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ORIGINAL ARTICLE

Root and rhizome systems of perennial grasses grown in Inner Mongolian grassland, China

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Abstract

The root and rhizome systems of dominant perennial grasses in Inner Mongolian grassland were clarified. We surveyed the vertical distribution of root and rhizome biomass in the natural stands, and the changes of under-ground biomass and the branching pattern of rhizomes for transplanted plants in a container experiment. Most roots of *Leymus chinensis*, *Bromus inermis*, *Elymus dahuricus* and *Agropyron cristatum* were distributed in the soil depth of 0–10 cm. Roots of *E. dahuricus* and *A. cristatum* were distributed in a shallower soil layer, but those of *L. chinensis* and *B. inermis* were distributed in a deeper soil layer. Biomass of above-ground parts increased with growth, resulting in a decreasing ratio of under-ground parts to total biomass. Rhizomes of *L. chinensis* and *B. inermis* were distributed in the soil depth of 0–10 cm, but *E. dahuricus* and *A. cristatum* did not have rhizomes. *L. chinensis* had longer rhizomes and new ramets were produced away from their mother plant. *B. inermis* had many short rhizomes and produced daughter plants near their mother plant.

Introduction

Grassland degradation and desertification are advancing over wide areas in China in spite of the efforts such as banning of grazing, grassland improvement and artificial pasture establishment (Akiyama and Kawamura 2007). Due to the extremely harsh climate of northern Inner Mongolia, especially severe winter chilling, growing period for grasses is short and hence species used for the recovery of vegetation are limited. Recently, selection and breeding of strains tolerant to severe climatic conditions from native species are showing some extent of success (Yun 2008).

Roots and rhizomes of perennial grasses have a crucial role in the establishment, maintenance, improvement and recovery of grasslands, and also in the conservation of grassland soil (Kobayashi 1977). Soil erosion by wind depends on the total length and biomass of roots and rhizomes per unit area (Yu and Okumura 2001). Although a number of studies have been conducted for grasses found in Inner Mongolia grassland, especially on *Leymus chinensis* (Trin.) Tzvel. (Zhang *et al.* 2003; Ding *et al.* 2004; Liu *et al.* 2005; Fan *et al.* 2006; Zhang *et al.* 2006; Wang *et al.* 2007; Liang *et al.* 2008; Lin *et al.* 2008), relatively little information is available on the root and rhizome systems of the grasses (Chen and Wang 1985; Zhang *et al.* 2003; Shi *et al.* 2008).

In this study, we investigated root and rhizome systems of four perennial grasses that are particularly important in the Hulunbeier grassland in Inner Mongolia. Vertical distribution of root and rhizome biomass was quantified in the natural stands in Hailaer, then changes in under-ground biomass and branching pattern of rhizomes were clarified for transplanted plants grown in containers.

Materials and methods

The four grasses studied were *L. chinensis*, *Bromus inermis* Leyss., *Elymus dahuricus* Turcz. and *Agropyron cristatum* (L.) Gaertn. These species have both cold and drought resistance, and have relatively long growth duration. Their nutritive values are higher than other species growing in the same area. Among the four species, *E. dahuricus* is the hardiest and can withstand as low temperature as −41°C. *B. inermis* and *A. cristatum* have the longest growth duration and the grassland dominated by these two species can be maintained for 10 years under mowing or grazing. *L. chinensis* is one of the most palatable grasses for livestock (Liang 2001).

On-site study in Hailaer, China

The biomass and vertical distribution of roots and rhizomes of *L. chinensis*, *B. inermis*, *E. dahuricus* and *A. cristatum* were investigated in July 2006 in the grassland at Beishan Experiment Station, Hailaer (49°13′N, 119°45′E, 611 m a.s.l.), the northeast region of Inner Mongolia, China. The above-ground parts of three plants for each species were cut at the soil surface. Then, roots and rhizomes of each plant in a 50 cm × 50 cm area were sampled to a depth of 50 cm at 10-cm intervals. The samples were dried at 80°C for 24 h in a fan oven and weighed.

Container experiment in Kyoto, Japan

Seeds of *L. chinensis*, *B. inermis*, *A. cristatum* and *E. dahuricus* were collected in the same grassland in Hailaer in August 2003, and were kept at 5°C until 13 April 2006, when 40 seeds of each species were sown individually in cells (1.6 cm × 1.6 cm) of a plug tray. On 22 May 2006, 20 seedlings of each species were individually transplanted in a container (56 cm × 26 cm × 18 cm) filled with sandy loam soil. The containers were kept outdoors in the experiment field of Kyoto University (35°00′N, 135°46′E, 62 m a.s.l.).

Three to seven plants of each species were harvested on 15 November 2006, 11 May 2007 and 26 November 2007, except for *A. cristatum*, which showed a very poor growth in Kyoto. The harvested plants were divided into above-ground parts, rhizomes and roots, and dried at 80°C for 48 h in a fan oven and weighed. Each rhizome length of a plant was measured.

Statistical analysis

ANOVA was performed to test the significant difference in biomass production of each species using R 2.8.1.

Results

Dry-matter weight of above-ground parts of *L. chinensis*, *B. inermis*, *E. dahuricus* and *A. cristatum* harvested in Hailaer was 17.7, 6.9, 9.2 and 12.4 g plant^{-1}, and that of under-ground parts was 24.1, 34.0, 38.7 and 46.5 g (0.25 m^2)$^{-1}$, respectively. The proportion of the biomass allocated to under-ground parts was 58%, 83%, 81% and 80%, respectively.

Among the four grasses, *L. chinensis* and *B. inermis* have rhizomes whereas the other two species, *E. dahuricus* and *A. cristatum* do not. The rhizomes of *L. chinensis* and *B. inermis* were distributed in the soil depth of 0–10 cm and the rhizome dry weight of *L. chinensis* and *B. inermis* was 9.9 and 0.6 g (0.25 m^2)$^{-1}$, respectively (Figure 1). Most parts of the roots were in the soil depth of 0–10 cm for all species, but the vertical distribution pattern varied among the species. Ninety-five percent of root dry matter of *E. dahuricus* was in a soil depth of 0–10 cm and decreased drastically with the increase of depth. *A. cristatum* showed a similar pattern to *E. dahuricus*. The root dry matter of *L. chinensis* in a soil depth of 0–10 cm was 76% of total root dry matter and that of *B. inermis* was 66%. The roots of *L. chinensis* and *B. inermis* were distributed in the deeper layer.

In the container experiment, the increase of above-ground biomass of *E. dahuricus* was slower as compared

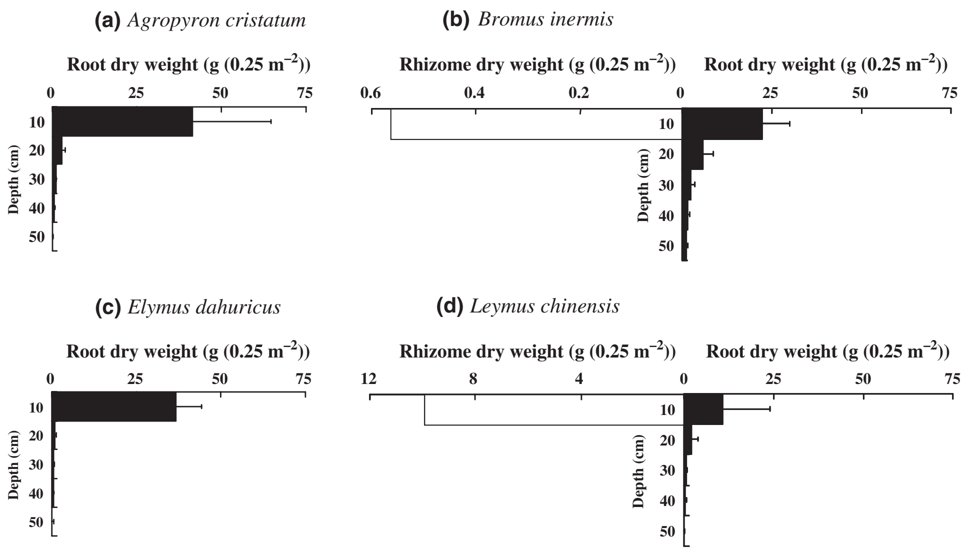

Figure 1 Vertical distribution of roots and rhizomes of (a) *Agropyron cristatum*, (b) *Bromus inermis*, (c) *Elymus dahuricus* and (d) *Leymus chinensis* in the on-site study in Hailaer. Each bar shows standard deviation.

with that of *L. chinensis* and *B. inermis* (Table 1). The changes in the biomass of under-ground parts were different from that of above-ground parts. The under-ground biomass of *L. chinensis* and *B. inermis* decreased from November 2006 to May 2007 and increased thereafter, whereas that of *E. dahuricus* decreased throughout. The ratio of under-ground parts to total biomass was different among species and decreased from 2006 to 2007. *B. inermis* showed the largest allocation to under-ground parts of 91% in November 2006, 80% in May 2007 and 76% in November 2007 among the three species. Above- and under-ground biomass of *B. inermis* was the largest among three species ($P < 0.001$).

Rhizome numbers and dry weight per individual increased and the increase was conspicuous in November 2007 (Table 2). Rhizome number and dry weight were not significantly different between *B. inermis* and *L. chinensis* ($P > 0.05$). However, the pattern of rhizome development was different between the two grasess (Figure 2). *L. chinensis* formed the tertiary rhizomes in November 2006, the fifth rhizomes in May and the sixth rhizomes in November 2007. *B. inermis* formed the secondary rhizomes in November 2006, the tertiary rhizomes in May and the fourth rhizomes in November 2007.

Leymus chinensis had longer rhizomes than *B. inermis* (Figure 3). The longest rhizome of *L. chinensis* reached 1.92 m in November 2007. Rhizomes shorter than 0.1 and 0.3 m occupied 47% and 81% of the total number of rhizomes, respectively, in *L. chinensis* in November 2006. In *B. inermis*, rhizomes shorter than 0.1 m occupied 96% in November 2006, and more than 97% in May 2007 and 81% in November 2007. The number of longer rhizomes generally increased with growth in both species.

The number of shoots per individual of *L. chinensis* and *B. inermis* generally increased from November 2006 to November 2007, but that of *E. dahuricus* decreased (Table 3). Consequently, the number of shoots of *E. dahuricus* was fewer than those of *B. inermis* and *L. chinensis* in November 2007 ($P < 0.01$). Shoot dry weight of *L. chinensis* and *B. inermis* increased from November 2006 to November 2007, but that of *E. dahuricus* had its peak in May 2007 and decreased until November 2007.

Table 1 Changes in above- and under-ground biomasses (g DM plant^{-1}) and percentage of underground parts for transplanted plants of *Bromus inermis*, *Elymus dahuricus* and *Leymus chinensis* in the container experiment in Kyoto

Species	Part	November 2006	May 2007	November 2007
Bromus inermis	Above-ground	11.48	15.81	28.10
	Under-ground	116.04	64.09	90.44
	% under-ground	91.0	80.2	76.3
Elymus dahuricus	Above-ground	7.29	9.76	8.45
	Under-ground	29.36	15.73	7.19
	% under-ground	80.1	61.7	46.0
Leymus chinensis	Above-ground	3.72	7.88	15.25
	Under-ground	18.21	15.08	30.04
	% under-ground	83.0	65.7	66.3

Table 2 Changes in number of rhizomes plant^{-1} and rhizome dry weight (g plant^{-1}) for transplanted plants of *Bromus inermis* and *Leymus chinensis* in the container experiment in Kyoto

	Bromus inermis		*Leymus chinensis*	
Sampling date	Number	Dry weight	Number	Dry weight
November 2006	46 ± 11†	2.0 ± 1.0	30 ± 36	2.6 ± 1.1
May 2007	53 ± 24	2.6 ± 0.1	58 ± 19	4.8 ± 3.5
November 2007	146 ± 74	9.5 ± 3.0	136 ± 65	10.7 ± 5.9

†Mean ± standard deviation.

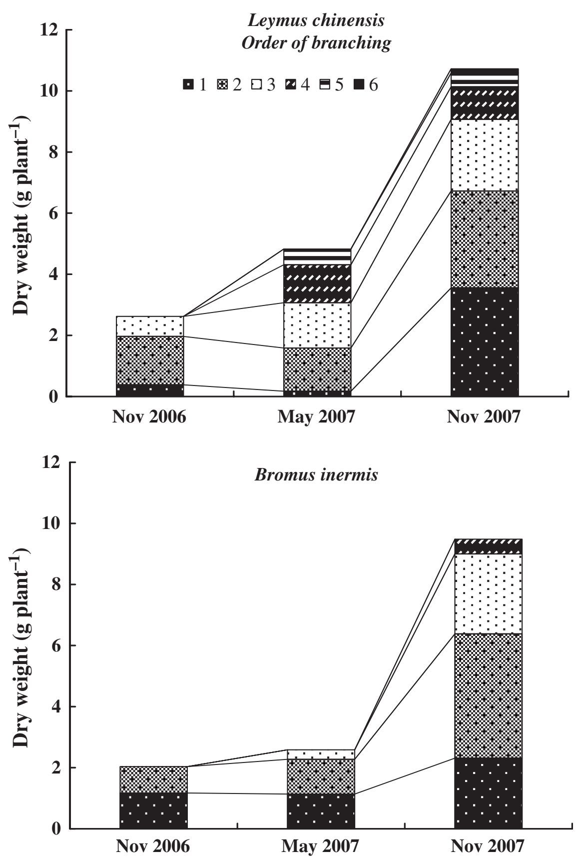

Figure 2 Changes in rhizome biomass for transplanted plants of *Bromus inermis* and *Leymus chinensis* in the container experiment in Kyoto.

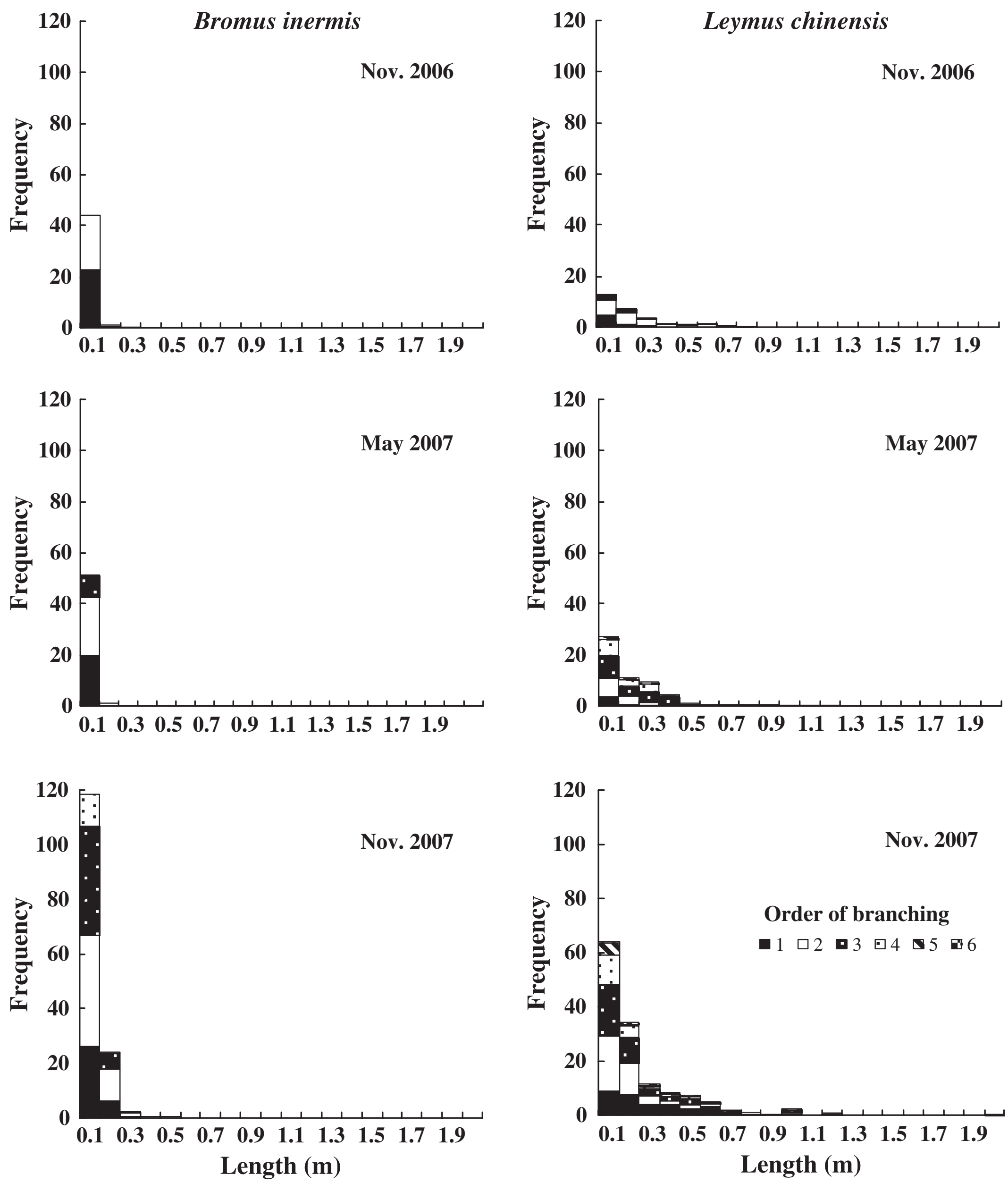

Figure 3 Frequency distribution of rhizome length for transplanted plants of *Bromus inermis* and *Leymus chinensis* in the container experiment in Kyoto.

Discussion

The vertical distribution of roots and rhizomes of four grasses in the natural stands was different (Figure 1). Most roots of the four species were distributed in a soil depth of 0–10 cm. The roots of *E. dahuricus* and *A. cristatum* were distributed in a soil depth of 0–10 cm, and decreased drastically with the increase of depth. The roots of *L. chinensis* and *B. inermis* were distributed to the deeper layer of the soil. These results on the vertical distribution of roots of the four grasses agree with other reports in other regions of China (Su *et al.* 2004; Wang *et al.* 2005). *L. chinensis* and *B. inermis* have rhizomes and the other two species, *E. dahuricus* and *A. cristatum*, do not have rhizomes. The rhizomes of *L. chinensis* and *B. inermis* were distributed in a soil depth of 0–10 cm. *L. chinensis* had longer rhizomes and *B. inermis* had many short rhizomes (Figure 3).

Table 3 Changes in number of shoots plant^{-1} and shoot dry weight (g plant^{-1}) for transplanted plants of *Bromus inermis* and *Leymus chinensis* in the container experiment in Kyoto

	Bromus inermis		*Elymus dahuricus*		*Leymus chinensis*	
Sampling date	Number	Dry weight	Number	Dry weight	Number	Dry weight
November 2006	76.3	2.21	88.4	1.08	71.7	3.46
May 2007	68.3	4.73	59.0	4.70	75.0	4.92
November 2007	140.8	7.30	34.3	1.99	123.8	11.63

The shallow distribution of roots of *E. dahuricus* and *A. cristatum* is sensitive to trampling, and the sexual reproduction of *A. cristatum* is greatly influenced by grazing and mowing (Zhao *et al.* 2006). The decrease of the two species in grazing grassland in Inner Mongolia seems to be partly caused by these characteristics.

Bromus inermis, *E. dahuricus* and *L. chinensis* had relatively higher ratios of under-ground parts (Table 1) compared to other grasses, such as *Imperata cylindrica* (L.) Beauv. of 40–50% (Tominaga *et al.* 1989) and Kentucky bluegrass of 22% (Fukuyama *et al.* 1990). The storage in the under-ground organs is used for emergence and growth of the above-ground parts in the early season of the growth. This should be the reason for the temporal decrease in the biomass of under-ground parts of *L. chinensis* and *B. inermis* in May 2007. The ratio of under-ground parts to total biomass was different among species and it decreased with the growth. The volume and dry weight of roots are gradually reduced with the harvest of above-ground parts in mixed pasture of *B. inermis* and alfalfa (Zhao *et al.* 2007) and *B. inermis* appears in lightly grazed grassland and path (Ao *et al.* 2008). *B. inermis* may not be adapted to heavy mowing and grazing. The ratio of under-ground parts to total biomass was the lowest in *E. dahuricus*. This is caused by the tufted-form of the plant (Zhang *et al.* 2006).

The rhizomes of *L. chinensis* and *B. inermis* distributed in a soil depth of 0–10 cm (Figure 1), and the distribution was shallower than other rhizomatous species, such as *I. cylindrica* in a 0–30-cm layer (Tominaga *et al.* 1989), *Solidago altissima* L., *Artemisia princeps* Pampam., *Aster yomena* Kitam., *Petasites japonicas* (Sieb. et Zucc.) Maxim subsp. *giganteus* (Fr. Schm.) Kitam., *Calystegia japonica* Choisy and *Agropyron repens* (L.) Beauv. in a 0–20-cm layer (Ito and Morita 1999). Vertical distribution of rhizomes becomes shallower by grazing (Institute of Grassland Science, NENU 1977). Therefore, the shallow distribution of *L. chinensis* in the field seems to be caused by grazing.

The longest rhizome of *L. chinensis* reached 1.92 m in November 2007 (Figure 3). Rhizomes shorter than 0.1 m occupied 47% of the total number of rhizomes in *L. chinensis*, but they occupied 96% in *B. inermis* in November 2006. These patterns correspond to the ‘‘guerrilla’’ and the ‘‘phalanx’’ strategy recognized by Lovett-Doust (1981), respectively. Clonal architecture of *L. chinensis* tended to be ‘‘guerrilla’’ as observed in quackgrass (*A. repens*), and *B. inermis* tended to be ‘‘phalanx’’ as in redtop (Hongo and Iwahashi 1982). The rhizome length and the degree of rhizome branching in clonal perennial plants may change in response to environmental conditions, enabling plants to more efficiently capture unevenly distributed resources (de Kroon and Knops 1990). *L. chinensis* and *B. inermis* may share resources by having different rhizome systems.

The number of shoots of *L. chinensis* and *B. inermis* generally increased from 2006 to 2007, but that of *E. dahuricus* decreased (Table 3). Wang and Gao (2003) suggested that *L. chinensis* adjusted to decreasing precipitation/increasing aridity by alterations in shoot density, reproductive allocation and shoot biomass along the drought gradient in the North-east China Transect. The effects of long-term grazing on *L. chinensis* shoots seem to be manifested in the shoot density and height (Watanabe *et al.* 2001). Biomass allocation strategy of *L. chinensis* populations is different under different conditions of disturbance (Tian and Yang 2003). The gradual decrease in the number of shoots of *E. dahuricus* agrees with the short period for the utilization of *E. dahuricus* in an artificial grassland.

The results of our study showed that *L. chinensis* has longer rhizomes and new ramets are produced away from the mother plant (guerrilla). In contrast, *B. inermis* has many short rhizomes and produces daughter plants near the mother plant (phalanx). The difference of root and rhizome systems among the four grasses may be resulted from the differences in the adaptive strategy to climate and disturbance such as grazing or mowing in Inner Mongolian grassland.

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References

Akiyama T, Kawamura K (2007) Grassland degradation in China: methods of monitoring management and restoration. *Grassl Sci* 53: 1–17.

Ao M, Ito M, Ito K, Yun J, Miura R, Tominaga T (2008) Floristic compositions of Inner Mongolian grasslands under different land-use conditions. *Grassl Sci* 54: 173–178.

Chen M, Wang Y (1985) The observation on the biological characteristics of *Aneurolepidium chinensis* under cultural conditions. In: *Research on Grassland Ecosystem (No. 1)*. Science Press, Beijing, 212–224. (In Chinese with English abstract.)

de Kroon H, Knops J (1990) Habitat exploitation through morphological plasticity in two chalk grassland perennials. *Oikos* 59: 39–49.

Ding X, Wang Y, Yang Y (2004) Age structure of *Leymus chinensis* populations in different soil substrates on the Songnen Plain. *Pratacultural Sci* 21: 45–47. (In Chinese.)

Fan G, Li H, Yang Y (2006) Analysis of the modular structures of populations on *Leymus chinensis* and *Hierochloe glabra* in different succession series in cutting grassland. *Pratacultural Sci* 23: 34–37. (In Chinese with English abstract.)

Fukuyama M, Simamura M, Ushiyama M, Oikawa M (1990) Comparisons of under-ground organs of some short grasses. *Grassl Sci* 36: 39–46. (In Japanese with English abstract.)

Hongo A, Iwahashi S (1982) Spreading abilities of rhizome in three weedy grasses of quackgrass, Kentucky bluegrass and redtop. *J Weed Sci Tech* 27: 98–102. (In Japanese with English abstract.)

Institute of Grassland Science, NENU (1977) The biological characteristics, cultivation and breeding of *Leymus chinensis*. *Materials Grassl Sci Tech* 1: 8–20. (In Chinese.)

Ito M, Morita A (1999) *The Under-Ground Invasion of Clonal Weeds*. Laboratory of Weed Science, Graduate School of Agriculture, Kyoto University, Kyoto, 1–113. (In Japanese.)

Kobayashi H (1977) Studies on physical interaction of forage roots on grassland soil I. Root-system distribution and mechanical strength of forage grass roots. *Grassl Sci* 23: 135–139. (In Japanese with English abstract.)

Liang T (2001) *Grassland Management and Production Technology*. Inner Mongolia Culture Publishing Company, Hailaer, 113–118. (In Chinese.)

Liang Y, Han G, Zhou H (2008) The effects of above-ground biomass variations on root system in *Leymus chinensis* steppe with different degradation degrees. *Pratacultural Sci* 25: 110–115. (In Chinese with English abstract.)

Lin J, Chen B, Li X, Zhang H (2008) Effects of grazing and cutting on growth of vegetative shoots and rhizomes of *Leymus chinensis* in bashing grassland. *Grassl Turf* 126: 49–53. (In Chinese with English abstract.)

Liu Z, Wang S, Han J, Chen Z (2005) Decomposition and nutrients dynamics of plant litter and roots in Inner Mongolia steppe. *Acta Prataculturae Sin* 14: 24–30. (In Chinese with English abstract.)

Lovett-Doust L (1981) Population dynamics and local specialization in a clonal perennial (*Ranunculus repens*) I. The dynamics of ramets in contrasting habitats. *J Ecol* 69: 743–755.

Shi H, Zhou Q, Yan H, Liu W, Yang Y (2008) Preliminary study on the space and time expanding of three rhizome type grasses in clonal reproduction stage. *Pratacultural Sci* 25: 127–132. (In Chinese with English abstract.).

Su J, Geng H, Ma H, Yang Q (2004) *Wild Grass Introduction and Acclimatization*. Chemical Industry Press, Beijing, 59–77. (In Chinese.)

Tian X, Yang Y (2003) Biomass age structure of *Leymus chinensis* populations under different disturbance conditions. *Acta Prataculturae Sin* 12: 50–54. (In Chinese.)

Tominaga T, Kobayashi H, Ueki K (1989) Seasonal change in the standing-crop of *Imperata cylindrica* var. *koenigii* grassland in the Kii-Ohshima island of Japan. *Weed Res Jpn* 34: 24–29.

Wang C, Long R, Shi J, Ding L (2005) Study on the change of vertical structure and productivity of artificial grassland community sowed in different year in alpine area. *Grassl China* 27: 16–21. (In Chinese with English abstract.)

Wang G, Li X, Wan L, He F, He D, Wang H (2007) Effect of cutting rate on water-soluble carbohydrate contents and rhizome components of *Leymus chinensis*. *Grassl China* 29: 74–80. (In Chinese with English abstract.)

Wang R, Gao Q (2003) Climate-driven changes in shoot density and shoot biomass in *Leymus chinensis* (Poaceae) on the North-east China Transect (NECT). *Global Ecol Biogeogr* 12: 249–259.

Watanabe N, Chen Z, Li Y, Itano S, Okube T (2001) Effects of stocking density on the rates of appearance and death of *Aneurolepidium chinensis* shoots. *Grassl Sci* 47: 509–512.

Yu Y, Okumura T (2001) The effect of grass roots on wind erosion in sands. *J Jpn Soc Reveget Tech* 26: 223–233. (In Japanese with English abstract.)

Yun J (2008) Developing strategy of forage breeding in China. *Acta Agrestia Sin* 16: 211–214. (In Chinese with English abstract.)

Zhang B, Wang D, Cao Y (2003) The growth and reproductive trends of *Leymus chinensis* on sown pastures. *Acta Prataculturae Sin* 12: 59–64. (In Chinese with English abstract.)

Zhang G, Li Z, Pan Q, Ning T, Yang J (2006) Changes of carbohydrate contents in below ground organs of *Leymus chinensis* and *Stipa grandis* in the Inner Mongolian steppes. *Acta Prataculturae Sin* 15: 42–49. (In Chinese with English abstract.)

Zhao H, Huang X, Zhu Z, Jia J (2007) Effect of mowing on the volume, weight and sugar content of root in mixed pasture of *Bromus inermis* and alfalfa. *Grassl Turf* 123: 50–57. (In Chinese with English abstract.)

Zhao M, Yun J, Shan D, Han B, Gui M (2006) Morphological variation of *Agropyron cristatum* under different degradation series. *Chinese J Grassl* 28: 13–17. (In Chinese with English abstract.)