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中国东北羊草草原生长季内产量生态模拟及信息参数应用

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摘要：通过对中国北方羊草草原生物量动态、生物量垂直空间格局及其与环境因子相互关系等主要产量生态数量特征的模拟与内在相关性的研究，结果表明，草地地上生物量的生长规律呈“单峰”型，最大地上生物量出现在 8 月 5 日，其值为 197.3g・m^{-2}干物质，而后下降；在达到峰值前，符合 logistic 模型，进一步分析模型有关特征值获得了草地有效管理期为返青后的第 73 天到第 119 天等十分重要的产量生态信息参数。生长季内地上生物量动态与前一个月的平均气温($R=0.8287$)和积累降雨量($R=0.8932$)均呈极显著正相关，这是实施科学水肥管理的重要参数；而地上部生物量最大绝对增长速率(AGR)出现在 6 月 20 日至 7 月 5 日，平均为 3.3533g・m^{-2}・d^{-1}干物质；而地上部生物量最大相对增长速率(RGR)出现在 5 月 20 日至 6 月 5 日，平均为 0.0662g・g^{-1}・d^{-1}干物质；在生长后期绝对增长速率和相对增长速率均出现负值，这表明地上部生物量的生长效率在生长初期最高。地上生物量垂直空间格局由下向上呈幂函数变化，其模型为：$Bn=aX^b$，其中 93%的产量集中在 40cm 以下，这对不同的家畜的选择利用与刈割利用提供了依据；不同种群对草原牧草产量形成的作用是不同的，羊草种群对草原牧草产量形成的正向效应最大，因此以建群种羊草的高度、盖度和密度特征为指标建立起来的牧草产量非破坏性预测模型，是一种简单可行、预测准确的好方法，其预测模型为：$Ba=-169.7343+0.8368H+0.8631D+3.6231C$；地下生物量垂直空间格局由上至下呈负幂函数变化，其模型为 $Bu=a(D+10)^{-b}$，而且在生长季内地下生物量的变化不明显，只是到秋后有所增加，其中在 0～30 cm 深度中地下生物量占总地下生物量的 77%～82%。根据这样的产量生态信息参数，在考虑相关根系问题的生态改良时，则深度在 0～20 cm 即能达到良好的改良效果。该项研究的意义在于获得羊草草原有关重要的产量生态信息参数，为建立优化管理方案及合理利用草地提供科学依据。

关键词：羊草草原；生物量；生物量垂直空间格局；模型；产量生态；信息参数应用

Yield Ecology Simulation and Information Parameter Application of *Leymus chinensis* Grassland in Northeast China During Growing Season

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Abstract: The experiment was carried out in *L. chinensis* grassland of northeast China. It simulated main quantity characteristics of yield ecology, such as biomass dynamics, vertical spatial pattern of biomass as well as their relationships with environmental factors, also it studied internal relativity. The results showed that the rule of aboveground biomass growth of the grassland appeared as “single peak” type in growing season. The maximum aboveground biomass was 197.3 g ・m^{-2} which occured on Aug. 5, then the biomass declined. It conformed to Logistic model $Ba=k(1+e^{a-rt})$ before the peak. Further analysis on related characteristic values of the model gave us a very important information parameter of yield ecology, the effective management period that should be from the 73th day to the 119th day after the grassland re-

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turnes green. During growing season, aboveground biomass dynamics had strikingly positive correlation with both average temperature of the former month ($R=0.8287$) and accumulated rainfall ($R=0.8932$). This was the important parameter to carry on scientific management of water and fertilizer. Maximum absolute growth rate of aboveground biomass occured during June 20 and July 5, its average was 3.3533 g · m^{-2} · d^{-1} DM (dry matter), and maximum relative growth rate (0.0662 g · g^{-1} · d^{-1} DM) occured during May 20 and June 5. Both absolute growth rate (AGR) and relative growth rate (RGR) appeared negative increase in late stage of growing season. It suggested that the highest efficiency of aboveground biomass be in early stage of growing season. The vertical spatial pattern of the aboveground biomass decreased as positive exponential function with height increasing, the model was: $Bn=ax^b$. The yield of the plants under 40cm height made up 93% of the total yield. This provided a basis for choosing different animal to use and mowing use. Different population of the grassland played a different role in yield formation, and positive effect of *L. chinensis* was the biggest . For this reason, features of height, cover-degree and density of edificato-*L. chinensis* were used as index to set up nondestructive model of yield prediction. It was a simple, accurate predictive method, the model was $Ba=-169.7343+0.8368H+0.8631D+3.6231C$. The vertical spatial pattern of underground biomass decreased as negative exponential function with depth increasing, the model was: $B_u=a(D+10)^{-b}$. The variation of underground biomass was not marked, but more or less increased in late autumn. Underground biomass of the grassland plants above 30cm depth made up 77%～82% of the total underground biomass. According to such yield ecology parameter, when ecological improvement on root system problems was considered , the depth of 0～20 cm would give good effect. The significance of the study was to obtain relative important information parameters of yield ecology in *L. chinensis* grassland and to provide scientific basis for establishing the best management scheme and utilizing grassland rationally.

Key words: *L. chinensis* grassland; biomass; vertical spatial pattern of biomass; model; yield ecology; information parameter application

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In 1970s, "man and the biosphere" (MAB) plan in essence was various studies taking yield ecology as center. Under such background, with the rapid development of modern yield ecology, various studies taking grassland herbage yield resources as center have been paid much attention by scholars over the world. Therefore, further studies on grassland herbage yield , reasonable utilization of grassland resources and protection of ecological environment have become important fields for scientists in grassland ecology[1～5]. After entering into 1980s, with national and some provincial grassland resources investigations , large scientific data on yield resources had been obtained, and some papers about grassland yield ecology had been published in China[6～10]. However, on the whole, from the viewpoint of taking grassland ecological system as a whole, study on yield ecology of Chinese grassland, especially comprehensive, deep and qualitative simulated study on yield ecology of various types of grassland was not thorough in the field, and further information parameters carried on effective management of different grassland were hardly recognized[11]. This paper simulated vertical spatial pattern of biomass and established nondestructive model by probing into information parameter of internal yield ecology. There was no reference report on this study. With regard to studies on process of life and ecology, most scholars only paid attention to several studied contents, such as some studies stressed on aboveground biomass of grassland[12～14], some studies stressed on vertical spatial pattern of aboveground biomass[3,15,16], some paid much attention to quantity characteristics of main populations and community[10,17], some only stressed on vertical spatial pattern of underground biomass[18~21], and also some scholars paid much attention to relationships of ecological fators and yield[22~28].

L. chinensis grassland is lush growing grassland which has *L. chinensis* as edificato. Its grass quality is high nutritive and has good palatability, and it is one of the grasslands with high yield in temperate zone over the world. It may be said that it is the most valuable natural property in the grassland resources of the world. Among which there is a half in China[29]. In 1950s～1960s, some scholars had studied yield dynamics of *L. chinensis* grassland in northeast China. But on the whole, these studies were in simple qualitative analysis level, and without scientific simulated process and quantitative analysis. So they had their historical limitations on grassland ecological system management and rational utilization under modern science and technology. Entering into 1980s～1990s, some scholars began to further study yield dynamics of *L. chinensis* grassland, and some simulated models on dynamics during growing season appeared. Though these studies made certain progress on the basis of former studies, they didn't make thorough study on simulation of grassland yield ecology quantity characteristics such as biomass and vertical spatial pattern, their internal relativity, and establishment, management and utilization of internal information parameters. By studying *L. chinensis* grassland yield ecology and information parameter application, the goal is to carry on scientific management of water and fertilizer on the grassland ecological system, to establish superior management programme and to provide a scientific basis for sustainablly utilizing grassland. Meanwhile, there is an important meaning for directing study and application of grassland yield ecology in China[30]

1 General situation of sample plot and studied methods

1.1 Sample plot

1.1.1 General weather situation　The sample plot is set up in typical region of *L. chinensis* grassland in Songnen plain of northeast China. It is situated 125°7′ east longitude and 45°35′ northlatitude. It belongs to monsoon climate of temperate zone, controlled by the Mongolia high pressure, cold and dry in winter, and controlled by the Pacific high pressure, warm and humid in summer. In the hottest month-July, the average temperature is 22.7℃, its maximum is 38.1℃. In the coldest month (January), the average temperature is −19.4℃, its minimum is −28.9℃. Annual average temperature is 3.8℃ and annual average accumulated temperature which is larger than 10℃ is about 2800℃. The frost-free period is about 130～156 days. Average sunshine time is 2787.5 hours a year, and annual average precipitation is 490 mm, mainly concentrated in June to September, which makes up 80% of the total precipitation a year. In winter, the precipitation is the lowest between November and March, which makes up 3.7% of the total annual precipitation. Therefore, water and heat in same pace will benefit growth and development of grassland herbage. The annual average evaporation capacity is 1599.8 mm, 3.3 times annual average precipitation in the region. Topography of the region is flatlands with alkaline meadow soil and 0.1% salinity. There is no caliche in the soil.

1.1.2 General situation of vegetation　Vegetation type of the grassland is meadow steppe with *L. chinensis* formation, *L. chinensis* + mesophytic hetrbs association and edificato-*L. chinensis* occupies absolutely a dominant position. The grassland vegetation is divided into two layers for adaption to the environment. The first layer is high and lush herbage, *L. chinensis* is in this layer, and its main dominant species are: *Festuca chelungkiangnica*, *Cleistogenes squarrosa*, *Calamagrostis epiqeios* and *Arundinella hirta*; and its main companions have *Vicia amoena*, *Lathyrus quinquenervius*, *Clematis hexapetala*, *Sophora flavescens*, *Vicia multicaulis*. The second layer is low and lush herbage, its main dominant species are: *Potentilla flagellaris*; and its main companions have *Taraxacum sinicum*, *Ixeris chinensis*, *Anemarrhena asphode-*

loides and so on. In addition, seasonal evolution of each companion in the community is very complicated. Populations which grow luxuriantly in early spring have *Oxytropis myriophylla*, *Viola dissecta*, *Viola prionantha*, *Senecio integrifolitus*, *Iris ventricosa*, *Leibnitzia anandria* etc. In midsummer, *Astragalus danicus*, *Polygonum divaricatum* and *Allium polyrrhizum* grow luxuriantly. In the fall, populations *Sanguisorba officinalis*, *Artemisia subulata* and *Artemisia laciniata* grow luxuriantly.

1.2 Studied methods

1.2.1 Quadrat arrangement The sample plot was chosen in typical region with identical community composition, grass group structure and habitat condition. Its area is 100×100 m^2. The experiment adopted objective sampling according to biological statistics that was the quadrat was random arranged in order to increase the accuracy of determination[31,32].

1.2.2 Index determination From the 40th day (April 10) of turning green that was May 20 to September 20, sampling observation was conducted 9 times at an interval of half a month. The quadrat with area of 1×1 m^2 was repeated 6 times, sampling with harvest method. Grass samples mowed were put into plastic sack at once, then into special cloth bag. The samples were taken back laboratory. *L. chinensis* was divided from other mesophytic herbs, and their fresh weights were weighed. The samples weighed were put into cloth bag to dry in the shade. After about half a month, when their weights were constant, dry weights were weighed and assumed as aboveground biomass. The determination of vertical spatial pattern of grassland aboveground biomass and seasonal dynamics was carried out by layer mowing. From June 22 to Sep. 19, the determination was conducted once every half a month, 7 times altogether. The standard quadrat of 1 m^2 was chosen and repeated 2 times. In laboratory, the grass sample was cut into sections of every 10 cm from bottom to top, then leaf, stem, flower and ear of each section were separated, and their weights were weighed, air-dried to constant weight, in order to obtain the distribution of quantity and height of grass different organs in time and space. Seasonal dynamics determination of height, cover-degree and density was carried out at the same time with aboveground biomass determination, which was repeated 6 times with 1×1m^2 quadrat. The average height of high plants, middle-high plants and low plants of each population in quadrat of height determination was assumed as the plant height of the population determined. Cover-degree determination was gone on by the method of rope-drawing check. Density determination was conducted by the method of quadrat count. Vertical spatial pattern of underground biomass was determined twice in summer (Aug. 16) and the end of autumn (Oct. 16). Underground soil sample of the grassland was taken with quadrat of 25×25 cm^2 area. Every 10 cm was a layer, 10 layers all, total depth was 1 m. The two determinations were repeated 19 and 20 times respectively. Lastly, the roots were divided into live roots and dead roots, air-dried to constant weight, then weighed respectively. In this study, rootstock of *L. chinensis* was included in underground biomass because rootstock situation of *L. chinensis* population is a main index of its reproductive ecology, it is also to be considered concerning ecological improvement of soil. The water content of the soil was determined by three layers, every layer was 10 cm, repeated 3 times, and at the same time with the determination of aboveground biomass. Moreover, the temperature and precipitation were monitored every day.

1.2.3 Information parameter analysis and aim Logistic model is one of basic key models in the field of modern mathematical ecology. It and its developed model have enough ecological information parameters. By probing into its characteristics, the aim is to get very important information parameters of yield ecology such as effective management period of grassland. There is no comparision between it and other models only simulating yield ecology process. This is the reason that the study used the model. The aim of simulating vertical spatial pattern of biomass is to provide precise scientific basis for choosing different animals to use, mowing to use and formulating ecological improvement programme of grassland soil. Because seasonal dynamics of biomass growth is limited by environmental factors such as water and temperature, it also is limited by internal ecological factors, relative model of biomass and water, temperature factors is set up by analysing the relativity of them, and nondestructive model of biomass is set up by studying internal information parameters of community quantity characteristics. The aim is to make yield ecology information parameters more scientific, accurate and applied widely.

2 Results and analyses

2.1 Dynamics simulation of aboveground biomass and information parameter analysis in growing season

The determined results of aboveground biomass dynamics in growing season were showed in Table 1. From the beginning of total biomass with zero in early spring (about April 10), with the progress of bearing period, biomass increased gradually. The biomass of *L. chinensis* population reached maximum around Aug. 20, which was 106.1 g·m^{-2}(dry weight). The total biomass of mesophytic herbs and community all reached maximum about Aug. 5, which were 112.6 g·m^{-2} and 197.3 g·m^{-2}(dry weight) respectively. Near the maximum, community biomass varied a little, appeared a relatively stable period, then as the coming of autumn, plants waned gradually, withered increasingly. So the dynamic change of biomass appeared as dropping tendency. Seen from references, during growing season, aboveground biomass of many kinds of grassland in north China grew as "S" curve, which conformed to logistic model. In view of this growth feature of biomass, though one unit cubic or the fourth order regressive equation can be used to simulate this growth process, getting high correlative coefficient, they ignored important turn information of yield ecology, loosing important turn information parameter of yield ecology. According to this situation, logistic model is with much superiority, being able to meet the aim and demand of the study.

Table 1 Seasonal dynamics of *L. chinensis*, mesophytic herbs and community biomass (g·m^{-2})

Date		May 20	June 5	June 20	July 5	July 20	Aug. 5	Aug. 20	Sep. 5	Sep. 20
L. chinensis	Fresh weight	6.9	32.2	58.8	108.8	148.1	168.8	206.8	169.5	135.2
	Dry weight	3.5	13.5	25.2	43.2	71.0	84.7	106.1	96.0	81.2
Mesophytic herbs	Fresh weight	9.9	42.0	137.2	198.6	256.1	282.9	209.8	175.8	136.1
	Dry weight	6.1	14.2	40.1	72.4	94.0	112.6	74.7	77.2	64.8
Community	Fresh weight	16.8	74.2	196.0	307.4	404.2	451.7	416.6	345.3	271.3
	Dry weight	9.6	27.7	65.3	115.6	165.0	197.3	180.8	173.2	147.3

This model contains enough information parameters of yield ecology. These parameters has very important applied value. In the study, aboveground biomass dynamics of *L. chinensis* population, mesophytic herbs and community conformed to logistic model $Ba=K/(1+e^{a-rt})$, the fitted coefficients all reached extremely striking standard (refered to Table 2). Logistic model contained much information on ecological features of community. These information parameters can be obtained by special operation with the model. Using these information parameters, the growth features of community biomass can be explained well, and can be quantized. The second derivatives of biomass (B) and sampling time (t) were computed and assumed as zero so as to find the solution of the turn of logistic model's curve with "S" shape (a/r, $k/2$). But $t_{max}=a/r$ is the growth days needed by AGR of community biomass when it reached maximum. When t is greater than 0 and less than a/r, the curve is concave-up, and when t is greater than a/r and less than $+\infty$, the curve is convex-up. The third derivatives of biomass (B) and sampling time (t) continued to be computed and assumed as zero so as to find the solution of two time turns of community biomass logistic curve. Between t_1 and t_2, community biomass increased as straight line, among which $t_1=[a-\ln(2-\sqrt{3})]/r$, $t_2=[a-\ln(2+\sqrt{3})]/r$. $GT=rK/4\cdot(t_2-t_1)=AGR_{max}\cdot\Delta T$ was named as characteristic value of colony growth. $D=[a-\ln(K/RB_m-1)]/r$ is theoretical growth days needed by community biomass reaching maximum (B_m is the maximum real determined value of biomass).

By computing information parameters of Logistic model, we can obtain (Table 2): it took 85 days after turning green (April 10) to make AGR_{max} of community biomass to reach maximum, it was 11 days and 8 days respectively shorter than that needed by *L. chinensis* population and mesophytic herbs biomass. At this time, on "s" curve, the turn's coordinates of *L. chinensis*, mesophytic herbs and total biomass were (96 days, 59.61g·m^{-2}), (93 days, 74.62g·m^{-2}) and (85 days, 112.30g·m^{-2}) respectively. The turn's coordinate was as limit, when t was between 0 and turn, the curve was concave-up, and when t was between turn and maximum, the curve was convex-up. D ($[a-\ln(K/RB_m{}^{-1})]/r$) was theoretical growth days needed by community biomass reaching maximum. In *L. chinensis* + mesophytic herbs grassland, it took 133 days to make *L. chinensis* population biomass reach maximum, longer than that needed by mesophytic herbs and community biomass (112 and 114 days). The curve's peak of *L. chinensis* population biomass would appear theoretically about 20 days later than that of mesophytic herbs and community biomass. GT ($AGR_{max}\cdot\Delta T$) is the characteristic value of colony growth, which of *L. chinensis* population made up 76.12% of total increase of *L. chinensis* population biomass in observed period, that of mesophytic herbs made up 92.30% of total increase of mesophytic herbs biomass in observed period, and GT of community made up 78.53%. In the parameters calculated, t_1, t_2 represented the two turn of time on logistic curve of community biomass increase. Between t_1 and t_2, plant biomass of grassland increased as straight line, so in practical work, sampling between t_1 and t_2 can be prolonged, it is not necessary to determine frequently. It is good to lower experimental cost, to raise efficiency. Besides, if the grassland was to be enforced management measures such as irrigation, fertilization, it would be best go on between t_1 and t_2 in order to raise reward of grassland's putting into, lower cost, reach the effect of getting twice the result with half the effort. But before t_1 and after t_2, the increase of grassland plant biomass was slow. ΔT(t_2-t_1) represented continued time of the community in lush growth period. A new concept can be introduced by try, which is named as "effective management period" for ΔT. In addition , to manage *L. chinensis* + mesophytic herbs grassland must follow a principle which is to make *L. chinensis* population develop well and luxuriantly, but to control mesophytic herbs which has negative effect to grow too luxuriantly, because mesophytic herbs' lush development must weaken *L. chinensis* population's good development. So to give *L. chinensis* + mesophytic herbs grassland management measure such as irrigation, fertilization etc. should take *L. chinensis* population's "effective management period" as the standard, that was during the 73th day after turning green (April 10) and the 119th day. If want to enhance grass quality, moreover to prevent and kill off weeds, it is necessary to take mesophytic herbs' "effective management period" as the standard, that was during the 70th day after turning green (April 20) and the 116th day, the management measure was the most effective and economic.

Table 2 Information parameters in Logistic model of aboveground biomass

Content	K	a	r	R^2	F	AGR_{max}	GT	t_1	t_2	ΔT	t_{max}	D
L. chinensis	119.2149	5.4887	0.0570	0.9923**	257.7403	1.6988	78.1	73	119	46	96	133
Mesophytic herbs	149.2320	5.3022	0.0573	0.9748**	58.0238	2.1377	98.3	70	116	36	93	112
Community	224.6038	5.6988	0.0673	0.9987**	1152.3460	3.7790	147.4	65	104	39	85	114

2.2 Analysis of aboveground biomass increase rule and information parameters

The speed of biomass increase and decrease has clear difference in different stages of growing season. In order to analyse the variable law of biomass, absolute growth rate (AGR) and relative growth rate (RGR) of biomass are adopted to describe the variation.

Absolute growth rate is the variable rate of aboveground biomass to time, its differential formula is $AGR = d_B / dt$. B stands for biomass, t represents time. In the formula, AGR is absolute growth rate of aboveground biomass, dB is differential of abroveground biomass; dt is differential of time. To determine the instantaneous growth rate of aboveground biomass is very difficult without tested equipment sampling of nondestruction. In practical work, it is easy to calculate the average absolute growth rate during time t_i to t_{i+1}, named as $\overline{AGR}$. The more the times of sampling, the shorter the interval of time, and $\overline{AGR} \rightarrow AGR$ (instantaneous).

$$\overline{AGR}(t_{i+1} - t_i) = \frac{B_{i+1} - B_i}{t_{i+1} - t_i}$$

B_{i+1} and B_i were the biomass at time t_{i+1} and t_i respectively. The biomass values (B) determined in each period of growing season and sampling time (t) were put into the formula above one by one, absolute growth rate of total biomass of *L. chinensis* population, mesophytic herbs and community can be calculated (Table 3). From this we can see that in early spring, because of low temperature, dry climate and young photosynthetic organs of plants, $\overline{AGR}$ value was very low; then along with temperature went up and precipitation increased, photosynthetic organs develop day by day, $\overline{AGR}$ value rose quickly. The total law was that before growing season biomass increased fast, reached maximum at flower period, then continously decreased.

Of course, AGR only reflected the rate of biomass increase or decrease per time per area. It couldn't represent growth efficiency of which plant is high. For example, one plant 1g *L. chinensis* seedling and one plant 10g mature individual, if they gained 1g weight at same period, their $\overline{AGR}$ values were the same, because $\overline{AGR}$ was only related to ΔB and Δt, irrelevant with the weight of plant itself. In fact, there was a large difference between the two individuals' productive efficiency, the former was 9 times much larger than the latter. In order to reflect plant's productive efficiency, the concept of relative growth rate was introduced to reveal seasonal dynamics of organic matter's productive efficiency in *L. chinensis* + mesophytic herbs grassland. The so-called relative growth rate (RGR) of biomass was organic matter's growth rate per plant in per growing time. According to the law of plant growth and development, relative growth rate of biomass was a instantaneous value variable as growing time. It can be expressed into diffenential form : $RGR = 1/B \cdot dB/dt$. B is biomass; dB/dt is variable rate of biomass to time.

Under similar circumstances, limited by sampling conditions, it can be inverted into average form :

$$\overline{RGR}(t_{i+1} - t_i) = \frac{\ln B_{i+1} - \ln B_i}{t_{i+1} - t_i} \quad B, t \text{ are the same as above.}$$

From Table 3, biomass' relative growth rate ($\overline{RGR}$) of *L. chinensis* population, mesophytic herbs and community were large in early stage of observation. During the period, leaves were relatively large, photosynthesis was vigorous, organic matter accumulated was much, but consumption was relatively little. After that, $\overline{RGR}$ value droped as wave, till the second and the last ten days of August, it appeared negative values. This showed that relative growth rate of aboveground biomass of grassland had restrictive relationship with ripe degree of plants and consuming degree of reproductive growth on photosynthetic product. Entering reproductive period from nutritive period, owing to reproductive growth needed to consume a great deal of nutrient, plants were short of nutrient to grow, so as to make relative growth rate of biomass drop.

Table 3 $\overline{AGR}$(g·m^{-2}·d^{-1}) and $\overline{RGR}$(g·g^{-1}·d^{-1}) dynamics of aboveground biomass

Date		May 20 ~June5	June 5 ~June 20	June 20 ~July 5	July5~ July20	July20~ Aug. 5	Aug. 5~ Aug. 20	Aug. 20~ Sep. 5	Sep. 5~ Sep. 20
L. chinensis	$\overline{AGR}$	0.6250	0.7800	1.2000	1.8533	0.8563	1.4267	−0.6313	−0.9867
	$\overline{RGR}$	0.0844	0.0416	0.0359	0.0331	0.1856	0.0150	−0.0063	−0.0112
Mesophytic herbs	$\overline{AGR}$	0.5063	1.7267	2.1533	1.4400	1.1625	−2.5267	0.1563	−0.8267
	$\overline{RGR}$	0.0528	0.0692	0.0393	0.0174	0.0113	−0.0274	−0.0021	−0.0117
Community	$\overline{AGR}$	1.1313	2.5067	3.3533	3.2933	2.0188	−1.1000	−0.4750	−1.7400
	$\overline{RGR}$	0.0662	0.0572	0.0381	0.0237	0.0055	−0.0058	−0.0027	−0.0108

2.3 Dynamics of vertical spatial pattern of aboveground biomass and simulation

From Table 4, the peak stage of aboveground biomass of *L. chinensis* + mesophytic herbs grassland appeared in August with herbage height 70~80cm. The administrative structure of yield in each stage of observation basically arranged as "pyramid" type. The yield at the bottom was the highest, in 0~10cm, the early two results made up about 57.9% and 44.6% of total yield, middle three results about 27.6%, 31.4% and 35.2%, the last two results about 26.2% and 47.8%. 55% of yield was concentrated below 20cm, 93% below 40cm that was the distribution range of most plants' leaf layer. In the peak of growing, if the administrative structure of each population distribution was analysed, we could discover that there were complete populations below 10cm, most annual plants were in this layer. Mesophytic herbs were mainly distributed below 40cm. In the peak of growing, by analysing the distribution of herbage's leaf yield, stem yield and flower ear yield in each layer, conclusion could be obtained : stem of plant was most in each layer below 30cm, leaf below 40cm and flower ear mainly above 20cm. The aboveground yield structure dynamics of community in each stage and administrative structure height complies with regression model of power function. Among which B_n is biomass within 0~x cm layer, fitted results showed (Table 5) that coefficients of correlation were all more than 0.91, among which there was striking difference among June 22, July 5, Sep. 19, other fitted results all reached very striking standard.

Table 4 Seasonal dynamics of aboveground biomass vertical spatial pattern of the grassland community (g·m^{-2})

Layer (cm)	June 22			July 5			July 20			Aug. 4			Aug. 19			Sep. 4			Sep. 19	
	Leaf	Stem	Flower	Leaf	Stem	Flower	Leaf	Stem	Flower	Leaf	Stem	Flower	Leaf	Stem	Flower	Leaf	Stem	Flower	Leaf	Stem
70~80												1.5								
60~70									0.6		0.3	0.2			1.3		0.1	0.1		
50~60							0.3	0.3	1.9	1.9	0.5	1.7	0.4	0.4	0.3	0.2	0.2			
40~50		0.2	0.2	1.4			3.2	1.6	0.8	5.3	1.7	0.7	2.0	0.5	1.3	2.5	0.2	0.3	0.8	
30~40	0.3	0.2		4.5	1.1	0.3	16.0	2.4	0.6	14.7	3.0	0.9	12.6	1.8	0.8	17.4	1.7	0.8	4.7	0.4
20~30	3.9	1.0	0.8	13.9	2.5	0.6	34.2	8.5	1.2	33.4	5.2		30.7	6.6	0.8	38.0	6.3		18.1	1.2
10~20	16.6	3.9	1.0	29.7	10.1	0.3	40.3	22.1		49.3	15.3	0.5	40.9	16.8		35.5	13.7		45.2	7.8
0~10	22.5	16.0	0.2	25.3	26.6		16.5	34.6		29.6	32.8		31.7	32.0		19.5	22.1		51.5	17.9

Table 5 Exponential function model of the community structure dynamics

Date	Regressive equation	R	N
June 22	$B_1=19.4258X^{0.3378}$	0.9166*	5
July 5	$B_2=21.3510X^{0.4292}$	0.9286*	5
July 20	$B_3=14.1342X^{0.6493}$	0.9375**	7
Aug. 4	$B_4=22.9909X^{0.5287}$	0.9289**	8
Aug. 19	$B_5=18.9537X^{0.5840}$	0.9524**	6
Sep. 4	$B_6=10.4489X^{0.6880}$	0.9399**	7
Sep. 19	$B_7=25.9274X^{0.4729}$	0.9376**	5

2.4 Analysis on information parameter of yield ecology quantity characteristics and establishment of nondestructive model

Analysis on linear regression of main population, community's quantity characteristics and aboveground biomass in *L. chinensis* + mesophytic herbs grassland showed that *L. chinensis* population's height, cover-degree and density quantity characteristics had positive linear correlation with aboveground biomass, their coefficients reached extremely striking standard (Table 6). This indicated that *L. chinensis* population had completely positive effect on formation of aboveground biomass. Cover-degree and density of community were also positively related to aboveground biomass, and reached striking and extremely striking standard, but the correlativity with biomass was lower than that of *L. chinensis* with biomass. The correlativity of other populations' quantity characteristics with aboveground biomass were all low as a whole, moreover, individual characteristic had negative correlation with biomass. This showed that these populations not only had smaller effect than *L. chinensis* population on formation of aboveground biomass, but also had negative effect on formation of biomass to a certain degree. Only from density, in the whole growing season, the density of *L. chinensis* population had extremely striking positive correlation with biomass (0.9646), *P. flagellaris* and clustered grass had negative correlation with biomass (−0.8749, −0.8825). In addition, in growing season, the ratio of *L. chinensis* population's biomass in total biomass tended to increase, showing that in the community, as the prolong of growth period , superior status of *L. chinensis* population increased so as to increase its positive effect on formation of biomass, to drop the status of *P. flagellaris* and clustered grass in the community, so to decrease the their negative effect on formation of biomass. Clustered grass was dominant species of typical clustered grass grassland (steppe); *P. flagellaris* was indicated plant of grassland degeneration. Therefore, in rootstock *L. chinensis* + mesophytic herbs meadow grassland, *P. flagellaris* and clustered grass were not possible to develop well like *L. chinensis* population, otherwise it was only said that regressive succession occured in the grassland. Analyses on correlation of quantity characteristics and yield of main populations, species group and community of *L. chinensis* + mesophytic herbs grassland indicated that in community, the effect of edificato- *L. chinensis* population on formation of herbage yield was positive. So in nondestructive prediction process of herbage yield of *L. chinensis* + mesophytic herbs grassland, it is easy to think of having the height (H), cover-degree (C) and density (D) characteristics of *L. chinensis* population which was edificato in community of grassland as indexes to set up nondestructive prediction model of herbage yield of the grassland. The practical result proved this point too. Fitted coefficient of the model reached extremely striking standard, the result conformed to precision demand (Table 7). The model was $B = -169.7743 + 0.8368H + 0.8631D + 3.6231C$ ($R = 0.9951^{**}$, $F = 169.0484$). Among many predictive models of herbage yield, some related to many environmental factors which were difficult to determine and needed high-precision instrument and complicated analysis. In addition, having total quantity characteristic of the community as index to set up nondestructive prediction model of herbage yield needed more amount of work than having quantity characteristic of a individual in community as index to set up that. Also the former was usually not precise because there

Table 6　Linear regressive equation of main population, community's quantity characteristics and aboveground biomass

Content	Linear regressive equation	R
L. chinensis	$B=-88.3097+6.1047H$	0.8850^{**}
	$B=-34.0113+7.2627C$	0.9846^{**}
	$B=-320.0998+2.0713D$	0.9646^{**}
P. flagellaris	$B=13.3010+15.3443H$	0.5270
	$B=66.0869+11.5957C$	0.2617
	$B=312.6797-1.9421D$	-0.8749^{**}
Clustered grass	$B=-3.2521+6.1182H$	0.9933^{**}
	$B=126.7707-1.3410C$	−0.0370
	$B=231.8337-1.8503D$	-0.8825^{**}
Community	$B=-76.0856+3.7707C$	0.9431^{**}
	$B=-255.8541+0.3391D$	0.7188^{*}

$n=9$, $R_{0.05}=0.666$, $R_{0.01}=0.798$, B is aboveground biomass ($g \cdot m^{-2}$), H is height (cm), C is cover-degree (%), D is density (plants or clusters $\cdot m^{-2}$)

were populations in the community which had negative effect on the formation of herbage yield. Owing to the negative effect of these populations, the accuracy which had total quantity characteristic of community as index to predict herbage yield droped. In the community of the grassland, the precision of the yield predictive model (coefficient 0.9611) which was set up having total quantity characteristic of community as index was clearly lower than that of the model (0.9951) which was set up having edificato- *L. chinensis* population quantity characteristic as index.

Seasonal dynamics of biomass is limited by many ecological factors in growing season. So study on yield ecology information parmeters of it is a very complicated problem. Through analyzing yield ecology information parameters, very precise nondestructive model was set up. It made yield ecology information parameters of logistic seasonal growth in this study in one growing seasin more scientific and widely used.

Table 7 Use height(cm), **density**(plants · m^{-2}) **and cover-degree**(%) **of *L. chinensis* population to estimate aboveground biomass of community**(g · m^{-2})

Date	May 20	June 5	June 20	July 5	July 20	Aug. 5	Aug. 20	Sep. 5	Sep. 20
Height	14.9	20.2	34.7	39.3	44.5	41.5	40.7	38.8	32.8
Density	166	170	184	218	222	256	250	232	225
Cover-degree	7.7	9.5	11.5	19.5	30.5	30.8	30.0	27.2	24.2
Real value	9.6	27.7	65.3	115.6	165.0	197.3	180.8	173.2	147.3
Estimated value	13.9065	28.3155	59.7787	121.9582	169.6161	197.5380	188.7915	161.5211	139.5893

2.5 Dynamics and simulation of vertical spatial pattern of underground biomass

The underground biomass of grassland community was determined twice in summer (Aug. 16) and the end of autumn (Oct. 16). The result (Table 8) showed that underground biomass vertical spatial pattern as reverse "pyramid" type.

Table 8 Underground biomass distribution of the grassland (g/25× 25 × 10cm^3)

Layer(cm)	Aug. 16			Aug. 16		
	Weight of live root	Weight of dead root	Weight of total root	Weight of live root	Weight of dead root	Weight of total root
0～10	29.7	12.8	42.5	35.1	15.5	50.6
10～20	10.9	3.3	14.2	10.7	3.5	14.2
20～30	7.5	1.2	8.7	7.2	1.3	8.5
30～40	6.8	1.0	7.8	5.1	0.9	6.0
40～50	3.3	0.5	3.8	3.1	0.5	3.6
50～60	2.0	0.3	2.3	2.1	0.3	2.4
60～70	1.45	0.2	1.65	1.3	0.2	1.5
70～80	1.35	0.15	1.4	0.7	0.1	0.8
80～90	1.1	0.15	1.25	0.4	0.07	0.47
90～100	0.7	0.1	0.8	0.3	0.05	0.35
Total	64.7	19.7	84.4	66.0	22.42	88.42

In summer (Aug. 16), the underground biomass in 0～30cm soil-layer was 1046.4 g · m^{-2}, made up 77.49% of total root amount. In the end of autumn with aboveground plant withering (Oct. 16), the underground biomass in 0～30cm layer was 1172.8 g · m^{-2}, made up 82.9% of total root weight. Because the soil in 0～30cm layer in this region was porous, with abundant nutrient, root system mainly distributed in this layer. But in 30～100cm soil layer, root weight only made up 22.51% and 17.1% of total root weight. In the whole determined depth 0～100cm soil layer, live root weight accounted for 76.66% and dead root 23.34% in summer. In the end of autumn (Oct. 16) with plant withering, live root made up 74.64% and dead root 25.36%. From this, live root of summer (Aug. 16) was more than that of the end of autumn (Oct. 16). The total weight of live root (Aug. 16) was compared with that of Oct. 16 ($P>0.05$). Also the total weight of total root (Aug. 16) was compared with that of Oct. 16 ($P<0.05$). The reason was that some early spring annual plants' roots were dead in the end of autumn. In summer (Aug. 16), in 0～100cm soil layer, underground average total root weight per area of grassland community was 1350.4 $g \cdot m^{-2}$, but in the end of autumn (Oct. 16) that was 1414.72 $g \cdot m^{-2}$, which was 64.32g per square meter more than that in summer (Oct. 16). This showed that in the end of autumn (Oct. 16) with plant withering, aboveground nutrient tended to move to roots, preparing for plants surviving the winter. So underground root weight in the end of autumn (Oct. 16) was more than that in summer (Aug. 16), among which root weight increased mainly distributed in 0～10cm soil layer, possibly because root of edificato- *L. chinensis* mainly distributed in shallow layer, and *L. chinensis* population needed more nutrient to resist long and cold winter. The distribution of underground biomass of grassland community varied as exponential function. The models were $Bu_1=2562.1448(D+10)^{-1.7010}(R=-0.9866^{**}, N=10)$ in summer (Aug. 16), and $Bu_2=5241.1698(D+10)^{-1.9302}(R=-0.9759^{**}, N=10)$ in autumn (Oct. 16). Bu is the root weight of depth $[D, D+10]$ in area determined. All reached extremely striking standard.

2.6 Water, heat conditions in growing season and their correlation with aboveground biomass

In growing season, effective water, heat conditions can provide advantages for plant growth and development and dry matter accumulation. Between June and August, with highest temperature and most precipitation, plants of *L. chinensis* + mesophytic herbs community were in lush growth. Their biomass increased quickly and reached maximum in this period. But in former and later stage of growth and development, because of poor water, heat conditions, plants grew slowly or stopped growth and waned (biomass dropping). In growing season, aboveground biomass dynamics of community was on extremely striking positive correlation with average temperature ($R=0.8287$) and accumulated precipitation ($R=0.8932$) of the former month (Table 9). By determining the soil moisture, we can obtain the conclusion as follow : as the depth increased, the stablity of the soil's water content of the grassland increased, that was in deep soil of 20～30cm water content waved less than that in 10～20cm depth which waved less than that in 0～10cm depth. In addition, the correlativity of the soil water content of the under layer and the above layer reached striking standard. The correlative coefficient of 10～20cm and 20～30cm was 0.7243^{*}; that of 0～10cm and 10～20cm was 0.7877^{*}. But the correlativity of the soil water content of every other layer didn't reach striking standard. So a law can be concluded : precipitation controlled soil water content of above layer which controlled soil water content of under layer in 0～30cm. The correlative analysis of water content of each layer soil, 0～30cm soil layer and aboveground biomass showed no striking correlativity between them.

Through optimizing studies on correlative simulation, factors which limited seasonal dynamics of biomass were defined as water and temperature, and correlative model on seasonal dynamics of aboveground biomass and water temperature factors in growing season was set up. This not only provided necessary complement for that yield ecology information parameters of logistic seasonal growth had wide meanings, but also made the application of yield ecology information parameters more scientific, especially in using yield ecology information parameters to manage water and fertilizer of grassland.

Table 9 Linear regressive equation of average temperature(T), accumulated precipitation(P) of the former month and community aboveground biomass(B)

Content	Linear regressive equation	R
Average temperature of the former month	$B=-179.5723+15.5771T$	0.8287*
Accumulated precipitation of the former month	$B=-40.0050+1.6979P$	0.8932*

3 Discussion and conclusion

3.1 Grassland was taken as a whole ecological system. By simulation, the purpose was to probe comprehensively into internal yield ecology information parameters and their meanings. Seen from references, during growing season, growth dynamics of aboveground biomass appeared as "S" curve in many kinds of grassland in north China. The curve was as single peak and could be simulated by logistic model, but it didn't lose important information parameters of yield ecology. In addition, the purpose of this study was not only to simply mathmatically simulate a process of life and ecology, but to probe into internal fine information parameters of the process. Above study and analysis showed that logistic model could meet needs well. Seasonal dynamics of biomass was limited by environmental factors during growing season. In this study, through probing into information parameter of yield ecology, a very precise nondestructive model was set up. Moreover, by studying on related model optimization, water, temperature factors were defined as main factors to limit seasonal dynamics of biomass, and related model was set up. All these offered very necessary complement for that yield ecology information parameters of logistic seasonal growth were widely scientific and applied.

3.2 Plant community of grassland is made of various plant populations. The total effect of all populations showing in community is characteristic expression of the community[17,33]. In the whole growing season, different growth and development rhythm of different plant population of *L. chinensis* grassland formed the special seasonal succession of the grassland community. This reflected that within the community, plant populations had ecological relation of mutual adaption to a certain extent. So what could be showed was that each plant was located in different status in community. *L. chinensis* population was in superior status in the community, playing a leading role. In the whole growing season, the proportion of *L. chinensis* population biomass in total biomass of community gradually increased from the first determination to Aug. 20, which was from 36.5% to 58.7%. Only in later stage, it droped to 55.1%, and this was related to that *L. chinensis* population's nutrient transported increasingly to underground root in later stage and protective mechanism of *L. chinensis* population itself strengthened. In addition, the root weight increased in the end of autumn mainly distributed in 0～10cm soil layer which was the main distribution region of *L. chinensis* population root weight. This further proved that protective mechanism of *L. chinensis* population itself increased to the end of autumn that was population needs more nutrient to resist long and cold winter. Lush growth and development of edificato- *L. chinensis* marked the grassland community was in a good development period and there was no regressive succession. *L. chinensis* population made the greatest contribution to the formation of biomass. In a word, by studying information parameter of yield ecology, we could see that protective mechanism of *L. chinensis* population was strengthened in autumn, good development of edificato could further conclude that community has no regressive succession. Having edificato population's height, cover-degree and density as index to set up nondestrutive prediction model of herbage yield not only overcame the destructibility of harvest method but also had simple and convenient characteristic. Moreover the model reached precision demand.

3.3 The formation law and features of aboveground biomass of *L. chinensis* grassland were limited by its development rhythm and ecological factor. In growing season biomass varied as “single peak” type and reached the peak of biomass before Aug. 5 which was 197.3 g · m^{-2}. Among which the peak of *L. chinensis* population's aboveground biomass appeared about half a month later than that of community's biomass. The peak of mesophytic herbs and community's biomass appeared simultaneously. Logistic model contained much information on biological-ecological features of grassland herbage. These information could be obtained by means of parameters in logistic model and their special calculation, and these information was a basis to effectively manage the grassland. So before aboveground biomass of *L. chinensis* grassland reached maximum, logistic model was used on biomass of *L. chinensis* population, mesophytic herbs and the community, the coefficients all reached striking standard. Absolute growth rate and relative growth rate of aboveground biomass estimated accumulated dynamics of aboveground biomass and productive efficiency of organic matter from different angles. The results indicated the law of absolute growth rate and relative growth rate of aboveground biomass with *L. chinensis* grassland which was in growing season *AGR* and *RGR* was high in early stage, decreased gradually as plant developed, and appeared negative values in later stage, showing that after aboveground biomass formed, growth efficiency was the highest in initial stage of growth, gradually droped after that. According to this law, technical management measure should be exerted on grassland, especially water and fertilizer measure in early stage of grassland plant growth and development in order to play benefit of putting into, to lower production cost. Aboveground productive structure of grassland distributed basically as “pyramid” type, reflecting vertical structure law and features of aboveground herbage yield of *L. chinensis* grassland from the other aspect. Among which 93% yield was concentrated below 40cm, so if the height left by mowing was reasonably controlled about 5cm, biomass obtained by mowing approached 92% of total biomass. Underground biomass distributed as “reverse pyramid” type. The biomass in 0～30cm depth made up 77.5% and 82.9% of total underground biomass respectively. Compared with biomass of summer, underground biomass increased in the end of autumn with plant withering, showing that aboveground biomass had the tendency to transport to root in later stage. On the basis of the case above, if the improvement measure related to root system problems was carried on the grassland, the depth of 0～20cm can reach the good effect of improving the grassland.

3.4 By analysing the correlation of aboveground biomass of grassland community and accumulated precipitation, average temperature of the former month, we can understand obviously that in a certain range, the better the water and heat conditions, the more the aboveground biomass accumulation of the grassland community. But the increase of grassland aboveground biomass didn't show that in each stage biomass accumulation completely tallied with accumulated precipitation and average temperature of the former month. For example, on July 20, aboveground biomass of grassland community was 165.0 g · m^{-2}, but the corresponding precipitation was 143.4mm; on Aug. 5, biomass was the highest, 197.3 g · m^{-2}, but the corresponding precipitation was not the highest, it was 124.8mm, lower than that of July 5. So the feature of “whether water and heat conditions in each stage could satisfy the need of plant growth or not” was especially important. If the seasonal distribution of water and heat conditions was not even (that was when grassland community needed good water and heat conditions, there were not; but when the community needed ordinary water heat conditions, there were over-good water heat conditions), though total water heat conditions in a year was very good, aboveground biomass accumulation of the whole grassland community had relatively bad correlation with water heat conditions and grassland biomass couldn't be raised clearly. With regard to temperature and precipitation, the correlation coefficient ($R=0.8932$) of aboveground biomass of the grassland community and accumulated precipitation of the former month was larger than that ($R=0.8287$) of biomass and average temperature, showing that biomass had stronger correlation with precipitation than with temperature. Precipitation factor had larger effect on formation of grassland aboveground biomass than temperature factor. Under the same conditions, the correlativity of *L. chinensis* + mesophytic herbs grassland aboveground biomass with precipitation and temperature is relatively worse than that of Stipa baicalensis grassland aboveground biomass with precipitation and temperature[25], showing that *L. chinensis* + mesophytic herbs grassland had better water and heat conditions than Stipa baicalensis grassland.

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