Forest Ecology and Management 334 (2014) 106–113

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Wood density: A tool to find complementary species for the design of mixed species plantations

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ARTICLE INFO

Article history:
Received 11 April 2014
Received in revised form 4 August 2014
Accepted 5 August 2014

Keywords:
Functional traits
Shade tolerance
Native species
Small-scale forestry
Rainforestation
Polycultures

ABSTRACT

The successful establishment and growth of mixed-species forest plantations requires that complementary or facilitatory species be identified. This can be difficult in many tropical areas because the growth characteristics of endemic species are often unknown, particularly when grown at potentially higher densities in plantations than in natural forests. Here, we investigate whether wood density is a useful and readily accessible trait for choosing complementary species for mixed species plantations. Wood density represents the carbon investment per unit volume of stem with a trade-off generally found between fast (low wood density) and slow (high wood density) growing species. To do this, we use data collected from 18 highly diverse mixed species plantations (4–23 mostly native species) aged from 6 to 11 years at the time of data collection located on Leyte Island, Philippines. We found significant negative correlations between wood densities and the height of the most abundant species, as well as with measures of overall stand growth and tree diameter size distribution.

Not only do species with denser woods have slower growth rates, but also mixed-species plantations with higher average wood density and higher stem density were also less productive, at least in these young plantations. Similarly, stands with a high diversity in wood densities were less productive. There is growing interest in making greater use of native multi-species mixtures in smallholder and community planting programs in the tropics, and our results show databases of wood density values may help improve their design. In the early development stages of plantations, canopy closure and rapid height growth are usually key silvicultural targets, and wood density values can predict the rapid height development of species. If plantations are being grown for the livelihood of small landholders then the best target is to choose some species with different wood densities. This allows an early harvest of low-wood density species for early income, and will also reduce competition for slower growing trees with higher wood densities for later income generation.

1. Introduction

Increasing concern over climate change impacts and the unprecedented loss of biodiversity has increased interest in using diverse mixtures of native species in tropical plantations for reforestation (Lamb et al., 2005; Chazdon, 2008; Venter et al., 2009). Mixed species plantations have the potential to provide increased benefits in terms of biodiversity, forest products, bush foods, and increased resilience to diseases and pests (e.g. Hung et al., 2011; Le et al., 2014). Diverse mixtures are particularly suited to small-scale and community forestry. In contrast to industrial (large-scale) forest owners who typically manage their plantations to maximise productivity in terms of standing volume, many small-scale and community forest owners in the tropics are often more interested in growing a variety of forest products to provide income at different stages during plantation development. Mixed native species plantings may also increase community resilience to environmental changes including climate regulation, enhanced hill slope stability and improved carbon sequestration (Guariguata et al., 1995; Montagnini et al., 1995; Parrotta and Knowles, 1999; Díaz et al., 2009; Richards and Schmidt, 2010). Despite the advantages of using multiple native species in plantations, this approach presents a higher risk when little is known about the silviculture of the constituent species.

Growing trees in mixtures, as opposed to using monocultures, is technically and practically more challenging and requires an

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http://dx.doi.org/10.1016/j.foreco.2014.08.022
0378-1127/© 2014 Published by Elsevier B.V.

in-depth knowledge of species silviculture (Wormald, 1992; Forrester et al., 2005; Montagnini and Jordan, 2005; Kelty, 2006; Petit and Montagnini, 2006; Lamb, 2011). Some silvicultural information exists for just a handful of fast growing tropical timber species of genera such as *Tectona*, *Eucalyptus*, *Pinus* and *Acacia* spp. (Calvo-Alvarado et al., 2007; Plath et al., 2011). But regional analyses show most tropical regions have large numbers of potential tree species to use in reforestation schemes. For example, there are more than 110 tree genera growing in the forests of Southeast Asia with most of these having many individual species of commercially attractive timber trees (Lemmens and Soerianegara, 1993; Lemmens et al., 1995).

Little is known about the silviculture of many native tropical tree species, including growth rates in plantations, site requirements and tolerance of competition. Because of this paucity of information, it can be a challenge growing some of these species in monoculture plantations let alone in species mixtures. What is needed is a readily accessible indicator that managers could use to make predictions about how tree species will grow and function in mixtures with other species and in stands planted at higher densities than are normally found in diverse natural forests.

Some indication of how a species is likely to grow under different environmental conditions could be gained from examining plant traits such as wood density (Chave et al., 2009), leaf dry matter content and specific leaf area (Wright et al., 2004). Wood density, the oven dry mass divided by green volume that is determined by the structure of the xylem (Baas et al., 2004), has emerged as an important predictor of growth performance from studies that have also collated large databases that include tropical species (Reyes et al., 1992; Zanne et al., 2009; World Agroforestry Centre, 2010). The development of the wood economic spectrum has found wood density can be used as a surrogate measure for growth strategies, where fast-growing trees tended to have low wood densities and slow-growing trees high wood densities (Chave et al., 2009). From an evolutionary perspective, it is proposed that woody stems developed to help species gain height and a competitive advantage by reducing competition for light (Falster and Westoby, 2005), increased nutrient storage, and increased specialisation for conducting water and nutrients along soil-plant-atmosphere continuum. Wood or the structure of the xylem diversified over millions of years in response to environmental change that has manifested into physiological and biomechanical changes (Jagels, 2006). Relative growth and mortality rates have both been found to decrease with increased wood density (Enquist et al., 1999; Chave et al., 2009). Strong evidence suggests then that wood density may be useful as a predictor of tree growth in mixed species plantations.

A key necessity for designing mixed species stands is the need to combine species that are complementary in characteristics such as shade tolerance, height growth rate, crown structure, foliar and root phenology and root depth (Kelty, 1992). Thus, a mixed-species plantation may contain short-lived species with long-lived species, fast-growing with slower-growing species or shade-tolerant and shade-intolerant species able to occupy different positions in the forest canopy. Such mixtures of species can potentially reduce competition for light and increase overall light interception (Haggar and Ewel, 1997; Menalled et al., 1998; Forrester, 2004; Forrester et al., 2005; Manson et al., 2006). In such cases, species requirements are more likely to differ as species will have varying resource needs and therefore occupy different niche space, allowing them to continue to grow complimentarily.

Unfortunately, the light requirements and shade tolerance of many tropical tree species are not well known. However, tree wood densities are readily available and could be a useful surrogate for more difficult physiological characteristics to measure like growth rate and shade tolerance (Muller-Landau, 2004; King et al., 2005, 2006; Chave et al., 2009; Poorter et al., 2010). The xylem structure of most tropical hardwoods is described as diffuse-porous where the relative distributions of pores are uniform and vessels are similar sizes throughout the growth ring (Jagels, 2006). This makes tropical trees a good option for testing wood density values from databases as diffuse-porous hardwoods are generally considered less variable in strength and density because of year-round growth periods that characterise the tropics, which means no differentiation into early and late wood (Jagels, 2006).

Here, we investigate whether wood density (a readily available trait from several public databases) can be used to predict the performance of native tree species in mixed plantations using young mixed-species plantations in the Philippines. First, we test whether wood density can predict the performance, measured as height and diameter at breast height, of young tree species grown under plantation conditions. Second, we explore whether overall Stand Wood Density (i.e. the weighted average of wood density of individual trees in the stand) in the mixed species plantations (including the diversity of wood densities present) correlates with various measures of stand growth. Finally, we examine whether the wood density of trees used in plantation mixtures can predict future tree size class distributions – since it is tree size rather than overall stand volume that is of interest to most farmers and the buyers to whom they sell their trees. In our study, we purposely use values of wood density sourced from databases (as opposed to measuring wood density) because these are available ex ante to those designing mixed species plantations.

2. Materials and methods

2.1. Study sites

The study was conducted in small-scale mixed-species plantations arising from the Rainforestation Farming program. This program was initiated in 1992 and resulted in the establishment of 28 plantations on land owned by local communities and private properties in Leyte province in the Philippines (Milan, 1997a,b; Milan et al., 2004). Leyte province is one of two provinces on Leyte Island, the eighth largest island in the Philippines. The province lies between 124°17′ and 125°18′ east longitude and between 9°55′ and 10°48′ north latitude (Milan, 1997a,b) and is characterized as a humid monsoon climate.

Approximately 100 species were used in the program, including endemic pioneer tree species, longer-lived species, mostly of Dipterocarpaceae, fruit trees and a limited number of exotic timber species. Various combinations of these were used to create a series of small-scale (about one hectare) plantations on private land (Margraf and Milan, 1996). At the beginning of the project, pioneer and light demanding species were planted at a spacing of 2 × 2 m, and in the second year, shade-tolerant, as assessed by local knowledge, timber and fruit tree species were inter-planted at a general spacing of 2 × 1 m^2 (Schulte, 2002). While the main objective of the Rainforestation Farming project was to grow mixed-species plantations to meet social, economic and environmental needs (Schulte, 1998, 2002), the sites also present an ideal opportunity to explore basic questions associated with the silviculture of mixed species plantations (Herbohn et al., 2014; Nguyen et al., 2012).

2.2. Data collection

We studied 18 of the 28 Rainforestation plantations because we were not granted access by landholders to several of the sites and other sites had been damaged by fire and harvesting or even cleared for agriculture. The plantations studied were established on similar soil-types, 15 plantations on volcanic soils and three plantations on limestone soils and are spread across the Leyte