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Relationship between structure and aboveground biomass of typical steppe and climate in Inner Mongolia

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Abstract— Typical steppe in Inner Mongolia belongs to a part of Central Asia sub-region in Eurasian temperate steppe region. In climate distinct wet and dry season, coherence of water and heat result in single peak type of seasonal dynamic of steppe biomass. Community biomass has linear regressional equation with community height, its correlation coefficient (R) is 0.959***. Growth rate of biomass in June, July and August is usually at 1.5–3.0 $g/m^2 \cdot d^{-1}$. Community standing dead occurs in June and equates green living biomass by mid-September. Community biomass is only standing dead biomass in the mid-October. Biomass, green production and standing dead have linear regressional relation with days of plant growing, their correlation coefficient (R) are 0.9919***, 0.9878*** and 0.9923***, respectively. Yearly dynamic of typical steppe biomass is variable, the maximum value is 2.4 times as much as the minimum. The peak biomass of *Stipa grandis* steppe was 87g/m^2 in dry 1980 and 210g/m^2 in rainy 1981, and their height and coverage were 60cm and 30% in 1980, 95cm and 40% in 1981. Major population biomass and individual plant dry weight at the peak time in 1980 is 50–70% lower than in 1981. In 1980, grass over the layer of 40 cm high became dead and community standing dead biomass amounted to 32.07% of the total production, 2.5 times as much as that in 1981 (13.08%). In addition, growth rate of biomass before the peak time in 1980 were negative value for 2 times. Seasonal dynamic curve of dry matter content is in negative proportion to biomass increase and dry matter content is higher in dry 1980 than in rainy 1981.

Keywords: aboveground biomass; typical steppe; Inner Mongolia.

INTRODUCTION

Typical steppe, distributed at the Xilingguole League, Inner Mongolia, China belongs to temperate steppe, and is important grazing pasture. At present, most of the area is overgrazed

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and vegetation productivity is decreasing rapidly. Our study aims to investigate the development course of typical steppe community and its biomass formation process under natural condition, to understand variation of community structure and productivity under various climatic conditions. It will give out valuable information to arrange rationally animal husbandry and to use wisely grassland resources.

PHYSICAL CHARACTERISTICS OF THE STUDIED AREA

The studied area is located at Baiyinxile Livestock Farm in the middle Xilingguole River Basin, Inner Mongolia Plateau, with 43°26′N–44°08′N in latitude, 116°04′E–117°05′E in longitude and 1000-1300m above sea level in altitude. Typical steppe consists mainly of *Aneurolepidium chinense* steppe on the areas of relative high relief, more humid and dark chestnut, and *Stipa grandis* steppe on the areas of low relief, more arid and typical chestnut. In our study, natural steppe communities were observed, which were fenced in 1980 and since then had no grazing and other human activities except for small amount of rodents and grasshoppers. Climate is the key factor that influences community growth.

Climatically, it is cold, semi-arid, aridity being about 1.2. Mean annual temperature is -0.4°C and $\geq$ 10°C effective accumulated temperature is 2128.93°C. Mean annual precipitation is about 300mm and annual evapotranspiration is 1665.2mm. Steppe plants start germinating (or turn green) usually from the mid-April, and become dead in mid-October. The growing season lasts about 160–170 days, during which period grass plants can still grow if there is frost and /or thin snow. Large fluctuation of annual rainfall is one of major characters of climate in the region. Annual precipitation in rainy year might be 2–3 times as much as that in dry year. So, Walter's climate type of the region belongs to forest steppe in some years, or to typical steppe in other years, even to desert steppe type (Fig. 1). It influences much productivity and structure of steppe.

SEASONAL AND YEARLY DYNAMICS OF ABOVEGROUND BIOMASS

General rule of seasonal dynamic of aboveground biomass

During growing season, aboveground biomass of typical steppe increases gradually as time goes on, temperature rises and rainfall increases. Plants turn green usually at the middle April, and reach biomass peak in August-September after 120–150 day's growing. Later on, biomass decreases as autumn comes in and temperature declines. The seasonal dynamic of aboveground biomass shows single-peak curve, which is in accordance with climatic characteristics of Central Asia such as coherence of water and heat, and distinct dry and wet seasons.

Seasonal increase of community aboveground biomass and height have the same tendency. The maximum aboveground biomass and height appear in August, the maximum growth rate

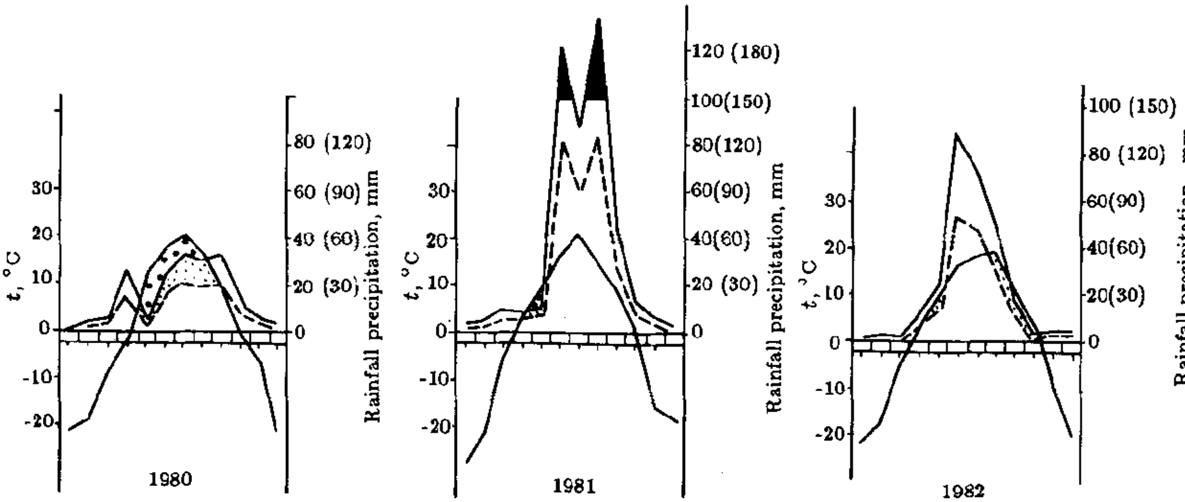

Fig. 1 Walter's climate type of the studied area in three years of various annual precipitation

in July. Community biomass and height decline obviously by the late August, because of withering of leaf tips. From mid-September on, community biomass decreases at larger rate than community height does, because large amount of aboveground organic substance is transferred to roots and consumed through inevitable respiration. Community aboveground biomass has linear regressional relation with community height, correlation coefficient (R) being 0.959 (Fig. 2).

According to observation in eight years, growth rate of aboveground biomass reaches the maximum before the peak of community aboveground biomass comes. It has sufficient rainfall and high temperature in July, which is suitable for plant to grow. Thus, growth rate (GR) of steppe usually amounts to 1.5–3.0g/m^2. d^{-1}, the maximum being 5.0g/m^2·d^{-1}. After mid-August, the growth rate declines. Aboveground biomass has negative increase by the early september. As concerned relative growth rate (RGR), it reaches the maximum at early spring, 0.05–0.10g/g. d^{-1} in May, at which time plants are at the early vegetative stage and aboveground part grows fast under the condition of high soil moisture and suitable temperature, there: $GR=(w_2-w_1)/p(t_2-t_1)$, $RGR=(\text{In}w_2 \text{ -In}w_1)/(t_2-t_1)$, w_1 is the biomass from the first measuring; w_2 is the biomass from the second measuring; p is the area of surveying, m^2; t_1 is the time for the first measuring; t_2 is the time for second measuring.

In the year of thick winter snow, the relative growth rate of aboveground biomass is up

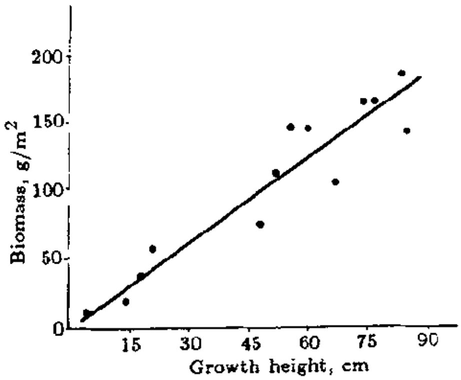

Fig. 2 Relationship between aboveground biomass and height of steppe community

to 0.20 g/g.d^{-1}. The growth rate in July is the highest but the relative growth rate is comparatively low, the minimum value appears in August. This situation could be referred that community already has large amount of aboveground biomass (Table 1).

Table 1 The growth rate of aboveground biomass and height in steppe

Date		Biomass		Height
		Growth rate, g/m^2·d^{-1}	Relative growth rate, g/g·d^{-1}	Growth rate, cm/d
May	1–15th	0.8202	0.1085	0.4368
	16–31th	1.5584	0.0539	0.5103
June	1–15th	0.6842	0.0145	0.3732
	16–30th	1.7207	0.0285	0.8434
July	1–15th	2.6184	0.0287	1.2801
	16–31th	1.1059	0.0440	1.2459
August	1–15th	1.6102	0.0112	0.3714
	16–30th	0.3225	0.0036	-0.4898
September	1–15th	-0.6932	-0.0040	-0.2487
	16–31th	-1.1135	-0.0086	-0.2771

Relationship between green living and standing dead of steppe community in the seasonal course

Green living and standing dead have evident variation in the seasonal course. Plants turn green at mid-April and start to form standing dead at mid-June. Appearance of standing dead might also be at the early June or at the late June, depending upon rainfall and temperature. Standing dead amount increases slowly at its early stage but increase enormously after community aboveground biomass reaches the peak as large amount of green living bodies be-comes dead, and is equal to green living in weight by early-middle September. Green living will disappear by mid-October and all the community biomass is thus the standing dead (Fig. 3).

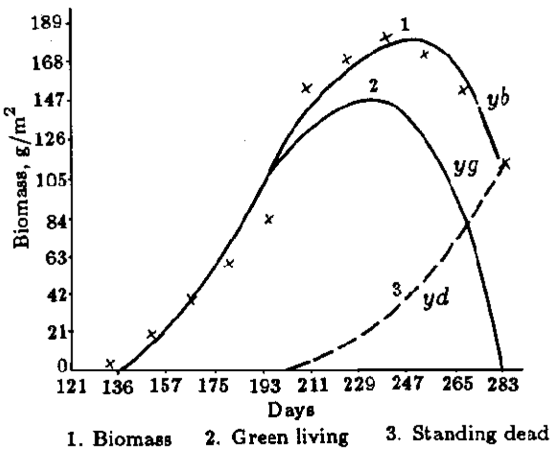

Fig. 3 Seasonal dynamic of biomass, green living and standing dead of *Stipa grandis* steppe

$$yb = 1180.4 - 21.881x + 0.12754x^2 - 0.00022417x^3$$
$$R = 0.9919^{***} \qquad N = 95;$$
$$yg = 1350.7 - 25.341x + 0.15060x^2 - 0.00027462x^3$$
$$R = 0.9838^{***} \qquad N = 55;$$
$$yd = -170.52 + 3.4628x - 0.023075x^2 + 0.000050474x^3$$
$$R = 0.9923^{***} \qquad N = 40$$

Yearly dynamic of aboveground biomass of steppe

Various types of steppe have its own peak biomass as the consequence of floristic composition and environmental conditions, that is, they have difference in productivity. On the average, *A.chinense* steppe has 212g/m^2 aboveground biomass, and *S.grandis* steppe has 145g/m^2 aboveground biomass, the former being 32% higher than the latter. The same steppe type might also have distinct difference in aboveground biomass in various years as the results of climate variation, in particular, rainfall fluctuation. The yearly dynamic of steppe in 1980–1987 is given in Fig. 4 and Fig. 5. The peak aboveground biomass of *A. chinese* steppe ranges from $126g/m^2$ to $302g/m^2$, that of *S. grandis* steppe from $87g/m^2$ to $210g/m^2$. The maximum and minimum biomass of *A. chinense* steppe are 2.4 times as much as those of *S.grandis*. Fig. 6 illustrates that both steppes have almost the same tendency in yearly variation of aboveground biomass.

As regards the time of peak biomass, *A. chinense* steppe is usually within the early-middle August, *S.grandis* steppe between mid-August and mid-September, which is related to the early maturing of *A. chinense*.

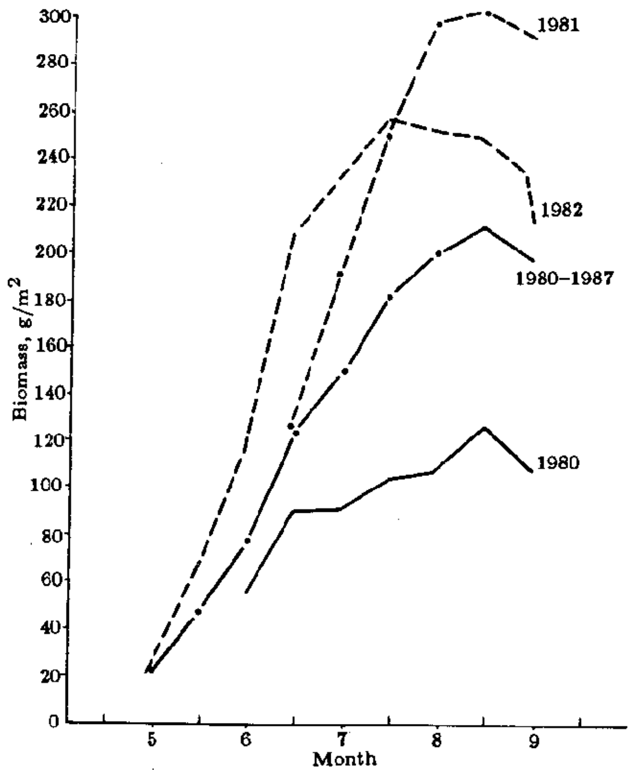

Fig. 4 Dynamic of biomass of *Aneurolepidium chinense* steppe

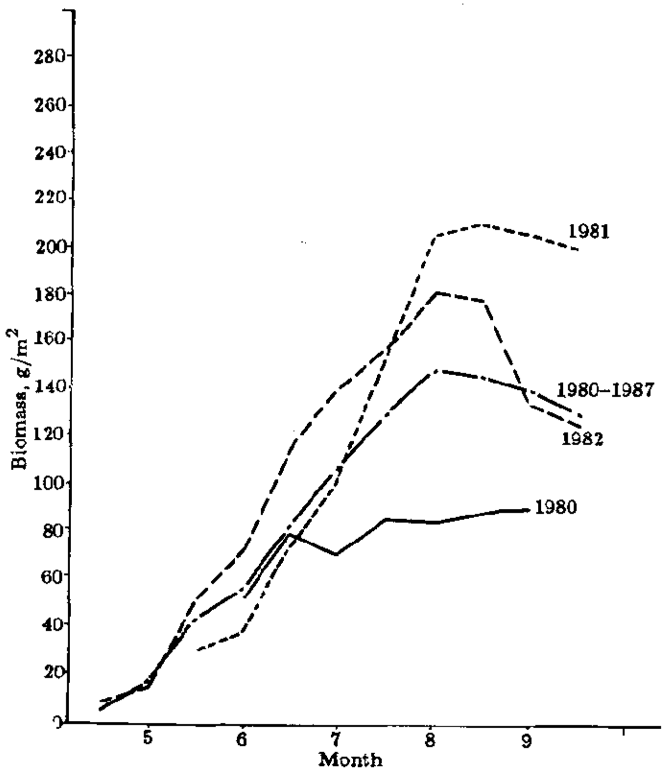

Fig. 5 Dynamic of biomass of *Stipa grandis* steppe

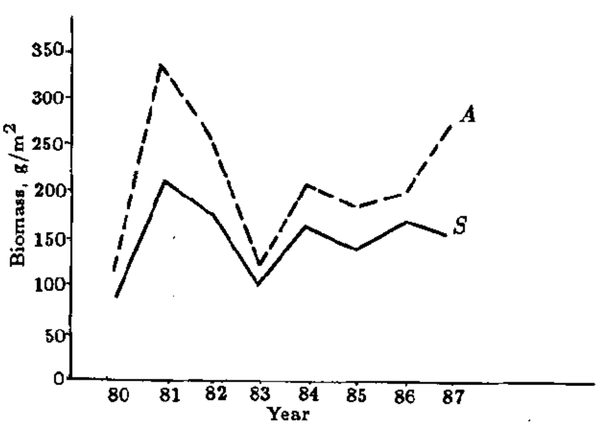

Fig. 6 Yearly dynamic of biomass of *Aneurolepidium chinense* steppe and *Stipa grandis* steppe

EFFECT OF EXTREME CLIMATE ON STRUCTURE AND BIOMASS OF STEPPE COMMUNITY

In the arid and semi-arid region, water is the limiting factor for plant growth. So, how and what will the variation in rainfall affect steppe community? The data from two years of large variation in rainfall are taken for comparative study.

The year 1980 is the extreme dry year in our studied area, annual precipitation is only 182mm; while the year 1981 is a rare wet year, annual precipitation is 449.7mm. The difference in annual precipitation between 1981 and 1980 is 268.5mm. Rainfall in the growing season is 130mm in 1980 and 370.7mm in 1981 (Fig. 7). At the same time, observed were remarkable difference in growth height, coverage, biomass seasonal dynamic and net productivity of steppe community. *S.grandis* community is here taken as an example.

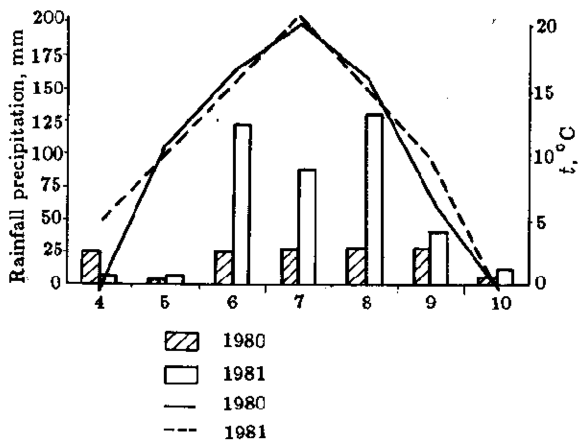

Fig. 7 Comparison on monthly rainfall in 1980 and 1981

Community physiognomy

In 1980 plant growth and development were severely limited. Plants were generally short, small and weak, and so community physionomy looked short and sparse. In the vigorous growing period *S. grandis* plant was 60cm high on the average, being 30–40cm lower than in 1981 (90–100cm high in 1981), and community coverage was 30%, being 10–15% lower than in 1981. The seasonal dynamics of community coverage and height in both the years show the relevant change (Fig. 8).

Population biomass

Population biomass reflects development of individual plants. Compared biomass of major

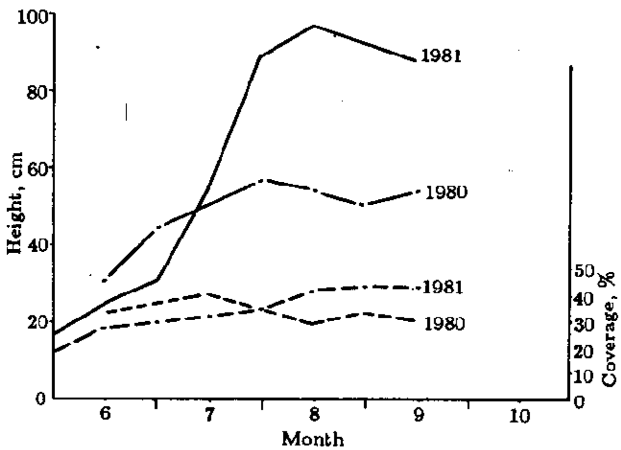

Fig. 8 Seasonal dynamic of community hight and coverage of *Stipa grandis* steppe

plant populations in 1980 with that in 1981(Table 2), it is found that population biomass and individual plant dry weight in 1980 are all considerably lower than those in 1981, in particular, individual plant dry weight in 1980 is 50–70% lower than that in 1981.

Table 2 The comparison of population biomass and individual plant dry weight of *Stipa grandis* community between year 1980 and 1981

Species	Population biomass, g/m^2		Individual plant dry weight, g/indi.	
	13/09/80	27/08/81	13/09/80	27/08/81
Stipa grandis	53.40	110.75	0.8770	3.1108
Aneurolepidium chinense	6.50	6.58	0.2032	0.5672
Agropyron cristatum	2.62	10.72	0.1711	0.2629
Koeleria cristata	1.4	1.61	0.3453	0.3443
Artemisia frigida	4.66	14.12	0.1908	0.5282
Artemisia comutata	4.82	30.61	1.0674	1.6284
Heteropappus altaicus	17.16	6.03	0.4162	0.7014

Table 3 gives out the ratio of biomass of constructive species and plant groups to the peak community biomass. The ratio have little difference between year 1980 and 1981. It indicates that their ratio and role in steppe community are consistent although the population biomass in 1980 and in 1981 has large difference. There is no much change in species composition. It further indicates that *S. grandis* community is rather stable, even in the extreme dry year like 1980.

Table 3 The proportion of biomass of plant groups to community biomass in *Stipa grandis* community

Plant group	1980	1981
Stipa grandis	53.30	52.70
Grass	9.89	9.63
Sedge	1.12	0.40
Semi-shrub	7.31	8.10
Forb	28.38	29.19

Production structure of community

Production structure of community is the vertical distribution of community biomass. Taken the data in the late August as an example, Fig. 9 depicts clearly that the production at each vertical layer of community in 1980 is less than that in 1981. Grass over the layer of 40cm high became dead at the late August, 1980, because of drought. Correspondingly, standing dead production of each layer increased distinctly and is equal to 32.07% of the total production, being 2.5 times as much as that in 1981 (only 13.08%).

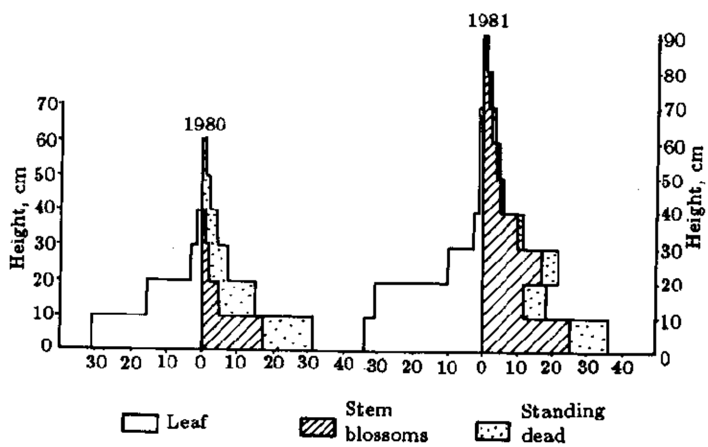

Fig. 9 Community production structure of *Stipa grandis* steppe

The proportion of assimilation organ to non-assimilation organ, i.e., leaf/stem (F/C) is 2.11 in 1980 and 1.01 in 1981. Evidently, stems, branches and blossoms of plants did not extend fully in 1980 and became dead earlier, as the result, community biomass in 1980 is 40–50% as much as that in 1981.

Seasonal change in aboveground biomass and net productivity of community

The annual climate change brings much influence on seasonal dynamic of community aboveground biomass (Fig. 5). During growing season in 1981, it had abundant monthly rainfall except for May, precipitation within April–August was 360mm. Monthly precipitation in June, July and August was 113.1mm, 123.5mm and 86mm, respectively. Plants grew and developed fully and biomass increased positively before its peak was reached. Biomass had growth rate of 2.5093–4.2029$g/m^2 \cdot d^{-1}$ and amounted to 210.07g/m^2 as the peak biomass. While in Spring 1980, soil condition was good and community biomass was well accumulated in May and June. The biomass at mid-June was 51.28g/m^2 and its growth rate was 0.9327$g/m^2 \cdot d^{-1}$ (The community biomass at the same sampling date in 1981 was 35.29g/m^2 and growth rate 0.4856$g/m^2 \cdot d^{-1}$). But there was no much increase in rainfall after June. Monthly rainfall in June, July and August was 25.2mm, 33.0mm and 30.8mm, respectively. As temperature rose, evaporation increased, too. Soil water content declined thus below the plant wilting index. As standing dead increased, community biomass did not increased but decreased a little. Daily growth rate in early July and early August was negative value and plant growth was hampered. Dynamic curve of biomass also took a flat shape without distinct peak which was 87.40g/m^2 only and occurred at mid-September.

Based on accumulation of weight increase, annual net productivity is 210.1g/m^2 (2.10 t/ha) in 1981 and 92.7g/m^2 (0.92t/ha) in 1980.

Seasonal change of dry matter content

According to the proportion of dry matter to fresh matter, dry matter content was low when community biomass increased fast, and vice versa. This rule is clearly reflected in the seasonal dynamic of dry matter content in 1980 and 1981. Although community biomass in 1981 is higher than in 1980, dry matter content of each month in 1980 was usually within 55–66% and that in 1981 was within 49–61%. It is noticeable that dry matter content in Spring 1981 is 56–64%, higher than that in spring 1980 (46–50%). The cause is that there was less rainfall in spring 1981 and biomass at mid-June was only 35.28g/m^2 but biomass at mid-June, 1980 was 51.28g/m^2 (Fig. 10).

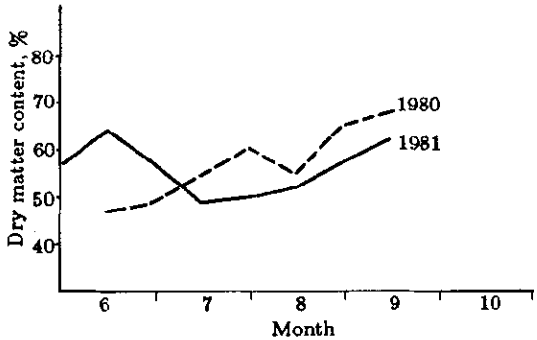

Fig. 10 Seasonal dynamic of dry matter content of *Stipa grandis* steppe

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