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Original Research

Effects of Water Deficit on Growth of Two Tree Species Seedlings in Changbai Mountains of Northeast China

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Abstract

To understand how temperate coexisting tree species respond to water deficit, the seedlings of two coexisting species, *Phellodendron amurense* Rupr. And *Fraxinus mandshurica* Rupr., were transplanted into plastic flowerpots. Three water deficit treatments were used, W1 (60-90% field moisture capacity), W2 (40-60% field moisture capacity), and naturally occurring precipitation (CK), with the aim of investigating the effects of water deficit on the growth of seedlings and competition between them. The result showed that the relative height and diameter of the *P. amurense* seedlings decreased in the control groups (CP, single *P. amurense* seedling; CF, single *F. mandshurica* seedling) but increased in the mixed groups (one *P. amurense* seedling and one *F. mandshurica* seedling together) with the water deficit. The water deficit affected the plants by altering the growth of the seedlings and competition between the two species. It was shown that there were greater negative effects on *P. amurense* due to the manufactured water deficit than on *F. mandshurica*.

Keywords: water deficit, competition, associate species, *Phellodendron amurense, Fraxinus mandshurica*

Introduction

Plants are continuously exposed to environmental stimuli that influence development and growth, and determine productivity. Water deficit occurs when the rate of transpiration exceeds water uptake, and is a component of several different stresses-including drought, salinity, and low temperature. The ability of the whole plant to respond and survive depends on whole-plant mechanisms [1]. The response depends on the species and genotype, the length and severity of water loss, the age and stage of development, organ and cell type, and the subcellular compartment [2]. Resistance to water deficit occurs when a plant withstands the imposed stress, and may arise from either tolerance or a mechanism that permits avoidance of the situation. Whole-plant mechanisms can contribute to the avoidance of water deficit during the plant's life cycle. The determination of the function of an observed response is one of the most complex issues in plant stress biology. In trying to understand responses to stresses involving a water deficit component, many genes induced by periods of water deficit have been identified and characterized [3-5]. In an unfavorable environment, plants must withstand multiple abiotic and biotic stresses, and a response observed during one type of stress may in fact have a role in the amelioration of another condition [6].

A better understanding of the dynamics of forests under various climate conditions is important to address the main-

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Table 1. Chlorophyll content and chlorophyll *a*/*b* of seedlings with N addition.

	Chlorophyll content (mg/L)				Chlorophyll *a*/*b*			
	CP	CF	MP	MF	CP	CF	MP	MF
CK	2.55(0.2)a	2.09(0.6)a	2.69(0.1)a	2.16(0.2)a	2.77	2.65	2.80	2.75
W1	0.72(0.2)a	1.55(0.3)ab	0.74(0.3)a	1.71(0.6)ab	2.76	2.84	2.76	2.84
W2	0.72(0.1)b	1.42(0.2)c	0.69(0.2)a	1.37(0.3)c	2.76	2.83	2.75	2.83

Each data represent the mean value of the chlorophyll content with the standard deviation. The different lower case letters represent significant differences between water deficit ($P<0.05$, repeated-measure ANOVA).
CP – one *P. amurense*; CF – one *F. mandshurica*; MP&MF – the *P. amurense* and *F. mandshurica* in the mixing group.

tenance of biodiversity, conservation, and future management options [7], although the responses of plants to water deficit have been studied in many species [8-11]. We sought to use *Phellodendron* amurense and *Fraxinus mandshurica* to take advantage of the species distributions of the associated species under water deficit.

The *Phellodendron amurense* Rupr. and *Fraxinus mandshurica* Rupr. are native to Changbai Mountain, in northeastern China [12]. They are important associated species in the broadleaved Korean pine forest, and also endangered because of their low productive rate and that they are widely used by people [13-15].

Different groups of *P. amurense* seedlings and *F. mandshurica* seedlings with various precipitations were investigated. In this study, we intend to:

1) compare the growth of the two coexisting species under the same precipitation,
2) clarify how intra-specific relationships affected the growth of these two coexisting species and find their correlation with the precipitation.

Study Site

This study was conducted in the Changbai Mountain Natural Reserve in northeastern China (42º24′09″N, 128º05′45″E). The area is situated in the temperate continental climatic zone. Mean annual temperature is 3.6ºC with monthly mean temperatures of -15.6ºC in January and 19.7ºC in July [16]. Mean annual precipitation is 695 mm. The period of snow cover is from November to April, with a maximum depth of 30 cm. Most precipitation occurs from June to September (480-500 mm). The vegetation type is dominated by the tree species *Pinus koraiensis* Sieb. Et Zecc., *Quercus mongolica* Fisch., *Tilia amurensis* Rupr., and *F. mandshurica* Rupr. [17]. The soil type is characterized as brown forest soil that is 60-80 cm thick [18].

Methods

Seedling Planted

A target-neighbor design [19] was used to test the competitive effect and response of each species. The target-neighbor design is one in which the density of the target species is maintained throughout the experiment, and the density of the neighbor species is varied [19, 20] in order to assess the response of a target plant to increasing density of a particular neighbor.

One-year-old seedlings of *P. amurense* and *F. mandshurica* were nurtured from seeds in late September 2011. We chose seedlings that have similar height and root collar diameter. One individual of a particular target species was placed in a plastic flowerpot with two possible competition levels, i.e. either a control treatment with no competitor, or with one competitor species.

Each group's seedlings were planted in plastic flowerpots (38.2×27.4) with added 25 kg uniform loamy soil. Each of these neighbor density treatments was replicated five times. All potting bags were arranged in a completely randomized design within the arboretum.

Water Deficit Treatment

The forest field moisture capacity is 27.4%. Three moisture treatments were established: CK (field moisture capacity), W1 (60%-90% field moisture capacity) and W2 (40-60 field moisture capacity).

The seedlings growth index was recorded at the beginning of the growing season on May 28 and after the growing season on August 22, 2013. Chlorophyll content, seedling height, stem basal diameter, and leaf area were recorded. The seedling height was defined as the length of the shoot and was measured from the stem top to the ground surface. Spectrophotometric methods were used to determine the Chlorophyll contents.

Statistical Analyses

Growth Measurement

Considering the effect of seedling size on seedling growth, the average relative growth rate (R) was calculated using the following formula:

$$R = (\ln Q_2 - \ln Q_1)/(t_2 - t_1)_{(1)} \qquad (1)$$

...where Q_1 is the dry weight of the algal cells at the first time sampling point (t_1) and Q_2 is the dry weight at the second time sampling point (t_2). The data were collected at 48 h intervals with three replications per sample.

Competition Definition

In a previous study [21, 22] the following general formulation was advanced:

$$R = Rm/(1 + W) \quad (2)$$

...where: R is the growth or reproductive output of an individual; Rm is the maximum growth or reproductive output of an individual in the same environment, i.e., in the absence of neighbors; and W is the measure of competition.

All the data were analyzed using a one-way ANOVA procedure. The differences between species in all the treatments were analyzed by a repeated-measure ANOVA. All the analyses were performed with SPSS 16.0. The significance was examined at the level P<0.05.

Results

To study the effect of water deficit on the growth of *P. amurense* and *F. mandshurica* seedlings, three moisture treatments were established. We studied growth responses that were elicited by water deficit of the seedlings.

Dry Weight

The whole plant dry weights of seedlings decreased with the increasing water deficit (Fig. 1). The dry weights of *F. mandshurica* were smaller than *P. amurense* in the mixing group (MP&MF), but greater in the control group (CP&CF). The dry weight of the root system increased at a moderate deficit and decreased at a severe deficit.

Relative Height Growth

This enhancement of *F. mandshurica* in the mixing group was greater, which enlarged the gap of *P. amurense* and *F. mandshurica* seedlings with the water deficit. Results for relative height growth of the seedlings are shown in Fig. 2. Water deficit changed the growth rate of the seedlings group. Seedlings in mixing groups (MP&MF) were lower than control groups (P&F). Seedling relative height growth of CF and MP groups under water deficit was higher than the control groups. Water deficit decreased the height growth of the seedlings in the CP and MF groups. Seedling relative height growth in the P group was significantly higher (p<0.01) than the other seedlings group.

Relative Basal Diameter Growth

Water deficit decreased the relative diameter growth rate of the control seedlings groups (CP&CF) and increased the relative diameter growth rate of the mixed seedling groups (MP&MF). Seedlings of the CP group had the biggest relative diameter growth while the MF group had the smallest. There was a significant difference (P<0.01) in relative diameter growth for W2 treatment of the CP group.

Chlorophyll Content

Chlorophyll content decreased significantly with the water deficit, similar to the response of chlorophyll *a* and chlorophyll *b*. The highest value was observed in the CK treatment for MP and the lowest value was found in the W2 treat for MP (74.35% lower than the highest). Chlorophyll *a*/*b* were decreased with water deficit in *P. amurense* (CP&MP) and increased in *F. mandshurica* (CF&MF).

Competition Between Seedling Groups

Water deficit decreased the competition of the seedling groups' basal diameter and height except the relative height growth of *F. mandshurica*. Water deficit reduced the competition gap of relative height growth and relative diameter growth between two different species seedlings. The competition affected height growth of *F. mandshurica,* which is still smaller than *P. amurense,* although it increased with the W2 water deficit.

Discussion and Conclusions

Many plant seedlings were acutely sensitive to water deficit, growing slowly at moderate stress and not at all severe stress. Plant responses to water deficit are dependent on the amount of water lost, the rate of loss, and the dura-

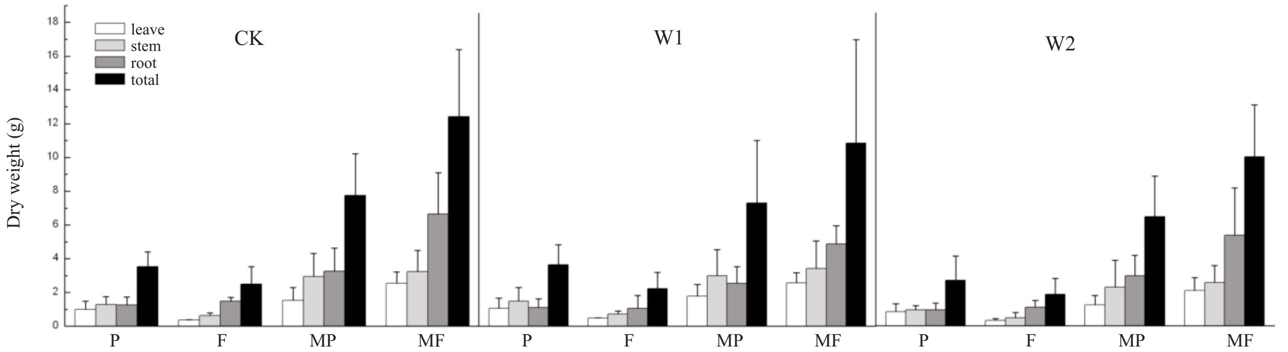

Fig. 1. Leaf, stem, and root dry weight of seedlings under water deficit. Each column represents the mean value of relative height growth.

tion of the stressed condition [23]. It is now clear that stress responses are dependent on the tissue, cell type, and developmental stage of the plant.

Drought is more likely to stress or kill seedlings, rather than adults, because of their poorly developed root systems [24]. A number of factors including seedling density, seedling age, and light availability are likely to magnify the impact of drought on woody seedlings. Former research found that some of the responses to water deficit are similar in tolerant species such as *Mesembryanthemum crystallinum* and *C. plantagineum*, and in crop plants such as tomato and maize or even in the model plant Arabidopsis [2].

The *F. mandshurica* seedlings in mixed groups have the highest biomass in three treatments under W1. Water deficit increased the biomass of seedlings with moderate condition while severe stress reduced all the biomass of the seedlings. Former research indicates moderate water deficit increased cell length modestly, whereas severe stress had little effect [25].

The CP group has the highest relative height growth as well as the decrease between water deficit and control groups. Height growth of seedlings in CP and MF under water deficit was lower than the control groups, while CF and MP was higher. Height growth of *F. mandshurica* increased with water deficit, which indicates that *F. mandshurica* spends more on height growth with the water deficit. Diameter growth of seedlings decreased with water deficit in the CP and CF groups. As expected [25], diameter growth would decrease for the sake of conserving water at least at moderate stress levels. The mixing groups under water deficit responded differently with the competition affected.

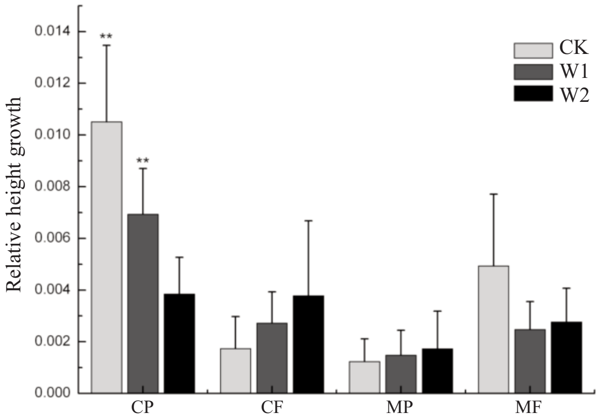

Fig. 2. Relative height growth of the seedling pairs with different water deficit. Each column represents the mean value of the relative height growth. (**) denotes significant differences in *P. amurense* with different seedling pairs .

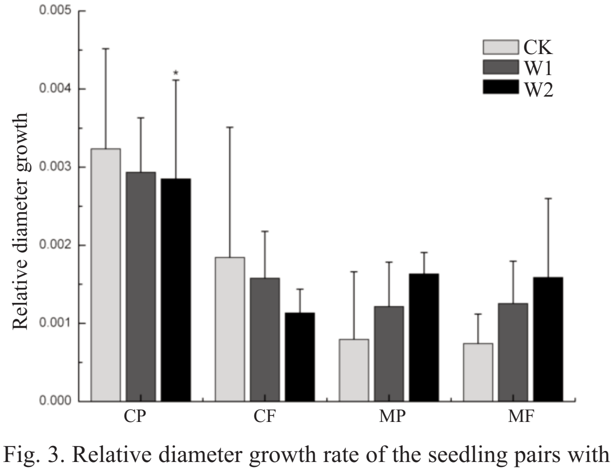

Fig. 3. Relative diameter growth rate of the seedling pairs with different water deficits. Each column represents the mean value of the relative diameter growth. (*) denotes significant differences in *P. amurense* with different pair seedlings.

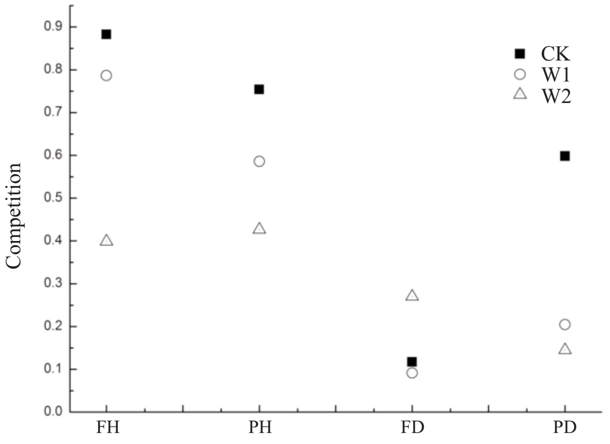

Fig. 4. Competition affection of two seedlings with N addition defined by relative diameter growth and relative height growth. Water deficit decreased the competition of the seedling groups' basal diameter and height, except relative height.

The competition affected height growth of seedlings, which decreased with the water deficit, especially the *P. amurense* seedlings, which decreased most in all the groups. Water deficit reduced the competition gap of relative height growth and relative diameter growth between two different species of seedlings. The competition affected height growth of *F. mandshurica,* still smaller than *P. amurense,* although it increased with the W2 water deficit. The competition affected *P. amurense* seedlings more than *F. mandshurica* seedlings.

Species diversity significantly influences ecosystem functioning and in turn provides support for conservation of biodiversity. It is well known that different plant species can associate with microbial communities with unique characteristics [26, 27]. Coexisting species promoted constructive species' growth by changing soil pH, increasing soil ash, and nutrition. Coexisting with other native species and mechanisms to permit or forbid the invasion of non-native species maintained ecosystem sustainability and function. Given this, learning more about associate species is one important branch of forest ecology.

Finally, in considering the whole-plant response, it is important to provide plants with stress conditions similar to those experienced in the field. Controlled conditions can never fully mimic field conditions, because in the field plants may experience multiple abiotic and biotic stresses. *F. mandshurica* is a dominant companion tree in both broad-leaved Korean pine forest and betula platyphylla secondary forest, while *P. amurense* was much rarer [28].

With the climate changing, the forests may be more suitable for *F. mandshurica* and the amount of *P. amurense* may be reduced. More research was needed to confirm the adaption mechanism of the species with the climate change.

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