ECOLOGIA BALKANICA

2011, Vol. 3, Issue 1 July 2011 pp. 33-49

Comparison of growth, nutrition and soil properties of pure stands of Quercus castaneifolia C. A. Mey. and mixed with Carpinus betulus L. in the Hyrcanian forests of Iran

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Abstract. In the present study, *Quercus castaneifolia* (Oak, as target species) and *Carpinus betulus* (Horn beam, as native component species) were planted in five proportions (100Q, 70Q:30C, 60Q:40C, 50Q:50C, 40Q:60C) in the Noor region (North Iran). After 12 years, the effects of the species on the growth of the trees, nutrient concentrations in the live and senescent leave and on soil properties were assessed. The results showed the survival and diameter at breast height (dbh) of the individual Oak trees were positively affected by the presence of Horn beam. Percent retranslocation of the nutrients in *Quercus* trees was: K>N>P. Leaf-litter fall production ranged from 4.70 to 6.80 Mg ha^{-1} $year^{-1}$. N concentration in fully expanded leaves, N and Ca concentrations in the senescent leaves of *Quercus* trees and N concentration in topsoil were higher in some of the mixed plantations than in the monocultures of the *Quercus* trees. N fluxes, N and P retranslocation, and soil P concentrations in the monocultures were intermediate relative to mixed plantations. The obtained results somewhat indicated that the mixing with hornbeam increased the productivity and sustainability of the oak sites. Within the framework of this experiment, it appeared that production was maximized when these two species were grown together in the proportion of 50% *Quercus castaneifolia* and 50% *Carpinus betulus.*

Keywords: Tree growth, Mixed plantation, Nutrition, Nutrient flux, Nutrient retranslocation, Soil property.

Introduction

The development of human societies often has caused an overexploitation of forests and a decrease in their area (AUGUSTO *et al.*, 2002). Over the last few years, interest in establishing reforestation projects with native species in forest plantations as a means to supplement existing wood markets and as a way to detain the overexploition of natural resources has increased (PIOTTO *et al.*, 2004). While plantations proliferate, local communities are looking for suitable native species to cultivate in plantations (PETIT & MONTAGNINI, 2004).

The growth of dominant species is faster in mixed than in pure plantation, and that mixed plantations have high volume and biomass production in comparison with pure stands (MONTAGNINI & PORRAS, 1998; MONTAGNINI, 2000). 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; PIOTTO *et al.*, 2004).

To assess the growth performances of a species, it is important to study the productivity and nutrient dynamics (SHANMUGHAVEL & FRANCIS, 2001). Repeated harvesting of planted trees may deplete site nutrients. Heavy nutrient drain is an adverse impact on long-term site quality and sustained production (HOPMAN *et al.*, 1993; KHANNA, 1997; SWAMY *et al.*, 2006). Forest productivity is limited by the supplies of one or more nutrients in almost all forests, and forest nutrition management is a key issue in the management of commercial forests (STAPE *et al.*, 2006).

Within the same community, foliar nutrient concentrations vary largely among different species and among different individuals of the same species despite similar soil conditions (NIINEMETS & KULL, 2003), but the plant and species characteristics responsible for this variability are still poorly understood. Degree of retranslocation or resorption of nitrogen and phosphorus within the plants is also an important factor to be considered. Within-Plant cycling of these elements decreases plantation dependence on the biogeochemical processes to fulfill nutrient requirements after the initial exponential phase of tree growth (MILLER, 1984). It also decreases potential losses from the system due to leaching and erosion, as resorption maintains the nutrients within the living biomass (CUEVAS & LUGO, 1998).

In Iran, Hyrcanian vegetation zone is a green belt stretching over the northern slopes of Alborz mountain ranges and covers the southern coasts of the Caspian Sea. It has a total area of 1.84 million ha comprising 15% of the total Iranian forests and 1.1 % of the country's area (KHOSROSHAHI & GHAVVAMI, 2006). Hyrcanian or northern forests of Iran stretch out from the sea level up to an altitude of 2800 m and encompass different forest types thanks to their 80 tree and shrub species (SAGHEB-TALEBI *et al.*, 2004). Among these species, *Quercus castaneifolia* C. A. Mey. (Fagaceae) is the most commercial species after beech (*Fagus orientalis* Lipsky), which includes 6.6 % of the area and 8.01 % of the standing volume of these forests and it can reach 50 m in height and 2 m in dbh.

The potential for maintenance and expansion of the oak forests by natural regeneration appears to be at best limited (WATT, 1919; LINHART & WHELAN, 1980, LANGBEIN, 1997; MIRKAZEMI, 1997; MOHAJER, 1999; PALMER *et al.*, 2004). In order to promote expansion and rehabilitation of the oak forests, a program of oak seedling planting may be required (TRUSCOTT *et al.*, 2004). Oaks can be established as pure or mixed plantations on the old fields or other open areas largely devoid of forest vegetation (JOHNSON *et al.*, 2002).

It should be noted that many native Hyrcanian tree species are also potentially valuable commercially and that using such species, aside from satisfying economic objectives, could be more acceptable ecologically and socially. We examined oak growing in mono-specific and two-specific plantations with *Carpinus betulus* L. (Corylaceae). We chose these species as they are native species of Hyrcanian Forests in the north of Iran and have potential value in wood production. There are considerable surfaces of Querco-carpinetum communities in the adjacent natural forests and other parts of the Hyrcanian forests (SABETI, 1994). These species were mixed by four planting ratios in 1995. The main objectives of the present study were to increase our understanding of the nutrient fluxes associated with litter fall and undertaken to assess the influence of plantations on soil fertility parameters, the influence of *Carpinus* on *Quercus* growth and nutrient concentrations of the fully expanded and senescent leaves and differences in the degree of internal cycling of N, P and K (retranslocation) among these species in monoculture and mixed plantations.

Material and methods

Site characteristic

The study area is located at the Chamestan experiment station in Mazandaran province, Iran input the map (36°29′ N, 51°59′ E). The experimental plots were located at an altitude of 100 m above the sea level. The area is on flat and uniform terrain with gentle slope (0-3%). Annual rainfall averages 803 mm, with wetter months occurring between September and February, and a dry season from April to August usually monthly rainfall averages <40 mm. Average monthly temperature ranges from 11.7 °C in February to 29.5 °C in August.

The soils are deep, moderately well drained and stone-free with organic matter of 1-3% prior to planting. They have a silty clay loam and clay loam textures with a pH of 6.0-7.5 and $CaCO_3$ of 0-15%. The soil order name is Alfisols. Approximately 50 years ago, this area has been dominated by the natural forests containing native tree species such as *Quercus castaneifolia*, *Zelkova carpinifolia*, *Gleditschia caspica* Desp., *Carpinus betulus* L., etc. The surrounding area is dominated by agricultural fields and commercial buildings.

Experimental design

Experimental plantations were established in 1995 using a randomized complete block design that included three replicate 25 m × 25 m plots of each of the following treatments:

(i) *Quercus castaneifolia* (100Q);
(ii) 70% *Q.castaneifolia*
+ 30% *Carpinus betulus* (70Q:30C);
(iii) 60% *Q.castaneifolia*
+ 40% *C. betulus* (60Q:40C);
(iv) 50% *Q.castaneifolia*
+ 50% *C. betulus* (50Q:50C);
(v) 40% *Q.castaneifolia*
+ 60% *C. betulus* (40Q:60C);
(vi) Unplanted control (grass).

Tree spacing within the plantations was 1m × 1m and two species were systematically mixed within the rows. The stands were never fertilized.

Site preparation and plantation of the seedlings

Site preparation for all the plantation and control plots consisted of disk harrowing to a depth of 10-15 cm. Containerized seedlings were used for transplanting in February, 1995. The seedlings were obtained from the nursery of Chamestan experiment station. The seedlings of both species were transplanted simultaneously in monoculture of oak and mixed (oak + hornbeam) plantations with different ratios.

Tree survival and growth measurements

In each plot, diameter at breast height (dbh) and total height were measured for each tree in the 21 m × 21 m area (excluding the outer two tree rows) of each plot. The averages of the total height, dbh, top height, basal area and survival were calculated for each plot. To quantify mean top height at each stand we considered the maximum height of the dominant trees by averaging the four highest trees for each species (LEWIS *et al.*, 1976; ROMANYA & VALLEJO, 2004).

Nutrition and nutrient return by the leaves

Foliage samples were collected from the stands in July 2006 (peak month of leaf maturity). The leaves were collected from the bottom one-third of the tree by clipping two small distal twigs located on the opposite sides of the crown (minimum 30 leaves). Six representative trees (two near the center of the sub-plot and one in each corner of it) of each species were sampled for the fully expanded mature leaves. In addition, senescent (soon to be shed) and freshly fallen leaves were collected from each species in each sub-plot in September, 2006 (leaf senescing period). In the mixed plots, the foliage samples were collected to compare nutrient concentrations between the trees growing in the mixed and in pure plantations. These foliar nutrient concentrations were used in subsequent calculations for species in the mixed plots.

The samples were oven dried at 70°C for at least 48 h and ground in a Willey mill to pass through a 2 mm sieve before chemical analysis. The powdered leave material of each species was analyzed for macro bioelements such as total nitrogen, phosphorous, potassium, calcium and magnesium. N was analyzed after digesting the sample in concentrated H_2SO_4 using a catalyst mixture (potassium sulphate and cupric sulphite in ratio 9:1) with a quick digestion unit. The total N was estimated following micro-kjeldhal method (JACKSON, 1967). P was estimated after digesting the samples in triple acid mixture (HNO_3 , H_2SO_4 and $HClO_4$ in 10:1:3 ratios). The total P was determined by vanado-molybdate phosphoric yellow color procedure (JACKSON, 1967). K, Ca and Mg were determined using an atomic absorption spectrophotometer after wet digestion of a 1 gram sample with triple acid mixture (10 ml of conc. HNO_3 , 4 ml of $HClO_4$ and 1 ml of conc. HCl). The digested samples were filtered through Whateman No. 42 filter paper and made up to 100 ml with distilled water and the obtained solution was stored and used for analysis (ISSAC & JOHNSON, 1975).

Litters collected in three litter traps were randomly distributed among the trees and away from the border in each stand in January, 2007 (the end of leave fall season). The size of each trap was 1×1 m^2 with 30 cm high wooden sides fitted with a nylon net bottom, horizontally placed 40cm above the forest floor in September 2006 (first autumn and beginning of litter falling). The amount of branch litter was negligible. This allowed estimating the flux of litter and through it also the real amount of nutrients which reached the soil with litter. Leave litter from each litter trap was oven-dried at 70°C to constant weight and separated by species. To determine mean nutrient contents of floor leaf litter, biomass values for each treatment (n=3) were multiplied by their average nutrient concentrations.

Net retranslocation is determined in two successive years was quantified as the total amount of an element in year n, minus leaching intervening months and the total amounts retained in older tissues in the year n + 1 (SWITZER & NELSON, 1972; LIM & COUSENS, 1986). Percentage net retranslocation was calculated as Equation 1 (PARROTTA, 1999; SALIFU & TIMMER, 2001; LODHIYAL & LODHIYAL, 2003):

$$\% \, Re = [1 - (A / B)] \times 100$$

Equation 1

where, Re is nutrient retranslocation percent, A is the nutrient mass in senesced leaves, and B is the nutrient mass in mature green leaves. The A and B were calculated on the basis of nutrient per unit weight of mature green and senesced leaf, respectively, multiplied by total amount of leaf litter fall. Since rainfall is negligible in the region when leaves senesce, leaching is likely to have only a minimal effect on nutrient loss from the leaves (MILLER *et al.*, 1976; LIM & COUSENS, 1986; LODHIYAL & LODHIYAL, 2003).

Soils

In the experimental area, the soil investigations were carried out with the aim of estimating the effect of plantation type on soil fertility. Composite samples were taken for every plantation and control treatment in each of the three replicate plots at 0-20 cm (A layer) and 21-60 cm (B layer) depths during February 2006 using a 7.6 cm diameter core sampler (n=3 cores/plot). The air-dried soil samples were sieved (aggregates were broken to pass through a 2 mm sieve) to remove roots prior to chemical analyses.

Soil texture was obtained by the Bouyoucos hydrometer method (BOUYOUCOS, 1962). pH was determined using an Orion Ionalyzer Model 901 pH meter in a 1: 2.5 mixture of soil and deionized water. EC (electrical conductivity) was determined using an Orion Ionalyzer Model 901 EC meter in a 1: 2.5 mixture of soil and water solution. Soil organic carbon was measured with the Walkley-Black technique (ALLISON, 1975). The total nitrogen was measured using a semi Micro-

Kjeldhal technique (BREMNER & MULVANEY, 1982). The available P was determined by spectrophotometer using Olsen method (HOMER & PRATT, 1961). The available K, Ca and Mg (by ammonium acetate extraction at pH 9) were determined with Atomic absorption spectrophotometer (BOWER *et al.*, 1952).

Statistical analyses

The data on the growth, biomass and nutrients among the experimental treatments were analyzed following the randomized block design. Normality of the variables was checked by Kolmogorov-Smirnov test and Levene's test was used to test the equality of the variances. One- way analysis of variance (ANOVA) was used to compare the data among the experimental treatments. Tukey-HSD and Duncan tests were used to separate the means of the dependent variables significantly affected by the treatment. The soil parameters were analyzed following two-way analysis (ANOVA) procedure, treating plantation and soil depth as factors with interaction. Within each layer (soil horizon), the effects of plantation type were also tested using one-way analysis of variance (ANOVA). Significant difference between treatment means for different parameters were tested at $P \leq 0.05$ using least significant difference (LSD) test. SPSS v.11.5 software was used for all the statistical analyses.

Results

Tree survival and growth

Measurements in the experimental plantations (at 12 years of age) indicated that *Quercus* had the higher survival rate in the 50Q:50C treatment than in the 100Q, 70Q:30C and 60Q:40C treatments ($P<0.05$, Tukey-HSD). For *Carpinus*, no significant differences were observed among all the mixed-treatments with oak (Fig.1a).

The stem basal diameter of *Quercus* was positively affected by the presence of Carpinus in all the planting ratios (Fig.1b). In the 50Q:50C, the stem basal diameter of *Quercus* was higher than 70Q:30C treatment and pure oak treatment. ($P<0.05$, Tukey-HSD). For *Carpinus*, this parameter in the 40Q:60C was greater than in the 60Q:40C and 50Q:50C treatments ($P<0.05$, Tukey-HSD).

The mean of the total tree heights for *Quercus* (Fig.1c) in the 50Q:50C were higher than in the 70Q:30C treatment ($P<0.05$, Tukey-HSD). The mean of the top height, as a reliable indicator of site quality of forest stands (ASSMANN, 1970; LEWIS *et al.*, 1976; OLIVER & LEARSON, 1990; ZINGG, 1994), for oak ranged from 11.34 to 11.75 m which did not show any significant differences in monocultures compared to mixed plantations in our study (Fig.1d). For *Carpinus*, this parameter in the 40Q:60C was greater than in the 60Q:40C and 50Q:50C treatments ($P<0.05$, Tukey-HSD).

In the stand basal area trends, as shown in Fig.1e, total basal-area development ranged from 12.25 to 14.10 m^2/h which was generally unaffected by the presence of *Carpinus* with different proportions. But, this parameter for oak was higher in the 100Q and 50Q:50C treatments than in the 40Q:60C treatment ($P<0.05$, Tukey-HSD).

Litter fall production, nutrient content and nutrient fluxes

Fully expanded and senescent leave nutrient concentrations showed significant differences in the two species among the different planting ratios (Table 1). Nitrogen concentrations in the fully expanded leaves of *Quercus* were higher in the 40Q:60C than in the pure oak treatments ($p<0.05$, Duncan). Mg concentrations of fully expanded leaves of *Quercus* in the 70Q:30C and 40Q:60C treatments were different ($P<0.05$, Duncan) from those of 60Q:40C treatment. The other macronutrient elements (P, K and Ca) did not show any significant differences for *Quercus* leaves among the different planting ratios with *Carpinus.* Phosphorus concentrations in the fully expanded leaves of *Carpinus* were higher in the 60Q:40C than in the 50Q:50C treatment ($p<0.05$, Duncan). For other macro elements, leaf concentrations of *Carpinus* were not found any significant differences among plantations.

For *Quercus*, senescent leaf concentrations for N were highest in the 40Q:60C among all

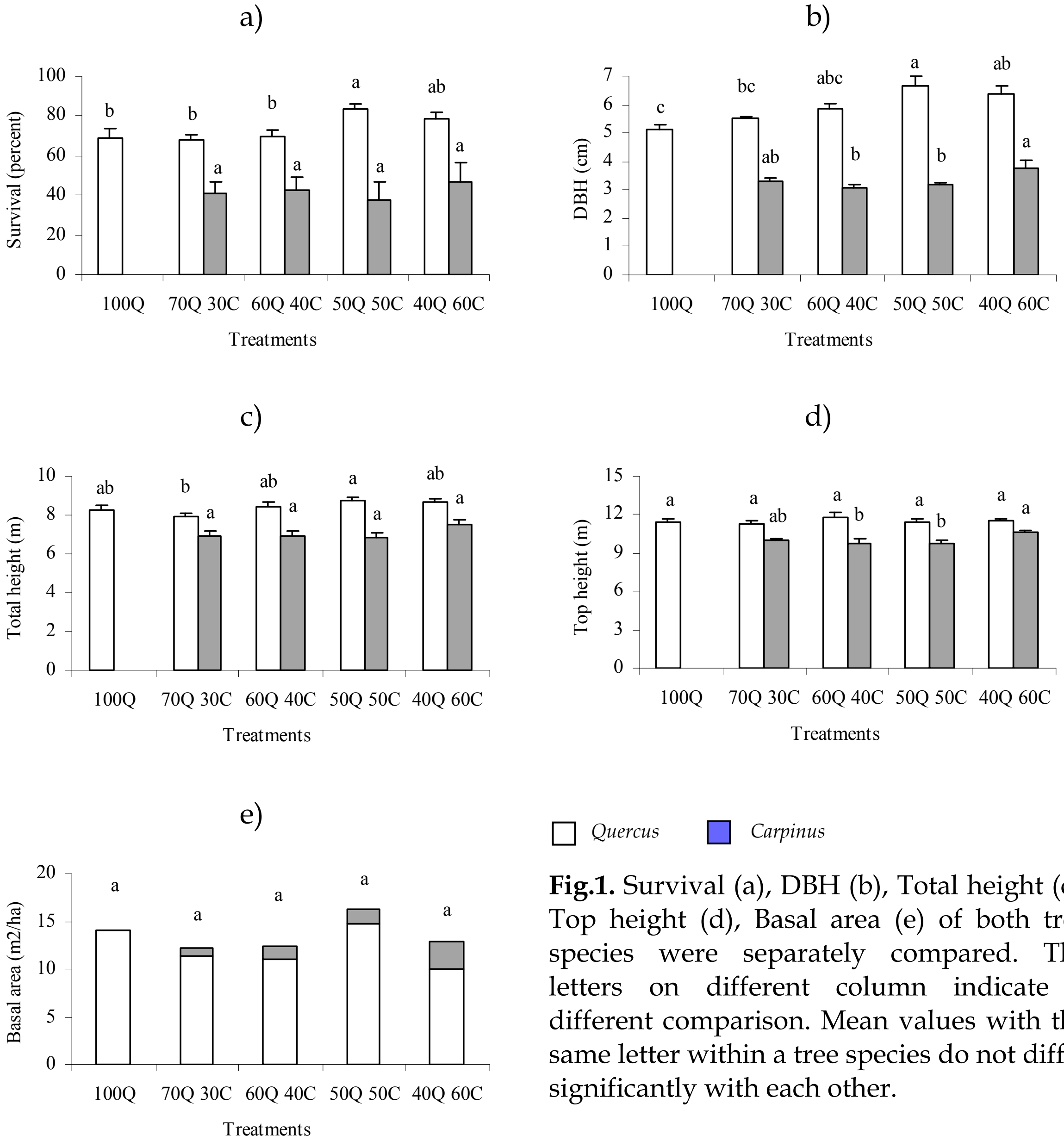

Fig.1. Survival (a), DBH (b), Total height (c), Top height (d), Basal area (e) of both tree species were separately compared. The letters on different column indicate a different comparison. Mean values with the same letter within a tree species do not differ significantly with each other.

plantation treatments (*P*<0.05, Duncan). Ca return by senescent leaves of *Quercus* in the monoculture plantations was significantly lower than in 50Q:50C plantations (*P*<0.05, Duncan). P, K and Mg returns by senescent leaves of *Quercus* did not show any significant differences among the different treatments. Senescent leave nutrient concentrations of *Carpinus* showed significant differences among the different planting ratios only for P which was higher in the 60Q:40C treatment than in the 40Q:60C treatment (*P*<.05, Duncan).

Significant differences in nutrient retranslocation .i.e. the percentage of N, P, or K withdrawn from the leaves prior to leaf-fall, were observed for N and P in each species among the treatments (Table 2). In *Quercus,* N retranslocation was significantly greater in the 60% than the 40% proportion with hornbeam (*P*<0.05, Duncan) and P retranslocation in the 50Q:50C was higher than in the 70Q:30C (*P*<0.01, Duncan). In contrast, N retranslocation in *Carpinus* was significantly greater in the 40Q:60C treatment than in the 60Q:40C treatment (*P*<0.05, Duncan). P retranslocation for this species in the 60Q:40C was higher than in the 50Q:50C and 40Q:60C treatments (*P*<0.01, Duncan). However, retranslocation percent of the nutrients (NPK) in *Quercus* was in order: K (48-68%) > N (22-42%) > P (20-37%) while in *Carpinus*, it was in order: N (22-44%) > K (19-42%) > P (18-40%).

Leaf-litter fall production ranged from 4.70 to 6.80 Mg ha^{-1} year^{-1}, showing no significant differences among the planting ratios (Table 2). Due to the account of the treatment differences in litter production and species differences in litter-nutrient concentrations, the leaf-litter fall fluxes were significantly different among the treatments only for N ($P<0.05$, Duncan) (Table 2). This element, ranged from 89.05 to 120.47 Kg ha^{-1} year^{-1}, was higher in the 60Q:40C than in the 70Q:30C and 50Q:50C treatments. No obvious differences were found in leaf-litter flux rates for P (3.86-5.77 Kg ha^{-1} year^{-1}), K (25.61-15.70 Kg ha^{-1} year^{-1}), Ca (59.40-85.63 Kg ha^{-1} year^{-1}) and Mg (9.26-12.57 Kg ha^{-1} year^{-1}) among the treatments.

Table1. Nutrient concentrations in live and senescent leaves with their standard error in the parenthesis.

	Pure	70 Q + 30 C		60 Q + 40 C		50 Q + 50 C		40 Q + 60 C	
	Quercus	*Quercus*	*Carpinus*	*Quercus*	*Carpinus*	*Quercus*	*Carpinus*	*Quercus*	*Carpinus*
live leaves									
nitrogen (mg/g)	27.42 (0.64)	28.47 (1.59)	30.13 (1.36)	28.23 (0.63)	28.27 (0.92)	28.57 (0.50)	28.67 (0.59)	30.47 (0.52)	32.23 (1.52)
phosphorous (mg/g)	1.26 (0.09)	1.57 (0.03)	1.24 (0.05)	1.23 (0.03)	1.29 (0.05)	1.21 (0.00)	0.99 (0.06)	1.22 (0.09)	1.18 (0.05)
potassium (mg/g)	9.13 (1.00)	6.80 (1.78)	6.97 (1.02)	5.75 (0.91)	5.62 (1.83)	8.20 (0.68)	7.87 (3.02)	8.52 (0.47)	8.53 (1.09)
calcium (mg/g)	4.15 (0.62)	4.73 (0.91)	5.98 (0.52)	4.59 (0.87)	4.28 (1.06)	4.10 (1.45)	6.46 (1.70)	5.77 (1.20)	3.80 (1.07)
magnesium (mg/g)	2.13 (0.28)	2.63 (0.18)	2.75 (0.38)	2.13 (0.12)	2.17 (0.46)	2.33 (0.50)	2.67 (0.88)	2.46 (0.15)	2.17 (0.58)
Senescent leaves									
nitrogen (mg/g)	17.35 (0.65)	18.53 (0.60)	21.20 (2.00)	16.37 (1.52)	22.07 (1.82)	18.10 (0.72)	17.10 (1.28)	23.67 (0.88)	17.80 (1.15)
phosphorous (mg/g)	0.93 (0.08)	0.94 (0.04)	0.81 (0.02)	0.88 (0.01)	0.77 (0.04)	0.76 (0.02)	0.83 (0.06)	0.83 (0.05)	0.82 (0.01)
potassium (mg/g)	2.83 (0.22)	2.86 (0.30)	5.54 (0.68)	3.72 (0.03)	6.87 (0.70)	3.49 (0.2)	5.08 (0.29)	2.87 (0.09)	4.69 (0.57)
calcium (mg/g)	11.85 (0.23)	12.55 (1.18)	12.94 (0.46)	12.81 (0.06)	12.02 (0.59)	14.72 (0.96)	12.92 (0.32)	12.91 (1.71)	10.05 (1.50)
magnesium (mg/g)	1.65 (0.07)	1.84 (0.22)	2.53 (0.19)	1.60 (0.13)	2.52 (0.31)	2.19 (0.45)	2.73 (0.11)	1.95 (0.20)	2.23 (0.59)

Soil properties

There were few differences in soil properties among the experimental treatments after 12 years. The soils were characterized as fine-textured (Table 3). Soil pH, ranging from 6.31 to 7.24, did not show any significant differences between the treatments. Likely, soil EC (0.38 – 0.73 ds/m), organic carbon (1.38-3.76%), available K (310-450 mg/kg), available Ca (120-215 mg/kg) and available Mg (21.0-58.5 mg/kg) exhibited no significant differences between the soil horizons of treatments (Table 3). Total nitrogen ranging from 0.17% to 0.29%, in the upper soil layer was higher in the 50Q:50C treatment than in the pure oak and 60Q:40C treatments and no significant differences were found in the 21-60 cm depth of soil (Table 3). Carbon: Nitrogen ratio was significantly different, which was the highest in pure *Quercus* (15.33) among the

Table2. Leaf-litter fall production, nutrient fluxes and retranslocation in 11 year-old plantation stands with their standard error in the parenthesis.

	Pure	70 *Quercus* + 30 *Carpinus*			60 *Quercus* + 40 *Carpinus*			50 *Quercus* + 50 *Carpinus*			40 *Quercus* + 60 *Carpinus*			ANOVA
	Quercus	*Quercus*	*Carpinus*	total	*Quercus*	*Carpinus*	total	*Quercus*	*Carpinus*	total	*Quercus*	*Carpinus*	total	
Litter fall production (Mg/ha/year)	6.14	3.87	0.83	4.70	5.01	1.79	6.80	3.67	1.32	4.99	4.07	1.15	5.23	n.s.
	(0.58)	(0.12)	(0.02)	(0.14)	(0.80)	(0.28)	(1.09)	(0.14)	(0.05)	(0.19)	(0.23)	(0.05)	(0.30)	
Litter fall nutrient flux (Kg/ha/year)														
Nitrogen	105.21ab	71.67	17.58	89.25b	81.95	38.52	120.47a	66.52	22.53	89.05b	95.92	21.72	117.64ab	*
	(7.35)	(1.65)	(2.12)	(2.90)	(9.95)	(3.56)	(13.36)	(4.51)	(0.85)	(3.66)	(2.11)	(0.72)	(2.22)	
Phosphorous	5.70	3.65	0.66	4.31	4.39	1.38	5.77	2.77	1.09	3.86	3.42	1.01	4.43	n.s.
	(0.82)	(0.20)	(0.00)	(0.21)	(0.73)	(0.24)	(0.96)	(0.02)	(0.08)	(0.11)	(0.41)	(0.05)	(0.46)	
Potassium	17.71	11.13	4.57	15.70	13.59	12.02	25.61	12.77	6.71	19.48	11.65	5.75	17.40	n.s.
	(2.45)	(1.46)	(0.59)	(1.46)	(2.05)	(1.47)	(3.26)	(0.64)	(0.20)	(0.82)	(0.62)	(0.76)	(1.31)	
Calcium	72.82	48.74	10.66	59.40	64.09	21.54	85.63	53.96	17.12	71.08	53.32	12.11	66.43	n.s.
	(7.17)	(5.68)	(0.04)	(5.64)	(10.15)	(3.50)	(8.46)	(3.87)	(0.75)	(3.80)	(9.83)	(1.34)	(7.87)	
Magnesium	10.13	7.18	2.08	9.26	8.22	4.35	12.57	8.04	3.61	11.65	7.96	2.65	10.61	n.s.
	(1.08)	(1.03)	(0.09)	(0.97)	(1.90)	(0.40)	(2.15)	(1.72)	(0.15)	(1.62)	(1.02)	(0.55)	(1.13)	
Percent retranslocation														
Nitrogen	36.55ab	34.41ab	29.53ab		41.79a	22.17b		36.62ab	40.46a		22.38b	44.48a		*
	(2.88)	(4.90)	(6.72)		(6.56)	(4.11)		(2.52)	(3.44)		(1.54)	(4.92)		
Phosphorous	26.97ab	19.56 b	34.35ab		28.46ab	40.46 a		37.28 a	17.65 c		31.77ab	29.87 b		**
	(1.44)	(4.18)	(0.80)		(1.30)	(2.75)		2.39)	(5.66)		(6.84)	(1.86)		
Potassium	68.00	47.74	26.25		49.75	18.96		56.33	37.12		66.03	41.55		n.s.
	(3.00)	(9.79)	(8.35)		(9.05)	(8.96)		(6.38)	(10.89)		(2.36)	(13.42)		

ANOVA results: n.s. –treatment effect not significant; * - $p < 0.05$; ** - $p < 0.\ 0.01$. Similar letters within a row indicate that means were similar (Tukey HSD).

Table 3. Soil properties in plantations and control plots in two soil layers (A and B horizons) with their standard error.

Soil properties	Depth cm	100Q	70Q:30C	60Q:40C	50Q:50C	40Q:60C	Control	ANOVA[b]
Clay (%)	0-20	38.0 a (1.08)	26.5 b (3.00)	28.5 ab (5.50)	27.5 ab (4.50)	24.5 b (2.50)	31.5 ab (0.95)	*
	21-60	35.5 (2.17)	31.5 (0.50)	23.5 (0.50)	28.5 (9.50)	24.5 (1.50)	29.5 (2.62)	ns
Silt (%)	0-20	38.25 (4.73)	40.00 (7.00)	45.50 (9.50)	40.50 (4.50)	48.00 (10.00)	37.50 (3.30)	ns
	21-60	42.25 (6.81)	40.00 (12.0)	56.50 (9.50)	36.00 (13.00)	41.00 (18.00)	48.50 (8.42)	ns
Sand (%)	0-20	23.75 (5.46)	33.50 (5.50)	31.00 (8.00)	32.00 (6.00)	26.50 (8.50)	31.00 (3.91)	ns
	21-60	22.25 (6.20)	28.50 (10.50)	20.00 (8.00)	35.50 (20.50)	34.50 (12.50)	22.00 (6.55)	ns
pH (1:2.5 H2o)	0-20	6.84 (0.28)	7.04 (0.08)	7.00 (0.33)	6.82 (0.09)	7.24 (0.66)	7.12 (0.09)	ns
	21-60	6.88 (0.27)	7.07 (0.11)	6.82 (0.19)	6.31 (0.19)	6.60 (0.09)	7.02 (0.26)	ns
EC (ds/m)	0-20	0.45 (0.02)	0.73 (0.14)	0.54 (0.05)	0.50 (0.20)	0.64 (0.05)	0.60 (0.03)	ns
	21-60	0.60 (0.04)	0.50 (0.20)	0.47 (0.09)	0.38 (0.02)	0.42 (0.03)	0.40 (0.05)	ns
Organic Carbon (%)	0-20	2.90 (0.27)	2.85 (0.02)	2.21 (0.25)	3.76 (0.66)	2.52 (0.45)	2.22 (0.14)	ns
	21-60	1.97 (0.27)	1.55 (0.15)	1.38 (0.18)	2.15 (0.19)	1.48 (0.28)	1.60 (0.42)	ns
Total N (%)	0-20	0.20 b (0.02)	0.30 ab (0.04)	0.24 b (0.11)	0.41 a (0.03)	0.25 ab (0.00)	0.24 ab (0.04)	*
	21-60	0.18 (0.02)	0.18 (0.02)	0.20 (0.03)	0.23 (0.07)	0.17 (0.02)	0.21 (0.04)	ns
P available (mg/kg)	0-20	23.38 ab (3.49)	26.25 ab (3.75)	14.00 b (1.00)	31.00 ab (6.00)	32.50 a (4.50)	29.75ab (2.42)	*
	21-60	28.31abc (1.74)	23.50 bc (1.50)	21.90 c (4.10)	35.00 a (5.00)	33.00 ab (3.00)	29.75abc (2.24)	*
K available (mg/kg)	0-20	320.0 (14.14)	410.0 (45.00)	335.0 (40.00)	450.0 (30.00)	375.0 (25.00)	417.5 (41.70)	ns
	21-60	315.0 (15.00)	325.0 (25.00)	355.0 (25.00)	365.0 (15.00)	310.0 (10.00)	317.5 (23.93)	ns
Ca available (mg/kg)	0-20	200.0 (63.90)	170.0 (10.00)	155.0 (25.00)	165.0 (10.00)	120.0 (25.00)	215.0 (30.95)	ns
	21-60	165 (25.33)	155 (25.00)	125 (15.00)	125 (5.00)	125 (15.00)	180 (12.24)	ns
Mg available (mg/kg)	0-20	42.0 (16.79)	42.0 (6.00)	27.0 (10.00)	42.0 (13.00)	21.0 (3.00)	58.5 (15.75)	ns
	21-60	39.0 (14.14)	42.0 (12.00)	21.0 (3.00)	27.0 (3.00)	24.0 (6.00)	40.5 (6.65)	ns

a Based on three composted 7.6 cm diameter core samples per plot

b ANOVA results: ns = treatment effect not significant ; *, p<0.05 Duncan. Mean values with the same letter within the soil layer do not differ significantly with each other.

all treatments in 0-20 cm (*P*<0.05, Duncan). Also, it was the highest in the 70Q:30C treatment (12.73) followed by the 40Q:60C (11.73), pure *Quercus* (10.74), 50Q:50C (9.00), control plots and 60Q:40C treatments (7.64 and 7.80, respectively) in the 20-60cm depth (*P*<0.01, Duncan). Available P in 0-20 cm depth of the 40Q:60C (32.50 mg/kg) was higher than in the 60Q:40C (14.0 mg/kg) treatment and in 21-60 cm depth of the 50Q:50C (35.00 mg/kg) was the highest and in the 60Q:40C (21.90 mg/kg) treatment was the lowest among the treatments (*P*<0.05, Duncan) (Table 3).

Discussion

In the study, trees in the mixed plantations of *Quercus* with *Carpinus* in 50% proportions exhibit faster rates of growth than trees in monocultures. Our results are similar to those obtained by ASSMANN (1970), PROKOPEV (1976), REUKEMA & BRUCE (1977), FRY & POOLE (1980), POLENO (1981), KAWAHARA & YAMAMOTO (1982, 1986), LAMPRECHT (1986), HAGGAR & EWEL (1995), MENALLED *et al.*, (1998), BERGQVIST (1999), PARROTTA (1999), MONTAGNINI (2000), SIMARD & HANNAM (2000), LAMB & GILMOUR (2003), PIOTTO *et al.* (2004), PETIT & MONTAGNINI (2004, 2006), FAHLVIK *et al.* (2005), KANOWSKI *et al.* (2005), SHEIL *et al.* (2006), SAYYAD *et al.* (2006).

Kelty (2006) suggested that higher stand-level productivity in mixtures has been found with two kinds of species interactions: (1) complementary resource use between species that arises from development of a stratified canopy (and possibly root stratification); (2) facilitative improvement in nutrition of a valuable timber species growing in mixture with a nitrogen-fixing species (but only if combined with complementary resource use as well). The mixed-species plots may have been more productive than the monocultures because they were able to take advantage of the available growing space, by growing in strata (LAMPRECHT, 1986; WHYTE & WOOLLONS, 1990).

A key concept for designing highly productive mixed-species stands is the need to combine species that differ in characteristics such as shade tolerance, height growth rate, crown structure (particularly leaf area density), foliar phenology, and root depth and phenology (KELTY, 1992). *Quercus* and *Carpinus* differ substantially in these characteristics; they may capture site resources more completely and/or use the resources more efficiently in producing biomass, resulting in greater total stand biomass production than would occur in monocultures of the component species. Such species are said to have complementary resource use (HAGGAR & EWEL, 1997) or good ecological combining ability (HARPER, 1977). This a question that why oak with 50% mixture rate showed better growth than other mixture rates?

AUGUSTO *et al.* (2002) suggested that in temperate forests, the chemical composition of foliar is dependent on tree species and site. In the present study, none of the plantations showed foliar macro-elements concentrations lower than the limit for possible deficiency. Full expanded leave N and senesced leave Ca concentrations of *Quercus* in the pure plantations were lower than the mixed plantations. These trends can be due to different leaf- litter fall mass and quality of both two species regarding the different planting ratios. Also, AUGUSTO *et al.* (2002) reported that the effect of overstory species on tree nutrition is strongly influenced by forest management (e.g. low density stands or mixed stands can promote litter decomposition).

In temperate forests, the annual amount of litter fall of a mature stand is only slightly influenced by the species of the overstory because the major influences are latitude, that is climate (VOGT *et al.*, 1986), and stand management (AUGUSTO *et al.*, 2002). We found that the litter fall production of plantations did not have any significant differences, and so their levels were higher than the average annual litter fall in European temperate forests (between 3.5 and 4.0 t ha^{-1} yr^{-1}; 3.7 and 3.8 t ha^{-1} yr^{-1} for *Quercus petraea* and *Quercus robur*, respectively; AUGUSTO *et al.*, 2002) and the 30 years old plantations of *Quercus serrata* in India (419.9 g cm^{-2} $year^{-1}$; PANDEY *et al.*, 2007). These trends may be due to low plant spacing in our study.

There were few differences in the nutrient fluxes among the treatments. These trends can be due to different leaf- litter fall mass and quality of both two species regarding the different planting ratios. For instance, CUEVAS & LUGO (1998) detected relationship between litter and nutrient fluxes among contrasting species stands. Differential resources uptake, and release of carbon and nutrients are important factors at the stand level, because they represent major fluxes through the system (MILLER, 1984). The rate of fall and subsequent decay dynamics of litter affect soil organic matter formation and nutrient storage (LUGO *et al.*, 1990). Knowledge of the timing of nutrient and mass return through litterfall to the forest floor is important for plantation management (CUEVAS & LUGO, 1998). Internal differences between species on the basis of nutrient flux may cause effects on soil fertility, due to this case the species selection for plantation is very important (STANLEY & MONTAGNINI, 1999).

Degree of retranslocation or resorption of nutrients within the plants is also an important factor to be considered (MILLER, 1984). Retranslocation may be regulated by soil nutrient supply, nutrient uptake rates, the size of plant nutrient reserves, and age of trees (MUNSON *et al.*, 1995; MALIK & TIMMER, 1998; HAWKINS *et al.*, 1999). Furthermore, the relative contributions of nutrients from retranslocation and from external uptake to skins of new growth are unknown (HAWKINS *et al.*, 1999; SALIFU & TIMMER, 2001). Similar to our study in the case of *Quercus*, LODHIYAL & LODHIYAL (2003) found that the percent retranslocation of nutrients (NPK) in tree layers of Bhabar Shisham forests in central Himalaya was in order K > N > P. The present estimates of the percent of retranslocation of the nutrients from senesced leaves are higher than those from *Quercus rubra* (23-39%; GRIZZARD *et al.*, 1976). LODHIYAL & LODHIYAL (1997) argued that the higher is the leaf tissue nutrient level, the greater would be the percent of retranslocation capacity. However, CHAPIN & KEDROWSKI (1983) pointed out that both percent of retranslocation and concentrations of nutrients are positively correlated. This trend is consistent with our results about P for *Carpinus*.

CUEVAS & LUGO (1998) reported the species that return the most mass are not necessarily the ones that return the most P and N. Moreover, the species can adjust their performance though differences in retranslocation rates before leaf fall. Translocation of nutrients during the ageing of tissues especially in foliage of trees during senescence is an important mechanism for maintaining tree growth (LIU *et al.*, 2004).

There were few differences in soil properties among the experimental treatments at 12 years. This might be a result of fairly short time frame, i.e., longer time spans are required for an influence of the tree species to develop in the mineral soil (VESTERDAL *et* al., 2002). No statistically significant differences were observed in soil pH between the treatments. MONTAGNINI (2000) and GIARDINA *et al.* (1995) reached the same results as ours, whereas RHOADES & BINKLEY (1992), BINKLEY (1996) and PARROTTA (1999) found lower soil pH in mixed plantations. Higher planting density and lower age of our plantations might be the main reasons for lack of significant differences in soil pH. AUGUSTO *et al.* (2002) reported *Quercus* spp. as the second tree species that reduced topsoil pH.

No significant differences were observed in soil organic carbon content in both soil layers between the treatments. PARROTTA (1999) and SAYYAD *et al.* (2006) came to the same conclusion. In contrast to our results, GARCIA-MONTIEL & BINKLEY (1998) found that organic carbon content in the 0-20 cm depth of the soil under NFT *Albizia* was higher than in the soil under *Eucalyptus*. AUGUSTO *et al.* (2002) suggested that the soil carbon content and the soil organic weight are dependent on the canopy species.

Soil total nitrogen in the 50Q:50C treatment was higher than in the pure oak plantation. The effect of tree species on total nitrogen stocks in the soil is inconsistent (AUGUSTO *et al.*, 2002). PARROTTA (1999), and to some extent, MONTAGNINI (2000) did not observe any significant differences in soil nitrogen between monoculture and mixed plantations.

Due to lack of litter, the control plots had lower values in the C/N ratio than the other treatments. Pure oak and 70Q:30C treatment had the highest C/N ratio in A and B layers, respectively. PARROTTA (1999) and SAYYAD *et al.* (2006) did not found any significant differences in monoculture and mixed plantations. The impact of an overstory species on soil varies significantly with factors like climate, geology and silvicultural management. Thus, the soil carbon stock and the C/N ratio depend on the species of over story but they also depend strongly on soil type and climate (MEENTEMEYER & BERG, 1986).

LUGO *et al.* (1990) suggested that amounts of nutrients return to the forest floor have a measurable impact on soil nutrient characteristics, especially in the surface layers. Mixed plantations have intermediate values of soil N, P and K, but lower soil Ca and Mg relative to pure plantations (STANLEY & MONTAGNINI, 1999; MONTAGNINI, 2000). This trend is consistent with our results about soil P. In our study, no significant differences were observed between the monoculture and mixed plantations in concentrations of K, Ca and Mg in soil. MONTAGNINI (2000) came to the same results in monoculture and mixed plantations as we did. For some nutrients, like phosphorous, it is difficult to show a constant influence of overstory species on soil nutrient content because of inconsistent results (AUGUSTO *et al.*, 2002).

The mixed designs provided intermediate to fast decomposition rates, releasing nutrients to the soil and allowing a litter layer to protect the soil (BYARD *et al.*, 1996). Nutrient cycling characteristics must also be taken into account when assessing the potential impacts of plantation species on site nutrients. To ensure the sustainable management of forests, resiliency of the ecosystems should be estimated to determine the most appropriate tree species and silvicultural management (AUGUSTO *et al.*, 2002).

Conclusions

Although the plantations are still young and it may be too soon to determine the behavior of the species studied, it is evident that the best growth for oak was somewhat demonstrated in the mixed systems. Introduction of one mixture as the best one is somewhat difficult but 50Q:50C treatment could be the most productive and sustainable one. In the present study, 50Q:50C treatment obtained a significantly higher values for survival, diameter at breast height, Ca foliage concentration, total N (in A horizon) and available P (in B horizon) than the 100Q treatment. Thus, for the purposes of forest rehabilitation and restoration in the Hyrcanian forests, mixed-plantations such as with *Quercus* and *Carpinus* under appropriate can serve a dual role by accelerating natural recovery of the species-rich forest ecosystems while providing required wood products to populations facing with shortages of fuel wood, timber and other forest products.

There exists very little information on the growth of tree species native to the Hyrcanian forests and information on experiences comparing pure and mixed forest plantation with different mixturing degrees is limited. These results would be helpful in understanding the nutrient behavior in a highly productive forest plantation and thereby providing decisive information for their sustainable management. Moreover, this information may be used in the selection of species, planting ratios and harvest regimes in order to conserve or replenish plantation soil fertility.

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Received: 27.11.2010
Accepted: 18.05.2011