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Influence of neighbouring woody treatments on Mediterranean oak development in an experimental plantation: Better form but weaker growth

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ABSTRACT

Mixed plantations have been receiving increasing attention for their documented or supposed potential benefits over monospecific plantations. In particular, the use of neighbouring (or nurse) vegetation around target plants can enhance their performance through limitation of the competing herb layer, and can also improve their morphology.

Here we examine the benefits and drawbacks of using neighbour treatments on the response of target trees in open plantations. We set up an experimental plantation in southern France, in which two co-occurring target oak species (the evergreen *Quercus ilex* and the deciduous *Quercus pubescens*) were introduced in different neighbour treatments using a tree (*Pinus halepensis*) and a shrub species (the nitrogen-fixing *Coronilla glauca*). Oaks were planted with pine neighbours at two densities, with shrub neighbours, in a mixture of pines and shrubs or without neighbours. The ground vegetation was either regularly weeded or left to grow in order to detect any indirect facilitation interactions. Target oak responses (survival, growth, and morphology) were monitored over 7 years. Soil water content and light availability were also measured throughout the experiment.

We found competition to be the dominant process driving interactions between neighbours and target tree species. Growth was reduced by neighbour treatments for both species, but more in weeded than in unweeded treatments, showing an alleviation of competitive interactions by neighbours through limitation of herb layer development. However, in both ground vegetation treatments, growth was severely reduced with *Coronilla* shrubs. Survival was only significantly impaired for the less shade-tolerant *Q. pubescens* oak used in combination with shrubs. The negative influence of the neighbour treatments was mainly attributable to light interception, which was particularly high by shrub canopy. Soil moisture was also slightly reduced by shrub neighbours, but it remained high with pines in the unweeded treatment owing to a limited abundance of herbs. However, stem form was improved by the neighbour treatments: oaks developed narrower crowns and greater slenderness with neighbours, whereas oaks in the open showed a bushy morphology. These findings emphasise the need to clearly identify key objectives before implementing mixed plantations (*e.g.* maximising growth, survival, improving morphology, etc.) and to use active management to control potential undesirable effects of the neighbouring vegetation on target plants.

1. Introduction

There is an increasing interest in promoting mixed rather than monospecific plantations. Potential benefits of mixed plantations have been reviewed by Kelty (2006): they come mainly from increased productivity due to complementary characteristics (*e.g.* growth rates, root depth, phenology, etc.) (Vilà et al., 2007; Paquette and Messier, 2011), higher plant diversity in mixed than in monospecific stands (Felton et al., 2010), improvement of stem quality in the early stage of stand development (Löf et al., 2014) and reduced risks of pest damage (Jactel and Brockerhoff, 2007). Some of these advantages have been well documented (*e.g.* reduction of pathogen outbreaks, Jactel and Brockerhoff, 2007) but other

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are still being debated (*e.g.* competition for water resource, Grossiord et al., 2014; Forrester, 2015). Besides these advantages, the use of mixtures can be a valuable tool for alleviating competitive interactions among target species and promote facilitation (Kelty, 2006). Interactions among plants are complex and can be both positive and negative: the net balance can vary in response to types of biotic and abiotic stress factors, species identity, time, site conditions (e.g. Callaway, 2007; Gómez-Aparicio, 2009), and according to the nature of the response variable selected (*e.g.* growth, survival, and morphological responses, Prévosto et al., 2012). However, the role of facilitative interactions is reportedly more important in stressful conditions, such as Mediterranean environments (Castro et al., 2004; Gómez-Aparicio et al., 2004; Padilla and Pugnaire, 2006; Gómez-Aparicio, 2009), arguing for using accompanying plants that can nurse target plants in plantation operations. The use of nurse vegetation can directly improve the performance of the target trees (*i.e.* direct facilitation) by buffering the harsh climatic conditions prevailing in the open, such as excessive light radiation and extreme temperatures, and also by improving nutrition conditions, in particular when nitrogen-fixing plants are used (Gómez-Aparicio et al., 2004; Kelty, 2006). However, a major constraint in planting operations is the growth of a herb layer, which can limit tree seedling establishment (*e.g.* Rey Benayas et al., 2005; Prévosto et al., 2011b). Herbs are effective competitors for water due to canopy interception or direct uptake by roots. This is particularly detrimental to seedling survival and growth in water-limited environments (Ludwig et al., 2004; van der Waal et al., 2009), while competition for nutrients is more important in more mesic conditions (Pages and Michalet, 2003). The use of neighbouring vegetation can slow the growth of the competitive herb layer by light reduction, and so benefit the planted seedlings through indirect facilitation *sensu* Levine (1999). Another possible negative consequence of trees being introduced in totally open conditions is poor stem form, the development of thick lateral branches and the loss of apical dominance, clearly visible for some species (oak in particular), which can impair wood quality (Gauthier et al., 2013; Löf et al., 2014). Using neighbours around target trees can therefore improve their morphological response through space limitation and reduced light availability.

To test the potential benefits and drawbacks of using neighbour treatments on the response of target trees in open plantations, we devised an experiment in which two co-occurring target oak species (the evergreen *Quercus ilex* and the deciduous *Quercus pubescens*) were introduced in different neighbour treatments using a tree and a shrub species. As a tree neighbour we used *Pinus halepensis*, a pioneer light-demanding tree widespread in our area and forming stands that are naturally replaced by oaks in the course of succession (Quézel and Barbero, 1992). For a shrub, we selected *Coronilla valentina* subsp *glauca*, a common N-fixing species capable of rapid growth in open conditions. Shrubs, and in particular legume shrubs, have been successfully tested as nurse species in many planting operations or restoration experiments (Gómez-Aparicio et al., 2004; Kelty, 2006; Forrester et al., 2006). Tree and shrub species, alone or combined, were tested with one of the two target oaks. To clearly determine whether the influence of the neighbour treatments on target species responses also operates through indirect interactions (*i.e.* by the intermediate of the ground vegetation), we manipulated the herb layer, which was either removed or left to grow.

In this experiment, we specifically tested the following three hypotheses:

(i) Neighbours could positively influence survival and growth of target species particularly in the unweeded system due to limitation of herb competition (*i.e.* indirect facilitation).
(ii) Stem form of target oaks would be improved by the neighbours.
(iii) Responses of target plants would be species-specific and depend on density and life-form (shrub/tree) of the neighbourhood, which influences main resource uptake (light and soil moisture here).

2. Materials and methods

2.1. Study site

The experimental plantation was in south-eastern France (43°54′01″–4°44′55″, 80 m a.s.l.) under a Mediterranean climate in a previously abandoned agricultural field. Mean annual temperature was 14 °C. Mean annual rainfall was 689 mm. The soil was homogeneous, with a loamy-sandy texture, a low stone load and a high depth (>1 m), and possessed a high water-holding capacity and fertility. In summer 2007, the pre-existing vegetation was mechanically removed and the ground was scarified to obtain a bare soil. Planting was carried out in February 2008 using 1-year-old plants grown from a local nursery in 1.2 L containers for the oak species and 0.56 L containers for the other species. As the target species, we used two late-successional oak species with contrasting leaf habit that co-occur in this region: the evergreen *Q. ilex* L. and the winter deciduous *Q. pubescens* Wild. For accompanying woody species, we chose the Aleppo pine tree *P. halepensis* Mill. and the N-fixing shrub *Coronilla valentina* subsp. *glauca*. Just before planting, the oak seedlings were cut to a height of 10 cm and the shrubs to 15 cm to limit transplant shock.

2.2. Treatments and experimental design

The two oak target species were planted using five neighbour treatments: pines at low density (Low pine), pines at high density (High pine), *Coronilla* shrubs (Coronilla), pines and *Coronilla* shrub in a mixture (Pine + cor) and a control with no neighbours (Control). Target species and neighbours were set up on a 2 × 2.5 m plot: 12 oaks were regularly arrayed in 3 lines of 4 oaks per line. Oak seedlings were spaced at 0.5 m intervals in rows 0.5 m apart (Fig. 1). Neighbours were regularly arrayed using 20 pines for treatment (Low pine) so that each oak had 4 neighbours, and using 51 plants, either pines or shrubs or alternating pines and shrubs, for treatments (Coronilla), (High pine) and (Pine + cor) respectively (8 neighbours per oak). We set up a line of neighbours around the plot to limit edge effects, using 18 (Low pine) or 36 (High pine, Coronilla, Pine + cor) regularly spaced plants. In the control plot we also installed 18 oaks around the perimeter, but as in the other treatments, only the 12 central plants were used for subsequent measurements.

Two treatments were applied for the control of the ground vegetation: herbs were either manually removed, twice a year in the two first years (spring and autumn) and then once a year up to 2012, or left to grow: vegetation that naturally developed comprised diverse weed species.

Treatments were replicated 4 times, giving a total of 80 plots (2 oak species × 5 neighbour treatments × 2 vegetation treatments × 4 replicates). Plots were distributed in 8 blocks (25 m × 12 m), with each block containing the 2 target species and the 5 neighbour treatments randomly distributed within the block. Plots were separated by a distance of 2 m in each block, and a minimum buffer distance of 4 m was left between each block.

Blocks were randomly assigned to the weeding treatments, with half of the blocks being manually weeded (only the plots were weeded), while the other half were left unweeded.