

Seed germinating characteristics of 54 gramineous species in the alpine meadow on the eastern Qinghai-Tibet plateau

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Abstract The germination experiment was started on March 3, 2004, and seeds were collected from July to October in 2003. We analyzed the percentage of germination, days to first germination, germination period and days to 50% germination. Among the 54 examined species, 26 species exceeded 80% germination, 11 species exceeded 60%–80% germination, 8 exceeded 40%–60%, 5 exceeded 20%–40%, and 4 showed less than 20%. A principal-component analysis revealed that the species were distributed along two statistically independent axes, the first primarily represented the germination rate and the second represented the time of germination process. Based on scores of germination characteristics, cluster analysis of the 54 gramineous species could be divided into 4 distinct groups: rapid, slow, intermediate germinating (germination percentage > 50%), and low germinating (germination percentage < 50%). The meaning of different groups to the vegetation regeneration was discussed.

Keywords alpine meadow, gramineous species, seed germination

1 Introduction

One challenge to the ecologist is how to explain why plants have selective adaptation to different environments. A comparative study could help the ecologist understand the main evolutionary approach of plants and the life history characteristics when the plants are in special habitats (Li et al., 2004). Seed germination had been noticed as an important part in the life history strategy of plants (Liu et al., 2003). Moreover, the formation, succession and structure maintenance of plant community were also correlated with their seed germination characteristics; even

the seed and seedling were involved in all the ecological matters of terrestrial plant population. The factors occurring in the population process (maintenance, dispersal and inheritance) could influence plant distribution, dynamics and diversity in a larger area (Du, 1994). To explain the maintenance and dynamics of plant population (Wang et al., 1998), and to constitute a feasible restoration strategy for the plant community, ecologists have done lots of comparative studies on seed germination (Sachiko and Izumi, 2000; Wang and Yi, 2003). These researches had important value to explore the evolution of plants, and to explain the occurrence, development and maintenance of vegetation (Grime, 1981; Wang et al., 1997; Huang et al., 2000). Thus, we should first understand seed germination in order to study the vegetation distribution and population dynamics.

Gramineous species distribute extensively and are dominant in the alpine meadow on the eastern Qinghai-Tibet plateau, China. The study of seed germination characteristics is important to protect vegetation and restore the ecosystem. At present, there are few germination data of the common gramineous species in the complex community.

This paper studied the germination characteristics of 54 gramineous species from the alpine meadow on the eastern Qinghai-Tibet plateau. The main aim of the study was to analyze the germination structure of these species and to explain the function of these species—how to build up the plant community structure via their germination characteristics. We expected to help the study on local vegetation distribution and population dynamics.

2 Materials and methods

2.1 Study site

The study site is located on the eastern Qinghai-Tibet plateau, China (101°–103°E, 34°–35°70'N). The altitude

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ranges from 2900 m to 4000 m with an annual rainfall of 450–780 mm. The annual average temperature is 1.8°C with below –10.7°C in January and 11.7°C in July, the highest temperature during the growth season can reach 23.6°C to 28.9°C, and there are, on average, 270 frost days annually. The grassland type mainly belongs to alpine meadow (59.32%). The alpine meadow plant community is dominated by gramineous species such as *Gramineae*, *Cyperaceae*, and various dicotyledon, such as *Ranunculaceae*, *Polygonaceae*, *Saxifragaceae*, *Compositae*, *Scrophulariaceae*, *Gentianaceae* and *Leguminosae*.

2.2 Materials and methods

2.2.1 Materials and database

Seeds were collected from an alpine meadow on the eastern Qinghai-Tibet plateau from August to October in 2003. We used random sampling method to collect as much species as we could when the seeds are naturally dispersed. We used air-drying to remove the impurities (seed consist of seed coat and planticle). The seeds were stored in an envelope with average room temperature at 15°C. The germination experiment was started on March 3, 2004. Seeds were placed in covered Petri dishes (9 cm diameter) on a double layer of moistened filter paper, and then placed in temperature chambers at a diurnal fluctuation of 20°C (25°C day, 12 h; 5°C night, 12 h) with 24 h darkness and a relative humidity of about 50%. All of the species have three replicates of 50 seeds. Every day, the percentage of seeds germinated was recorded, newly emerged seedlings were removed from the Petri dishes and seeds were regularly watered with distilled water. A seed was considered germinated when the length of the emerged radicle was equal to the length of the seed. Germination was adjudged to be completed when no further germination occurred for five successive days. In addition, the remaining non-germinated seeds were tested for viability by staining with 2,3,5-triphenyletetrazolium chloride (0.1% TTC) for 4 h at 30°C. The pink one is recorded and will be counted as the viability seed.

2.2.2 Characteristics of germination

Values for 4 parameters were calculated for each species:

DFG (days to first germination) was the time from sowing to first germination.

PG (percent germination) was defined as the proportion of seeds germinated.

GP (germination period) was defined as the time from first germination to the end of germination.

DG₅₀ (days to 50% germination) was the time from sowing to reaching 50% germination of seeds tested.

2.2.3 Statistical analysis

Results of germination characteristics are presented as mean \pm SE, which was analyzed using analysis of variance (ANOVA). The underlying correlation structure of the germination characteristics was investigated in a principal-component analysis (PCA) with the varimax rotation of the axes (Olf et al., 1994). The results of the PCA were interpreted by graphing both the scores of the germination characteristics and the species scores on the first two axes. Then the scores of germination characteristics (DFG, PG, GP and DG₅₀) were used to classify the species in a hierarchical cluster analysis with squared Euclidean distance. The cluster diagram showed the definite sort of the species. All analyses were performed with SPSS 11.5.

3 Results

3.1 Germination characteristics

For the germination rate, among the 54 examined species, 26 species exceeded 80%, 11 species reached 60%–80%, 8 were 40%–60%, 5 reached 20%–40%, and 4 had values of less than 20%; 14 species began to germinate within 3–5 days, 29 within 6–8 days, 10 within 9–10 days, and only 1 exceeded 10 days; 16 species had the germination period of 1–7 days, 28 of 8–14 days, 10 of 15–21 days; 11 species had days to 50% of the final germination of 1–7 days, 27 of 8–14 days, 5 exceeded 14 days, and 11 species had a value of less than 50% germination (Table 1). TTC tests were carried out and revealed that most non-germinating seeds were still good at the end of the experiment.

3.2 Germination pattern

The germination pattern of 26 species exceeding 80% were: (1) 12 species began to germinate within 5 days, which included *Bromus tectorum*, *Poa sinattenuata*, *Mellica scabrosa*, *Orinus kokonorica*, *Achnatherum inebrians*, *Arundinella anomala*, *Roegneria nutans*, *Elymus dahuricus*, *Ptilagrostis mongholica*, *Elymus tangutorum*, *Agrostis alba* and *Aneurolepidium dasystachys*. Among these species, *Poa sinattenuata* had the shortest GP (3 d) and DG₅₀ (3 d), *Ptilagrostis mongholica* had the longest GP (16d) and DG₅₀ (11d), *Orinus kokonorica* had long GP (12 d) and DG₅₀ (8d), and others had a GP of 5–8 days and DG₅₀ of 4–7 days; (2) 10 species began to germinate within 6–8 days, which included *Roegneria stricta*, *Poa botryoides*, *Poa poophagorum*, *Deschampsia caespitosa*, *Deyeuxia* sp, *Agrostis stolonifera*, *Poa Pratensis*, *Poa schoenites*, *Ptilagrostis roshevitsiana* and *Festuca sinensis*. In these species, *Poa*

Table 1 Species included in the germination experiment

species	life form	percent germination/% \pm SE	days to 50% germination/d	germination period/d	days to first germination/d
1. <i>Achnatherum inebrians.</i>	P	93.00 \pm 1.15	4	6	4
2. <i>A. sibiricum</i>	P	67.33 \pm 2.85	15	17	8
3. <i>A. splendens</i>	P	68.67 \pm 2.60	9	14	5
4. <i>Agrostis alba</i>	P	92.00 \pm 2.85	7	7	5
5. <i>A. sp1.</i>	-	91.52 \pm 1.33	10	6	9
6. <i>A. sp2.</i>	-	6.67 \pm 2.40	-	5	8
7. <i>A. hugoniana</i>	P	52.00 \pm 2.89	9	11	9
8. <i>A. stolonifera</i>	P	86.67 \pm 2.95	10	6	7
9. <i>A. trinii.</i>	P	17.33 \pm 1.86	-	8	10
10. <i>Aneurolepidium dasystachys</i>	P	94.67 \pm 1.20	7	7	5
11. <i>Aristida trisetata</i>	P	23.33 \pm 1.15	-	7	10
12. <i>Arundinella anomala.</i>	P	97.33 \pm 0.33	5	5	4
13. <i>Brachypodium sp.</i>	P	55.33 \pm 2.96	7	9	5
14. <i>B. sylvaticum</i>	P	65.33 \pm 1.27	17	19	8
15. <i>Bromus magnus</i>	P	75.78 \pm 0.61	12	9	7
16. <i>B. sinensis</i>	P	64.00 \pm 1.53	11	12	6
17. <i>B. tectorum.</i>	A	91.00 \pm 1.22	4	8	3
18. <i>Deschampsia caespitosa</i>	P	80.22 \pm 1.20	9	10	7
19. <i>Deyeuxia arundinacea</i>	P	72.44 \pm 2.62	14	8	7
20. <i>D. scabrescens</i>	P	86.00 \pm 1.33	12	12	10
21. <i>D. sp.</i>	P	83.33 \pm 1.53	9	8	7
22. <i>Elymus dahuricus</i>	P	82.00 \pm 0.33	7	7	5
23. <i>E. tangutorum</i>	P	90.00 \pm 2.89	6	6	5
24. <i>Festuca ovina</i>	P	58.67 \pm 2.52	14	8	6
25. <i>F. rubra</i>	P	51.33 \pm 2.96	8	8	6
26. <i>F. sinensis</i>	P	90.67 \pm 0.33	10	11	8
27. <i>Gramineae sp.</i>	-	64.00 \pm 2.65	12	8	7
28. <i>Helictotrichon leianthum</i>	P	84.67 \pm 0.33	11	10	9
29. <i>H. schellianum</i>	P	30.00 \pm 6.03	-	7	9
30. <i>H. sp1.</i>	P	22.00 \pm 1.86	-	6	9
31. <i>H. sp2</i>	P	42.00 \pm 0.88	-	17	7
32. <i>H. tibeticum</i>	P	60.67 \pm 1.33	11	8	7
33. <i>Koeleria cristata</i>	P	33.33 \pm 2.31	-	13	7
34. <i>Mellica scabrosa</i>	P	97.09 \pm 0.69	4	6	3
35. <i>Orinus kokonorica</i>	P	83.33 \pm 1.45	8	12	4
36. <i>Oryzopsis munroi</i>	P	36.67 \pm 3.93	-	9	7
37. <i>Poa botryoides</i>	P	85.33 \pm 0.81	10	12	6
38. <i>P. declinata</i>	P	54.00 \pm 2.42	11	8	6
39. <i>P. poophagorum</i>	P	97.33 \pm 0.33	8	6	6
40. <i>P. pratensis</i>	P	88.67 \pm 1.05	9	9	7
41. <i>P. schoenites</i>	P	92.00 \pm 1.53	8	10	7
42. <i>P. sinatenuata</i>	P	95.33 \pm 0.00	3	3	3
43. <i>Ptilagrostis dichotoma</i>	P	83.33 \pm 1.59	15	16	9
44. <i>P. junatovii</i>	P	65.33 \pm 4.33	16	16	7
45. <i>P. mongholica</i>	P	89.33 \pm 1.76	11	16	5
46. <i>P. roshevitsiana</i>	P	98.00 \pm 0.00	11	18	8
47. <i>Roegneria kokonorica</i>	P	54.67 \pm 1.53	10	8	6
48. <i>R. nutans</i>	P	83.17 \pm 1.42	7	8	5
49. <i>R. stricta</i>	P	92.22 \pm 0.77	8	15	6
50. <i>Stipa aliena</i>	P	41.00 \pm 6.00	-	20	8
51. <i>S. capillacea</i>	P	68.00 \pm 4.06	10	14	7
52. <i>S. przewalskyi</i>	P	64.67 \pm 0.67	17	16	10
53. <i>S. purpurea</i>	P	0.67 \pm 0.33	-	1	19
54. <i>S. penicillata var. hirsuta</i>	P	15.33 \pm 1.15	-	9	8

Note: A: Annales ; P: Perennial; -: Species unknown life form or un reached 50% germination.

poophagorum and *Agrostis stolonifera* had the shortest GP (6d), *Ptilagrostis roshevitsiana* and *Roegneria stricta* had the longest GP (18d and 15d respectively), and other species had GP of 8–12 days and DG₅₀ of 9–10 days; (3) 4 species began to germinate within 9–

10 days, which included *Ptilagrostis dichotoma*, *Helictotrichon leianthum*, *Agrostis sp1* and *Deyeuxia scabrescens*. Among these species, *Agrostis sp1* had the shortest GP (6 d), and the other three species had longer GP and DG₅₀ (exceeding 10 d) (Table 1).

The pattern of 11 species had 60%–80% germination: (1) The species which had 8–9 d GP included *Helictotrichon tibeticum*, *Gramineae* sp., *Deyeuxia arundinacea* and *Bromus magnus*. All these species had the same DFG (7 d); (2) The other species including *Bromus sinensis*, *Achnatherum splendens*, *Stipa przewalskyi*, *Achnatherum sibiricum* and *Brachypodium sylvaticum*, had a GP of 12–19 d, DFG of 5–10 d and over 10 d DG₅₀ (Table 1).

The pattern of 8 species had 40%–60% germination: *Brachypodium* had 5 d DFG, 9 d GP and 7 d DG₅₀; *Poa declinata*, *Festuca rubra*, *Roegneria kokonorica* and *Festuca ovina* had 6d DFG and 8d GP, and had DG₅₀ of 11 d, 8 d, 10 d and 14 d, respectively; *Helictotrichon* sp2, *Stipa aliena* and *Agrostis hugoniana* had DFG of 7 d, 8d, and 9 d, GP of 17 d, 20 d and 11 d; *Agrostis hugoniana* had DG₅₀ of 9 d, the other two species had a germination less than 50% (Table 1).

Species that had germination less than 40% were *Stipa purpurea*, *Koeleria cristata*, *Oryzopsis munroi*, *Agrostis* sp2, *Stipa penicillata* var. *hirsute*, *Helictotrichon* sp1, *Helictotrichon schellianum*, *Agrostis trinii* and *Aristida trisetata*. Within these species, *Stipa purpurea* had the longest DFG (9 d), the shortest GP (1 d) and the lowest percent germination (0.67%); *Koeleria cristata* had the longest GP (13d), and the other species had DFG of 7–10d, and GP of 5–9 d (Table 1).

3.3 Germination types

Principal-component analysis (PCA) can reveal the correlation structure of the germination characteristics (Olf, 1994). The attributes DFG, PG, GP and DG₅₀ for all the 54 gramineous species were used in this PCA. The first two axes of the PCA explained 57.99% and 25.13%, respectively, of the variation in the data set (Table 2), thus, they can explain the correlation to the characteristics among these species.

Figure 1 shows that the first axis mainly represented variation in PG, DFG and DG₅₀, PG, which were negatively correlated with the axis, as well as DFG and DG₅₀, which were positively correlated with the axis. The second axis was mainly determined by GP, which was positively correlated with the axis. This means that the first axis separated species according to germination rate, so that species with a high score on this axis

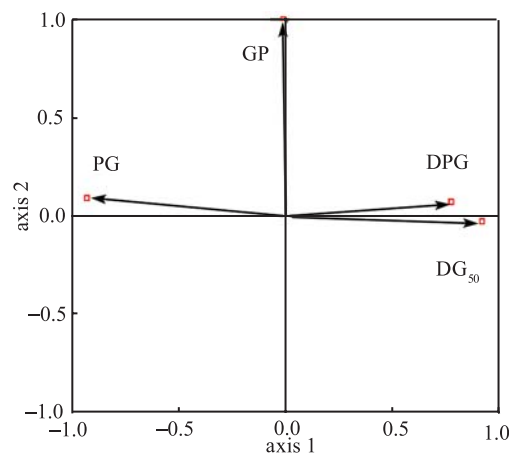


Fig. 1 Results of a principal component analysis of germination characteristics, where the arrows point to the scores on the first two axis of the variable percent germination, days to first germination, germination period, and days to 50% germination.

germinated slowly. The second axis separated species according to their time of germination process, thus species with a high positive score on this axis germinated dispersedly.

The species scores on the first two PCA axes are presented in Fig. 2. The top left quadrant (high GP and PG, low DFG and DG₅₀) represents earlier germination,

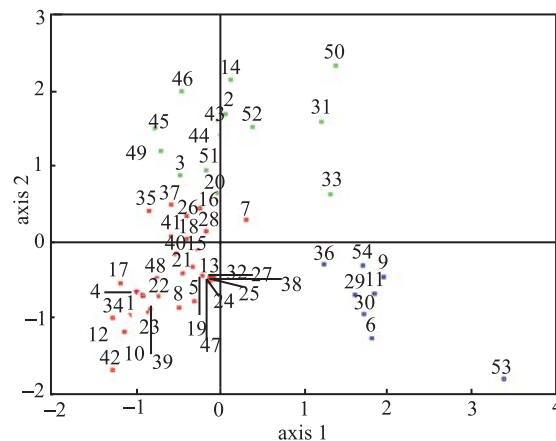


Fig. 2 Axis scores for the principal components of Fig. 1 for 54 species. See the number of plant species in Table 1

Table 2 Total variance explained (results of a principal component analysis of germination characteristics)

component	initial eigenvalues			extraction sums of squared loadings		
	total	percentage of variance	cumulative %	total	percentage of variance	cumulative %
1	2.32	57.99	57.99	2.32	57.99	57.99
2	1.01	25.13	83.12	1.01	25.13	83.12
3	0.54	13.50	96.62			
4	0.14	3.38	100.00			

high percent germination and longer germination period. Species in the bottom right quadrant (high DFG and DG_{50} , low GP and PG) are characteristic of dormancy. Species in the bottom left quadrant (high PG, low DFG, DG_{50} and GP) germinated rapidly and most species found here are characteristic of high percent germination.

Cluster analysis of the 54 gramineous species based on their scores of germination characteristics (DFG, PG, GP and DG_{50}) illustrated strong heterogeneity among these species. Multivariate analysis indicated that the germination characteristics could be used to separate the species investigated along the first two axes. Cluster analysis of the 54 gramineous species based on their scores of germination characteristics (DFG, PG, GP and DG_{50}) could divide them into distinct groups (represented by the three corners except the top right quadrant, and the middle left side in Fig. 1, 2), species of which are shown in Fig. 3.

(1) Rapid germinating: species with a higher percent germination began to germinate earlier and had shorter germination time, and reached 50% germination earlier. The type of germination strategies included such species: *Achnatherum inebrians*, *Agrostis alba*, *Aneurolepidium dasystachys*, *Arundinella anomala*, *Bromus tectorum*, *Elymus dahuricus*, *Elymus tangutorum*, *Mellica scabrosa*, *Poa poophagorum*, *Poa sinattenuata* and *Roegneria nutans*.

(2) Intermediate germinating: species had a high percent of germination, began to germinate late, had long germination time, and reached 50% germination long. The type of germination strategies included the species: *Agrostis* sp1, *Agrostis hugoniana*, *Agrostis stolonifera*, *Brachypodium* sp, *Bromus magnus*, *Bromus sinensis*, *Deschampsia caespitosa*, *Deyeuxia arundinacea*, *Deyeuxia* sp, *Festuca ovina*, *Festuca rubra*, *Festuca sinensis*, *Gramineae* sp, *Helictotrichon leianthum*, *Helictotrichon tibeticum*, *Orinus kokonorica*, *Poa botryoides*, *Poa declinata*, *Poa pratensis*, *Poa schoenites* and *Roegneria kokonorica*.

(3) Slow germinating: species had a middle percent germination, began to germinate later, had longer germination time, and reached 50% germination longer. The type of germination strategies included the species: *Achnatherum sibiricum*, *Achnatherum splendens*, *Brachypodium sylvaticum*, *Deyeuxia scabrescens*, *Ptilagrostis dichotoma*, *Ptilagrostis junatovii*, *Ptilagrostis mongholica*, *Ptilagrostis roshevitsiana*, *Roegneria stricta*, *Stipa capillacea* and *Stipa przewalskyi*.

(4) Low germinating: species with a low percent germination (< 50%), began to germinate very late. The type of germination strategies included the species: *Agrostis* sp2, *Agrostis trinii*, *Aristida trisetata*, *Helictotrichon schellianum*, *Helictotrichon* sp1, *Helictotrichon* sp2, *Koeleria cristata*, *Oryzopsis munroi*, *Stipa aliena*, *Stipa purpurea* and *Stipa penicillata* var. *hirsuta*.

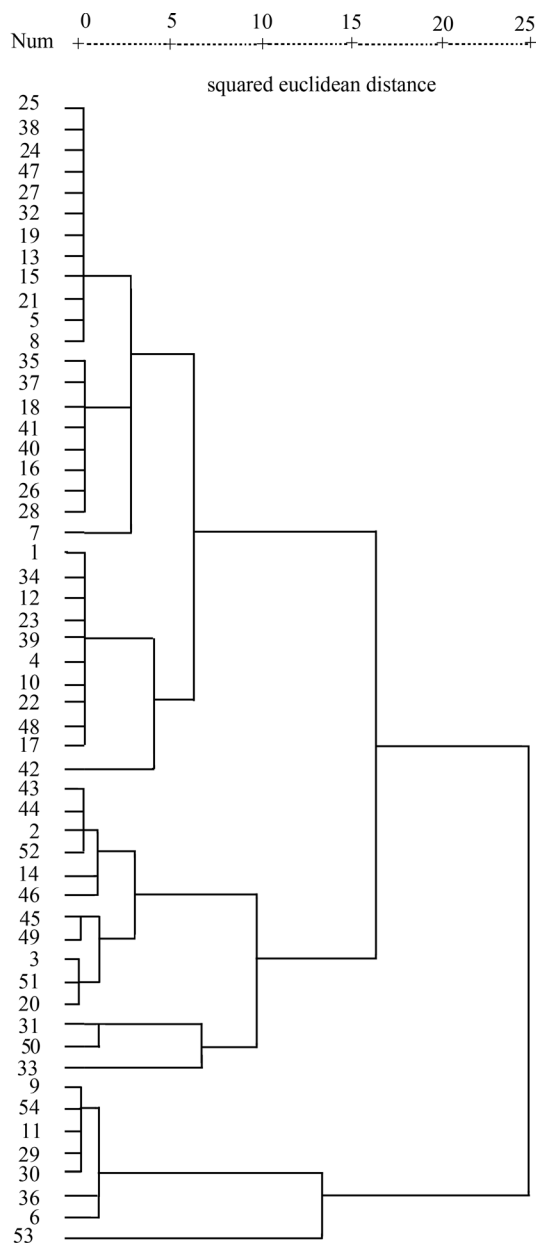


Fig. 3 Cluster diagram of 54 gramineous plants. The tree was computed from nearest neighbor clustering using Squared Euclidean Distance between species based on four germination characteristics: percent germination, days to first germination, germination period and days to 50% germination. See the number of plant species in Table 1.

4 Discussion

The 54 gramineous species from the alpine meadow on the eastern Qinghai-Tibet plateau were heterogeneous in their germination characteristics. We divided the 54 gramineous species into 4 germination types: rapid, intermediate, slow and low germinating. The proportion of intermediate germination was high, but the rapid, slow and low germination were low (Fig 3).

One of the traits of rapid germination was that most seeds had been germinated in a short time after the beginning of germination. There were 11 species that belonged to rapid germination in the present study. Once these species encountered a suitable environment, they would germinate immediately. Most of these species could complete germination within 3–8 days and achieve over 90% germination. Therefore, germination may not act on the regime of apportionment of risk in these populations of the species. Seed germination is a key to vegetation regeneration and species propagation in the life cycle of the seed plant. Once there is a suitable environment, the rapid germinating of these species could take possession of a bare land in a short time and have the spatio-temporal advantages. However, it is risky and likely to result in dying out in an area where the seeds germinate rapidly on the inducement of a single environmental factor (such as the increase of soil temperature) (Harper, 1977; Freas and Kemp, 1983), especially in the unpredictable environment of the alpine meadow. Therefore, these species could not exist in various habitats because of their lower fitness. However, most of these gramineous species are perennial, their dominant status in the populations cannot be affected even if they fail in production of seedlings in a bad year. For example, *Poa schoenites*, which grows in the alpine meadow with an altitude of 3700 m, is the dominant species of some communities; *Roegneria nutans* is also a dominating member of vegetation; and *Achnatherum inebrians* is a wild distributing weed.

There are 21 species that belonged to the intermediate germinating group in the present study. Germination rate of these species was lower relative to the rate of the rapid germinating species, but faster than the rate of the slow germinating species. Most of them could complete germination within 6–12 days and their percent germination was higher or lower, which may present partly the share of population risk. These species distribute extensively in the alpine meadow and dominate in populations. For example, the plants of *Poa* and *Deyeuxia* are the dominating members of vegetation and the dominant species or composite species.

There were 11 species that belonged to the slow germinating type in the present study. These species germinated slower and had a longer germination period, correspondingly. Most of them could complete germination over 12 days. This may be a definite indication to the share of population risk on seed germination. Some studies showed that some slow germinating species could germinate successfully under suitable environmental conditions over a long time (Huang et al., 2000). However, there is a low possibility of sustaining a suitable condition over a long time in the alpine meadow where natural conditions are atrocious. Hence, these species may emerge in large numbers of germination and recruitment of new seedling only once in many years. It is

the germination strategy of “opportunism”, of which the population regeneration is stochastic or periodical (Huang et al., 2000; Huang and Gutterman, 2000). The germination structure of these species decreases the danger of overall death induced by an unexpected change of the environment (such as temperature, rainfall, etc) after homochronous germination. Therefore, these species clearly had strong fitness consequence, which may produced some function for their extensive distribution. For example, the species of *Stipa* distributes extensively in various habitats on the alpine meadow, and also *Achnatherum splendens* and *Brachypodium sylvaticum*.

There were 11 species that belonged to the low germinating group in the present study. These species started to germinate later and had lower percent germination, which was the characteristic of strong dormancy. In a changeful environment such as the alpine meadow, successful establishment of vegetation is determined by seed germination in suitable conditions and dormancy in unfavorable conditions. It is an important strategy that seeds selected germination time by dormancy to withstand unfavorable environments or unexpected disturbances. These species germinate much slowly, and their population regeneration or seedling recruitment is very random and few at a time. Furthermore, seed dormancy also has a disadvantageous side to vegetation regeneration. Seeds may suffer from a great deal of predation because of their long-time shape, hence, the probability of seedling development is diminished. These species distributed extensively in the grassland but could not become dominant, such as *Oryzopsis munroi* and *Helictotrichon tibeticum*, which are the buildup of the grassland but not dominant. Dormancy of seeds is likely to act for the extensive distribution of these species.

We did not do some pretreatment to break dormancy before the germination experiment, and the species of low percent germination represented strong dormancy. Therefore, the emphasis of subsequent studies would be which regime of dormancy is in these species and how to break their dormancy. In addition, work on some of the other factors that influenced germination (e.g. light, temperature and storage methods) that influence germination is needed before we can fully understand the relationships between germination characteristics and field distribution.

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