Water and Ecophysiology Session

Germination Responses to Temperature in Three *Caragana* Species in Loess-gully Region, China

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Abstract: The leguminous *Caragana* species are important components of vegetation in the semi-arid Loess-gully region, China. These shrub species are important for maintaining the dynamics and function of the ecosystem in the region. They are potential plant resources for restoration of degraded ecosystems. The germination responses to temperatures in two indigenous and one exotic *Caragana* species were studied under controlled conditions in the laboratory. Treatments were nine temperature regimes (constant temperatures of 5, 10, 15, 20, 25, and 30°C and three alternating day/night temperature regimes of 10/5, 25/15, and 30/20°C). Germination response to temperature was different for the three species. For *C. intermedia*, the temperature range for germination was 5 to 30 °C and germination rate was quick. Percentage germination was low at all temperature regimes for *C. licentiana.* Germination was inhibited at 30°C for *C. opulens* and at 5°C for *C. licentiana*. The average incubation period needed for seeds to germinate was longer for *C. licentiana* than for the others. Alternating day/night temperature had no significant effect on germination in the three species. Hard-coat seeds existed at different percentages in this plant subfamily. Rate of hard-coat seeds was 5.14 percent for *C. licentiana* and 0.79 percent for *C. intermedia*, but *C. opulens* had no hard-coat seeds. Germination responses to temperature in the three species are related to their ecological distribution and habitat. The different germination patterns in the species imply different life cycles. The germination strategies for *C. licentiana* and *C. opulens* mean that these two endemic species include potential value as good candidates for restoration of degraded land in the semi-arid Loess-gully region, China.

Introduction

Semi-arid gully-hill region covers a great many acres of China. In this region, vegetation degradation and severe soil erosion are obstacles to the sustainable development in the region. Vegetation rehabilitation is essential for ecological restoration in the region and sustainable development. Selection and use of species adaptation to the local environment are directly related to succession of vegetation rehabilitation and efficiency of water and soil protection.

In the region, water is the limiting factor for the development of the vegetation. Plants have to take maximum advantage of the scarce and irregular rainfall, which varies between 380 mm annually distributed over a rainy period of 3 months (June-September). The most common vegetation in these regions is desert steppe, but the most common plant in south-sloping land is *Caragana licentiana*. Precipitation varies from year to year in theses regions and droughts can last up to 5 years. Under these conditions, plants species have become adapted to tolerate, evade, and escape drought and have developed germination, establishment, growth, and reproduction strategies that allow for the perpetuation of the species in these conditions. The subfamily *Caragana* Febr. includes major leguminous shrubs in the semi-arid region of China. There are 62 species in China (Liu 1987) and 15 species in Loess Plateau region (BINC 1992). *Caragana* species are key components of vegetation in the loess-gully region (Wu Zhengyi 1995). These species are examples of plants that have successfully colonized these semi-arid loess-gully zones and they are important for maintaining the dynamic and function of the ecosystem. They are also important for restoration of degraded ecosystems. In particular, some indigenous *Caragana* species have potential value for vegetation establishment, but they have attracted little attention from restoration ecologists and researchers. Lack of knowledge on their pattern of seed

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germination and life cycle is a major factor restricting their use in ecological restoration.

The three *Caragana* species are of particular importance because they are drought resistant and two of them are endemic. *Caragana licentiana* Hand-Mazz is a species found in the Dingxi, Lanzhou, and Yongdeng regions in Gansu Province, China. It is drought resistant and carries on the active phases of its life cycle when soil moisture is abundant. It can survive and grow well in extreme habitats in the region. *Caragana opulens* Kom is distributed in some regions of the Loess Plateau. *Caragana intermedia* Kuang has been planted on Gansu Loess Plateau to prevent soil erosion, but it is difficult to regenerate by seed in this region for population expansion.

Seed germination of mimosa and acacia species, leguminous shrubs, has been reported by several authors (Orozco-Almanza 2003; Abulfatih 1995). Studies on temperature range of seed germination of *C. intermedia* and *C. korshinskii* were reported by BINC (1992). But studies on germination patterns of others *Caragana* species have not been carried out, especially regarding comparative studies of seed germination in this species.

This study was carried out to answer the following questions: What is the effect of temperature on the seed germination of the three species? What are the germination patterns of each species and the implications of its restoration? Are the seeds dormant after dispersal? Are there differences in dormancy among the three species? Are there any moisture or temperature mediated mechanisms preventing germination under unfavourable conditions?

Species and Methods

Seed Collection

Seeds of *C. licentiana* and *C. opulens*, endemic to Dingxi County, were collected from the species of the genus *Caragana* growing in natural communities in the Dingxi County Gansu province (35°44′14.9″N, 104°24′17.2″E) in June 2002 and seeds of *C. intermedia* were collected from the species in semi-artificial communities in the county in July 2002. Seeds were stored in a laboratory in Dingxi County without heat or air condition. Seeds that had been attacked by insects were excluded from the test. Dingxi County is considered a typical representation of gully-hill region in Loess Plateau, China. The plant communities are dominanted by *Stipa ungeana* Trin, *Stipa breviflora* Griseb, *Ajania fruticolosa* Ledeb, and *Artemisia frigida* Willd. Average annual precipitation and temperature (over 10 years) in the region were 380 millimeters and 6.3°C.

Germination under Laboratory Conditions

Trials were carried out in May 2003. Treatments were nine temperature regimes: six constant temperatures of 5, 10, 15, 20, 25, and 30°C and three alternating day/night temperature regimes of 10/5, 25/15, and 30/20°C. For each thermal treatment, 200 seeds of each species were divided into four replicates of 50 seeds each. Each replicate was placed in a 9 cm Petri dish (in diameter) on 1 percent 20 ml water agar and incubated in a germination chamber at each temperature. The seeds were inspected every day and were considered to be germinated when the radical penetrated the seed coat and reached about 1mm in length (Teketay 1996). Germinated seeds were removed after counting. Trials were run until no more seeds germinated for 5 days. Percent germination was calculated as the number of seeds germinated divided by the number of viable seeds. Dead seeds were excluded. Hard-coat seeds were counted.

Statistical Analysis

The results of the germination experiment were analyzed for statistical significance with a general linear model analysis of variance (ANOVA) from the SPSS package for personal computer (version 11.0, SPSS Inc.). Percent germination data were arcsine-square-root transformed prior to analysis. Arcsine-transformed means and standard errors were back transformed for graphic presentation. Multiple comparisons of means were made with Tukey tests. A significance level of alpha = 0.05 was used for all statistical analyses.

Results

Germination Response

Seed germination of the three *Caragana* species, tested in the laboratory on a constant and alternating temperature gradient bar, showed three patterns of response to temperature. The pattern of seed germination for *C. intermedia* was germination over a broad range of temperatures between 5°C and 30°C. The pattern for *C. licentiana* was cold-evading germination between 10°C and 30°C. The pattern for *C. opulens* was heat-evading germination between 5°C and 25°C. The seeds of each species germinated within a specific temperature range (table 1, fig.1).

C. intermedia and C. opulens showed a very high percentage of germination at their respective optimum temperatures (100 percent and 99. percent ±1 percent). The percent germination for C. licentiana was lower at its optimum temperatures (89.0 percent ± 2.5) than the other two species. The effect of alternating day/night temperature on germination in the three species was not significant.

Germination Process

The average incubation period needed for seeds to germinate was longer for *C. licentiana* than for the other species (fig. 2). Seeds began germination after 4 days at 25°C and total percent germination reached 25.5 percent ± 6.3 after 8 days. Few seeds germinated each day for *C. licentiana*. Germination rate was very quick for *C. intermedia* and

Table 1. Seed germination percentage of three Caragana species at constant and alternate temperatures.

Temperature (°C)	Species		
	C. licentiana	*C. opulens*	*C. intermedia*
5	0a[1]	78.5 ± 1.3a	7.0 ± 1.3 a
10	8.7 ± 4.2 a	100 b	66.8 ± 3.9 b
15	64.8 ± 11.7 b	100 b	98.0 ± 0.9 c
20	81.5 ± 2.4 c	100 b	99.0 ± 1.0 c
25	89.0 ± 2.5 c	100 b	99.0 ± 1.0 c
30	65.0 ± 7.7 b	0 d	98.5 ± 1.0 c
0 / 5[2]	1.0 ± 0.6 a	97.9 ± 0.8 c	11.5 ± 4.7 a
25 / 15	90.3 ± 1.9 c	100 b	99.5 ± 0.6 c
30 / 20	93.2 ± 4.0 c	100 b	99.5 ± 0.5 c

[1] Percentage germination with same letter are not significant at P < 0.05.
[2] 10h in light and then transfer 14h in dark.

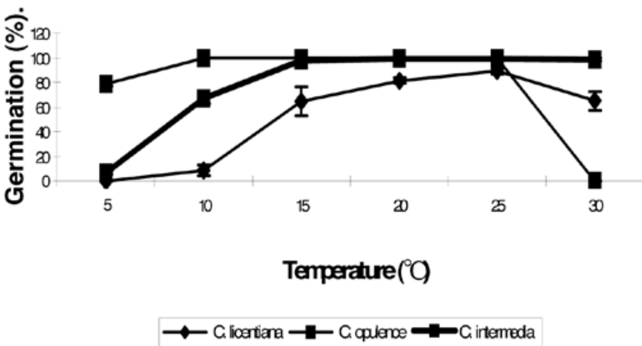

Figure 1. Percent seed germination at constant temperatures in three Caragana species after 20 days of incubation.

C. opulens (fig. 3). *C. opulens* seeds began germination after 3 days at optimum temperature and total percent germination reached. 67.6 percent ± 6.6 after 4 days. *C. intermedia* seeds began germinating after 2 days and total percent germination reached 70.9 percent ± 1.3.

Hard-Coat Seeds

No hard-coat seeds were found for *C. opulentce* in the germination trial. The rate of hard-coat seeds was 0.79 percent for *C. intermedia* and 5.14 percent for *C. licentiana*.

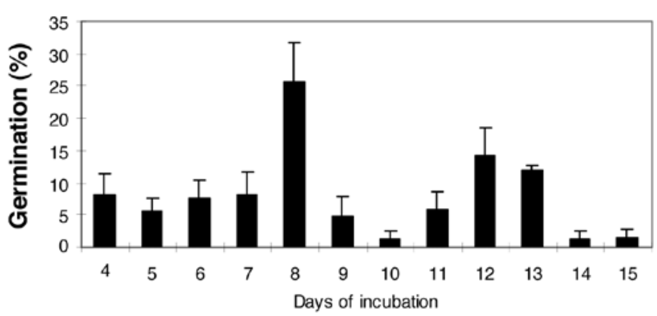

Figure 2. Percent germination of *C. licentiana* after different time periods of incubation at 25°C.

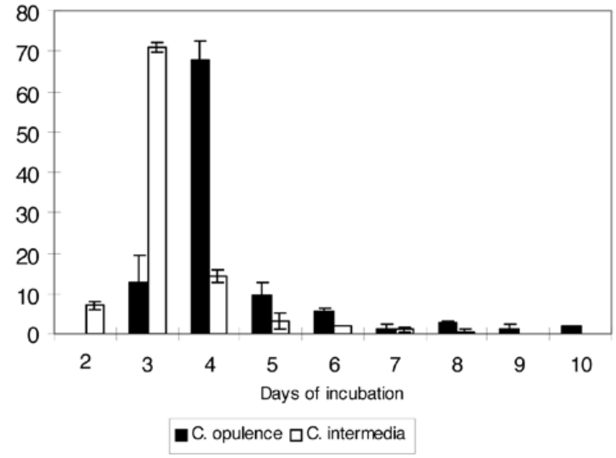

Figure 3. Percent germination of *C. opulens* and *C. intermedia* after different time periods of incubation at 25°C.

Discussion

Plants are generally in areas with temperatures that are appropriate for their germination and growth (Krebs 1978; Bewley and Black 1994). This is true for leguminous shrubs (Orozco-Almanza, 2003), as well as others species (Baskin and Baskin 1971; Linington 1979; Probert 1985; Abulfatih 1995). Differences in the temperature requirement for seed germination in the three species reflected the distribution and habitat of the species. The place of origin for *C. intermedia* is sandy desert (Liu 1987) where temperature in the growing season is high and temperature fluctuations are great. These conditions determine the wide range of temperature within which *C. intermedia* can germinate.

C. opulens is distributed in some regions of higher altitude in the Loess Plateau (Liu 1987). It grows in the northwest sloping habitat of the Dingxi County. Therefore, germination was inhibited at 30°C for this species and germination percentage at 5°C still reached 78.5 percent ± 1.3. *C. licentiana* grows mainly in southeast sloping habitat and seeds can not germinate at 5°C.

Germination over a wide range of temperatures has important practical implications in the Loess Plateau, where different temperature conditions prevail as a result of the topography of the region. Furthermore, seeds can artificially propagate the species in regions with different temperature conditions. Such characteristics make these species good candidates for restoration in semi-arid region of Loess Plateau, China.

Speed of seed germination presents a strategy for species survival and development in habitats where precipitation is unpredictable such as in semi-arid regions (Gutterman 1993; Wang 1998). Only a fraction of *C. licentiana* seeds germinated every day under adequate moisture that could decrease seedling mortality rate following a drought. This germination strategy coincides with the desert plants *Agriphllum wquarrosum* (Wang 1998). Seed-coat imposed dormancy is a delaying mechanism that prevents germination under conditions that might prove to be unsuitable for establishment, thereby separating germination in both time and space (Charper 1995). A small percentage (5.14 percent) of hard-coat seeds did not germinate under unfavorable conditions and have a lower percentage of predation. This allows them to persist in unpredictable environments, and may be another strategy that adapts the species to the habitat. This strategy suggested that *C. licentiana* might have a potential value in rehabilitation of degraded sloping land, especially dry southeastern sloping land.

A majority of seeds germinate and a fraction do not germinate in suitable conditions for *C. intermedia*. This germination response may ensure that a majority of seeds germinate in the suitable season to increase seedling survive rate in its original sandy habitat. But in the gully-hill loess habitat of Dingxi County, this germination behavior increases the risk of seedling mortality in a following drought. This may be one of reasons that little seedlings of *C. intermedia* were found in an artificial community in Dingxi County. Seeds almost synchronously germinated in favorable conditions for *C. opulens*. This may increase seedling survival rate in suitable conditions and decrease seeds predation by rodents.

Conclusions

Seeds of three *Caragana* species can germinate in different ranges of temperatures in the laboratory. This is directly related to their distribution and habitats. Speed of seed germination in the species is different and this may be a strategy that ensures the species persist in specific habitats. Seeds in the three species were dormant at different percentages and this has important ecological significance. These germination strategies mean *C. licentiana* and *C. opulens*, the endemic species, have potential value as good candidates for revegetation of different habitat in Loess Plateau region.

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