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Environmental Factors Controlling Leaf Emergence in *Caragana microphylla*, a Deciduous Shrub of the Mongolian Steppe

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Abstract: We examined the effect of temperature and rainfall on the timing of leaf emergence in *Caragana microphylla*, a representative deciduous shrub found in the Mongolian steppe over a three-year period. Two peaks of leaf emergence were identified, the first of which appeared to be induced by temperature, while the second was controlled by rainfall.

Keywords: *Caragana*, Phenology, Pulse-response, Unpredictable rain, Steppe

1. Introduction

Plants growing in arid regions exhibit morphological, physiological, and phenological adaptations to avoid water deficits. Coincident leaf emergence at the beginning of the rainy season is a typical phenological adaptation in the Mediterranean regioin (Gill and Mahall, 1986) and in dry tropical forests (Williams *et al*., 1997; de Bie *et al*., 1998; Borchert *et al*., 2002). In such regions with distinct wet and dry seasons, the trees are able to set their leaves about one month prior to the beginning of the rainy season (Singh and Kushwaha, 2005; Elliott *et al*., 2006) based on changes in the photoperiod (Nilsen and Muller, 1981). However, in many regions, rainfall is unpredictable, and occurs occasionally or in pulses, such that the timing and amount of rain per year can vary widely (Noy-Meir, 1973). Therefore, desert plants set their leaves only after significant rainfall (Beatley, 1974).

In the Mongolian steppe, the timing and intensity of rainfall are variable and unpredictable. Rain falls mostly during the summer without a distinct rainy season. The vegetation in the Mongolian steppe consists primarily of grasses, but shrubs are also common. *Caragana microphylla* (Fabaceae) is a representative deciduous shrub of the Mongolian steppe, found in the sandy grasslands of northern and eastern Mongolia, and which dominates some parts of the steppe. Its thick woody roots penetrate deeply into the soil (> 1 m), while its more abundant fine roots are found 5-10 cm below the soil surface (Yamada Y., personal observation).

The phenology of the grasses in the steppe has already been clarified in terms of emergence and growth, which are depend on the amount of rainfall in the spring (Kondoh *et al*., 2005); however, no phenological studies on shrubs have been reported. Shrub phenology may differ from that of herbaceous plants in the same habitat (Hoffmann *et al*., 2005; Campanella and Bertiller, 2008). We therefore surveyed the leaf and shoot phenology of *C. microphylla* and clarified its relationship with unpredictable rainfall and temperature.

2. Materials and Methods

This study was conducted near Mandalgobi City in Mongolia (45˚47'N, 106˚11'E). The mean annual temperature at Mandalgobi City was 2 ˚C while the mean annual precipitation was 150 mm. The vegetation Mongolia may be divided into distinct categories from north to south, according to the amount of precipitation, namely, taiga, steppe, semi-desert, and desert. Mandalgobi City, which is located at the southern end of the steppe, is bounded by a semi-desert region. The main species of the steppes are Graminaceae, e.g., *Stipa krylovii* and *Cleistogenes squarrosa*. The soil at the site is sandy (Sasaki *et al*., 2008), with an accumulation of calcium carbonate about 40 cm below the surface (Yamada Y., personal observation). Water sources on the surface, such as rivers or lakes, are absent around the site.

Climate data, including the average maximum and minimum temperatures and the daily amount of rainfall, were obtained from the National Climatic Data Center (2007).

Five patches of *C. microphylla* were selected in a fenced area protected from livestock grazing. In

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each patch, five (in 2005) or two (in 2006 and 2007) terminal branches (target branches) were selected. The number of leaves on each target branch was measured about once a week.

3. Results and Discussion

Over a three year period, most of the branches showed two periods of intensive leaf emergence during the growing season; however, the timing differed (**Fig. 1**). Turkey's test was used to identify peak periods of leaf emergence (**Fig. 2**). In 2005, the first peak was from 22 May to 21 June, while the second peak was from 28 July to 8 August. In 2006, the first peak was from 5 to 9 June, while the second peak was from 1 to 16 July. In 2007, the first peak was from 17 May to 22 June, while the second peak was from 2 to 28 July.

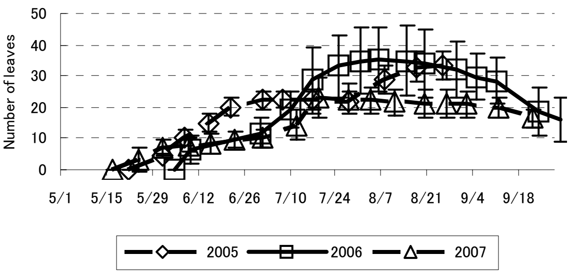

Fig. 1. Seasonal change in the number of leaves on each target branch (average±SD). The number of leaves on each target branch was averaged per patch, then averaged for each date.

Because the Mongolian steppe has extremely cold winters and dry summers, the limiting factor for leaf emergence in *C. microphylla* could be temperature and/or rainfall. We analyzed the temperature in the region using 21-day running averages to avoid effects of short-term changes in the environment (Lieberman, 1982; Jolly *et al.*, 2005). In each year, the first peak of leaf emergence began when the 21-day running average was around 3 ˚C (**Fig. 3**). However, the amount of rainfall before the first peak of leaf emergence differed among the three years, especially between 2005 and 2007. The monthly precipitation in May was 16 mm in 2005, but was only 3 mm in 2006 and 4 mm in 2007. Thus, the amount of rainfall prior to leaf emergence may not be a major factor in controlling the first peak of leaf emergence.

No relationships between the second peak of leaf emergence and temperature was identified (**Fig. 4**); however, it coincided with the first heavy rain (> 10 mm day^{-1}) during the growing season in 2005 and 2006 (Fig. 4). The second peak of leaf emergence appeared to begin prior to the first heavy rain in 2006 (Fig. 4), but this may have been due to the observation interval (observation dates: 1 and 10 July; first

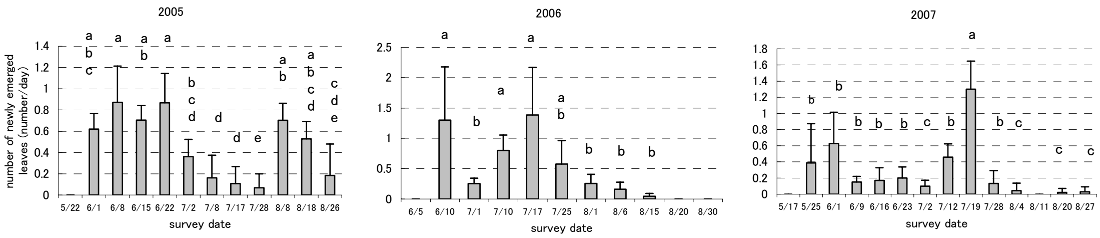

Fig. 2. Number of newly emerged leaves. Different letters indicate significant differences according to Turkey's test (p<0.05).

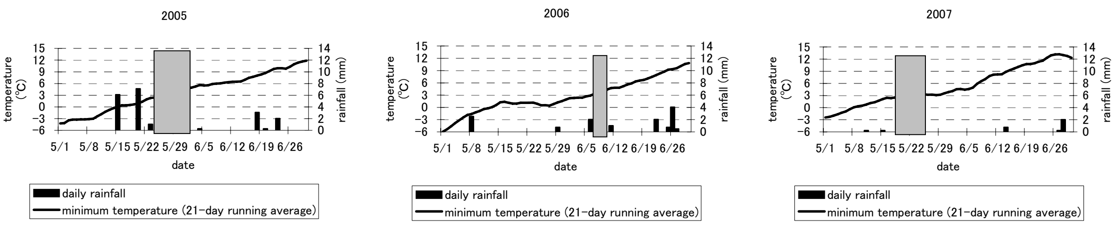

Fig. 3. Twenty-one-day running averages of the minimum temperature and daily rainfall. Shadowed boxes indicate the beginning of leaf emergence in each year.

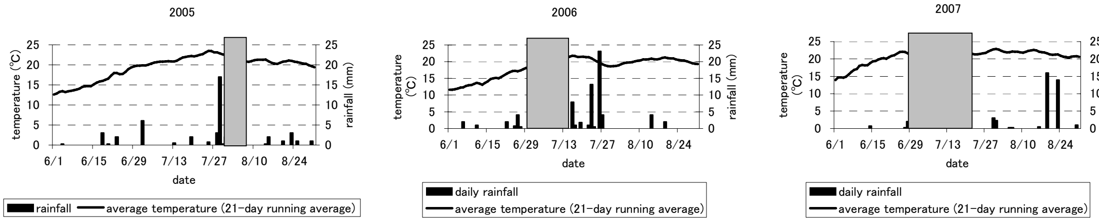

Fig. 4. Twenty-one-day running averages of the average temperature and daily rainfall. Shadowed boxes indicate the second peak of leaf emergence in each year.

heavy rainfall: 8 July). In 2007, although there was no heavy rain (> 10 mm day^{-1}) before the second peak of leaf emergence, successive periods of light rain (each about 2-3 mm day^{-1}) occurred before the second peak of leaf emergence that amounted to almost 10 mm per week (Fig. 4).

Previous studies indicate that a threshold amount of rain is required to induce leaf emergence (Beatley, 1974; Reynolds *et al*., 1999). For example, in the Mojave Desert, leaf emergence in shrubs occurred after 25 mm of rain (Beatley, 1974). However, the response of plants to rainfall events in a temperate steppe has not been analyzed. Thus, the threshold amount of rain required to induce leaf emergence in the Mongolian steppe is unknown. Our data suggested that the threshold is about 10 mm in a week, but further study is needed.

Coincident leaf emergence with a rise in temperature is common in humid temperate regions, especially at high latitudes (Fenner, 1998), and coincident leaf emergence with rainfall is common in arid regions (Noy-Meir, 1973; Beatley, 1974). However, this is the first observation of a plant that responds to two environmental factors at different times.

A study period of three years is inadequate to detect the triggers of leaf emergence in the steppe. Also, we were unable to investigate the generality of the leaf emergence traits for *C. microphylla* (i.e., whether it is common to other shrubs in the Mongolian steppe, or to plants in other regions), because of the rarity of phenological studies of shrubs in temperate arid regions.

4. Conclusions

Leaf emergence in *C.microphylla* occurs in two peaks. The first-time peak of leaf emergence appeared to be induced by temperature while the second was controlled by rainfall.

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