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Full Length Research Paper

Effects of pure and mixed plantations of *Populus deltoides* with *Alnus glotinosa* on growth and soil properties: A case study of Foman Region, Iran

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Plantation and application of fast-growing species, such as *Populus deltoides* increasingly, are common in the northern part of Iran. Concerns about decline in soil fertility and long-term productivity of fast-growing plantations have promoted interest in using nitrogen-fixing trees in mixed species plantations. *P. deltoides* and *Alnus glutinosa* were planted in five proportions (100P, 70P:30A, 50P:50A, 30P:70A, 100A) in Foman, Iran. After 13 years, the effects of species interactions on tree growth and nutrient concentration in live and senescent leaves and soil properties were assessed. Diameter at breast height and total height of individual *Populus* trees were positively affected by the presence of *Alnus*. Nitrogen concentrations in fully expanded and senescent leaves of *Populus* were higher in mixed plantations than monoculture plantations. The results of nutrition and nutrient return and growth indicated that mixed plantations of these two species were more productive and sustainable than their monoculture plantations. Within the framework of this experiment, it appeared that production was maximized when these two species were grown together in the relative proportions of 30% *Populus* and 70% *Alnus*.

Key words: Mixed plantation*, Alnus*, *Populus*, growth, soil.

INTRODUCTION

Poplars (*Populus* L. spp.) are preferred plantation species, because their fast growth is expected to meet the extensive demands of wood for poles, pulp and fuel (Ziabari, 1993; Ghasemi, 2000; Kiadaliri, 2003). Productivity of plantations depends strongly on soil nutrient supply and it may be malleable under the influence of management practices and species (Binkley, 1997). Almost all the industrial plantations are monocultures, and questions are being raised about the sustainability of their growth and their effects on the site (Khanna, 1997). Repeated harvesting of fast-growing trees such as poplar plantations on short rotations may deplete site nutrients. Nitrogen losses are likely to be very important for future growth. It is, therefore, appropriate to explore new systems of plantation management in which N may be added via fixation (Khanna, 1997). Mixed plantation systems seem to be the most appropriate for providing a broader range of options, such as production, protection, biodiversity conservation, and restoration (Montagnini et al., 1995; Keenan et al., 1995; Guariguata et al., 1995; Parrotta and Knowles, 1999). Mixed plantations yield more diverse forest products than nonspecific stands, helping to diminish farmer’s risks in unstable markets. If planned with consideration for each species’ response to mixed conditions, mixed designs can be more productive than nonspecific systems. In addition, a mixture of species,

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each with different nutrient requirements and different nutrient cycling properties may be overall less demanding on site nutrient than monoculture stands (Montagnini, 2000). Mixed plantations can produce more biomass per unit area because competition among individuals is reduced and the site is used integrally (Montagnini et al., 1995). The roots of different species may occupy different soil strata allowing more complete utilization of soil and water resources (Lamb and Lawrence, 1993). More solar energy can be captured because different species have different light requirements and crowns are broadly distributed in the vertical plane (Guariguata et al., 1995). However, the success of the establishment of mixed forest plantations depends on plantation design and an appropriate definition of the species to be used, taking into consideration ecological and silvicultural aspects (Wormald, 1992). Concerns about decline in soil fertility and long-term productivity of fast-growing plantations have promoted interest in using nitrogen- fixing trees in mixed species plantations (Rhoades and Binkley, 1996). Nitrogen-fixing trees, mainly leguminous species, have been widely extolled for their soil-improving characteristics related to their production of nitrogen-rich, often rapidly decomposing leaf litter (Parrotta, 1999). Although there have been some documented cases of increased productivity in mixed-species plantations in both temperate and tropical regions, the collective results of such studies have been inconclusive and show that accurate species/site matching and choice of complementary species strongly influence mixed-species plantation productivity (FAO, 1992). Experiments in some parts of world such as North America have shown enhanced growth of *Populus* sp. when grown as an intercrop with *Alnus* L. spp. (FAO, 1992; Coté and Camiré, 1987; Hansen and Dawson, 1982; Radwan and DeBell, 1988). The present study was undertaken to assess the influence of *Alnus subcordata* C.A.Mey and *Populus deltoids* Marsh. plantations on soil fertility parameters, the influence of *Alnus* on *Populus* growth and nutrient concentration of fully expanded and senescent leaves in monocultures and mixed plantations. Although there have been some documented cases of increased productivity in mixed-species plantations and/or species diversity in both temperate and tropical regions (Assmann, 1970; Khanna, 1997; Brockway, 1998; Montagnini and Porras, 1998; Parrotta, 1999; Genda et al., 2000; Montagnini, 2000; Piotto et al., 2003, 2004; Petit and Montagnini, 2004, 2006; Ashagrie, 2005; Sayyad, 2006; Forrester et al., 2006a, b).

MATERIALS AND METHODS

Site characteristics

The study area is located at the Foman experiment station, in Guilan province, on the northern parts of Iran (35° 5'N, 49° 15'E). Experimental plots were located at an altitude of 10 m above sea level and with low slope (0 to 3%). Annual rainfall averages 1260.1 mm, with wetter months occurring between September and February, and a dry season from April to August monthly rainfall usually averages < 40 mm for 4 months. Average daily temperatures range from 11.3°C in February to 29.2 °C in August. The soils are well-drained, and have a silty loam texture with a pH 4.8 to 5.9. 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., etc. The surrounding area is dominated by agricultural fields and commercial building.

Experimental design

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

(i) 70% *P. deltoides* + 30% *A. subcordata*(70P:30A),
(ii) 50% *P. deltoides* + 50% *A. subcordata*(50P:50A),
(iii) 30% *P. deltoides* +70% *A. subcordata*(30P:70A),
(iv) *P. deltoides* (100P),
(v) *A. subcordata* (100A),

Tree spacing within plantations was 4 m × 4 m and tow species were systematically mixed within rows.

Site preparation and planting of seedlings

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

Tree survival and growth measurements

Diameters of trees at 1.3 m height (DBH), crown diameter, tree volume and tree heights were measured in the central 20 m × 20 m area (subplot) of each plot, excluding the outer two tree rows, in July 2008.

Soils

Soils were sampled to a depth of 60 cm in all plantations and control plots in August using a 7.6 cm diameter core sampler (n = 3 cores/plot) taken at two 15 cm and a 30 cm interval. After air drying, soils were passed through a 2.0 mm sieve to remove roots prior to chemical analyses. Soil pH was determined using an Orion Ionalyzer Model 901 pH meter in a 1:2.5, soil: water solution. EC (electrical conductivity) was determined using an Orion Ion analyzer Model 901 EC meter in a 1:2.5, soil: water solution. Soil organic matter was determined using the Walkley-Black method. Total N was determined using the Kjeldhal method (Bremmer, 1960). Available P was determined with spectrophotometer by using Olsen method (Homer and Pratt, 1961). Available K, Ca and Mg (by ammonium acetate extraction at pH 9) were determined with Atomic absorption Spectrophotometer (Bower et al., 1952).

Statistical analyses

One-way analyses of variance (ANOVA) were used to compare tree growth, soil properties, and leaf nutrients data among experimental treatments. Tukey-HSD and Duncan tests were used to separate

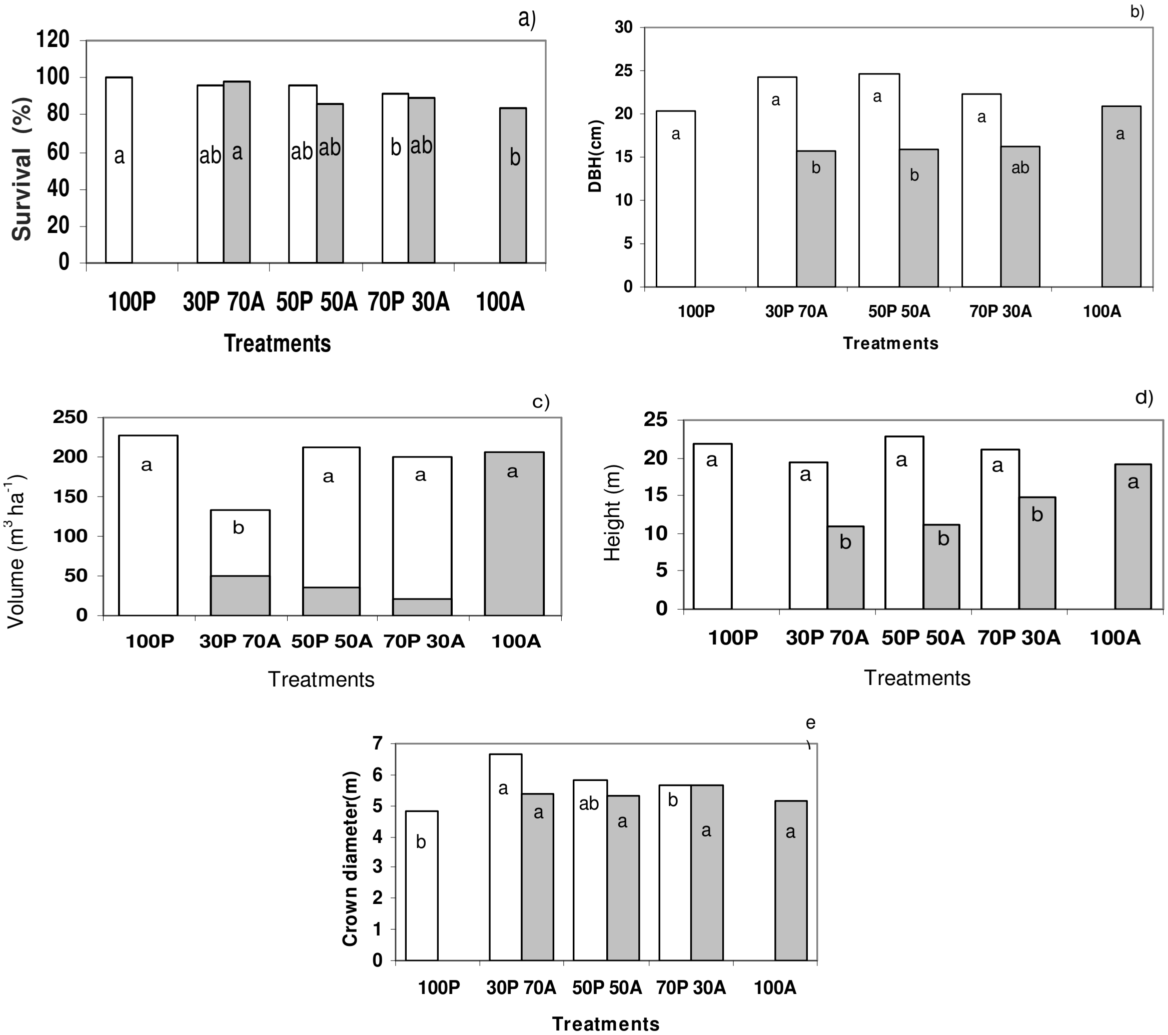

Figure 1. a) Survival, b) DBH, c) Volume, d) Height and e) Crown diameter of both tree species were separately compared. The letters on different column indicate a different comparison. Mean values with the same letter within a tree species do not differ significantly with each other.

the means of dependent variables, which were significantly affected by treatment.

RESULTS

Tree survival and growth

The survival of Populus was generally unaffected by the presence of Alnus with the exception of higher Populus survival when the two species were grown in equal proportion (70P:30A) than 30P:70A (Figure 1a).

Alnus survival, in contrast, was unaffected by the presence of Populus in any proportion. Mixed plantations had no positive effect on the DBH of Populus when compared with the trees growing in monoculture. The DBH of Alnus was reduced when this species was grown in combination with Populus as compared with not further monocultures, but the relative proportion of Populus did affect this result (Figure 1b).

Total volume of both species was not affected by relative proportions of the two species (Figure 1c). Within the 30P:70A treatment, Populus accounted for significantly less of the total volume than Alnus did. Height growth of Alnus was affected by the presence of Populus (Figure 1d). In the 100A treatment, Alnus height was higher than in the other treatments. The height growth of Populus however, was unaffected by the presence of Alnus. Similarly, the crown diameter of Populus was positively affect by the presence of Alnus, but the crown diameter of Alnus was unaffected by the presence of Populus (Figure 1e).

Soil properties

There were great differences in soil properties between treatments. Soil pH, ranged from 4.21 to 5.46. Soil EC in

Table 1. Soil properties in plantations in different soil layers with their standard deviation.

Soil properties	Depth	100P	70P:30A	50P:50A	30P:70A	100A	ANOVAb
pH	0–15	4.85	5.46	4.63	4.56	4.21	ns
EC(ds/cm)	0–15	0.26 b	0.39 a	0.40 a	0.27 b	0.43 a	***
Total N (%)	0–15	0.21c	0.18 c	0.33ab	0.38a	0.29b	***
	15–30	0.08	0.10	0.07	0.09	0.13	ns
	30–60	0.04	0.07	0.06	0.06	0.04	ns
Organic matter (%)	0–15	3.06c	2.11 d	3.93 b	4.53 a	3.47 bc	***
P available	0–15	81.70 b	161.02 a	175.53 a	132.48ab	184.30 a	***
K available (mg/kg)	0–15	197.16 b	183.92 b	177.33b	289.56 a	171.83 b	***

a: Based on three composite 7.6 cm diameter core samples per plot; b: ANOVA results: ns = treatment effect not significant, ** = p < 0.05, *** = p < 0.01, Duncan.Mean values with the same letter within the soil layer do not differ significantly with each other.

0 to 15 cm depth of monoculture Alnus and monoculture Populus treatments was different (Table 1). Organic matter was different between 0 to 15 cm depth of monoculture Populus and 50P:50A, as well as 30P:70A treatments (Table 1). Total nitrogen had some differences between the treatments in 0 to 15 cm soil layers. Available P in 0 to 15 cm depth of monoculture Populus was different with monoculture Alnus, and 70P:30A and 50P:50A treatments (Table 1). Available K in 0 to 15 cm depth of 30P:70A treatments was different with other treatments (Table 1).

DISCUSSIONS

Because the survival of both species (Populus and Alnus) did not show, in most cases, any differences between monocultures and mixed plantations, it can be concluded that there was little competition between the two species, as a result of their planting spacing. Parrotta (1999) found more survival in monoculture plantations of *Eucalyptus robusta* than mixtures with Casuarina and Leucacna. The differences between our results and those obtained by Parrotta (1999) were probably due to differences in planting space. The other reason might be the difference in growth rate and crown diameter of his target and associated species in comparison with our species. Our results were however, similar to those obtained by Khanna (1997) about *Eucalyptus glabulus* and *Acacia mearnsii* in monocultures and mixed plantations. Higher Alnus diameter growth was observed in treatments with less proportion of Alnus. This could be due to a decrease in light competition, as the most important competition factor (Binkley, 1992). Results of our work correspond with the work of Khanna (1997) on monocultures and mixed plantations of Eucalyptus and Acacia. It was also found that N-fixation by Acacia in mixed plantations resulted in increased diameter growth of Populus (Khanna, 1998). Rapid diameter growth was also found to be due to domination of the target species (Montagnini, 2000). No influence of nitrogen fixing trees on diameter growth on non nitrogen fixing tree was observed by Parrotta (1999), but Binkley (1983) found contrary results with *Alnus rubra* having a positive effect on the diameter growth of *Pesudotsuga menziesii* in poor sites. The Volume of both Populus and Alnus did not show any significant differences in monocultures compared to 50P:50A and 70P:30A treatments in our study. In contrast, Parrotta (1999), Khanna (1997) and Montagnini (2000) found bigger basal area for target species in mixed plantations compared to monocultures. Increased light competition in mixed plantations containing a grater proportion of Populus may explain the greater height growth of this species in these plots. Populus did not show any differences in height growth between the monocultures and mixtures. Our results are similar to those obtained by Parrotta (1999) and Khanna (1997) in monocultures and mixed plantations of Eucalyptus and Acacia, and Hansen and Dawson (1982) in monocultures and mixed plantations of Poplar species and *Alnus glotinosa*. In contrast to our results, Heilman (1985) did not observe greater height of target species in mixed plantations (FAO, 1992). The crown diameter of Populus was significantly smaller in monoculture plantations in comparison with that in the 30P:70A treatment. It might be the result of decreasing light competition in mixed plantations with less proportion of Populus. Water and light competition in mixed plantations result in decreasing crown diameter (Fisher and Binkley, 1999). These results have strong correlation with other results, such as increasing diameter in the treatment with high Alnus proportions and increasing height in treatment with low Alnus proportions. No statistically significant differences were observed in soil pH between the treatments, whereas significant reductions in soil pH have been found in half of the studies about the effect of nitrogen fixing trees (NFT) on soil (Fisher and Binkley, 1999). Montagnini (2000) and Giardina et al. (1995) reached the same result as we, whereas Rhoades and Binkley (1996) and Parrotta (1999) found lower soil pH in mixed plantations. Higher planting density and low age of our plantations might be the main reasons for no significant difference in soil pH. The main reason for the reduction of soil organic matter in 0 to 15 cm depth in monoculture of

Populus treatment compared to that in the mixed plantations might be the result of increasing biological activities in the soil. Parrotta (1999) came to the same conclusion. In contrast with our results, Garcia-Montiel and Binkley (1998) found that organic matter content in 0 to 20 cm depth of soil under NFT Albizia was higher than in soil under Eucalyptus. It is obvious that Alnus increased soil nitrogen more than Populus. The decrease in soil nitrogen of mixed plantations with high proportions of Populus might be the result of invading Populus roots to nodules of Alnus (Binkley, 1992). Binkley (1997) and Garcia-Montiel and Binkley (1998) found that Albizia increased soil nitrogen more than Eucalyptus. Parrotta (1999) and to some extent Montagnini (2000) did not observe any significant differences in soil nitrogen between monocultures and mixed plantations. Whereas Hansen and Dawson (1982) observed that mixed plantations of Populus and *Alnus glutinosa* resulted in increasing soil nitrogen in comparison with their monoculture plantations (FAO, 1992). Few significant differences were observed between the treatments in concentrations of available K and P in soil. We can relate these differences to previous soils condition, such as what Parrotta (1999) did. Montagnini (2000) came to the same results in monocultures and mixed plantations as we did.

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