Forest Ecology and Management 409 (2018) 890–898

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Productivity and dynamics of pure and mixed-species plantations of *Populous deltoids* Bartr. ex Marsh and *Alnus subcordata* C. A. Mey

Masoud Ghorbani[a], Hormoz Sohrabi[a,*], Seyed Ehsan Sadati[b], Fariba Babaei[a]

[a] Department of Forestry, Tarbiat Modares University, Nour, Mazandaran, Iran

[b] Research Department of Natural Resources, Mazandaran Agricultural and Natural Resources Research and Education Center, AREEO, Sari, Iran

ARTICLE INFO

Keywords:
Aboveground biomass
Inter- and intraspecific competition
Nutrient cycling
Pure plantation
Randomized block design
Stand stability

ABSTRACT

Mixed-forest plantation with native species have gradually become the focus of forest research. The need to better understand their performance and productivity is, nowadays, a matter of particular relevance to forestry practice. The objective of this study was a long-term analysis of the effects of species-mixing of *Populus deltoides* Bartr. ex Marsh and *Alnus subcordata* C. A. Mey on aboveground biomass and net primary production, growth dynamics, and their relative yields total in pure and mixed stands. The experiment consisted of a replacement series that was established in 1996, using a randomized block design with five treatments (100P:0A, 67P:33A, 50P:50A, 33P:67A, 0P:100A) in four replicate blocks and two species were systematically mixed within rows. In the early stages, both species had a similar growth trend, while the differences were more pronounced at higher ages. The results show that inter- and intraspecific competition and nutrient cycling had the most pronounced effect on stand growth over time. *Populus deltoides* benefited from growing in mixture; canopy stratification reduces interspecific competition for light, and this species functioned best in mixed stands. In contrast, *A. subcordata* was sensitive to competition and had the highest growth in pure stands. In general, positive interactions between the two species led to the highest relative yield total and productivity in mixtures compared with pure stands. Within the framework of this experiment, it seems that the relative proportions of 50% *Populus deltoides* and 50% *Alnus subcordata* could provide economic and environmental benefits and increase the stability and productivity of the stands.

1. Introduction

Base on ecological theory, the productivity of mixed-species plantations can be greater than that of single-species plantations, because resources of a particular site can be exploited more completely and efficiently (Vandermeer, 1989, Amoroso and Turnblom, 2006). The multi-functionality of mixed-species plantations can improve management sustainability (Schuldt and Scherer-Lorenzen, 2014) as well as increase the diversification of products (Forrester et al., 2004). Different studies showed advantages of mixed versus pure species plantations in terms of greater production of biomass (DeBell et al., 1997; Forrester et al., 2004; Nunes et al., 2013), more diversified products (Keenan et al., 1995; Piotto et al., 2004), improved nutrient cycling and soil fertility (Binkley et al., 2000; Montagnini, 2000; Bristow et al., 2006; Potvin and Dutilleul, 2009; Manson et al., 2013), increased foliar nutrients (Brown, 1992, Richards et al., 2010, Nunes et al., 2011), improved risk management, reduced incidence of pests and diseases (Montagnini et al., 1995; Nichols et al., 1999; Piotto et al., 2004), higher stability against abiotic factors and climate change (Pawson et al., 2013), and increased carbon sequestration rate (Kaye et al., 2000, Resh et al., 2002, Forrester et al., 2006a, Bristow et al., 2006). Some studies point out that the benefits of mixed plantations depend on the effects of the tree species on nutrient supply, the nutrient use efficiency of the species, and the competitive interactions for light and water (Binkley et al., 1992; Binkley et al., 2003).

Fast-growing species such as poplars (*Populus* spp.) are preferred plantation species and meet the extensive demands for wood for poles, pulp, and fuel (Koupar et al., 2011). The interplanting of nitrogen-fixing tree species such as *Alnus* spp. with non-nitrogen-fixing tree species may increase the growth of the non-nitrogen-fixing trees by enhancing nitrogen availability (Binkley, 1983; Patricio et al., 2010; Hansen and Dawson, 1982; Sayyad et al., 2006).

About 9% of the Hyrcanian forests in northern Iran are composed of two nitrogen-fixing species (*A. subcordata* C.A. Mey and *A. glutinusa* (L.) Gaertn), which are the forth commercial species after oriental beech, oak, and hornbeam (Talebi et al., 2013) and grows in acidic and disturbed sites. The ability to establish a symbiosis with nitrogen-fixing actinomycetes colonizing the tree roots enables the fixation of

* Corresponding author.
E-mail addresses: hsohrabi@modares.ac.ir (H. Sohrabi), sadati10@yahoo.com (S.E. Sadati).

https://doi.org/10.1016/j.foreco.2017.11.016
Received 24 May 2017; Received in revised form 2 November 2017; Accepted 6 November 2017
0378-1127/

atmospheric nitrogen into soil-soluble nitrate, which can be used by alder and associated plants and enhances soil fertility. In addition, leaf litter from the alder trees represent a good source of compost (Taleshi et al., 2009). The results of some studies indicate that mixed plantations of poplar and alder species were more productive and sustainable than their respective monoculture plantations (Koupar et al., 2011, Sayyad et al., 2006). Apparently, these species increase the biological activities related to litter decomposition and nutrient cycling (Taleshi et al., 2009) and increase the ability of an ecosystem to return to its former natural condition.

Nowadays, the economic value of fast-growing exotic species is being questioned, and slow-growing, but higher-valued native species are more commercially and environmentally attractive. Native species often provide some additional ecological benefits. For example, they are better adapted to local conditions than exotic ones and are more attractive for local wildlife. It should be noted that the native species of the Hyrcanian forests are hardly commercially attractive because of the long rotation; however, using such species could be more acceptable ecologically and socially. Overall, it seems that admixtures of native and fast-growing exotic species could provide economic and environmental benefits. However, in some experiments changes with tree ontogeny were found (Sayyad et al., 2006), so long terms are needed but often scarce.

In this context, the purpose of this study was to: (i) to study the species-specific growth dynamic in these species under different species composition; (ii) to identify whether there is over or under-yielding in terms of tree biomass and if this net mixing effect changes with stand age; (iii) to analyse whether different species compositions influence annual aboveground net primary production.

2. Material and methods

2.1. Study area

The study area was located at the Chamestan Research Station of Forest and Rangeland, Mazandaran Province, northern Iran (36°29′N, 51°59′E). Experimental plots were located at an altitude of 100 m above sea level on a slight slope (0–3%). Annual rainfall averages 803 mm, with wetter months occurring between September and February and a dry season from April to August. Monthly rainfall usually averages < 40 mm over a period of four months. Average daily temperatures range from 11.7 °C in February to 29.5 °C in August. The soil is deep, well-drained, with a silty loam texture and a pH of 7.6–8.1. There are not differences in soil properties among treatments at the beginning of the experiments (Table 1). Previously, approximately 50 years ago, this area was dominated by natural forests containing native tree species such as *Quercus castaneifolia* C.A.Meyer., *Gleditschia caspica* Desp., *Carpinus betulus* L. Currently, the area is surrounded by agricultural fields and commercial buildings.

The soil properties of the study site in different treatments are presented in Table 1.

2.2. Experimental design

The plantations were established in 1996, using a randomized complete block design that included four replicate 40 × 40 m plots of each in the following treatments:

(1) Populus deltoides (100P:0A),
(2) 67% *P. deltoides* + 33% *A. subcordata* (67P:33A),
(3) 50% *P. deltoides* + 50% *A. subcordata* (50P:50A),
(4) 33% *P. deltoides* + 67% *A. subcordata* (33P:67A),
(5) Alnus subcordata (0P:100A).

Tree spacing within the plantations was 4 m × 4 m, and two species were systematically mixed within rows (Fig. 1).

Site preparation consisted of disk-harrowing to a depth of 10–15 cm. Containerized seedlings, 50–100 cm in height, were used for planting in April 1996. Seedlings of both species were planted simultaneously in monocultures and mixed plantations.

2.3. Field work and laboratory methods

All trees were numbered in each block, and the density of each block was measured as calculation of mortality. Initial height and diameter at collar height of each tree were measured in 1998. Height and diameter at breast height (DBH – 1.30 m above the ground) were measured again in 1999, 2000, and 2004. The final assessment was made in May 2015. The DBH was measured with a diameter tape; for each tree, two measurements were performed. These data were used to calculate the basal area and density for each tree species. Total height, defined as the maximum vertical distance from the ground level to the tree top, was measured for all the trees using a Haglöf SWEDEN-VERTEX IV. Fig. 1 shows the experimental design of the treatments.

2.4. Aboveground biomass

Total aboveground biomass was calculated for each tree component (stem, foliage, branch) and for the total tree, using allometric equations from Eslamdoust (2015). These equations were applied under similar site conditions and stand properties as described for this study for both species in the pure and mixed treatments (Table 2). Biomass components of both species were estimated using the following equation (Eq. (1)):

$$B = a(DBH \times H)^b, \tag{1}$$

where

B = oven-dried weight of biomass component (kg),
DBH = diameter at breast height (cm),
H = height (m),
a and *b* = model parameters.

Total biomass was calculated as the sum of the dry biomass of all components (foliage, branches, and stem).

2.5. Relative yield

Many indices have been proposed to describe the growth outcome of mixed-species stands in replacement series (Jolliffe, 2000; Williams and

Table 1
Mean values (± standard error) of soil properties in different sites of *A. subcordata* and *P. deltoids*.

Soil property	100P:0A	67P:33A	50P:50A	33P:67A	0P:100A	F	Sig.
pH	7.17 ± 0.5	6.88 ± 0.1	7.03 ± 0.2	7.01 ± 0.4	7.10 ± 0.5	0.130	0.969
EC (C (µs/Cm)E	157.63 ± 10.2	139.30 ± 6.9	162.20 ± 15.8	143.93 ± 30.8	148.78 ± 23.9	0.234	0.915
Organic matter (%)	5.49 ± 0.2	5.08 ± 0.3	4.70 ± 0.3	4.40 ± 0.7	4.31 ± 0.6	1.121	0.383
N (%)	0.27 ± 0.01	0.25 ± 0.01	0.23 ± 0.01	0.21 ± 0.04	0.21 ± 0.03	1.120	0.381
P (mg/kg)	8.35 ± 2.6	6.61 ± 1.4	6.31 ± 0.3	5.32 ± 0.4	5.32 ± 0.3	0.840	0.521
K (mg/kg)	198.01 ± 30.4	174.1 ± 12.1	206.5 ± 21.9	152.8 ± 14.6	133.5 ± 11.5	2.451	0.091