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GROWTH AND NUTRITION OF RESTORED *QUERCUS CASTANEIFOLIA* C.A. MEY. VERSUS NATIVE *CELTIS AUSTRALIS* L. TREE SPECIES: CONSERVATION PERSPECTIVES OF HYRCANIAN FOREST (IRAN)

ABSTRACT: For native species, mixed plantation systems seem to be the most appropriate for providing a broader range of options such as production, protection, biodiversity conservation and restoration. After 11 years, growth and nutrition and soil properties were examined in young plantation of two indigenous tree species in Hyrcanian forests of Iran. *Quercus castaneifolia* C.A. Mey. (as target species) and *Celtis australis* L. (as native component species) were planted in five proportions (100Q, 70Q:30C, 60Q:40C, 50Q:50C, 40Q:60C) in Noor, Iran. Diameter at breast height of individual *Quercus* trees and total basal area were affected by the presence of *Celtis*. Percent retranslocation of nutrients in *Quercus* followed in order: K> P> N. Leaf-litter fall production ranged from 4.10 to 6.14 t ha⁻¹ year⁻¹. Ca and Mg concentrations in fully expanded leaves of *Quercus*, N and K retranslocation of *Quercus*, concentration of available P in soil were higher in some of the mixed plantations than in monoculture of *Quercus*. On the other hand, N concentration in fully expanded leaves of *Quercus*, N fluxes and soil C/N ratio were higher in monoculture of *Quercus*. Within the framework of this experiment, it appeared that production was maximized when these two species were grown together in the proportion of 60% *Quercus* and 40% *Celtis*.

KEY WORDS: tree growth, mixed plantation, nutrition, nutrient flux, nutrient retranslocation, soil properties

1. INTRODUCTION

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. This zone 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 and Ghavvami 2006). Hyrcanian or Northern forests of Iran stretch out from 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 about 7% of area and 8% of standing volume of these forests and it can measure 50 m in height and 2 m in breast diameter (DHB) (Hedayati 2001).

The continued existence of oakwoods is threatened by the lack of natural regeneration (Watt 1919, Linhart and Whelan 1980) which is in turn limited by grazing of live-stocks (Langbein 1997, Mirkazemi 1997, Mohajer 1999, Palmer *et al.* 2004), soil compaction (Mirkazemi 1997, Mohajer 1999), seed availability (Larsen and John-

son 1998), seed predation by many wildlife species (Wittwer *et al.* 1990, Dey 2002, Johnson *et al.* 2002, Gardiner and Oliver 2005) specially boar (Mirkazemi 1997, Mohajer 1999), competition between seedlings and herbaceous plants (Humphrey and Swaine 1997, Mirkazemi 1997, Mohajer 1999), low light levels reaching the forest bottom (Lorimer and Chapman 1994, Gardiner and Hodges 1998, Truscott *et al.* 2004) and continued harvesting of oak fruits and of oak trees in Hyrcanian forests (Parsapajoo 1994). Thus the potential for maintenance and expansion of oak forests by natural regeneration appears to be at best limited. In order to promote expansion and rehabilitation of 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 old fields or other open areas largely devoid of forest vegetation (Johnson *et al.* 2002).

Mixed plantation systems seem to be the most appropriate for providing a broader range of options, such as production, protection, biodiversity conservation, and restoration (Guariguata *et al.* 1995, Keenan *et al.* 1995, Montagnini *et al.* 1995, Parrotta and Knowles 1999, Kaya and Raynal 2001, Carneval and Montagnini 2002, Balandier *et al.* 2005, Jogiste *et al.* 2005, Kelty 2006) as they can ameliorate the sites to be more favorable to native tree seedling recruitment (Guariguata *et al.* 1995, Petit and Montagnini 2004). A mixture of species, each with different nutrient requirements and different nutrient cycling properties, may be complementary with regards to conservation, and/or replenishment of some soil nutrients (Smith 1986, Binkley *et al.* 1992, Stanley and Montagnini 1999) and may be overall less demanding in-site nutrient than monoculture stands (Montagnini 2000).

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, Piotta *et al.* 2003 and 2004, Petit and Montagnini 2004, 2006,

Ashagrie 2005, Sayyad 2006, Forrester *et al.* 2006a, b), 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, Wormald 1992, Piotta *et al.* 2004).

We examined the oak growing in mono-specific and twospecific plantations with *Celtis australis* L. (Ulmaceae). European hackberry (nettle tree) can measure 20–25 m in height and can occur as the species disperse and mixed with oak associations in the North forests of Iran (Sabeti 1994). The purpose of this plantation is the restoration associated with the production of timber and other forest products.

The main objectives of this study were: to assess the influence of plantations on soil fertility parameters, the influence of *Celtis* on *Quercus* growth and nutrient concentrations of fully expanded and senescent leaves, and to assess the differences in the degree of internal cycling of N, P and K (retranslocation) among these species cultivated in monoculture and in mixed plantations.

2. MATERIAL AND METHODS

2.1. Site characteristics

The study area is located at the Chamestan experimental station, in Mazandaran province, in the northern parts of Iran (36°29'N, 51°59'W). Experimental plots were located at an altitude of 100 m above sea level. The area is on flat, uniform terrain with low 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 for 4 months. Average daily temperatures range from 11.7°C in February to 29.5°C in August.

The soils are deep, moderately well drained, stone-free with organic matter 1–3% prior to planting. They have a silty clay loam and clay loam textures with a pH 6.0–7.5 and lime 0–15%. Previously (approximately 50 years ago) this area was dominated by natural forests containing native tree species such as *Quercus castaneifolia* C.A.M., *Zelkova carpinifolia* (Pall.) Dipp., *Gleditschia caspica* Desp.,

Carpinus betulus L., etc. The surrounding area is dominated by agricultural fields and commercial building.

2.2. Experimental design

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

- (i) *Quercus castaneifolia* (100Q);
- (ii) 70% *Q.castaneifolia* + 30% *Celtis australis* (70Q:30C);
- (iii) 60% *Q.castaneifolia* + 40% *C. australis* (60Q:40C);
- (iv) 50% *Q.castaneifolia* + 50% *C. australis* (50Q:50C);
- (v) 40% *Q.castaneifolia* + 60% *C. australis* (40Q:60C);
- (vi) Unplanted Control (grass).

Tree spacing within plantations was 1m × 1m and two species were systematically mixed within rows. The stands were never fertilized. The planted materials were one-year-old seedlings prepared in the nursery.

2.3. Tree survival and growth measurements

In each plot, diameter at breast height (DBH) and the total height were measured for each tree in the 21 m × 21 m area (excluding the outer two tree rows) of each plot, in June 2005. Diameter was measured at 1.37 m and total height by calibrated pole. The averages of total height, diameter at breast height, 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 and Vallejo 2004).

2.4. Nutrition and nutrient return by the leaves

Foliage samples were collected from the stands in July 2005 (peak month of leaf maturity). Leaves were collected from the lower part of tree crown by clipping two small distal twigs located on opposite sides of the crown

(minimum 30). Six representative trees (two near the centre of sub-plot and one in each corner of it) of each species were sampled for 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 (leaf senescing period) 2005. In mixed plots, foliage samples were collected to compare nutrient concentrations between trees growing in mixed and in pure plantations. These foliar nutrient concentrations were used in subsequent calculations for species in 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 leaf material of each species was analysed for macro-bioelements such as total nitrogen, phosphorus, potassium, calcium and magnesium. N was analysed after digesting the sample in concentrated sulphuric acid 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 were estimated after digesting the samples in triple acid mixture (nitric acid, sulphuric acid and perchloric acid in 10:1:3 ratios). 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. nitric acid, 4 ml of perchloric acid and 1 ml of conc. hydrochloric acid). The digested samples were filtered through Whateman No. 42 filter paper and made up to 100 ml with distilled water and this solution was stored and used for analysis (Issac and Johnson 1975).

Litter was collected in three litter traps randomly distributed among trees and away from the border in each stand in January 2006 (the end of leaf fall season). The size of each trap was 1 × 1 m² with 30 cm high wooden sides fitted with a nylon net bottom and they had been horizontally placed 40 cm above the forest floor in September 2005 (beginning of litter falling). The amount of branch litter was negligible. This allowed to estimate the flux of litter and through it also the real amount of nutrients which reached the soil with lit-

ter. Leaf 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.

Percentage net retranslocation was calculated as (Equation 1) (Parrotta 1999, Salifu and Timmer 2001, Lodhiyal and Lodhiyal 2003):

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

Where *Re* is nutrient retranslocation percent, *A* – the nutrient mass in senesced leaves, and *B* – 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.

2.5. Soils

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 (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 analyser 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 soil and water solution. Soil organic carbon was measured with the Walkley-Black technique (Allison 1975). Total Nitrogen was measured using a semi micro-Kjeldhal technique (Bremner and Mulvaney 1982). 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).

2.6. Statistical analyses

The data on growth, biomass and nutrients among experimental treatments were

analyzed following randomized block design. Normality of variables was checked by Kolmogorov-Smirnov test and Levene's test was used to test for equality of variances. One-way analyses of variance (ANOVA) were used to compare of data among experimental treatments. Tukey-HSD and Duncan tests were used to separate the means of dependent variables which were significantly affected by 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 (ANOVA) procedure. 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 statistical analyses.

3. RESULTS

3.1. Tree survival and growth

Measurements in the experimental plantations, at 11 years of age, indicated that the survival rates of *Quercus* and *Celtis* did not show any significant differences among different planting proportions ($P < 0.05$, Tukey-HSD test) (Fig. 1A).

The means of DBH for *Quercus* (ranged from 5.07 to 6.54 cm) in pure oak treatment was intermediate in relation to the mixed-species treatments (Fig. 1B). In the 40Q:60C treatment, the stem basal diameter of *Quercus* was higher than 70Q:30C treatment ($P < 0.05$, Tukey-HSD test).

The means of the total tree height (ranged from 7.59 to 8.76 m) of *Quercus* was generally unaffected by the presence of *Celtis* with different proportions (Fig. 1C), and so the mean of the top height which being regarded as a reliable indicator of site quality of forest stands (Assmann 1970, Oliver and Larson 1990, Zingg 1994) for oak (ranged from 11.00 to 11.70 m) did not have any significant differences among treatments (Fig. 1D). For *Celtis*, this parameters were remarkably similar among all treatments (Fig. 1C, 1D) ($P < 0.05$, Tukey-HSD test).

As shown in Figure 1E, total basal-area was significantly greater in the 100Q and

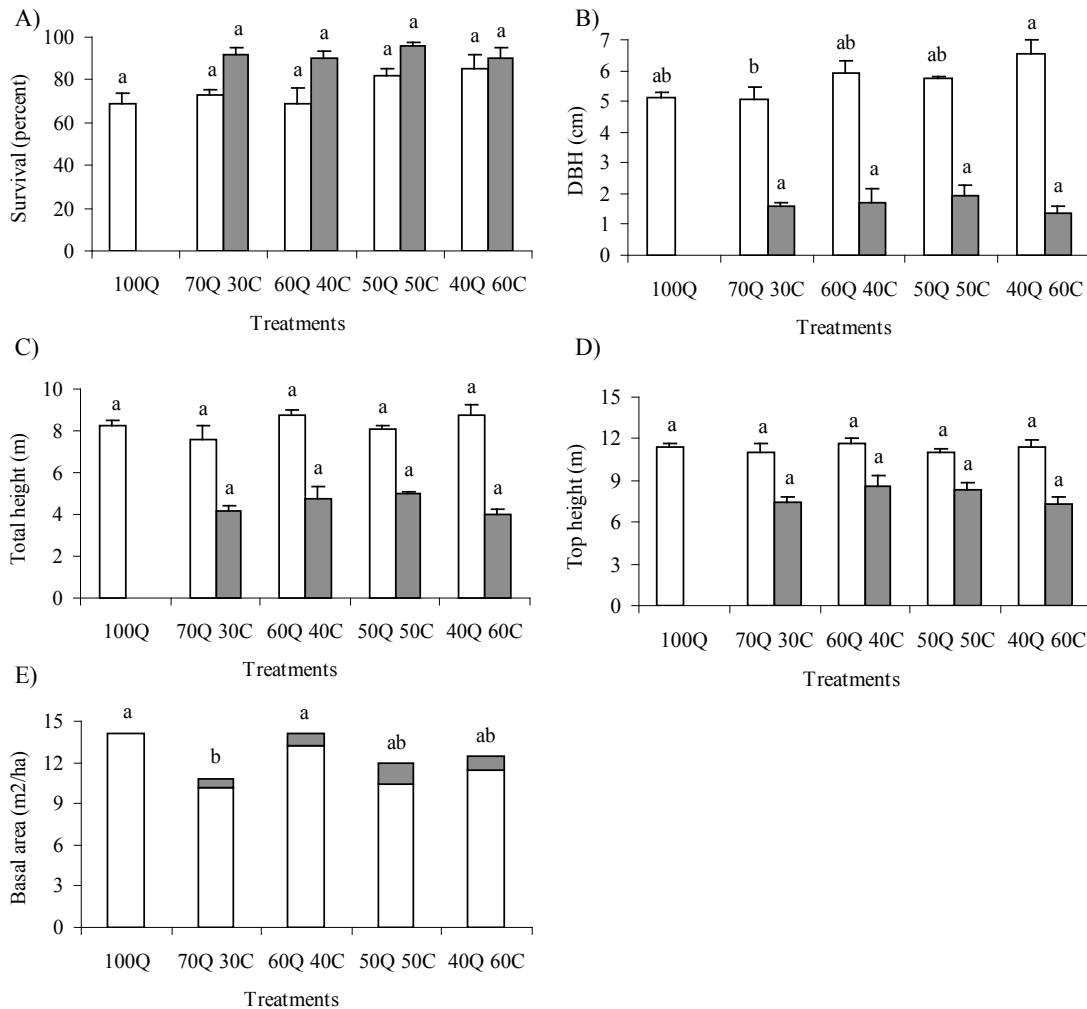


Fig. 1. Survival (A), DBH: diameter at breast height (B), Total height (C), Basal area (D), and Top height (E) of both tree species when separately compared. The letters on different column indicate a different comparison. Mean values with the same letter within a tree species do not differ significantly with each other. 100Q: 100% Oak, 70Q:30C: 70% Oak:30% Hackberry, 60Q:40C: 60% Oak:40% Hackberry, 50Q:50C: 50% Oak:50% Hackberry, 40Q:60C: 40% Oak:60% Hackberry.

60Q:40C treatments than the 70Q:30C treatment ($P < 0.05$, Tukey-HSD test).

3.2. Litter fall production, nutrient content, and nutrient fluxes

Fully expanded and senescent leaf nutrient concentrations showed significant differences in two species among different planting ratios (Table 2). Nitrogen concentrations in fully expanded leaves of *Quercus* were the highest in pure oak plantations and the lowest in 60Q:40C treatment ($P < 0.05$, Duncan test). On the contrary, Ca concentrations in fully expanded leaves of *Quercus* were higher in 60Q:40C than 100Q and 50Q:50C

treatments, and so Mg concentrations were higher in 60Q:40C than 100Q and 70Q:30C treatments ($P < 0.05$, Duncan test). The other macronutrient elements (P and K) did not show any significant differences for *Quercus* leaves among different planting ratios with *Celtis*. No significant differences among plantations were found for N, K and Ca leaf concentrations of *Celtis*. Concentrations in fully expanded leaves of *Celtis* were higher in 50Q:50C than 40Q:60C treatments. Mg concentrations in fully expanded leaves of *Celtis* were the highest in 60Q:40C treatment ($P < 0.05$, Duncan test).

For *Quercus*, senescent leaf concentrations for N were higher in 100Q than in

Table 1. Leaf-litter fall production, nutrient fluxes and retranslocation in 11 year-old plantation stands (standard error in the parenthesis) of different percent composition of oak and hackberry.

	Pure		70% Oak + 30% Hackberry		60% Oak + 40% Hackberry		50% Oak + 50% Hackberry		40% Oak + 60% Hackberry		ANOVA		
	Oak	Hackberry	Oak	Hackberry	Oak	Hackberry	Oak	Hackberry	Oak	Hackberry			
Litter fall production (t ha ⁻¹ year ⁻¹)	6.14 (0.58)	5.02 (0.05)	4.43 (0.05)	0.59 (0.00)	5.02 (0.05)	3.50 (0.38)	0.59 (0.06)	4.09 (0.45)	4.52 (0.31)	5.19 (0.36)	0.82 (0.11)	5.76 (0.91)	ns
Litter fall nutrient flux (kg ha ⁻¹ year ⁻¹)													
Nitrogen	105.21 a (7.35)	62.16 ab (3.03)	53.75 (1.19)	8.41 (1.83)	62.16 ab (3.03)	53.72 (6.76)	6.73 (0.85)	60.45 ab (7.34)	48.41 (7.41)	55.21 b (7.27)	7.16 (1.49)	65.65 ab (8.96)	**
Phosphorus	5.70 (0.82)	3.97 (0.31)	3.47 (0.31)	0.50 (0.01)	3.97 (0.31)	2.63 (0.20)	0.62 (0.08)	3.25 (0.25)	3.49 (0.16)	4.02 (0.09)	0.86 (0.08)	5.33 (1.19)	ns
Potassium	17.71 (2.45)	14.70 (2.50)	11.66 (1.93)	3.04 (0.75)	14.70 (2.50)	11.74 (1.53)	5.62 (0.63)	17.36 (2.14)	14.24 (0.78)	17.56 (0.38)	5.24 (0.88)	16.64 (5.38)	ns
Calcium	72.82 (7.17)	64.54 (8.77)	49.46 (7.66)	15.08 (1.16)	64.54 (8.77)	42.61 (4.79)	14.19 (1.38)	56.80 (5.85)	55.17 (5.07)	69.71 (2.28)	20.79 (4.23)	72.87 (9.68)	ns
Magnesium	10.13 (1.08)	9.20 (0.98)	7.64 (0.97)	1.56 (0.19)	9.20 (0.98)	5.33 (0.96)	2.00 (0.42)	7.33 (1.39)	8.35 (1.30)	9.75 (1.09)	2.43 (0.77)	9.86 (1.71)	ns
Percent retranslocation													
Nitrogen	36. ab (2.88)	42.93 a (3.30)	32.98 b (6.72)	15.87 b (5.23)	48.15 ab (2.02)	46.08 a (5.57)	44.44 ab (7.21)	40.65 a (8.00)	61.86 a (2.44)				*
Phosphorus	27 (1.44)	41.33 (6.39)	19.03 ab (4.33)	47.62 (2.47)	16.42 ab (5.39)	33.43 (7.47)	30.87 a (6.09)	38.15 (9.21)	10.76 b (1.28)				*
Potassium	68. ab (3.)	66.02 ab (7.85)	31.67 (8.37)	63.39 ab (1.13)	21.82 (5.15)	53.40 b (8.34)	37.02 (8.05)	71.62 a (8.20)	17.52 (4.54)				*

ANOVA results: ns –treatment effect not significant; * $P < 0.05$, ** $P < 0.01$. Similar letters within a row indicate that means were not statistically different (Tukey HSD test).

50Q:50C treatment ($P < 0.01$, Duncan test). K return by senescent leaves of *Quercus* in 60Q:40C plantations was significantly higher than in 40Q:60C plantations ($P < 0.05$, Duncan test). K return by senescent leaves of *Quercus* in 60Q:40C plantations was significantly higher than in 40Q:60C plantations ($P < 0.05$, Duncan test). P and Ca and Mg return by senescent leaves of *Quercus* did not show any significant differences among different treatments. For *Celtis*, senescent leaf concentrations for N were higher in 70Q:30C than in 40Q:60C treatment. K return by senescent leaves of *Celtis* in 60Q:40C plantations was significantly higher than in 50Q:50C and 70Q:30C plantations. The other macronutrient elements did not show any significant differences for *Celtis* leaves among different planting ratios ($P < 0.05$, Duncan test).

Significant differences in nutrient retranslocation .i.e. the percentage of N, P, or K withdrawn from leaves prior to leaf-fall, were observed for N and K in *Quercus* and for N and P in *Celtis* among treatments (Table 1).

In *Quercus*, N retranslocation in 60Q:40C was lower than other mixed stands and K retranslocation was higher in 40Q:60C than 50Q:50C treatment ($P < 0.05$, Duncan test). In *Celtis*, N retranslocation in 40Q:60C was higher than in 70Q:30C treatment and P retranslocation was higher in 50Q:50C than 40Q:60C treatment ($P < 0.05$, Duncan test). However, the retranslocation percent of nutrients (NPK) in *Quercus* was in order: K (53–72%) > P (27–47%) > N (15–46%) and in *Celtis* was in order: N (32–62%) > K (17–37%) > P (10–31%).

Leaf-litter fall production ranged from 4.10 to 6.14 t ha⁻¹ year⁻¹ in 60Q:40C and 100Q respectively showed no significant differences among planting ratios (Table 1). Due to the treatment differences in litter production and species differences in litter-nutrient concentrations, the leaf-litter fall fluxes were significantly different among treatments only for N ($P < 0.01$, Duncan test) (Table 1). The flux of this element was higher in pure oak than in 50Q:50C treatment

Table 2. Nutrient concentrations in live and senescent leaves (standard error in the parenthesis) in pure oak stand and in different percent combinations with hackberry.

	Pure	70% Oak +		60% Oak +		50% Oak +		40% Oak +	
	Oak	Oak	Hackberry	Oak	Hackberry	Oak	Hackberry	Oak	Hackberry
Live leaves									
Nitrogen (mg g ⁻¹)	27.42 (0.64)	21.43 (1.50)	21.20 (0.78)	17.73 (0.31)	21.93 (1.88)	19.87 (0.96)	18.67 (0.72)	21.60 (0.83)	22.10 (1.27)
Phosphorus (mg g ⁻¹)	1.08 (0.02)	1.34 (0.04)	1.06 (0.05)	1.46 (0.13)	1.12 (0.04)	1.18 (0.01)	1.15 (0.05)	1.41 (0.13)	0.98 (0.01)
Potassium (mg g ⁻¹)	9.13 (1.00)	8.17 (1.14)	8.50 (0.78)	9.15 (0.43)	12.23 (1.93)	7.23 (1.25)	8.95 (2.87)	8.88 (1.68)	6.77 (1.65)
Calcium (mg g ⁻¹)	4.15 (0.62)	5.45 (0.52)	11.94 (3.24)	6.24 (0.51)	14.72 (1.94)	4.23 (0.32)	8.05 (1.02)	5.43 (0.12)	9.50 (1.83)
Magnesium (mg g ⁻¹)	2.13 (0.28)	2.17 (0.30)	3.08 (0.22)	3.18 (0.28)	3.67 (0.08)	2.32 (0.09)	2.42 (0.22)	3.00 (0.28)	2.33 (0.58)
Senescent leaves									
Nitrogen (mg g ⁻¹)	17.35 (0.65)	12.13 (0.16)	14.27 (2.97)	15.10 (0.83)	11.30 (0.56)	10.60 (0.88)	10.23 (0.99)	12.50 (1.90)	8.47 (0.88)
Phosphorus (mg g ⁻¹)	0.93 (0.08)	0.78 (0.06)	0.86 (0.01)	0.76 (0.03)	1.04 (0.12)	0.79 (0.08)	0.79 (0.05)	0.91 (0.21)	1.07 (0.13)
Potassium (mg g ⁻¹)	2.83 (0.22)	2.62 (0.40)	5.17 (1.23)	3.34 (0.06)	9.45 (0.44)	3.16 (0.15)	5.04 (1.09)	2.25 (0.39)	5.76 (1.25)
Calcium (mg g ⁻¹)	11.85 (0.23)	11.13 (2.32)	25.72 (2.24)	12.18 (0.49)	23.97 (1.29)	12.18 (0.41)	22.42 (5.60)	9.84 (2.12)	25.14 (2.92)
Magnesium (mg g ⁻¹)	1.65 (0.07)	1.72 (0.20)	2.66 (0.31)	1.50 (0.13)	3.31 (0.44)	1.85 (0.25)	2.13 (0.43)	1.39 (0.30)	2.83 (0.50)

Table 3. Soil properties in plantations and control plots in two soil layers (A and B horizons) with their standard error. For combinations see Table 1.

Soil properties	Depth cm	100Q	70Q:30C	60Q:40C	50Q:50C	40Q:60C	Control	ANOVA ^b
Clay (%)	0–20	38.0 a (1.08)	29.5 b (1.50)	29.5 b (4.50)	31.5 ab (0.50)	38.0 a (6.00)	31.5 ab (0.95)	*
	21–60	35.5 (2.17)	33.0 (7.00)	37.5 (5.50)	36.5 (4.50)	37.5 (3.00)	29.5 (2.62)	ns
Silt (%)	0–20	38.25 (4.73)	54.50 (9.50)	50.50 (0.50)	37.50 (11.50)	47.50 (7.50)	37.50 (3.30)	ns
	21–60	42.25 (6.81)	51.00 (10.0)	48.50 (8.50)	38.50 (8.50)	47.50 (3.50)	48.50 (8.42)	ns
Sand (%)	0–20	23.75 (5.46)	16.00 (5.00)	20.00 (4.00)	31.00 (7.50)	14.50 (1.50)	31.00 (3.91)	ns
	21–60	22.25 (6.20)	16.00 (4.00)	14.00 (3.00)	25.00 (6.00)	15.00 (1.50)	22.00 (6.55)	ns
pH (1:2.5 H ₂ O)	0–20	6.84 (0.28)	6.57 (0.51)	6.67 (0.17)	6.67 (0.66)	6.41 (0.25)	7.12 (0.09)	ns
	21–60	6.88 (0.27)	6.50 (0.32)	6.53 (0.04)	7.12 (0.37)	6.67 (0.04)	7.02 (0.26)	ns
EC (ds/m)	0–20	0.45 (0.02)	0.63 (0.05)	0.52 (0.01)	0.59 (0.10)	0.56 (0.04)	0.60 (0.03)	ns
	21–60	0.60 (0.04)	0.55 (0.05)	0.46 (0.07)	0.56 (0.03)	0.51 (0.01)	0.40 (0.05)	ns
Organic carbon (%)	0–20	2.90 (0.27)	3.06 (0.26)	2.10 (0.50)	3.05 (0.15)	2.90 (0.20)	2.22 (0.36)	ns
	21–60	1.97 (0.27)	1.88 (0.32)	1.58 (0.37)	1.90 (0.40)	2.28 (0.32)	1.60 (0.42)	ns
Total N (%)	0–20	0.20 (0.02)	0.32 (0.02)	0.25 (0.09)	0.30 (0.01)	0.32 (0.02)	0.24 (0.04)	ns
	21–60	0.18 (0.02)	0.23 (0.04)	0.15 (0.03)	0.17 (0.03)	0.20 (0.03)	0.21 (0.04)	ns
P available (mg kg ⁻¹)	0–20	23.38 (3.49)	17.75 (4.75)	25.75 (5.25)	33.25 (2.75)	18.35 (1.65)	29.75 (2.42)	ns
	21–60	28.31 ab (1.74)	23.25 abc (5.75)	16.15 bc (5.85)	34.25 a (6.75)	11.05 c (3.95)	29.75 a (2.24)	*
K available (mg kg ⁻¹)	0–20	320.0 (14.14)	470.0 (50.00)	425.0 (25.00)	415.0 (45.00)	370.0 (30.00)	417.5 (41.70)	ns
	21–60	315.0 (15.00)	320.0 (30.00)	355.0 (5.00)	335.0 (15.00)	310.0 (10.00)	317.5 (23.93)	ns
Ca available (mg kg ⁻¹)	0–20	200.0 (36.90)	160.0 (20.00)	160.0 (10.00)	130.0 (20.00)	180.0 (30.00)	215.0 (30.95)	ns
	21–60	165 (25.33)	115 (25.00)	160 (20.00)	125 (5.00)	135 (15.00)	180 (12.24)	ns
Mg available (mg kg ⁻¹)	0–20	42.0 (11.79)	42.0 (6.00)	45.0 (3.00)	24.0 (7.00)	39.0 (3.00)	58.5 (11.75)	ns
	21–60	39.0 (14.17)	21.0 (7.00)	36.0 (12.00)	24.0 (6.00)	27.0 (3.00)	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 test. Mean values with the same letter within the soil layer do not differ significantly with each other.

(105.21 and 55.21 kg ha⁻¹ year⁻¹ respectively). Average P return through leaf-litter fall ranged from 3.25 to 5.70 kg ha⁻¹ year⁻¹ with no significant differences among treatments. Similarly, no obvious differences were found in leaf-litter flux rates for K (14.71–17.71 kg ha⁻¹ year⁻¹), Ca (56.80–72.87 kg ha⁻¹ year⁻¹) and Mg (7.34–10.13 kg ha⁻¹ year⁻¹) among treatments.

3.3. Soil properties

There were few differences in soil properties among experimental treatments at 11 years of age. Soils were characterized as fine-textured. The clay content was more than 29% and was higher ($P < 0.05$, Duncan test) in the A horizon of 40Q:60C and monoculture *Quercus* treatments than 60Q:40C and 70Q:30C treatments, whereas no significant differences were found in deeper soil layer (Table 3). Soil pH, ranging from 6.41 to 7.12, did not show any significant differences between the treatments. No significant differences were found in two soil layers for soil EC ($P < 0.05$, Duncan test) (Table 3). Carbon: nitrogen ratio was the highest in pure *Quercus* treatment (15.33) followed by 50Q:50C (10.32) and 70Q:30C treatments, control plots, 60Q:40C and 40Q:60C treatments (9.76, 9.20, 9.00 and 8.53 respectively) in 0–20 cm ($P < 0.05$, Duncan test). The highest value was found in 40Q:60C treatment (11.47) followed by 50Q:50C, 60Q:40C and pure *Quercus* treatments (11.54, 10.91 and 10.74 respectively) and 70Q:30C treatment (8.21) and control plots (7.64) in 21–60cm depth ($P < 0.01$, Duncan test).

Organic carbon (1.58–3.06%), total nitrogen (0.15–0.32%), available K (310–470 mg kg⁻¹), available Ca (115–215 mg kg⁻¹) and available Mg (21.0–58.5 mg kg⁻¹) exhibited no significant differences between the soil horizons of treatments (Table 3). Available P in 21–60 cm depth of 50Q:50C was the highest among different planting ratios ($P < 0.05$, Duncan test) (Table 3).

4. DISCUSSION

The survival of *Quercus* exhibited no significant differences between pure and mixed plantations. Our results were similar to those

obtained by Khanna (1997) and Sayyad *et al.* (2006).

In young age, when the individual is competing for light, the potential effect of different mixtures is on height growth, once priority of photosynthetic energy allocation is given to height growth over diameter growth (Kramer and Kozlowski 1960). In this research, advantage of the available growing space for oak trees, due to light crown and small size of hackberry trees, was responsible for the decrease of inter-specific competition (Kelty 2006). Hence, the diameter growth of oak in 40Q:60C treatment was higher than in 70Q:30C treatment and the height growth did not show any significant differences in monoculture and mixed plantations. Several studies comparing single and mixed plantations have reported that the growth of target species in mixed plantations were higher than in pure plantations. Khanna (1997) and Parrotta (1999) have found this situation in monoculture and mixed plantations of *Eucalyptus* and *Acacia*, and Hansen and Dawson (1982) – in monoculture and mixed plantations of poplar species and *Alnus glutinosa*.

In our study, the planting ratios affected the total basal area. This parameter was significantly greater in the 100Q and 60Q:40C treatments than the 70Q:30C treatment. In contrast, Khanna (1997), Parrotta (1999), Montagnini (2000) and Piotto *et al.* (2004) found the greater basal area in mixed plantations for target species compared to monocultures.

Augusto *et al.* (2002) suggested that in temperate forests, the chemical composition of foliage is dependent on tree species and site. In none of the plantations, the foliar N, K, Ca and Mg concentrations in *Quercus* was not lower than the limit for possible deficiency (12 mg g⁻¹ for N, 3–5 mg g⁻¹ for K, >1 mg g⁻¹ for Ca; and 0.6–1.5 mg g⁻¹ for Mg.) (Will 1985, Stefan *et al.* 1997). But foliar P and K concentrations for *Celtis* in some treatments were lower than deficient foliar concentrations. Different planting ratios affected the foliar N, K, Ca and Mg concentrations of oak foliage but N concentrations in fully expanded and senescent leaves of *Quercus* were the highest in pure oak plantations. This fact followed opposite trends for Ca and Mg concentrations. Augusto *et al.* (2002) reported the

effect of overstory species on tree nutrition that is strongly influenced by forest management (e.g. low density stands or mixed stands can promote litter decomposition).

Different planting ratios affected the retranslocation rates too. In the case of *Quercus*, N retranslocation was generally lowest in 60Q:40C stands and K retranslocation – in 40Q:60C treatment. Retranslocation rate for a given species usually increased in the poor sites (Boerner 1984, Lajtha 1987, Zas and Serada 2003). Nutrient retranslocation may be defined for the whole plant as the total amount of an element withdrawn from old tissues and transferred to new and growing tissues (Lim and Cousens 1986, Marschner 1991)

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). Salifu and Timming (2001) found that increased N availability in the soil (by fertilisation) enhanced N accumulation in the freshly transplanted *Picea mariana* but lowered N retranslocation. Lodhiyal and Lodhiyal (2003) found that the percent retranslocation of nutrients (NPK) in tree layer of Bhabar Shisham forests in central Himalaya followed in order $K > N > P$. The present estimates of percent retranslocation of nutrients from senescent leaves are somewhat higher than for *Quercus rubra* (23–39%; Grizzard *et al.* 1976). Lodhiyal and Lodhiyal (1997) argued that higher is the leaf tissue nutrient level, greater would be the percent retranslocation capacity. However, Chapin and Kedrowski (1983) pointed out that the both percent retranslocation and concentrations of nutrients are positively correlated. This trend is consistent with our results concerning nitrogen for *Quercus* and phosphorus for *Celtis*.

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 related to the latitude, that is climate (Vogt *et al.* 1986), and stand management (Augusto *et al.* 2002). We found that the litter fall production of different plantations did not differ significantly, but 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).

Despite of high significant differences in nutrient concentrations in senesced leaves, there were few differences in nutrient fluxes among treatments. This trend can be due to the different leaf litter fall mass of both two species regarding different planting ratios. For instance, Cuevas and Lugo (1998) detected relationship between litter and nutrient fluxes among contrasting species stands. In present study, the single-species stands had the higher values of nutrient fluxes comparing with mixed-species stands. This trend was significant only for nitrogen fluxes.

There were few differences in soil properties among experimental treatments after 11 years of cultivation. This may be a result of fairly short time period, i.e., longer time spans are required to detect the effect of cultivated tree species on the composition of mineral soil (Vesterdal *et al.* 2002). No statistically significant differences were observed in soil pH between the treatments. Giardina *et al.* (1995) and Montagnini (2000) reached the same result, whereas Rhoades and Binkley (1992), 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. Mohr *et al.* (2005) reported that soil pH was higher under young birch and hazel trees than under the oak. The effect of different tree species on soil pH is most significant in the first ten centimeters of the topsoil (Binkley and Valentine 1991, Norden 1994). Augusto *et al.* (2002) reported that *Quercus* spp. as second tree species 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 with our results, Garcia-Montiel and Binkley (1998) found that organic carbon content in 0–20 cm depth of soil under *Albizia* trees was higher than in soil under *Eucalyptus*. Augusto *et al.* (2002) suggested that the soil carbon content and the soil organic weight are dependent on the canopy species.

No significant differences were observed in soil nitrogen content in both soil layers between the treatments. The effect of tree species on total nitrogen stocks in the soil is inconsistent (Augusto *et al.* 2002). Parrotta (1999) and Montagnini (2000) did not observe any significant differences in soil nitrogen between monoculture and mixed plantations. Whereas Hansen and Dawson (1982) observed that mixed plantation of *Populus* and *Alnus glutinosa* resulted in increasing soil nitrogen in comparison with their monoculture plantations

Mixed plantations have intermediate values of soil N, P and K, but lower soil Ca and Mg relative to pure plantations (Stanley and Montagnini 1999, Montagnini 2000). In our study, this trend was consistent only for P. No significant differences were observed between monoculture and mixed plantation in concentrations of N, K, Ca and Mg in soil. Montagnini (2000) came to the same results in monoculture and mixed plantation. 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).

5. CONCLUSIONS

In this study, we did not observe considerable differences between pure and mixed plantations of oak with *Celtis*. However, the 60Q:40C treatment could be considered the most productive and sustainable one. In 60Q:40C treatment one has obtained the significant higher values for total basal area, Ca and Mg foliage concentrations for *Quercus* and Mg foliage concentration for *Celtis*, and the lowest N retranslocation for *Quercus*. In this treatment, we found also somewhat higher (but not significantly) P and K foliage concentrations for *Quercus*, and total and top height of *Quercus*. Thus, for the purposes of forest rehabilitation and restoration of Hyrcanian forests, such plantation ratio i.e. 60Q:40C, under appropriate management can serve a dual role – by accelerating natural recovery of species-rich forest ecosystems and providing the wood products for man.

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