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ECOLOGICAL IMPLICATIONS AND ENVIRONMENT DEPENDENCE OF THE SEED GERMINATION OF COMMON SPECIES IN COLD DESERTS

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Abstract

Vegetation is increasingly affected by climate change in cold deserts. Nonetheless, research is limited regarding the natural environmental demands of seed germination in such deserts. This study was conducted in Gurbantunggut Desert as a research base and 17 common species as subjects to investigate the moisture and temperature needs of seed germination in artificial settings, as well as the relationship between characteristics of seed germination and the local distribution of dune and shrubs. Results showed□(1) all tested species generally display low germination percentages that range between 2.9% and 79.6%. Winter snow melt dictates seed germination in cold deserts. Moreover, the subsequent spring rainfall can increase the survival rate of seedlings and significantly affect the process of seed germination. (2) seeds start to germinate only two days after snow melts at the average daily temperature (day/night) of 3.5°C (6.7 °C/-0.5°C) and at a soil volumetric water content of 24.2%. Fifteen days after snow melt, all species germinate when the soil volumetric water content is 6.0% and the average daily temperature is 12.9°C (18.3°C/7.1°C). (3) The seed germination of the tested species can be divided into four patterns: rapid, transitional, slow, and low. Low-pattern plants mainly grow on upper dunes and are significantly associated with shrubs. Rapid- and slow-pattern plants distribute in middle and lower dunes. A few of these plants are significantly associated with shrubs. Transitional-pattern plants generally develop in the low land between hills and middle dunes. This study provides a reference for the actual environmental needs of seed germination in cold deserts and for the temperature and moisture requirements of this process in future experimental settings.

Key words: Snow melt, Seed germination, Germination pattern, Inter-specific association, Nursing effect.

Introduction

Current plant growth is profoundly affected by climate change, especially seed germination. This process is a crucial phase in plant life cycles because it affects the sustainability, dynamics, and distribution of plant population (Walck & Dixon, 2009; Meyer & Allen, 2010; Walck *et al*., 2011; Luo & Cardina, 2012; Liu *et al*., 2013; Holt & Chesson, 2014). Hence, research on the conditions of seed germination and the response to environmental changes lays a foundation on which the dynamic influence of climate change on plant population can be clarified.

Seed germination is determined by gene and exhibits five dormancy characteristics (Finch-Savage & Leubner-Metzger, 2006). Many germination strategies have been identified (Cohen, 1968; Simons & Jonnston, 2006). For example, seeds germinate rapidly after a small amount of precipitation and settle successfully in opportunistic germination strategy (Gutterman, 2002). In between germination strategy, only a few seeds germinate, and the majority of the germination process is delayed even if conditions are suitable (Philippi & Seger, 1989). In cautious germination strategy, precipitation produces only a few seeds for germination. Temperature and water availability dictate seed germination; the changes in and interaction between these two factors affect the number of seeds germinated, as well as the time and process of seed germination. Seedling survival and the recruitment of the population are affected as well. However, the majority of research on seed germination is conducted in laboratories (Huang *et al*., 2004a; Pérez-Sánchez *et al*., 2011; Liu *et al*., 2011; Xu *et al*., 2014), and findings are limited with regard to the characteristics of natural seed germination at the population level. Micro-topography and associated plants also influence seed germination simultaneously when water availability and temperature are varied to influence population dynamics. Nonetheless, research on this topic is scarce as well. The lack of research on the characteristics of natural seed germination contributes to the incapability to fully comprehend seed germination adaptive significance under the condition of global climate change.

Desert is an important component of the terrestrial ecosystem and is among the largest areas affected by climate change. Despite this information, studies on plant diversity in arid deserts with variable precipitation are scarce (Roberto *et al*., 2012; Munson *et al.,* 2012). Cold deserts located in high-latitude or high-elevation areas differ from hot deserts in that the former experiences freezing temperature in the winter instead of the high temperature in the summer (Smith *et al*., 1997). Species in cold desert are relatively simple and are highly sensitive to precipitation and temperature. Nonetheless, few climate manipulation experiments have been conducted in semi-desert areas (Tielbörger & Salguero-Gómez, 2014). GurbantunggutDesert is a cold desert that is covered with snow in winter. This desert is located at the Junggar Basin in China. A total of 208 higher plants are found in this desert. Such plants consist of 92 common species that belong to 22 families and 71 genera (Zhang & Chen, 2002). Specifically, single families and single species with significant floristic advantages grow in this area. Herbaceous plants account for 81.5% of the 208 species. Furthermore, 40 species of ephemeral plants (including therophyte and perennial ephemeroid plants) constitute 53.3% of the herb species and 43.5% of the total population (Zhang & Liu, 2012).

Gurbantunggut Desert exhibits precipitation patterns that range between 70 and 180 mm annually. These patterns differ from those of the temperate deserts in North America and are mainly observed between April and July. The thickness of the winter snow in this desert usually exceeds 20cm (Li, 1991). Snow melt provides the moisture necessary for seed germination and plant growth in the early spring (Gutterman, 2000; Sun *et al*., 2009; Yuan & Tang, 2010, Fan *et al*., 2013). Moreover, the variation in plant diversities from region to region and from longitudinal dune slope to longitudinal dune slope reveals that the topography of Gurbantunggut Desert varies from east to west and from north to south. Moreover, longitudinal dunes are approximately 10–50 m high and 0.1–10 km long. The slopes of these dunes are gentle and long in the west and are steep and short in the east (Wu, 1997). Research reports that the precipitation of Gurbantunggut Desert displays an increasing trend (Wei & Liu, 2000) and influences the growth of species (Fan *et al*., 2014).

Seed germination is an important part of the plant life history. This process impacts the adaptability of plants and determines population dynamics. Thus, to what extent does a desert that encounters snowfall in winter and rainfall in spring influence seed germination, seedling settlement, and survival? What are the different characteristics of germination time and processes in various species? These issues must be analyzed further to determine the influence of precipitation change on different plants. Moreover, the change trend of plant diversity serves as an important reference, as do in-depth analyses of the effect of precipitation variation on different plants.

Nonetheless, the majority of studies on the seed germination of desert species involves indoor experiments (Zeng *et al*., 2011; Guan *et al*., 2013; Liu *et al*., 2013; Lu *et al*., 2014). Furthermore, reports are scarce with regard to the needs of seed germination in natural environments. Such reports are the foundation on which seed germination and the dynamic influence of climate change on the plant population can be comprehended (Fan et al., 2013; Gornish et al., 2014).

The current study selects 17 species with a high frequency of distribution and high value as research subjects. Desert soil is artificially simulated in a common garden. Seeds are sown in the autumn and are allowed to grow naturally in the snow-covered soil to identify the characteristics of the seed germination of different species, as well as their germination strategies. These characteristics are also analyzed along with the inter-specific associations of the actual distribution of slopes with arbors and shrubs to clarify the features of seed germination in Gurbantunggut Desert under global climate change. In the process, the foundation for vegetation trends can be laid.

Material and Methods

Overview of the research area: The research area is located the south of Gurbantunggut Desert (44°11’N–46°20’N, 84°31’E–90°00’E). The average annual evaporation capacity in this area exceeds 2000 mm. However, average annual precipitation generally does not exceed 150 mm. Moreover, average annual precipitation in the hinterland is only 70–180 mm mainly in spring and winter. The average annual temperature is 6°C–10°C. Therefore, the research area is under an inland desert climate (Zhang & Chen, 2002). Unlike other deserts, Gurbantunggut Desert has much research value because the vegetation coverage in this area is high. In particular, the coverage of herbaceous plants reaches 50%.

The experiment is conducted at the 150 Regiment of Shihezi, Xinjiang. This area is adjacent to the Mosuowan reclamation of south Gurbantunggut Desert (44°26’N, 86°00’E). The average annual precipitation in the research area is approximately 120 mm, the average annual evaporation capacity is 1979 mm, and the average annual temperature is 6.6 °C. The snowfall and precipitation in this desert generally is equal to that of the survey area of desert plant distribution.

Plot investigation and seed collection: In early June 2013, 51 plots were surveyed in the southern Gurbantunggut Desert. Sample seeds were also collected from this area. Typical longitudinal dunes were randomly selected from each plot, and transects measuring 100 m ×10 m were set. These transects were perpendicular to the longitudinal dunes. They were also divided into 10 quadrats of 10 m ×10 m. The number of species, slope, and slope distribution of each species were recorded in each quadrat.

Importance value and relative frequency are two key indexes with which to measure the degree of ecological dominance (Zhang, 2004). A total of 18 species was selected as references (Zhang & Liu, 2012), and 16 of these were dominant species with high frequency and importance value in the Gurbantunggut Desert. The other two species displayed low frequency and importance values and were dominant species in the Junggar Basin (Table 1). Ripe sample seeds were collected, dried out, and stored in rooms. Large seeds were mixed with small ones and regarded as experimental material.

Experiment design: The experiment was conducted on the edge of Gurbantunggut Desert in mid-October 2013. To simulate the wild habitat of the researched plants, a soil layer was dug with a depth of 0–40 cm in the experiment area. The blankets obtained from the sands of top dunes in Gurbantunggut Desert were then sieved, and seeds were removed from the soil seed bank.

To determine the influence of snowfall and spring rainfall on seed germination, the following two treatments were applied: (1) natural snowfall with spring rainfall and (2) conditions remain natural except that a canopy was used to prevent rain from falling on the area. A split plot design was implemented. The main areas were set for water treatment, and the sub-areas were for randomly distributed species. Seeds were sown in an area measuring 30 cm ×30 cm, and each treatment was repeated nine times. In addition, the treatments were spaced apart by a 0.5-mm deep plastic board to prevent the horizontal movement of water. Seeds were sown in a soil layer of 0–2 cm according to seed size.

To determine the soil temperature and moisture suitable for seed germination, soil hygrothermographs were positioned at 2 and 5 cm soil layers before winter (WatchDog, 1200).

Table 1. The family, genera and life form of 18 vascular plant species and their relative frequency (RF) and important value (IV).

Family	Genera	Species	Abbreviations	Life form	Relative frequency	Important value
Chenopodiaceae	Agriophyllum Bieb.	*Agriophyllum squarrosum*	*A. sq*	Long annuals plant	65.57	22.57
	Corispermum L.	*Corispermum lehmannianum*	*C. leh*	Ephemeral plant	78.69	31.45
	Haloxylon Bunge	*Haloxylon ammodendron*	*H. am*	Arbors	18.03	9.15
		Haloxylon persicum	*H. pe*	Arbors	81.97	34.66
	Salsola L	*Salsola affinis*	*S. af*	Long annuals plant	1.64	0.55
		Salsola korshinskyi	*S. ko*	Long annuals plant	1.64	0.55
Brassicaceae	Matthiola	*Matthiola stoddarti*	*M. st*	Ephemeral plant	16.39	5.48
	Tetracme Bunge	*Tetracme recurvata*	*T. re*	Ephemeral plant	70.49	24.15
	Malcolmia	*Malcolmias corpioides*	*M. ac*	Ephemeral plant	60.66	20.47
	SpirorhynchusKar.	*Spirorhynchus sabulosus*	*S. sa*	Ephemeral plant	39.34	13.26
Poaceae	Eremopyrum	*Eremopyrum orientale*	*E. or*	Ephemeral plant	62.3	21.9
	Schismus	*Schismus arabicus*	*S. ar*	Ephemeral plant	68.85	33.68
Boraginaceae	Arnebia Forssk.	*Arnebia decumbens*	*A. de*	Ephemeral plant	68.85	23.31
	Lappula V. Wolf	*Lappula semiglabra*	*L. se*	Ephemeral plant	78.69	26.65
Plantaginaceae	Plantago L.	*Plantago minuta*	*P. mi*	Ephemeral plant	47.54	15.96
Geraniaceae	Erodium L Herit.	*Erodium oxyrrhynchum*	*E. ox*	Ephemeral plant	62.3	27.03
Geraniaceae	Calligonum L	*Calligonum leucocladum*	*C. leu*	Shrub	78.69	28.74
Asteraceae	Seriphidium Fourr.	*Seriphidium terraealbae*	*S. te*	shrub	65.57	23.17

Note: Important value (%) = (Relative density + Relative frequency + Relative coverage) / 3, Relative frequency (rf) = n_i/N, ni represent the sample number of i species, N represent the total sample numbers

Data analysis

Characteristics of seed germination: The sown seeds were marked on March 15, 2014. The number of seeds germinated was recorded daily at 10:00 a.m. If one seed from each species germinated, then this phenomenon was logged as the day to initial germination. The numbers of surviving and dead seeds were recorded simultaneously. All data were analyzed with SPSS 17, and the figures were constructed using Origin 8.6. The formulas for the germination characteristics in each species are as follows:

$$\text{Germination percentage} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds}} \times 100\%$$

Days to initial germination: period from seeding to the germination of the first seed (d);

Germination period: period from the germination of the first seed to the end of germination (d);

Time for half-germination: half the time of the final germination percentage (d).

Analysis of species density in different slope positions: To clarify the relationship between seed germination and species distribution in micro-habitats, the species density in the 51 plots was analyzed with slope position in Gurbantunggut Desert. All of these data were compiled in Excel 2007.

$$\text{The density of a specific species in certain slope positions (\%)} = \frac{1}{N}\sum_{1}^{N}\frac{S}{T}\times 100\%, \qquad (1)$$

where N is the number of sample plots; S is the number of the specific specie with certain slope positions in all plots; and T is the sum of specific species with certain slope positions in all plots.

Analysis of the inter-specific association of dominant herbaceous plants with arbors and shrubs: In Gurbantunggut Desert, dominant arbors and shrubs include *H. persicum, Haloxylon ammodendron, Calligonum leucocladum,* and *Seriphidum terraealbae.* These plants occupy an important position and provide favorable micro-habitats for the germination of herbaceous seeds. Over the long process of evolution, each species finds a habitat suitable for its own growth. In this study, 500 quadrats measuring 10 m ×10 m were selected. The inter-specific association of the seed germination of different species with shrubs was analyzed as well. All of these data were compiled in Excel 2007 and analyzed using SPSS 17.

Association coefficient: $V = (ad-bc)/[(a+b)(c+d)(a+c)(b+d)]^{1/2}$, (2)

Significance test of association coefficient: $\chi^2 = n(ad-bc)^2/[(a+b)(c+d)(a+c)(b+d)]^{1/2}$, (3)

where n is the total number of quadrats; a is the number of any two species derived from a quadrat; b, c is the number of only one species obtained from a quadrat; and d is the number of any two species that are derived from a quadrat (the same is true below). When $V = ad\text{-}bc > 0$ is a positive association, then $V < 0$ is a negative association. The degrees of freedom of the 2 ×2 contingency table is 1; if $<\chi^2 < 6.635$ ($0.01 < 3.841$, $p<0.05$), then species pairs are significantly associated with each other. If $\chi^2 > 6.635$ ($p>0.05$), then a highly significant association is observed between species pairs; otherwise, associations are insignificant.

Results

Average changes in soil temperature and in soil volumetric water content at the germination stage: Without rainfall, the average annual soil volumetric water content in the 2 cm soil layer is always lower than that in the 5 cm soil layer. The average annual temperature increases. Conversely, the soil volumetric water content in both the 2cm and 5 cm soil layers increased with the increase in rainfall. In particular, the final soil volumetric water contents in both soil layers were very close to each other. The temperature increased rapidly around March 17, and soil volumetric water content increased significantly as well. In fact, this content was the highest in the plant life cycle until March 21 (day 4 of the snow melt). That in the 2 cm soil layer reached approximately 52.4%. With the increase in temperature, volumetric soil water content decreased sharply to below 10% (Fig. 1).

Differences in germination characteristics among species

Germination characteristics and temperature dependence of all species in natural snowfall and spring rainfall: The average temperature of 17 species for germination was low at the range of 5.26°C–12.85°C. Diurnal temperature (day/night) was approximately 18.29°C/0.66°C. Moreover, 11 species germinated at roughly 6.95°C/5.26°C. The remaining species germinated at approximately 12.85°C/9.15°C. The average temperature of germination from beginning to the end was roughly 14.64°C/12.40°C. The germination processes of the 17 species did not vary, as with the diurnal temperature (day/night) at approximately 20.60°C/7.09°C. Therefore, most species began to germinate when the temperature was low. If all species germinate, then the temperature reaches the average of the species in the minority (Table 2).

Germination process under treatments with natural snowfall alone and natural snowfall with spring rainfall: A total of 17 species for seed germination under the “natural snowfall with spring rainfall” treatment exhibited higher volatility (greater fluctuation) than that under the treatment “without spring rains. ”In the “natural snowfall with spring rainfall” treatment, 12 species reached the germination peak within three days following the first spring rainfall (i.e., days 8–10 of snow melt). In addition, compared with spring rains, anther treatment which actually without spring rains that three species reached this peak before the first spring rainfall, and 10 species peaked within three days after the first spring rainfall. When spring rainfall pulses were introduced, the number of seeds germinated increased. On the contrary, this number gradually decreased without spring rainfall. Furthermore, the germination process of most species in the treatment “without spring rainfall” is terminated earlier than those species under the “spring rainfall” treatment (Fig. 2).

Difference in seedling survival rate between treatments with “natural snowfall alone” and “natural snowfall with rainfall”: The number of seedlings per unit of all species was larger under the treatment of “natural snowfall with spring rainfall” than that with “natural snowfall alone.” Specifically, a significant difference was observed in the numbers of seedlings for seven species: *Corispermum lehmannianum, Calligonum leucocladum, Salsola korshinskyi, Agriophyllum squarrosum, Tetracme recurvata, Lappula semiglabra,* and *Plantago minuta.* The other 15 species did not display notable differences in survival rate under both treatments except in terms of *Schismus arabicus* and *Calligonum leucocladum* (Table 3). This result shows that survival rate is not only related to spring rains but is also connected to seedling density. Spring rainfall is a supplement for soil moisture. The conditions of water in the “natural snowfall with spring rainfall” treatment are superior to those in the treatment with “natural snowfall alone. ”This condition contributes to increased seedling survival. The germination percentage was high under spring rainfall, although most of the seedlings under both treatment did not differ significantly. This finding is mainly due to seedling density per unit. An extremely high density results in fierce intra-specific competition for limited water and increased rates of seedling death.

Principal component analysis of germination characteristics: Principal component analysis was conducted on four germination characteristics under the “natural snowfall with spring rainfall” treatment. These characteristics are germination percentage, days to initial germination; germination period, and time for half-germination (Fig. 3). This analysis can be represented by two principal component axes. A cluster analysis was also performed on these axes according to the specific scores of all species (Fig. 4).

Seventeen plants were classified into four patterns: rapid, transitional, slow, and low.

(1) Rapid-pattern: plants with high germination percentages, that germinate early, have long germination periods, and time for half-germination in a short time. Examples of such plants are *Haloxylon persicum, Spirorhynchus sabulosus, Eremopyrum orientale, Schismus arabicus, Haloxylon ammodendron, Tetracme recurvata, Lappula semiglabra* and *Plantago minuta.*

(2) Transitional-pattern: plants with a moderate germination percentage, that germinate early, have long germination periods, and time for half-germination in a short time. Examples include *Salsola korshinskyi* and *Salsola affinis*.

(3) Slow-pattern: plants with a low germination percentage, that germinate late, have short germination periods, and time for half-germination over a long time. Examples of such plants include *Matthiola stoddarti, Arnebia decumbens,* and *Erodium oxyrrhynchum*.

(4) Low-pattern: plants with a low germination percentage, that germinate late, have short germination periods, and time for half-germination over a long period. Examples include *Agriophyllum squarrosum, Calligonum leucocladum, Corispermum lehmannianum* and *Malcolmia scorpioides*.

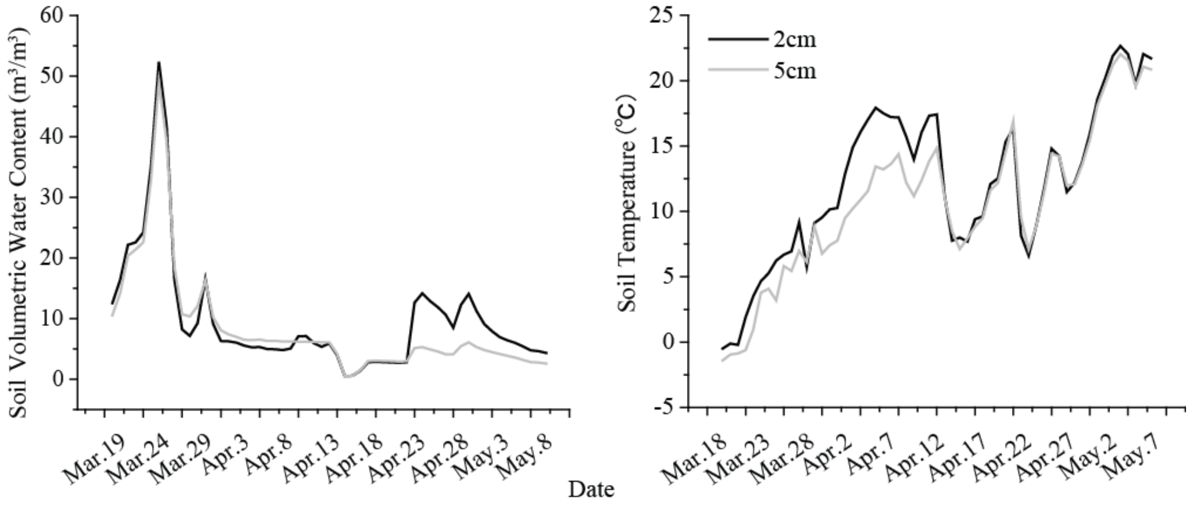

Fig. 1. The average soil volumetric water content and temperature changes with natural snowfall and spring rainfall.

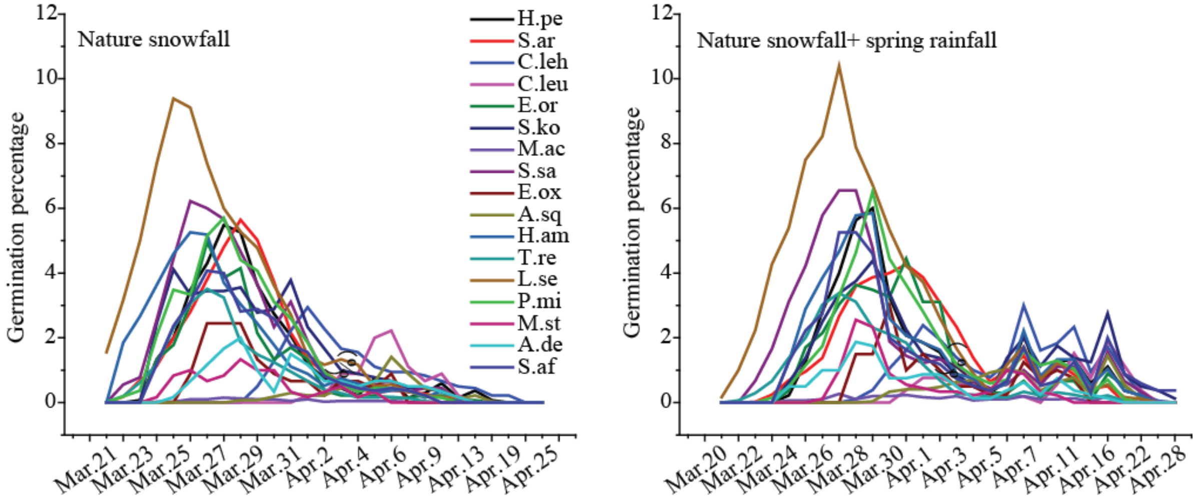

Fig. 2. The Germination process of 17 dominant species in Gurbantunggut desert.

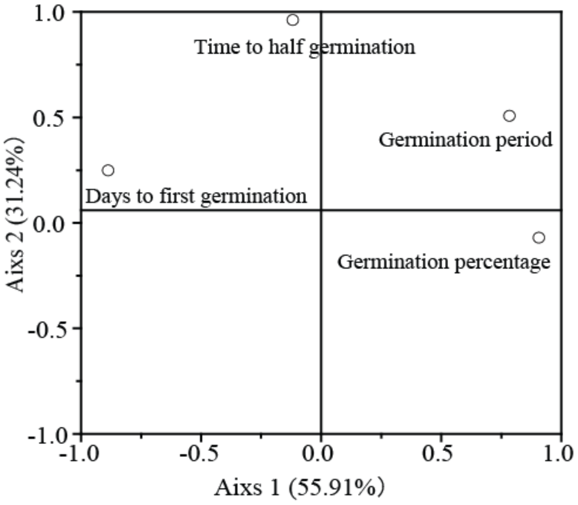

Fig. 3. A principal component analysis of germination characteristics.

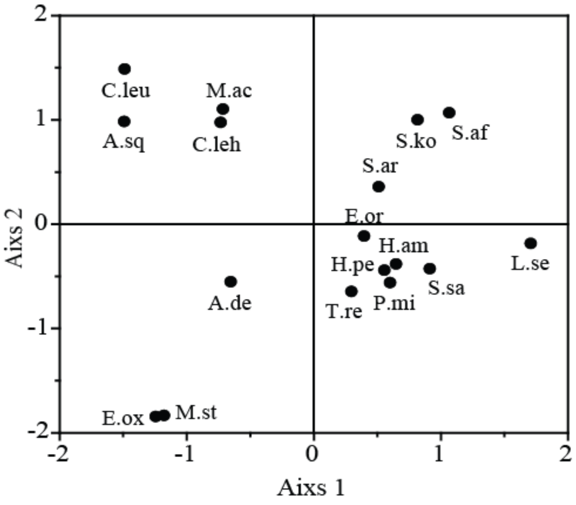

Fig. 4. A principal component analysis of axis of scores of 16 species.

Table 2. Germination characteristics of all species and temperature change in natural snowfall and spring rainfall plots.

Species	Germination percentage (%) ± SE	Days to first germination (d) ± SE	The average temperature of days to first germination (day/night) (^{o}C)	Germination period (d) ± SE	The average temperature of germination period (day/night) (^{o}C)
H. pe	38.67 ± 2.88	9.00 ± 0.24	6.95 (10.50/2.98)	25.44 ± 1.51	12.65 (17.62/7.63)
S. ar	39.09 ± 1.14	7.33 ± 0.24	6.24 (10.67/1.75)	22.11 ± 0.98	12.95 (18.48/7.34)
C. leh	23.11 ± 2.88	13.67 ± 0.44	10.1 (14.85/5.29)	21.22 ± 1.36	13.58 (18.87/8.26)
C. leu	9.90 ± 1.23	16.14 ± 0.34	12.8 (18.29/7.13)	19.43 ± 0.84	13.94 (19.31/8.56)
E. or	33.93 ± 3.74	9.33 ± 0.24	6.95 (10.50/2.98)	25.00 ± 1.43	12.65 (17.62/7.63)
S. ko	39.63 ± 5.32	8.75 ± 0.31	6.95 (10.50/2.98)	29.13 ± 1.62	12.61 (17.46/7.66)
M. ac	2.87 ± 0.83	10.17 ± 0.48	9.15 (12.21/6.49)	21.33 ± 1.58	13.04 (18.13/7.94)
S. sa	48.67 ± 8.66	8.11 ± 0.51	6.69 (10.69/2.36)	25.44 ± 1.95	12.54 (17.53/7.51)
E. ox	14.75 ± 5.14	13.00 ± 0.33	9.53 (13.95/5.42)	12.88 ± 0.90	14.64 (20.60/8.60)
A. sq	10.04 ± 1.19	15.89 ± 0.63	12.8 (18.29/7.13)	18.78 ± 0.94	13.94 (19.31/8.56)
H. am	42.89 ± 4.25	8.78 ± 0.28	6.95 (10.50/2.98)	24.67 ± 1.86	12.65 (17.62/7.63)
T. rc	24.4 ± 3.64	6.89 ± 0.35	6.24 (10.67/1.75)	21.56 ± 1.43	12.95 (18.48/7.34)
L. se	79.61 ± 5.69	5.78 ± 0.40	5.26 (9.19/0.66)	23.67 ± 1.34	12.56 (17.93/7.09)
P. mi	40.26 ± 3.8	8.00 ± 0.29	6.69 (10.69/2.36)	22.78 ± 1.08	12.95 (18.21/7.66)
M. st	11.56 ± 1.13	11.44 ± 0.24	5.74 (7.17/4.54)	12.00 ± 0.60	13.19 (18.72/7.47)
A. de	13.38 ± 4.2	9.88 ± 0.52	9.15 (12.21/6.49)	17.13 ± 1.34	13.55 (19.07/7.95)
S. af	38.44 ± 6.91	8.22 ± 0.15	6.69 (10.69/2.36)	32.00 ± 1.98	12.40 (17.06/7.76)

Table 3. The covariance relations between the seedling density and survival rate of each species under two kinds of processing.

Species	Sow seed/Number	Nature snowfall		Natural snowfall and spring rainfall	
		Density/Number	Survival rate/%	Density/Number	Survival rate/%
		34.22 ± 2.78	69.52 ± 4.68	40.33 ± 3.40	69.59 ± 2.98
S. ar	500	133.00 ± 11.68	72.95 ± 2.80	171.00 ± 7.57*	87.29 ± 1.93*
C. leh	75	2.83 ± 0.60	42.54 ± 10.00	7.14 ± 1.05*	94.05 ± 3.95*
C. leu	200	28.33 ± 7.92	65.53 ± 9.82	28.89 ± 4.42*	57.93 ± 7.61
E. or	150	29.56 ± 6.77	74.84 ± 4.15	34.22 ± 3.53	70.81 ± 6.50
S. ko	100	29.56 ± 3.54	76.73 ± 4.08	34.50 ± 6.33*	86.32 ± 8.05
M. ac	50	6.78 ± 1.28	91.11 ± 4.47	7.00 ± 2.51	93.83 ± 3.63
S. sa	500	3.75 ± 1.10	59.17 ± 11.98	11.67 ± 3.54	85.87 ± 7.36
E. ox	100	29.22 ± 5.10	63.86 ± 7.12	50.44 ± 5.87	55.76 ± 8.25
A. sq	300	10.11 ± 1.20	60.91 ± 7.02	19.00 ± 3.50*	61.64 ± 7.61
H. am	150	41.56 ± 4.98	69.93 ± 4.71	44.11 ± 4.17	68.97 ± 2.30
T. rc	500	72.00 ± 14.50	66.40 ± 5.86	77.56 ± 13.14*	60.98 ± 4.50
L. se	200	105.00 ± 11.61	71.51 ± 4.01	125.22 ± 10.58*	78.16 ± 3.41
P. mi	300	73.44 ± 9.72	65.52 ± 8.42	79.56 ± 11.73*	63.13 ± 4.67
M. st	100	3.83 ± 0.75	58.99 ± 11.92	10.00 ± 0.94	89.66 ± 6.34
A. de	100	2.75 ± 1.49	53.50 ± 13.48	8.63 ± 2.87	68.79 ± 8.50
S. af	150	32.44 ± 5.55	78.47 ± 4.36	50.44 ± 11.13	85.86 ± 6.47

Note:"*"represent the significant difference in density and survival of species between nature snowfall with spring rainfall and nature snowfall alone, respectively, $p<0.05$.

Table 4. The distribution of 18 species in 5 slope positions of Gurbantunggut desert.

Species	The bottom of shady slope	The middle of shady slope	The top of slope	The middle of sunny slope	The bottom of sunny slope
S. te	12.20%	44.30%	5.05%	23.01%	15.44%
H. pe	0.00%	5.80%	91.05%	3.15%	0.00%
S. ara	18.76%	46.00%	1.37%	19.77%	14.10%
C. leh	14.82%	28.68%	10.14%	29.19%	17.17%
C. leu	8.11%	29.20%	22.07%	35.15%	5.48%
E. ori	13.52%	54.49%	8.51%	16.89%	6.58%
S. kor	41.23%	0.00%	0.00%	0.00%	58.77%
M. aco	20.39%	32.32%	1.74%	29.46%	16.09%
S. sab	13.43%	37.78%	2.92%	25.71%	20.16%
E. oxy	23.06%	29.83%	22.47%	21.33%	3.31%
A. squ	6.70%	32.36%	30.74%	24.20%	5.99%
H. amm	26.08%	16.75%	0.00%	23.38%	33.80%
T. rec	7.20%	39.46%	10.44%	34.34%	8.56%
L. sem	12.55%	42.14%	14.44%	18.50%	12.37%
P. min	24.21%	37.21%	0.94%	19.91%	17.74%
M. sto	4.25%	58.24%	8.82%	25.01%	3.68%
A. dec	15.44%	40.64%	2.49%	22.12%	19.31%
S. aff	45.82%	0.00%	0.00%	0.00%	54.18%

Table 5. The inter-specific relationship between dominate herbs and shrubs in Gurbantunggut desert.

Species	*S. te*	*H. pe*	*C. leu*	*H. am*
S. ar	+0.167**	-0.169**	-0.114*	0.052
C. leh	-0.05	+0.120**	+0.203**	-0.073
E. or	-0.05	+0.120**	+0.203**	-0.073
S. kr	-0.003**	0	-0.002**	-0.003**
E. ox	+0.165**	-0.061	+0.189**	0.049
M. ac	0.018	-0.052	0.025	0.073
S. sa	+0.150**	+0.209**	+0.120*	-0.151**
A. sq	+0.126**	+0.139**	-0.044	-0.101*
T. re	-0.054	-0.04	+0.186**	0.081
L. se	+0.178**	+0.098*	+0.127**	-0.008
P. mi	0.074	-0.031	0.046	0.016
M. st	0.027	0.006	+0.110*	0.058
A. de	+0.164**	-0.085	0.072	+0.110*
S. af	-0.002**	0	-0.005**	-0.004**

Note: "-"represent negative correlation between species pairs, "+"represent positive correlation between species pairs, "0"represent no correlation between species pairs, "*"represent significantly correlation of χ^2 test between species pairs, "**"represent highly significantly correlation of χ^2 test between species pairs.

Characteristics of the distribution of tested species density on all slope positions: As shown in Table 4, the sand dunes in our 51 sample plots were divided into five groups in terms of slope positions: sunny bottom-slope, sunny middle-slope, top-slope, shady bottom-slope, and shady middle-slope. The slope positions of all tested species were not fixed. Moreover, slope positions at which the percentage of species density exceeded 10% were included. Then, the positions at which the percentage of species density exceeded 70% were regarded as the main distribution area. Thus, we ignore the slope of sunny and shady, the sand dunes can be categorized into five groups in terms of slope positions: top-slope, upper-slope, mid-slope, lower-slope, and bottom-slope. The slope positions of the mainly distributed chief species are as follows: *H. persicum* occupies 91.05% of the top-slope, *C. lehmannianum* (shady bottom-slope 29.2%, top-slope 22.07%, and sunny middle-slope 35.15%), and *A. squarrosum* (shady bottom-slope 32.36%, top-slope 30.74%, and sunny middle-slope 24.2%) at the upper-slope. *E. orientale* occupies the following areas: 54.49% of the shady bottom-slope and 16.89% of the sunny middle-slope. The species distributed mid-slope include *T. recurvata* (shady bottom-slope 39.46% and sunny middle-slope 34.34%) and *M. stoddarti* (shady bottom-slope 58.24% and sunny middle-slope 25.01%). Those in the lower-slope include *S. terraealbae, S. arabicus*, *C. leucocladum, E. oxyrrhynchum, M. scorpioides*, *Hammodendron, L. semiglabra, P. minuta,* and *A. decumbens*. *S. affinis* and *S. korshinskyi*are in the bottom-slope, whereas *S. sabulosus*is found at all slope positions.

Inter-specific association of tested species with arbors and shrubs: The analysis results of the inter-specific association among 500 quadrats in 51 sample plots is presented in Table 5. The species that are positively correlated with *C. leucocladum* include *C. lehmannianum*, *T. recurvata*, *E. oxyrrhynchum*, *S. sabulosus*, *L. semiglabra,* and *M. stoddart*. *S. arabicus*, *A. decumbens*, *E. orientale*, *E. oxyrrhynchum*, *S. sabulosus*, *A. squarrosum*, and *L.*

semiglabra all correlate positively with *S. terraealbae. H. ammodendron* has a positive correlation with *A. decumbens.* The species that are positively correlated with *H. persicum* include *C. lehmannianum*, *S. sabulosus*, *A. squarrosum*, and *L. semiglabra. S. sabulosus* has a positive correlation with *C. leucocladum* and with the *S. terraealbae* in the lower and upper arbors and shrubs. In general, 12 herbs have significantly positive associations with at least 4 kinds of shrubs, with the exception of *S. korshinskyi*, *M. scorpioides*, *P. minuta,* and *S. affinis*.

Discussion

Average changes temperature and volumetric water content at the germination stage in natural soil environment: The smooth transition of early life stages such as seed germination, seedling emergence, and seedling establishment influences the establishment of plant population and community assembly (Fenner, 1987; James *et al*., 2011). Consequently, the actual environment of seed germination and seedling survival in high-altitude and cold deserts must be investigated.

The present research suggests that seeds in Gurbantunggut Desert germinate at low average temperatures. Seeds began to germinate only two days after snow melt at an average daily temperature (day/night) of 3.5°C (6.7°C/-0.5°C) and a soil volumetric water content of 24.2%. When the snow melted completely, 10 species started germinating at a maximum soil volumetric moisture of 52.4% under an average daily temperature of 9.1°C (12.21°C/6.49°C). These species include one type of shrub, two annual plants, and seven ephemeral plants. In addition, all species germinated at an average daily temperature of 12.9°C (18.3°C /7.1°C). Therefore, the temperature at which seeds germinate generally ranges from 5.26°C to 13.94°C (8.56°C–19.31°C/0.66°C–9.19°C) in Gurbantunggut Desert. This range differs from the temperature settings in our experiment. A gradual increase in field temperature affects seed germination and seedling growth. Thus, the temperature settings of the seed germination experiment must be adjusted in future research to determine natural germination characteristics accurately.

Differences in germination characteristics among species: Unlike in the rain-shield treatment, all 17 species could germinate only after snow melt. Germination percentages did not differ significantly under the "winter snowfall with spring rainfall" treatment. However, all species varied considerably in terms of days to initial germination, germination period, and time for half-germination. Following the first spring rainfall, 14 species began germinating with soil volumetric water content of 16.5% in the 2 cm soil layer. The germination of six species peaked after three days of spring rain. The number of species for germination remained constant for both the rain-shield and "natural snowfall with spring rainfall" treatments. After three days of spring rain, the seed germination of nine species peaked under the rain-shield treatment. Therefore, spring rainfall promoted the process of germination for a few species in combination with snow melt and delayed the germination peak in all species.

The germination percentages of all 17 species did not differ significantly under the two treatments. However, percentage increased slightly under the spring rainfall treatment. The maximum and minimum germination percentages under both treatments are 72.8% and 1.1%, as observed in *M. scorpioides* and *L. semiglabra*, respectively. Spring rainfall enhances the germination percentages of these two species by 6.83% and 1.74%, respectively. Furthermore, the germination percentages of all species are generally low under the two treatments. In fact, the percentages of the majority are less than 40%. Therefore, winter snow melt is the key factor in the seed germination of herbaceous plants. Spring rainfall plays only a small role in this process.

Winter snow melt and spring rainfall can significantly affect the process of seed germination by expediting the germination period of slow-pattern species and by extending the time for half germination, as well as germination periods. Only three species differed significantly under both treatments in terms of "days to initial germination." These species began to germinate after the first rainfall. *L. semiglabra* and *C. leucocladum* germinated the earliest and the latest at 6 and 19 days, respectively, under both treatments. Nevertheless, both species germinated one and three days earlier with rainfall. Therefore, spring rains can prolong the time spent producing the 50% germination characteristics of six species (two–seven days). On average, this period lasts two days for all species. Eleven species displayed germination periods of 4–16 days.

The influence of micro-topography and associated plants to seed germination and plant distribution: The results show that germination is affected considerably by the micro-habitat of plant distribution (slope positions, arbors, and shrubs) and insignificantly by families and genera or life type. For example, chico plants such as *S. affinis* and *S. korshinskyi* are distributed in dune slacks. Their seed germination pattern is transitional. The plant spread in the lower dunes includes *H. ammodendron.* Its germination pattern is rapid. Plants distributed in the upper dune consist of *A. squarrosum* and *C. lehmannianum.* Their pattern is low, as with *Crucifer*. With respect to life type, perennial shrubs consist of *C. leucocladum* and *H. ammodendron.* These plants exhibits low and rapid patterns, and they differ from other species of annual herbs with the same pattern.

Seed germination is shaped by surrounding shrubs. Specifically, crowns can provide moderate moisture and temperature for seed germination and the survival of seedlings, thereby inducing the "nursing effect" (Freestone, 2006; Cavieres & Badano, 2009; Cavieres *et al*., 2013). The study of inter-specific association revealed that the annual herbs are not correlated with the shrubs in the low land between the hills and the middle dunes. Moreover, the seed germination pattern is transitional. In the upper and middle dunes, the annual herbs and shrubs are significantly correlated and exhibit rapid and slow patterns. A significant correlation is also observed in the upper dunes, and the seed germination pattern is low. The results suggest that the sufficient amount of water in the low land between the hills and the middle or lower dunes weakens the dependence of seed germination on shrubs. Meanwhile, the limited amount of water in the upper dunes strengthens the nursing effect on shrubs.

Parameters that mainly dictate the heat balance in the ecological systems of arid and semi-arid regions include soil moisture, reporting climate, vegetation, topography, and soil factors. These factors include vegetation pattern and soil conditions (Zhao, 2005). From November to February of the following year, stable snowfall acts as an important source of water for seed germination and for the sprouts of desert plants in Gurbantunggut Desert given that snow is the response factor that is most sensitive to climate change (Gao *et al*., 2005). Low underground water and increased salinity impedes the regeneration of *H. ammodendron* and *H. persicum* seedlings under climate change, thereby contributing to the downward tendency of their population and affecting the populations of *C. leucocladum* and *S. terraealbae* (Zhang *et al*., 2011; Zeng *et al*., 2012; Tao *et al*., 2013). Therefore, the nursing effect of arbors and shrubs must be given attention. The numbers of seeds germinated and surviving seedlings, plant coverage, and density changes in herbaceous plants are influenced by the increase in snowfall and rainfall (Gornish *et al*., 2014). This phenomenon may also either increase or stabilize plant diversity.

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