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Four-year Field Performance of *Fraxinus angustifolia* Vahl. and *Ulmus laevis* Pall. Seedlings Grown at Different Nursery Seedbed Densities

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ABSTRACT

Seedling morphological variables affect early field performance of tree species. Thus, the aim of this research was to evaluate field performances of 1+0 bareroot seedlings of *Fraxinus angustifolia* and *Ulmus laevis* grown at different nursery seedbed densities after 4 years of planting. *Fraxinus angustifolia* seedlings of three provenances were grown in nursery beds with 20 and 30 cm between rows and various spacings within rows (4.3, 5.0, 6.3, 8.3 and 12.5 cm). *Ulmus laevis* seedlings of one provenance were grown in beds with 20 cm between rows and different spacing within rows (2.9, 3.3, 5.0 and 6.7 cm). Provenance and seedbed density significantly affected diameter and height increments in *F. angustifolia* and seedling density affected diameter and height of the 1-year-old *U. laevis* seedlings in nursery. Survival, height and diameter growth of two species were evaluated 4 years after planting. Seedlings of both species showed high survival (≥98%) after four growing seasons. Provenance significantly affected diameter and height increments in *F. angustifolia*. However, there were no significant differences among seedlings that represented different rows and seedling spacings. After 4 years of growth, total height of *F. angustifolia* and *U. laevis* seedlings were the highest in the lowest seedling densities (40 seedlings m^{-2} and 75 seedlings m^{-2}, respectively). The results for both species suggest that when quality seedlings are planted, a wide range of seedling sizes can be selected that are suitable for the conditions of the study site.

Key words: Ash, elm, planting, seedling growth, spacing, survival

INTRODUCTION

Ash species (*Fraxinus excelsior*, *F. angustifolia* and *F. ornus*) are becoming increasingly important in European forestry due to their fast growth and valuable wood. *Fraxinus angustifolia* Vahl. (narrow-leaved ash) is the most common and useful native ash species and dominates the bottomland forests of northern coastal regions of Turkey. It also grows in riparian areas and is found in mixed hardwood stands in the mountains (Fraxigen, 2005; Ansin and Ozkan, 2006). Although the natural habitat of *F. angustifolia* is mostly bottomland areas which are regarded as marginal for plant growth (due to heavy textured soils, high water table, poor drainage (Pliura, 1999), *F. angustifolia* shows high productivity in such areas and the mean annual increment can reach 15 and 25 $m^3 ha^{-1}$ in natural stands and plantations, respectively (Kapucu *et al*., 1999).

Despite its relative importance, little is known about plantation establishment of *F. angustifolia*. *Ulmus laevis* Pall. (white elm) has a very limited distribution in Turkey and is found in bottomland forests dominated by *F. angustifolia* and in riparian deciduous forests (Mayer and Aksoy, 1986). The area of these bottomland forests has decreased over the centuries, through draining and reclamation for agriculture or poplar cultivation (Cicek, 2004). During reforestation of bottomland forests in the last 40 years, only the dominant tree, *F. angustifolia*, has been planted, giving rise to pure *F. angustifolia* plantations; other native species, such as *U. laevis*, *U. minor*, *Quercus robur*, *Q. hartwissiana* and *Acer campestre* were completely disregarded as species for reforestation. Furthermore, forest management practices have led to the elimination of these latter species from stands. Intense grazing has further impeded the natural regeneration of the above species, threatening their occurrence. To ensure conservation and sustainable use of *U. laevis*, more studies are needed on nursery practices and its field performance.

Seedling quality and nursery practices are important factors for successful plantation establishment. Morphological and physiological seedling traits are used in the assessment of seedling quality and field performance. However, since morphological traits (e.g., stem diameter, height, first-order lateral roots, dry and fresh weight, root volume, root/shoot dry ratio) are more easily measured than physiological traits, morphological traits are commonly used in assessing seedling quality (Stein, 1988; Mirzaei *et al.*, 2007; Famuwagun and Agele, 2010). Wilson and Jacobs (2006) noted that morphological traits are typically studied in conifers, whereas studies on hardwoods are limited. Hardwood seedling demand has increased in recent years, particularly for conservation purposes. Thus, quality assesment of hardwood seedlings is needed for successful plantation establishment, habitat restoration and horicultural planting.

Several studies have investigated the influence of seedling morphological variables on early field performance of hardwood tree species. Hashizume and Han (1993) reported that seedling size significantly affected field survival and growth of oak (*Q. acutissima*) seedlings and that taller seedlings (>150 cm) had lower survival than seedlings 100-120 cm high. Thompson and Schultz (1995) found a negative and significant correlation between initial height and first 2-year height growth in red oak (*Q. rubra*). Dey and Parker (1997) found that initial diameter, height and number of first-order lateral roots (FOLR) were positively and significantly correlated with 2-year field growth. Jacobs *et al.* (2005) found that initial diameter, height and root volume were the most important morphological traits for predicting first-year height and diameter growth of three hardwood species. The number of FOLR was significantly correlated with 4-year growth of oak seedlings (*Quercus alba* and *Q. velutina*) (Ponder, 2000).

In Turkey, the preferred method to regenerate *F. angustifolia* stands on bottomlands is clear cutting and replanting. Because of sites conditions, during the early years after planting, excessive weedy competition is common and weeds can grow up to 1.5 m high or more within several months (Cicek *et al.*, 2007a). In conventional planting, low-quality and small-size *F. angustifolia* seedlings raised at high seedbed densities (>200 seedlings m^{-2}) are used which necessitates replanting (at least 20-30%). Moreover, it takes at least 5 to 6 years for the seedlings to be high enough to compete with the weedy vegetation (Cicek *et al.*, 2006), thus increasing stand establishment costs. Seedlings of some ash species are commonly grown at less than 150 seedlings m^{-2} to increase field performance (Kennedy, 1990; Wright and Rauscher, 1990) and such higher quality seedlings should be used to take advantage of their fast growth, so as to reduce stand establishment costs and establish high quality plantations. Thus, more research is needed on seedling morphology in relation to field performance of these species. The main objective of the study was therefore to evaluate four years field performance of *F. angustifolia* and *U. laevis* seedlings grown in different nursery bed densities.

MATERIALS AND METHODS

Study site: The study was established on a bottomland hardwood area in Akyazi-Adapazari, Turkey (40°48' N, 30°33' E, 25 m a.s.l.). The mature natural stand on the site was dominated by *F. angustifolia,* with scattered trees of *Ulmus laevis, U. minor, Quercus robur, Q. hartwissiana, Acer campestre* and *Populus alba*. The area has alluvial clay soils (slightly to moderately alkaline) with a smooth and homogeneous soil structure. The soil on the site is deep and not well drained and the Ah horizon was very thin to absent due to rapid decomposition. Adapazari Meteorological Station (40° 47' N, 30° 25' E, 30 m a.s.l.) is about 15 km south-west from the study site. According to the station records, the area has a warm climate and receives approximately 846 mm of rainfall each year, to about 50% (420 mm) falling from April to October. Summers may include drought periods from mid-summer to early fall. The mean annual temperature is 14.3°C and the mean temperature during the growing season (April-October) is 18.8°C. Compared to the last 32-year mean rainfall during the growing season (420 mm), rainfall during the 2004 and 2005 growing seasons (559 and 474 mm) was higher but was lower in 2006 (268 mm) and 2007 (295 mm). Annual rainfall in 2006 (651 mm) and 2007 (679 mm) was also lower than the last 32-year mean (846 mm). Compared to the mean air temperature over 32 years, the mean annual and mean growing season values during 2004, 2005, 2006 and 2007 were higher (Table 1). Furthermore, mean relative humidity during the growing seasons of the study years, especially in summer, was lower compared to the 32 year mean value.

Older natural stands at the study site were clear cut and their stumps were uprooted in the fall of 2004. After the stumps and slash were disposed of, the soil was first ripped (60-80 cm soil depth) and then disked (20-30 cm soil depth) to aerate the soil. The operation was similar to the procedures for site preparation for *F. angustifolia* and other fast-growing tree species plantings/plantations in Turkey.

Seedling material: *Fraxinus angustifolia* seedlings from three provenances, Hendek (40°52' N, 30°36' E, 25 m a.s.l.), Demirkoy (41°49'N, 27°56' E, 20 m a.s.l.) and Sinop (42°02' N, 30°05' E, 20 m a.s.l.) from Turkey, were used in this study. These provenances were isolated from each other and represent the main bottoml and distribution of *F. angustifolia* in Turkey.

Table 1: Mean rainfall and temperature for the last 32 years and during the study years (2004- 2007)

		Month												
Trait	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Rainfall (mm)	Mean	94	74	68	62	48	71	56	50	44	89	88	102	846
	2004	195	85	70	48	42	125	20	129	7	20	148	55	944
	2005	140	83	87	51	28	60	164	12	68	92	166	77	1028
	2006	78	99	67	3	14	101	0	3	96	50	65	74	650
	2007	101	18	56	51	54	30	29	61	14	56	89	121	680
Temperature (°C)	Mean	6.0	6.2	8.4	12.7	17.1	21.3	23.2	22.8	19.4	15.3	11.0	7.8	14.3
	2004	5.5	6.2	9.8	13.2	17.1	21.2	23.1	23.2	20.6	16.9	11.8	9.1	14.8
	2005	7.5	7.4	8.3	13.6	17.6	20.5	24.4	25.1	21	14.7	11	9.5	15.1
	2006	4.5	6.2	10.1	13.3	18.1	22.2	23.4	26	20.2	17	10.4	7.4	14.9
	2007	6	8.9	10.3	11.6	19.7	24.1	25.4	25.8	21.1	17.1	11.4	7.3	15.7

Table 2: Summary of ANOVA (p values) for the effect of provenance and seedling size on growth variables of *Fraxinus angustifolia* and for the effect of seedling size on growth variables of *Ulmus laevis*

Species	Source	df	Initial BD	BD increment	Total BD	Initial SH	SH increment	Total SH
F. angustifolia	Block	2	0.032	0.825	0.980	0.034	0.018	0.125
	provenance (P)	2	0.000*	0.003*	0.000*	0.001*	0.000*	0.000*
	Seedbed density (S)	4	0.000*	0.626	0.110	0.000*	0.729	0.000*
	P×S	8	0.823	0.764	0.672	0.942	0.351	0.114
U. laevis	Block	2	0.407	0.488	0.576	0.663	0.115	0.193
	Seedling density	3	0.000	0.130	0.015*	0.000	0.190	0.010

**Significant. df: Degrees of freedom, BD: Basal diameter, SH: Shoot height

One-year-old bare-root *F. angustifolia* seedlings were grown at seedbed densities of 20 and 33 cm between rows and various spacings within rows (Table 2). Seedbeds with 20 cm row spacing had five rows while seedbeds with 33 cm row spacing had three rows. Seedlings representing mean seedbed height of each combination of provenance, row spacing and seedling spacing (3×2×5 = 30 combinations) were randomly chosen for field planting.

For WE, 1-year-old and bare-root seedlings of the Hendek provenance were grown in seedbeds with 20 cm between rows and a spacing of five seedlings per row (6.7, 5.0, 3.3 and 2.9 cm; equal to 75, 100, 150 and 175 seedling m^{-2}, respectively). According to the Turkish Standards Institute (TSI, 1988) guidelines for broadleaf trees, all seedlings of both species were first grade and seedlings within each species had similar height/diameter ratios (52-63 in *F. angustifolia*, 7.1-7.6 in *U. laevis*), root/shoot dry ratios (1.3-1.6 in *F. angustifolia*, 1.0-1.3 in *U. laevis*) and high root fibrosity (presence of many fine roots [Ø<2 mm] to total root numbers: 85-89% in *F. angustifolia* and 69-74% in *U. laevis*).

Experimental design: A split-split plot design with three blocks was used for *F. angustifolia*. The whole plot, the subplot and the sub-subplot represented the provenance, row spacing and seedling spacing, respectively. Each row was an experimental unit (sub-subplot) and contained 30 seedlings. A total of 2,700 seedlings (3 provenances×2 row spacings×5 seedling spacings×30 seedlings×3 replications) were used. For *U. laevis*, a randomized block design with tree replication was used. Each row contained 20 seedlings as an experimental unit (plot). In total, 240 seedlings (4 seedbed densities×20 seedlings×3 replications) were used. The seedlings were hand planted at a spacing of 3×3 m (equal to 2500 trees ha^{-1}) in early March 2004. To control weedy vegetation, the study plots were treated by hand hoeing a 70-cm radius circle of soil around the seedlings in early June 2004-2007.

Measurements: Basal diameters (2.5 cm above the root collar, ±0.1 mm) and heights (±1.0 cm) of the seedlings were determined in both species after planting in March 2004. Basal diameter (2.5 cm above ground) was measured instead of root collar diameter because of the muddy site conditions. Survival, diameter and height were recorded after four growing season.

Statistical analysis: Data were analyzed using the programme of SPSS 13.5 for windows. Analyses of variance (ANOVA) were used to evaluate the effects of provenance and nursery bed density/seedling size (treatment) on field growth variables of *Fraxinus angustifolia*. Analyses of variance were also used to determine the effect of nursery bed density/seedling size (treatment) on field performance of *U. laevis* seedlings. The variables analyzed were the mean subplot values (*F. angustifolia*) and plot values (*U. laevis*) of the trees. Growth increments were the difference between the initial and the fourth year tree sizes. The normal distribution of variables was controlled before ANOVA. If analyses of variance indicated significant effects, the treatment means were separated by Duncan's New Multiple Range test ($\alpha = 0.05$) (Zar, 1996).

RESULTS

In nursery, provenance and seedbed density affected diameter and height of the 1-year-old *F. angustifolia* seedlings and 1+0 seedlings of the Hendek provenance had the highest seedling diameter (7.8 mm) and seedling height (54 cm) when averaged over five seedling densities (Table 2, 3). The lowest seedbed density (40 seedlings m^{-2}) produced the highest seedling diameter (9.1 mm) and height (68 cm) but the highest seedbed density (120 seedlings m^{-2}) produced the lowest seedling diameter (5.5 mm) and height (37 cm) when averaged for three provenances.

Fraxinus angustifolia seedlings of all three provenances had similar and near-perfect survival (≥98%) after four growing seasons.

Provenance was the only factor that significantly affected 4-year diameter and height increments ($p<0.001$). Seedling density in nursery did not affect diameter and height increment of 4-year-old *F. angustifolia* seedlings in the field (Table 3). Effects of provenance or seedling spacing on total diameter and height were also significant ($p<0.001$) after 4 years in the field. The interaction had no significant effect on variables ($p>0.05$) (Table 2).

Seedlings of the Hendek provenance had a higher diameter (14%) and height increment (13%) than those of Demirkoy and Sinop provenances which had similar growth performance. Total diameter (30.5 mm) and height (254 cm) were also the highest in Hendek seedlings. Seedlings in different initial planting sizes had similar diameter and height increments at the end of the four growing seasons, but total height had the highest in the seedlings representing the lowest seedling density (40 seedlings m^{-2}) (Table 3).

Seedling density affected diameter and height of the 1-year-old *U. laevis* seedlings in nursery and total seedling height and diameter after 4 years in the field. However, 4-year diameter and height increments of the seedlings were similar (Table 4). Seedlings at the density of 75 seedhings m^{-2} produced the highest initial seedling height (49.5 cm) and basal diameter (7.5 mm) in nursery and total height (375 cm) and diameter (49.5 cm) after 4 years of growth in the field as

Table 3: Mean basal diameter and shoot height values of *Fraxinus angustifolia* seedlings for provenance and seedling size

Factor	Level	Initial BD (mm)	BD increment (mm)	TotalBD (mm)	Initial SH (cm)	SH increment (cm)	Total SH (cm)
Provenance	Hendek	7.8a	22.7a	30.5a	54a	201a	254a
	Demirkoy	6.4b	20.7b	27.1b	49b	174b	223b
	Sinop	7.0b	20.3b	27.3b	48b	175b	223b
Seedbed density (seedlings m^{-2})	40	9.1a	21.2a	30.3a	68a	186a	254a
	60	7.7b	20.4a	28.0a	55b	182a	236b
	80	7.0c	21.7a	28.7a	49c	184a	234b
	100	6.2d	21.4a	27.5a	42d	180a	222c
	120	5.5e	21.4a	26.9a	37e	184a	220c

Means within each column followed by the same letter are not significantly different ($\alpha = 0.05$). BD: Basal diameter, SH: Shoot height

Table 4: Mean basal diameter and shoot height values of *Ulmus laevis* seedlings

Seedlings density (seedling m^{-2})	Initial BD (mm)	BD increment (mm)	Total BD (mm)	Initial SH (cm)	SH increment (cm)	Total SH (cm)
75	7.5a	42.0a	49.5a	66a	309a	375a
100	6.3b	38.4a	44.7b	50b	296a	346b
150	5.2c	39.7a	44.9b	42c	300a	342b
175	4.0d	38.9a	43.0b	34d	306a	340b

Means within each column followed by the same letter are not significantly different (α = 0.05). BD: Basal diameter, SH: Shoot height

well. As in *F. angustifolia* provenances, all *U. laevis* seedlings representing different nursery seedbed densities performed similarly and had near-perfect survival (≥98%) after 4 years. After 4 years, *U. laevis* had a higher diameter and height increment than *F. angustifolia* (Table 3, 4).

DISCUSSION

Provenance and seedling density affected diameter and height of the 1-year-old *F. angustifolia* seedling in nursery and lowest seedbed density (40 seedlings m^{-2}) produced the highest seedling diameter and height. Seedling density affected diameter and height of the 1-year-old *U. laevis* seedlings in nursery and seedlings at the density of 75 seedlings m^{-2} produced the highest height and diameter. Slabaugh (1974) reported that seedling density was an important factor on height and diameter in *Ulmus pumila* as found for *U. laevis* and *F. angustifolia* in the present study. Bhardwaj *et al.* (1995) found that among the seedbed densities (33, 44, 66 and 100 seedling m^{-2}), the lowest density was proven to be most promising for producing more biomass per plant and healthy and vigorous seedlings. Seedbed density (22, 44 and 88 seedlings m^{-2}) significantly affected diameter and height growth in *Fraxinus pennsylvanica* and *Quercus nuttallii* (Kennedy, 1988). This is in agreement with the current study that seedling density affected diameter and height of the seedlings in nursery. This fact was also confirmed by Mishra and Feret (1996) and it was reported that seedbed density (33, 66 and 99 seedlings m^{-2}) affected collar diameter of oak seedlings (*Quercus alba* and *Q. rubra*) and the seedlings grown at the lowest plant density were greater. Seedling height, however, was not significantly affected by density in *Q. alba* (Wichman and Coggeshall, 1983). Cicek and Yilmaz (2006) found that lowering seedbed density apparently increased root collar diameter and height of the one-year-old white elm seedlings.

Seedling survival was very high (≥98%) in both *F. angustifolia* and *U. laevis* plantations. Initial seedling size obtained from different seedbed densities had no significant effect on 4-year field performance (survival, diameter increment and height increment) of *F. angustifolia* and *U. laevis* seedlings. Reynolds *et al.* (2002) found similar effects of seedbed density on survival and height growth through the first year in loblolly pine (*Pinus teada*). Others, however, have found that seedbed density significantly affected survival and growth in many tree species (Mullin and Bowdery, 1977; Stein, 1988; Howell and Harrington, 1998; Buckley, 2002). Larger seedlings produced at the lowest densities in *F. angustifolia* and *U. laevis* had the highest total diameter and height in the present study after 4 years of growth.

Studies on hardwoods such as *Betula pubescens, B. pendula, Liriodendron tulipifera, Liquidambar styraciflua, Quercus falcata* and *Q. rubra* showed that larger seedling size significantly increased survival and growth (Clausen, 1963; Funk *et al.*, 1974; Belanger and McAlpine, 1975; Howell and Harrington, 1998).

Another study on *F. angustifolia* of the Hendek provenance in the same site showed that 1-year-old seedlings and rooted cuttings of different sizes (50, 80 and 110 cm in height) had similar increment and survival rates within each stock type 2 years after planting (Cicek *et al*., 2006). *Ulmus laevis* seedlings in different initial sizes had also similar diameter and height increments through the first four years in the field. Therefore, it is possible that under the study site conditions, a wide range of stock sizes can be chosen for both species provided that quality planting stock is used. *Ulmus laevis* had higher growth than *F. angustifolia* under the study site conditions. This also shows that *U. laevis* can grow better than *F. angustifolia* on clay soils.

The highest diameter and height increment was found in seedlings of Hendek provenance because of the larger seedling diameter at planting. George and Frank (1973) found that large root collar diameter in green ash seedlings was related to greater height growth over a 29-year period. Differentiation in growth responses of various root collar diameter grades of sweetgum was significant after the first growing season and continued through seven seasons (Belanger and McAlpine, 1975). Dey and Parker (1997) also found that initial root collar diameter was a good predictor of second-year height and diameter of red oak. Williams *et al*. (1974) and Bresnan *et al*. (1994) reported that the use of seeds that are geographically adapted to a specific region increases survival and growth of seedlings. Hamann *et al*. (2000) also found that transferring red alder (*Alnus rubra*) provenances more than 100 km from their home site decreased survival and growth. A similar result was found in birch (*Betula alleghaniensis* and *B. lenta*) (Sharik and Barnes, 1976). Since low grade and small (20-40 cm height) seedlings from high seedbed densities are used in conventional *F. angustifolia* planting in Turkey, high seedling mortality (at least 25-30%) occurs in the early years of establishment (Cicek *et al*., 2007b). Moreover, in 2007, mortality of such seedlings reached 47% (A. Simsek, personal communication). Replanting and weed control treatments over at least the first 5 or 6 years increase the costs of plantation establishment. Application of inappropriate seedling material may lead to lower output and reduced quality of plantations. Using appropriate quality seedling material is crucial for the success of planting; as it will have an impact on all phases of planting, from establishment to harvest and will also decisively impact the success and quality of the future regeneration.

CONCLUSIONS

Seedling quality and nursery practices are important factors for successful plantation establishment. Initial seedling size obtained from different seedbed densities had no significant effect on 4-year field performance (survival, diameter increment and height increment) of *F. angustifolia* and *U. laevis* seedlings. Although smaller seedlings have lower seedling and planting costs, larger seedlings incur fewer costs for post-planting treatment. Since the study site contains vigorous weedy vegetation, larger planting stock can be advantageous for establishment and planting larger and higher quality seedlings will ensure less time spent on weed control as said by Cleary *et al*. (1978). Consequently, quality and larger stock can enable seedlings to reach a height where they can compete with the vigorous weedy vegetation and thus lower the cost of post-planting treatments.

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