of 10 to 30° with measurements of 11 km from south to north and 6.5 km from east to west, it covers an area of 7150 hm², loess layer between 50 to 150 m, agrotyp

include grey cinnamonic soil and Heilu soil in country region. The climate is a semi-arid area in a middle temperate zone, the temperature range is from 22 to 25°C in the hottest month (July) but with an average temperature at 5°C for the whole year, and the annual coldest month is January with the average lowest temperature at -14°C. Accumulative temperature below 0°C is from 2370 to 2882°C, sunshine time per year are from 2300 to 2500 h; frost-free days per year are 137 days, with a mean annual rainfall of 455.0 mm; the rainfall distribution is asymmetric per season and 60 to 75% rainfall to converge after three months (7 to 9). Atmosphere rainfalls are the main replenishment for soil and water resources, the groundwater are deeper; in general most of them being 70 to 100 m. This experiment region is the nature reserve of typical steppe that has the earliest protection and the abundant species, which have 186 plants, and it was protected in the year 1982. The species included 8 artificial arbors, 18 shrubs, 160 herbs, which account for 4.3, 9.7, and 86% of total number of plants, respectively. Herb mostly includes *Stipa bungeana*, *Stipa grandis*, *Thymus mongolicus*, *Artemisia sacrorum*, *Potentilla acaulis*, *Androsace erecta*, *Heteropappus altaicus*, *A. frigid*, *Aneurolepidium dasystachys*, and so on, and *S. bungeana* of the family Gramineae distributed widely.

Procedure

Experiment design

Based on 27 years (from 1982 to 2008) continuous monitoring of a Steppe Reserve in the Yunwu Mountains, Guyuan, Ningxia Hui Autonomous Region, the experiment design are classified into three groups: mowing once every two years (mowing time: September), mowing once a year (mowing time: September), and mowing twice a year (mowing time: July and September). The area per mowing zone was 10 hm², the quadrant of 1 × 1 m and three replications were set for per mowing. The long-term enclosed grassland with no mowing and feed application was used for the control.

Measurement index

For this measurement, similar plots were selected as observation point according to community character, landform types and growth status in three experiment regions. Five indexes were used which included plant above ground biomass, coverage, height, numerical richness and species saturation. Thereafter, each index was tested before mowing, and the plots were of 1 × 1 m; 6 replications were set for per mowing.

Biomass

We selected 3 plots randomly to mow and estimate biomass. Along the ground, we harvested, and then weight each square.

Coverage

One hundred of equidistance reseau were designed according to square method, the percentage covering rate of herbage were determined in per reseau and the total covering rate was calculated.

Height

Plants were selected at random in the plot. If numbers of species were more than ten in the plots, the natural heights of ten plants were determined; otherwise, all plant were detected and mean were calculate mean. The generative shoots heights were determined and the average was calculated if the plants had generative shoots.

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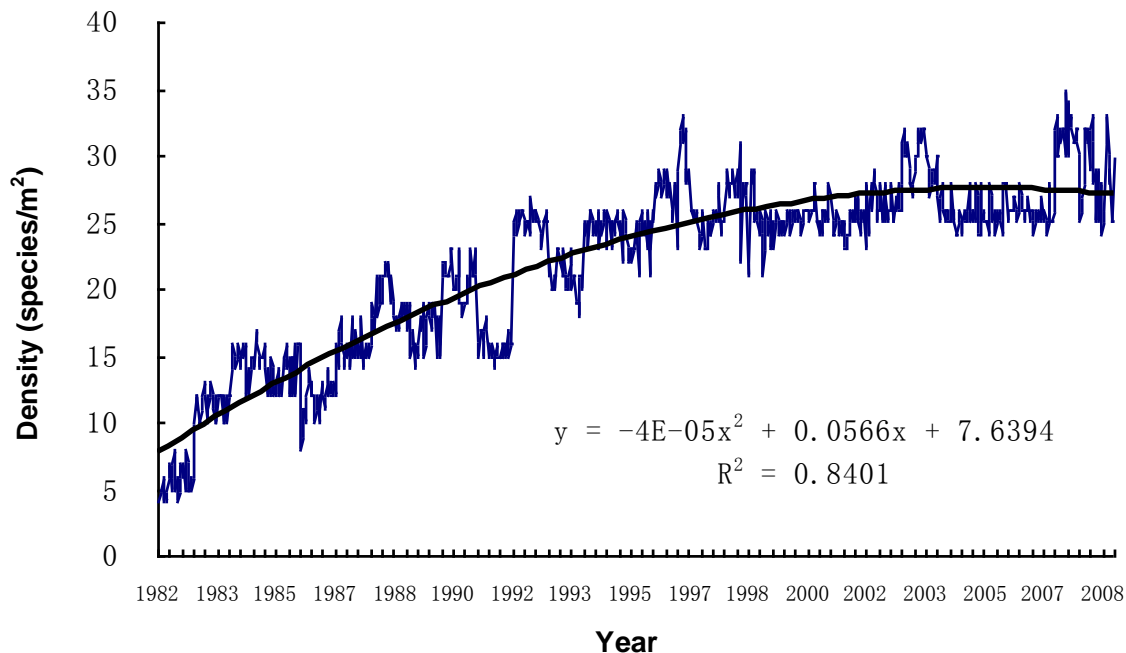


Figure 1. Species changes by mowing of once every two year.

Species richness

The numbers of various plants were counted in 1 m² quadrat, and recorded according to classification of family and genus.

Species saturation

Species numbers of all plants were recorded in 1 m² quadrat.

RESULTS

Effects of mowing disturbance on the species diversity of the grassland

To retain or restore the species diversity of grassland, and maintain the balance of grassland, the point of mowing disturbance that will bring positive effects is how one commands the reasonable mowing intensity, in this way the species diversity and productivity of grassland can be retained. Mowing experiments showed that the species diversity of the three treatments produced marked differences in 27 years (Figures 1 to 3), which are 22 (species /m²), 14.8 (species /m²) and 13 (species /m²) in average level, respectively. The species diversity of three treatments were the same in the early years of the experiment, 1 to 6 basically, but per treatment, it was influenced by rainfall. The rainfall was 633.9 mm in the third year and the average species diversity of the three treatments was 14.5±0.4 (species/m²). The rainfall was only 274.8 mm in the fifth year (year 1984) and the average species diversity of the three treatments was 11.6±1.5 (species/m²). The species diversity of three

treatments had notable changes for the seventh year and the differences showed remarkably: for one mowing zone in two years, the average species diversity for 21 years (1988 to 2008 year) was up to 24.1±0.64 (species/m²) and the variation was relatively smaller because of influence of rainfall; for one mowing zone in one year, the average species diversity was 15.5±0.37 (species/m²), $R^2 = 0.3657$, $N = 630$, $P < 0.01$; the average species diversity was 13.9±0.41 (species/m²) for two mowing zone in one year, $R^2 = 0.2064$, $N = 630$, $P < 0.01$; the fluctuates for the latter two treatments was obviously caused by rainfall. So, time and intensity of mowing are crucial factors for the diversity and productivity of grassland in this experimental region. Early mowing time resulted in the reproductive compensation of the ripe seeds which were not obtained in the soils and the species of root systems that were undeveloped and the ones only on seed reproduction were eliminated easily. Rhizome Grass took an advantage in this position, the species diversity of grassland got low, and the quality of grassland declined. In addition, the number of soil seed banks can be decreased and fertility of soil and quality of grassland can be reduced by high mowing intensity. Our studies indicate that over 90% of the plant stopped growing that year in Semi-Arid Region (September); one mowing in two years was beneficial to natural regeneration and sustainable utilization for grassland, and promoted the benign circle and progressive succession for the eco-system of the grasslands. However, one mowing in one year and two mowing in one year counteracted the natural regeneration of grassland and caused the deterioration of grassland gradually, so the application of these in

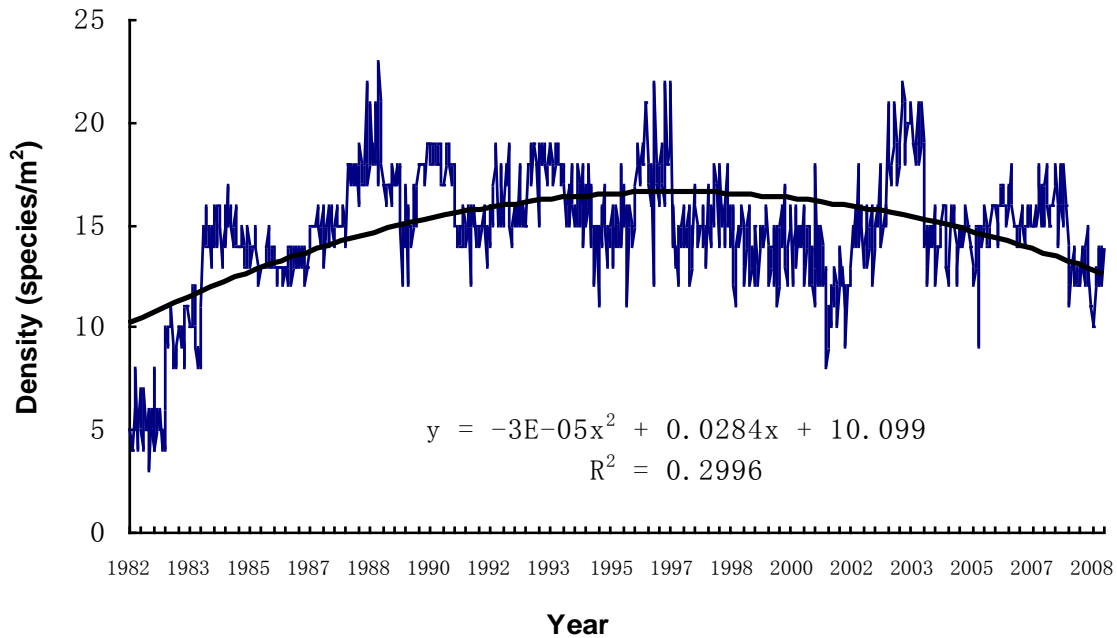


Figure 2. Species changes by mowing of once a year.

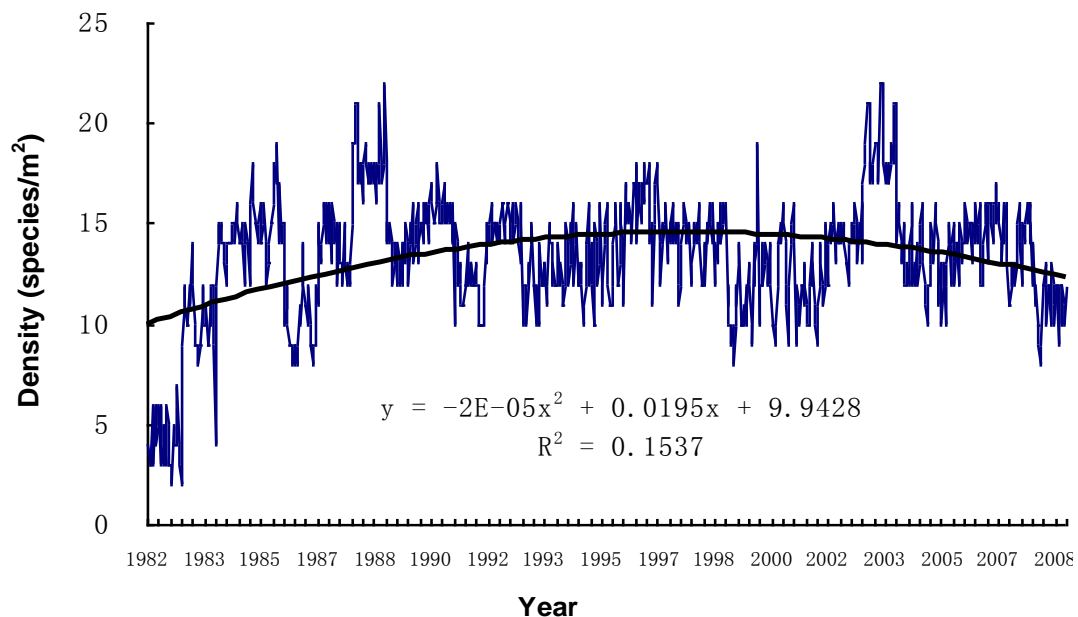


Figure 3. Species changes by mowing of twice a year.

production were improper (Figures 1 to 3).

Effects of mowing disturbance on the biomass of the grassland vegetation

Every disturbance experienced by vegetation has two sides: advantages and disadvantages, especially in semi-

arid region. A long time enclosure, without mowing and utilization may form a thick litter, which affects seeds contact with soil. Even though seeds can germinate and grow, it is difficult for its roots to enter deep soil. In this condition, seeds that are unable to germinate within 3 to 5 days may die immediately after exhausting their own internal nutrient and moisture. This is the reason that some plant species could not be updated and

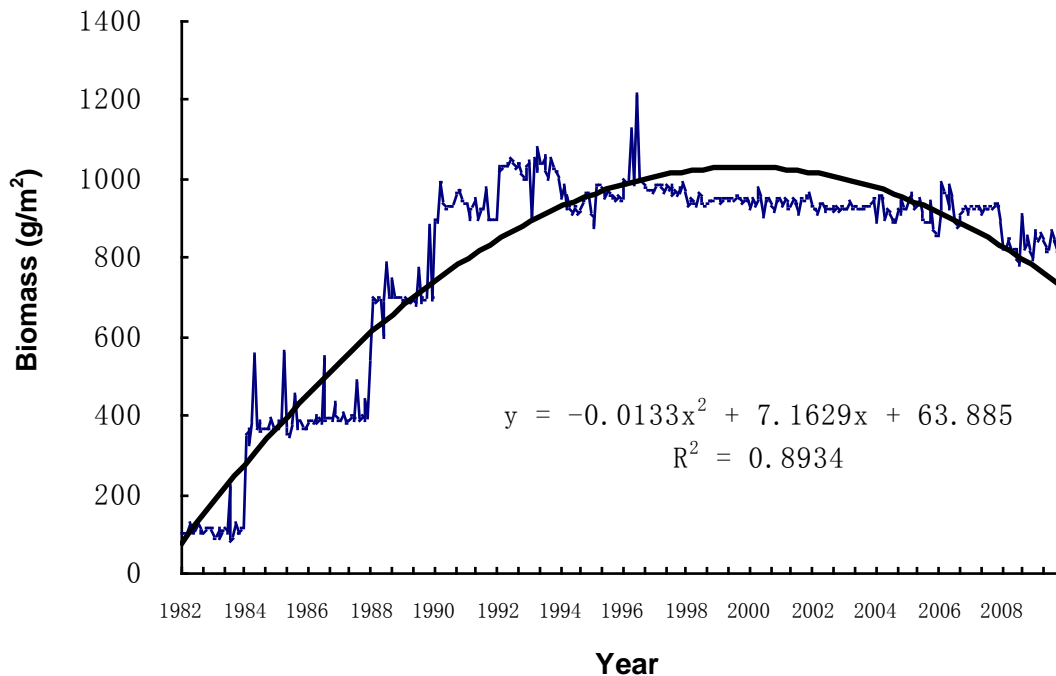


Figure 4. Biomass changes by mowing of once every two year.

propagated, and the number of species declined (Sun and Yang, 1998; Huo et al., 2001). However, the physiological and ecological characteristics of the biomass distribution of aboveground and underground and the content of plant nutrient component would be changed by mowing (Chen et al., 2003; Ferraro and Oesteheld, 2002). The biomass of aboveground was affected directly and the carbon and nutrient were decreased by the loss of photosynthetic tissue (Dobson et al., 1997). There are many effects on the level of population and community by mowing that changed the population density, community component and structure, biomass. But the species and numbers of plant can be increased for the grassland by appropriate mowing (Matson et al., 1997). Our results show that different intensity mowing resulted in great significances for biomass and the variety of biomass assumed parabola for the three treatments (Figures 4 to 6). The average aboveground biomass for 27 years was as follows: mowing once every 2 years was $785.6 \pm 111.84 \text{ g/m}^2$, mowing once a year was $630.8 \pm 115.1 \text{ g/m}^2$, and mowing twice a year was $501.5 \pm 120.53 \text{ g/m}^2$. For mowing once every two years, with the increasing years of mowing, rainfall had a little effect for biomass, and vegetation growth was stable and its biomass also lasted ten years. The duration of the extremely dry periods were 120 days in later periods (2007), the rainfall only reached 248.9 mm in the growing season and the decline extent of the biomass decreased by 123 g/m^2 than the last year. For mowing once a year and twice a year, biomass was decreased by rainfall, and their Change ranges were

wider, especially for mowing twice a year. Furthermore, because of the different intensity mowing disturbances, the species diversity of the community declined and the interspecies competition of the herbage also decreased such that the structure of the plant diversity for the grassland community changed, the biomass of the grassland community and the proportion of the good herbage decreased, meanwhile, the weeds increased, and the herbage community decreased (Li and Yan, 2006). Hofmann and Karn (1981) and Leyshon and Campbell (1992) reported that mowing had great influence on grasses. The proper mowing could promote the regeneration and tillering, whereas, excessive mowing could inhibit the growth of herbage (Li and Zhang, 1998; Mullahey et al., 1991; Huo et al., 2001). Each herb had a different response for mowing of different period and frequency in the over hundred herbage experiments of North American prairies. For the grassland of mowing every 3 to 4 years in *Aneurolepidium* Chinese Grassland in the Shong-Nen Plain, the species diversity index was higher than not mowing by 80.9% and the species richness index was 76.5%. Great quantity leguminous plants were distributed in *Aneurolepidium* Chinese grassland, however, due to serious mowing of 3 to 4 years in succession, the numbers of the grasses and leguminous plants decreased and even vanished, and the biology diversity index declined (Mcnaughton and Wallace, 1983; Chen et al., 2003). Our studies are similar with the results mentioned above, mowing once a year and twice a year were not beneficial for formation of the grassland

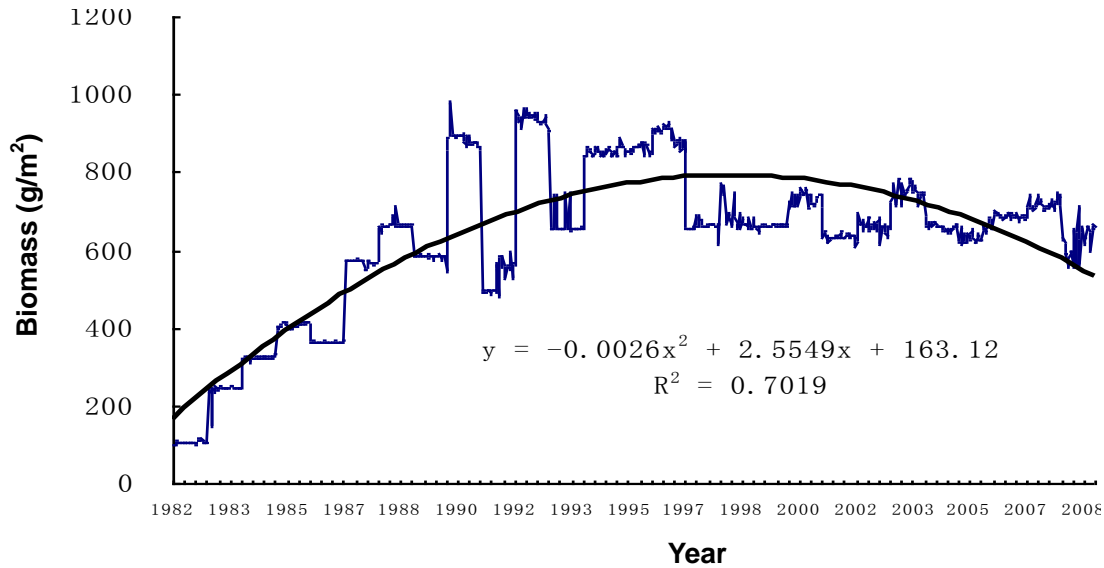


Figure 5. Biomass changes by mowing of once a year.

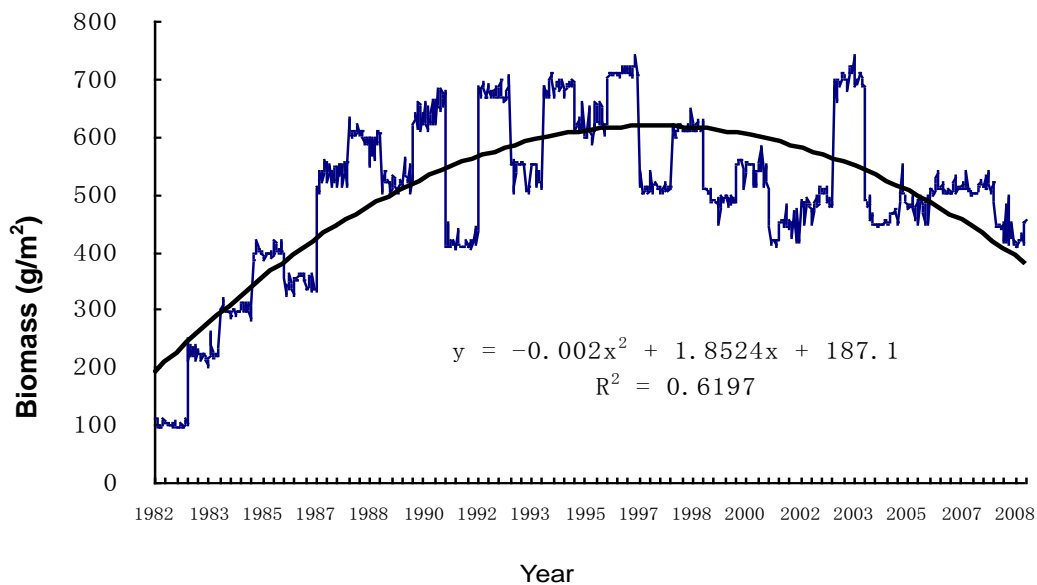


Figure 6. Biomass changes by mowing of twice a year.

biomass and the increase of the species diversity, but mowing once every two years was good for the natural regeneration and sustainable utilization of the grassland (Figures 4 to 6).

Effects of mowing disturbance on the vegetation succession of the grassland

The vegetation succession serial of the grassland had changed enormously by the different intensity mowing experiments in the enclosed plant community of typical steppe. The structure and physiognomy of the plant

community is characterized by the composition of the dominant species and the companion species; the succession of the dominant species became an important mark in the different succession period of the community. *S. bungeana* was the dominant species or the companion species in the mowing grassland. In this study, the superiority of *S. bungeana* assumed increasing tendency in one to two mowing in one year. This result indicates that the grassland community assumed degenerating tendency and the annual plants increased in the continual long-term mowing condition. However, the annual plants decreased for the restoration and succession of the grassland community in the next years mowing

Table 1. The succession variety of plant populations during the different period for the mowed grassland.

Succession period	One mowing in two years			One mowing in one year			Two mowing in one year		
	Constructive species	Dominant species	Accompanying species/ Occasional species	Constructive species	Dominant species	Accompanying species/ Occasional species	Constructive species	Dominant species	Accompanying species/ Occasional species
I (1982-1984)	1	2	42	1	2	32	1	1	30
II (1985-1989)	1	9	76	1	4	45	1	2	34
III (1990-1997)	1	15	135	1	6	65	1	3	44
IV (1998-2003)	1	16	142	1	9	75	1	4	52
V (2004-2008)	1	15	139	1	8	73	1	4	50

(Table 1).

As Table 1 shows, the mowing disturbances have large effects for the plant community species at different succession period. There were significantly different species numbers of succession period in three mowing treatments, which was mowing once every two years > mowing once a year > mowing twice a year. The succession process of the grassland community included five periods for the three mowing disturbances in 27 years. For the first succession period, *S. bungeana* as the constructive and indigenous species grew quickly in three mowing treatments, and *Artemisia vestita* and *Potentilla* as the dominant species were present in large numbers, and *Artemisia frigid*, *Artemisia scoparia*, *A. dasystachys*, *Hierochloe odorata* and 30 to 42 species were accompanying species and occasional species invaded; for the second succession period, through the stimulation of mowing for *S. bungeana* in three treatments, the new plumule formed in the healthy plant basal, after the plumule disengaged from the precursor, and it formed the new plants rapidly. This especially reproduce mode except for seed reproduction which promoted the individual numbers of community increase and cluster spread for some perennial plants (including

Lespedeza davurica, *A. scoparia*, *Gentiana squarrosa*, *Cleistogenes squarrosa* and so on) created the growth condition. Annual plant decreased largely by the ardent inter-species competition; for the third period, *S. bungeana* communities occupied the dominant position by inter-species competition. Dominant species of one mowing zone in two years improved 56 and 78% than one mowing zone in one year and two mowing zone in one year respectively, and accompanying species and occasional species improved 51.85 and 67.40% respectively. Due to the proportion of dominant species increase, the species richness declined and the plant communities were much more stabilized; for the fifth succession period, *S. bungeana* communities became the climax communities, the species numbers of the plant community reached 159 that improved by 46.54 and 64.15% than one mowing zone in one year and two mowing zone in one year respectively, and some plant species from the forest steppe grew in the surrounding slope of the mowing experiment zone, which included *Spiraea pubescens*, *Ostryopsis davaiiana*, *Berberis amurensis*, *Clematis brevicaudata*, *Cotoneaster zabelii*, *Viburnum mongolicum*, *Syringa ablata*, *Euonymus alatus* and so on. Furthermore, some perennial plant also grew such

as *Carex rigescens*, *C. lanceolata*, *Pennisetum centrasiatium* and most wormwood plant. It was a succession tendency from typical steppe to forest steppe and this phenomenon required continual observation; for the sixth period, accompanying species and occasional species changed little and grew stable. *S. bungeana* as a dominant specie changed suddenly that the individual numbers of the community declined substantially and clusters appeared with serious death phenomenon from outside to inside. The individual numbers increased quickly, and the growth occupied the dominant with 65 to 80 cm plant height. *S. grandis* community had the tendency that substituted *S. bungeana* and became the constructive species. However, because the tiller capacity of individual was poor, and the cluster was small, and the coverage and biomass were low for *S. grandis*, there is need for further observation to find out whether or not they reached the climax communities by succession.

DISCUSSION

After different intensity mowing tests at enclosing grassland for a long time, it was found that constructive species were *S. bungeana* and *S.*

bungeana, and dominant species were *H. altaicus*, *Lespedeza davurica* and *Artemisia scoparia* and some annual astatic bad plants appeared to accompany species and occasional species in the grassland communities in the Yunwu Mountains. With the change of mowing time in grassland, the species structure began to change: some dominant species gradually evaded so that the plant variety increased, and the species succession process was from thin to thick and then from thick to modest with the numbers of forage species decreased and the numbers of fine forage grasses increased, and the structure tended to be stable (Liu et al., 2008; Zhang, 1993; Zhong et al., 1991; Mcnaughton and Wallace, 1983; Ferraro and Oesteheld, 2002; Li and Yan, 2006).

Mowing intensity directly decides the influence degree of grassland. There are various losses as a result of mowing once a year and twice a year. First, it causes plants to lose provenance, when mowing time is early than the plant seed maturation and readiness then the soil cannot obtain the compensation of mature seeds, but the forage from future mowing carry easily the seeds that decreases the compensation of soil seed bank; secondly, it influences the soil fertility; mowing decrease the accumulation of litter layer in the soil surface that affect directly the formation of the soil organic matter; thirdly, to accelerate the consumption of the soil water, mowing prolonged the exposed time of the soil surface that began in October in a year to April of the next year, the long exposed time for 180 days in winter-spring of the drought accelerate the evaporation of the soil water; fourth, to destroy the soil crust, the frequent human activity for mowing can disturb the soil crust of the surface that causes soil and water loss; fifth, to decrease the numbers of species, the species of the root experiencing underdevelopment and only seed reproduction can be eliminated easily by mowing, and annual plant will gradually increase. However, rhizomatous forages occupy the dominant driving force; some grass seeds lose the capacity of sexual reproduction and the capacity of asexual reproduction enhanced to adapt mowing disturbance (Li et al., 2000; Matson et al., 1997). Reasonable mowing can avoid or decrease the above bad conditions from happening. In addition, the experiment of *Leymus chinensis* indicate that annual one mowing promote the growth of *L. chinensis* community and improve the total productivity of the grass; the influence of two mowing was less and three mowing was against the plant growth of *L. chinensis*.

The duplicated mowing use of continuous two years brought the total productivity of grassland to the level of Thornton and Millard (1996); especially for annual three mowing, the forage grass can be harvested in June; it ameliorated the difficult position lack of forage grass for domestic animals for *L. chinensis* community, the density and height of dominant species declined for the community, and the different mowing frequency had the different range decline. However, the density of forbs was

significantly increased, with increased mowing frequency, and the change trends was present with increase for the first after declining. The height of two mowing plots were maximum, the accumulation of the litter layer successively decreased according to the order of one mowing, two mowing and three mowing, in which the last mowing led to a bigger harvest that seriously impacted on the regenerative growth of grass vegetation to reduce the accumulation of litter layers. The mowing test showed that the biomass of grassland community declined for 17 years in Inner Mongolia, and the proportion of fine forage grass reduced and the forbs increased (Ding et al., 1993). Hofmann and Karn (1981) and Leyshon and Campbell (1992) studies show that the effect of mowing on perennial grasses were large and that suitable mowing promoted grass tillering, and regeneration, while excessive mowing inhibits the growth of forage grass.

Results from 27 years related to studies indicate that different intensity mowing disturbance had notable effect for the species diversity and productivity. Mowing once every two years was the most suitable for this zone, the important value of constructive species and dominant species was above 60% and the frequency above 50%. The species diversity reached a maximum (29.8 species/m²), and the biomass was 1027.4 g/m². The indexes of two other mowing disturbance treatments were low than mowing once every two years in the year 1992 (the rainfall were 521.5 mm). In addition, for mowing once every two years, the reasonable mowing grassland entered the sixth period in succession in the twenty-second year. *S. bungeana* community reached the climax and the species numbers of the plant community were 159, and the shrubs and herbage of forest-steppe zone appeared so that the successions of typical steppe community tend to create forest or bush steppe development. However, other two treatments lagged in this type for five-eight years. In the sixth succession periods, *S. bungeana* as constructive species created a mutation, and as a result of this, the individual numbers of the community declined substantially and the clusters caused lead to a serious death phenomenon. *S. grandis* communities have the tendency that can substitute *S. bungeana* and become the constructive species. However, because the tiller capacity of the individual was poor, and the cluster was small, the coverage and biomass were low for *S. grandis*. Consequently, there is the need for further study to ascertain if they actualize their climax communities by means of succession.

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