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Allelopathic effects of eucalyptus and the establishment of mixed stands of eucalyptus and native species

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ABSTRACT

Allelopathic effects of eucalyptus are widely reported and are considered the major factor limiting the establishment of native species in eucalyptus forests. However, reports of the allelopathic effects of eucalyptus are mostly based on laboratory bioassay, not on field trials. In the present study, we conducted field trials to determine the allelopathic effects of eucalyptus and to develop strategies for establishment of mixed stands of native species and eucalyptus. In the field, seed germination and seedling survivorship of native species were determined in the presence and absence of eucalyptus leaf litter or living roots. In the seed germination experiment, seed germination rate of *Delonix regia* was higher than for *Elaeocarpus sylvestris* and *Tsoongiodendron odorum*. Seed germination rates of *E. sylvestris* and *T. odorum* were low in both the presence and absence of eucalyptus treatments. The germination rate of *D. regia* was significantly inhibited by all eucalyptus treatments, but only during the early period. In the seedling establishment experiment, seedling survivorship of *E. sylvestris* and *Michelia macclurel* was not inhibited by any treatments, but the seedling survivorship of *Schima superba* was significantly inhibited by eucalyptus litter addition alone. Seedling height of *S. superba* and *M. macclurel* was significantly suppressed when eucalyptus roots were present in treatments, but the seedling height of *E. sylvestris* was only significantly suppressed by the treatment of roots alone. We propose two strategies for establishment of mixed stands of native species and eucalyptus: (1) direct seed-sowing is effective only for those species (e.g. *D. regia)* with high germination rates in natural conditions; (2) seedling transplants are more efficient approach for establishing species (e.g. *E. sylvestris*) with low germination rates. We suggest that mixed plantations of eucalyptus and *E. sylvestris* can be established by transplanting seedlings of *E. sylvestris* into eucalyptus plantations.

1. Introduction

Many native forests have been destroyed by the introduction and large-scale planting of fast growing exotic tree species. Consequently, some native species have become endangered and the ecosystem services provided by native forests are diminishing (Islam et al., 1999; Foroughbakhch et al., 2001; Sangha and Jalota, 2005). For example, continuous planting of eucalyptus in monoculture may cause accumulation of phytotoxins in soil which results in soil degradation and loss of productivity (El-Khawas and Shehata, 2005; Forrester et al., 2006). Thus, mixed plantations of eucalyptus and native species have been proposed to maximize the productivity and enhance the ecological services of forest plantations (DeBell et al., 1985; Turnbull, 1999; Forrester et al., 2005; Bristow et al., 2006; Erskine et al., 2006). In recent years, multiple-species plantations, which include high value native species, have been used in tropical systems (Erskine et al., 2005; Duarte et al., 2006; Guerrero and Bustamante, 2007). Since eucalyptus trees might negatively impact seed germination and growth of native species (Everett, 2000; Duarte et al., 2006), it is important to screen for native species candidates with high tolerance to allelopathic effects of eucalyptus. Further, the productivity of eucalyptus might be enhanced when mixed with native species under appropriate management (Erskine et al., 2006).

Eucalyptus spp. are indigenous to Australia; they have been widely introduced into countries throughout the world because of their rapid growth and the rising demand for paper and plywood (Turnbull, 1999; Cossalter and Pye-Smith, 2003). In southern China, 2,000,000 ha of eucalyptus have been planted in recent

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years; China is now the second largest producer of eucalyptus in the world (Huang et al., 2007). Because of their rapid growth rates (Cossalter and Pye-Smith, 2003), wide adaptability (Johansson and Tuomela, 1996; Gardner, 2007) and high productivity (Singh and Toky, 1995), eucalyptus plantations generate large economic returns. Nevertheless, there is continuing controversy about the ecological functions of eucalyptus. The trees have been reported to reduce diversity of understory species (DeBell et al., 1987; Turnbull, 1999; Forrester et al., 2006; Gareca et al., 2007), cause soil degradation (Turnbull, 1999) and have allelopathic effects on native species (Gareca et al., 2007).

The allelopathic effects of eucalyptus have been studied extensively (Del Moral and Muller, 1969; Willis, 1999; Sasikumar et al., 2002; Bajwa and Nazi, 2005; El-Khawas and Shehata, 2005). Phenolic acids and volatile oils released from the leaves, bark and roots of certain *Eucalyptus* spp. have deleterious effects on other plant species (Sasikumar et al., 2002; Florentine and Fox, 2003). Most reports have focused on the allelopathic effects of litter extracts; those of living root exudates have been less well investigated (Bernhard-Reversat, 1999; Malik, 2004; Singh et al., 2005; Bagavathy and Xavier, 2007). In fact, plant roots have the remarkable ability to secrete organic compounds into the rhizosphere; such living root exudates play important roles in interactions with other plant species (Bertin et al., 2003). Most bioassay studies have been conducted in the laboratory (Willis, 1985); field studies of allelopathic effects under natural conditions are rare (Willis, 1985; Jose et al., 2006) Thus, field trials are necessary for investigating the integrative allelopathic potential of plants (Wardle et al., 1998).

In the present study, we conducted a field trial to examine the potential allelopathic effects of eucalyptus leaf litter and living roots on seed germination and seedling survivorship of native species. Our ultimate goal is to develop suitable strategies for establishment of mixed stands of native species and eucalyptus.

2. Materials and methods

2.1. Site description

The field trial was conducted at the Heshan Hilly Land Interdisciplinary Experimental Station, Chinese Academy of Sciences, Guangdong province, China. The field station is located at 22°4′N and 112°54′E. The climate of the region is subtropical monsoon with a mean annual precipitation of 1700 mm, with the rainy season from April to September, the dry season from October to March. The mean annual temperature is 21.7 °C with the maximum mean monthly temperature is 29.2 °C in July and the minimum mean monthly is 12.6 °C in January.

2.2. The plant species

We tested germination of three common native tree species, *Delonix regia, Tsoongiodendron odorum* and *Elaeocarpus sylvestris*. Seeds were obtained from a seed company in Guangzhou, China. All seeds were pre-treated with hot water at 24 h before sowing. These species are shade-tolerant, evergreen and endemic with high economic value. *D. regia* is a nitrogen-fixing species that can improve the soil fertility. *T. odorum* is an endangered, broad-leaved species and its conservation is of major concern. This tree is dominant in some natural forests in southern China where it often coexists with *Cunninghamia Lanceolata*, a fast-growing tree species (Feng et al., 2008). *E. sylvestris* is a broad-leaved tree which grows moderately rapidly in tropical and subtropical regions of China. It is commonly used in mixed species plantations in southern China. The germination rates of *D. regia, T. odorum* and *E. sylvestris* are reported as 90%, 60% and 70% under nursery conditions, respectively (Guo, 2006; Xie and Lin, 2007).

Seedlings of *E. sylvestris, Schima superba* and *Michelia macclurel*, obtained from Heshan Institute of Forestry Research, Guangdong Province, were tested for growth and physiological characteristics. *S. superba* and *M. macclurel* are also broad-leaved and endemic tree species, which were used in mixed plantations with *Pinus massoniana* and *C. lanceolata*. Such mixed plantations are reported to have higher productivity and higher ecological values than monoculture plantations (Huang et al., 2005; Xue et al., 2005).

2.3. Experimental design

This study was conducted on a hillside with shrubs removed. There were four treatments: (1) planted with *E. urophylla*, at spacing 2 m × 3 m in 2005, where roots and litter were intact (R + L); (2) planted with *E. urophylla* but with litter removed from soil surface but with root system intact (R); (3) no trees planted but with the addition of *E. urophylla* litter (L); (4) no trees planted and no litter addition—the control (C). In treatments (3) and (4), artificial trees were installed to exclude the confounding effect of tree shade. Photosynthetically active radiation (PAR) under the plots of *E. urophylla* plantations and artificial trees were measured using a portable infrared gas analyzer photosynthesis system LI-COR 6400 (Li-Cor Inc., Lincoln, NE, USA). No significant variation in PAR was detected between the two environmental conditions ($F = 1.303$, $p = 0.101$). There were three replicate sites for each treatment. In each site, four plots were randomly assigned to the aforementioned four treatments with an area of 24 m^2 for each plot. The *E. urophylla* trees were two years old with an average height of 8 m and average diameter at breast height (DBH) of 7.5 cm. We did not find significant differences in soil properties among different trial plots.

2.4. Seed germination and seedling establishment in the field

2.4.1. Seed germination experiment

The experiment was conducted from March 2007 to July 2007. In each experimental plot, three mini-plots (1.2 m × 1.2 m) were established; 50 seeds of *D. regia, T. odorum* and *E. sylvestris* were separately sown in each mini-plot. The mini-plots were enclosed by plastic mesh to exclude rodents and other animals. Number of germinated seeds and the heights of germinated seedlings were recorded every two weeks. After four months, plants and roots were excavated; total seed germination, root length and dry weight of seedlings were measured.

2.4.2. Seedling establishment experiment

Since seed germination of *E. sylvestris* and *T. odorum* were poor in the germination experiment, we conducted a separate seedling establishment experiment to seek alternative strategies for forest management.

This experiment was conducted from July 2007 to June 2008 after the seed germination experiment, therefore the same plots were used for seedling establishment. In each plot, 20 seedlings of each test species: *E. sylvestris*, *S. superba* and *M. macclurel* were planted in 1.2 m × 1.2 m mini-plots separately. *E. sylvestris* was used in both seed germination and the seedling establishment experiments. In June 2008, the survivorship and the height of seedlings were measured, and leaf chlorophyll content was also determined. A portable meter SPAD-502, which non-destructively measures leaf absorbance at wavelengths 650 and 940 nm, was used to estimate chlorophyll index (CI) (Pinkard et al., 2006).

2.5. Soil sampling and analyses

Soil was sampled in March 2007 (at the initiation of experiment), July 2007 (at the end of the seed germination