Initial height and diameter are equally related to survival and growth of hardwood seedlings in first year after field planting

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Abstract

This study compares the relation of initial height and root collar diameter of bareroot hardwoods seedlings to survival and growth in first year after planting. A total of six species used in Serbian reforestation programs were tested (four native: *Fagus sylvatica*, *Ulmus laevis*, *Fraxinus excelsior*, and *Acer pseudoplatanus* and two exotic: *Robinia pseudoacacia*, and *Quercus rubra*), at 6 sites with a wide range of environmental conditions. Initial seedling height and diameter were equally related to field performance and better in forecasting growth than survival. The relation between seedlings initial morphological attributes and survival was species specific, while for all tested species growth was positively correlated to seedling size at planting. Although large seedlings kept their advantage in size, smaller seedlings grew at a higher rate. Both initial H and D should be considered as equally important in operational programs for hardwoods seedling quality testing.

Keywords

Seedlings; Morphological attributes; Survival; Field performance; Quality testing

Contents

1 Introduction

Testing for seedling quality provides information both to nursery managers related to whether stocktypes meet quality standards, and to reforestation silviculturists about the potential performance of seedlings in the field (Ivetić et al. 2016). The results of seedling quality testing play an important part in The Target Plant Concept as a flexible framework that nursery managers and reforestation silviculturists can use to improve the survival and growth of seedlings (Dumroese et al. 2016).

Despite rather contradictory experiments relating seedling size to field performance, seedling morphology remains the basis for stocktype characterization (Thompson 1985) with height and stem diameter as the most widely used attributes measured in seedling quality assessment (Mexal and Landis 1990; Haase 2007; Pinto 2011; Ivetić 2013). Many studies showed the relationship between the initial seedling morphological attributes and the after planting performance (Mexal and Landis 1990; Villar-Salvador et al. 2004; Mexal et al. 2009; Oliet et al. 2009; Grossnickle 2012) and additionally that the field performance can be reliably predicted (Jacobs et al. 2005; South et al. 2005; Tsakaldimi et al. 2012; Ivetić et al. 2016). However, for some attributes, reports are contradictory. In some instances, seedling height at planting time had a positive effect on growth (Kaczmarek and Pope 1993; Dey and Parker 1997; Puertolas et al. 2003; Gould and Harrington 2009; Pinto et al. 2011) while in some instances this relationship was negative (Rietveld and Van Sambeek 1989; Thompson and Schultz 1995; Ivetić et al. 2016). Root collar diameter was reported as better (compared to shoot height) measure of seedling quality (Chavasse 1977; Mattsson 1996), positively and significantly correlated with growth of hardwoods (Dey and Parker 1997) and conifers (Ward et al. 2000; South et al. 2005) as well as with field survival of five Mediterranean species (Tsakaldimi et al. 2012). However, initial root collar diameter, height, fresh mass and root volume show a similar forecasting ability of height for hardwood species (Jacobs et al. 2005).

There is no “silver bullet” (Puttonen 1997) as a single and universal test of seedling quality and separate testing standards need to be developed for seedlings produced from various combinations of species, seedlots and nursery culture (Grossnickle and Folk 1993). Increasing demands for hardwood seedlings emphasize the need for specific seedling quality testing protocols with morphological indicators widely used with hardwood species (as reviewed by Wilson and Jacobs 2006).

The most operational seedling quality standards set the minimal requirements for seedling height and diameter, related to species and stock type. The objective of this study was to compare the ability of height and root collar diameter, as the two most used morphological attributes in seedling quality testing, to forecast survival and growth of hardwood tree species in first year after planting.

2 Material and methods

Aiming to compare relation between initial height and root collar diameter to survival and growth of bareroot hardwood seedlings in first year after planting, a total of six species used in Serbian reforestation programs were tested, four native (*Fagus sylvatica* L., *Ulmus laevis* Pall., *Fraxinus excelsior* L., and *Acer pseudoplatanus* L.) and two exotic (*Robinia pseudoacacia* L., and *Quercus rubra* L.). Trials were established at 6 sites with a wide range of environmental conditions, from abandon agricultural land to forest fire and flooded sites, in both pure and mixed plantations.

2.1 Species and sites

Fagus sylvatica in Bukovik

The one-year-old bareroot seedlings (1+0) of *Fagus sylvatica* were planted in November 2014. Seedlings were produced in local nursery "Selište" managed by PE „Srbijašume", from seed collected from the same region of provenances (seed source reg.nr. RS-1-1-fsy-33-628, at 530 ma.s.l.). Seedlings were planted in manually prepared planting holes with 20-30 cm diameter and depth, at distance 2 x 2 m. The planting site is located at mountain Bukovik in Southeastern Serbia (43°42′48″N; 21°37′33″E), on a slope (15°) facing northwest, 420-460 m a.s.l., on crystalline schist with acid brown soil (dystric cambisol). Planting was performed at 1.4 ha, in the first year following a forest fire which totally burnt the previously planted stand of *Pinus nigra* Arnold, at age of 80 years. Before the fire, a succession was observed with a significant number of beech and oak saplings under the canopy of pine. The planting site was prepared by manually removing obstacles, residues, and competitive vegetation. There was no vegetation control in the first growing season after planting.

Robinia pseudoacacia in Subotica

The one-year-old bareroot (1+0) seedlings of *Robinia pseudoacacia* were planted in November 2015. Seedlings of *R. pseudoacacia* cv. szajki were produced in a local private nursery in Sombor. Seedlings were planted in mechanically prepared planting holes with 30 cm diameter and depth with amendment of hydrogel, at distance 1 x 2 m. The planting site is located near the town of Subotica in Northern Serbia (46°09′48″N; 19°37′24″E), on flat ground, 150 m a.s.l., on sand. Planting is performed on 1.5 ha in plantation for poles production. Initial seedling morphological attributes were measured at planting time in autumn. Seedlings were cutback in the beginning and re-measured at the end of first growing season. Seedlings were watered every three consecutive days without rain.

Ulmus laevis at sites Veliko Ratno Ostrvo and Bostanište

The three-year-old (1+2) seedlings of *Ulmus laevis* were planted on Veliko Ratno Ostrvo in November 2013, and in Bostanište in March 2014. Seedlings were produced in a private nursery in Manić, from seeds collected from natural population at Veliko Ratno Ostrvo, both near Belgrade. Seedlings were planted in mechanically prepared planting holes with 30 cm diameter and depth, at distance 3 x 3 m (Veliko Ratno Ostrvo) and 3 x 2 m (Bostanište). Both planting sites are located near the city of Belgrade, Serbia (VRO - 44˚50′18′′N; 20˚25′40′′E, on flat ground, 73 m a.s.l., on fluvisol; and Bostanište - 44˚30′54′′N; 20˚25′02′′E, on flat ground, 120 m a.s.l., on eugley, sub type amfigley). Planting on Veliko Ratno Ostrvo was performed on 0.7 ha of planting site at abandoned land. Planting at Bostanište was performed, at 0.2 ha of abandoned agricultural field. Both planting sites were prepared by manually removing obstacles, residues, and competitive vegetation, and there was no vegetation control in the first growing season after planting. During May 2014 both sites were flooded: Veliko Ratno Ostrvo for 2 weeks and Bostanište for 5 days.

Fraxinus excelsior in Stepin Lug

The two-year-old bareroot (2+0) seedlings of *Fraxinus excelsior* were planted in March 2015. Seedlings were produced in a local nursery „Ribnica" in Central Serbia, managed by PE „Srbijašume“, from seeds collected in the Belgrade region (seed source reg.nr. RS-2-2-fex-00-632, 130 m a.s.l.). Seedlings were planted in manually prepared planting holes with 30 cm diameter and depth, at distance 2 x 2 m. The planting site is located in the urban forest of the city of Belgrade, Serbia (44°43′51″N; 20°31′42″E), on a south facing slope (10°), 250 m a.s.l., on chernozem. Planting was performed on 1 ha of planting site prepared by manually removing obstacles, residues, and competitive vegetation. There was no vegetation control in the first growing season after planting.

Fraxinus excelsior, *Acer pseudoplatanus*, and *Quercus rubra*at at Senjski rudnik

The one-year-old bareroot (1+0) seedlings of *Fraxinus excelsior*, *Acer pseudoplatanus*, and *Quercus rubra* were planted in November 2015. Seedlings were produced in the local nursery „Lazićev salaš“ managed by PE „Srbijašume“ from seeds collected in local seed sources in Central Serbia (seed source reg.nr. *F. excelsior* RS-2-2-fex-00-050, 210 m a.s.l.; *A. pseudoplatanus* RS-2-1-aps-00-387, 140 m a.s.l.; and *Q. rubra* RS-2-2-qru-00-219, 110 m a.s.l.). Seedlings were planted in manually prepared planting holes with 30 cm diameter and depth, at distance 2 x 2 m in individual mixture (*F. excelsior* – 32%,*A. pseudoplatanus* – 14%, and *Q. rubra* – 54%). The planting site is located at the locality of Senjski rudnik, Central Serbia (43°59′11″N; 21°33′00″E), on a southeast facing slope (30°), 630 m a.s.l., on organogenic dense limestone with shallow Terra Rossa. Planting was performed in the second year following the forest fire which burnt the previous beech forest, on 3.7 ha of planting site prepared by manually removing obstacles, residues, and competitive vegetation. There was no vegetation control in the first growing season after planting.

2.2 Seedling measurements

At each planting site seedlings were measured for shoot height (H) and root collar diameter (D), at planting time and after first growing season. At planting time seedlings were marked with plastic tags so that the same seedlings can be re-measured after the end of the first growing season. The H was measured as the distance between the root collar and base of terminal bud of dormant seedlings, with an accuracy of 0.1 cm. The D was measured at or near the root collar; with an accuracy of 0.1 mm. At the site Senjski rudnik, for some seedlings D could not be re-measured at root collar due to soil sediment on planting spot at steep slopes, and these seedlings were excluded from further analysis. Sampling size differed between the sites depending on the homogeneity of site conditions. Survival of seedlings after the first growing season was also recorded. Survival of seedlings was calculated as a percentage of the number of living individuals from the total number of outplanted seedlings.

2.3 Statistical analysis

Based on mean values (MV) and standard deviation (SD) of H and D measured at planting time, seedlings were classified in three classes: (Large) L>MV+SD, (Medium) M=MV±SD, and (Small) S<MV-SD. Mean values of these classes were used for the calculation of two-tailed Pearson correlation coefficients (r) between initial values and values measured after growing season. An increment (%) relative to the initial values of H and D was calculated as (H2/H1)x100)-100 and (D2/D1)x100)-100.

3 Results

The one-year-old bareroot seedlings H ranged between 18 cm (*F. sylvatica*) and 49 cm (*A. pseudoplatanus*), D ranged from 4.3 mm (*F. excelsior*) to 7.7 (*A. pseudoplatanus*). The two-year-old seedlings of *F. excelsior* reached a height of 70 cm and a diameter of 8.5 mm. The height of three-year-old seedlings of *U. laevis* ranged from 130 to 150 cm, and diameter ranged from 13 to 16 mm (Tables 1 and 2).

Table 1. Survival and growth of seedling classes based on initial height.

Species, Stocktype and Locality	Nr. of samples	H mean value (in cm) and (standard deviation)	Class (limits)	Nr. (and percentage) of seedlings in class	H1 (standard deviation)	Survival (%)	H2 (standard deviation)	D2 (standard deviation)
***Fagus sylvatica* (1+0)**		17.8	L (>23.7)	17 (17%)	27.7 (3.8)	64.7	35.1 (5.5)	7.9 (1.4)
Bukovik	98	(6.0)	M	64 (65%)	17.2 (2.9)	45.3	23.7 (4.8)	6.2 (1.6)
			S (<11.7)	17 (17%)	10 (1.6)	41.2	15.9 (4.7)	5.6 (1.1)
***Robinia pseudoacacia* (1+0)**		51.5	L (>77.6)	22 (13%)	96.2 (17)	81.8	190.2 (36.5)	20.9 (3.5)
Subotica	163	(26.3)	M	113 (69%)	51.5 (14.6)	87.6	173.1 (48.3)	19 (4.8)
			S (<24.9)	28 (17%)	15 (6.1)	96.4	180.9 (44.6)	19.8 (4.2)
***Ulmus laevis* (1+2)**		130.2	L (>159.2)	120 (16%)	172 (11.7)	88.3	241.6 (46.9)	23.8 (4.3)
Veliko Ratno Ostrvo	770	(29)	M	525 (68%)	131.6 (15.4)	88	203.1 (46.4)	20.7 (4.3)
			S (<101.3)	125 (16%)	84.1 (15)	72.8	158.7 (45.1)	17.8 (4.5)
***Ulmus laevis* (1+2)**		150.5	L (>177)	43 (15%)	189.5 (8.2)	90.7	208.5 (19.6)	23.7 (3.5)
Bostanište	280	(26.6)	M	193 (69%)	151.5 (14.4)	89.6	169.5 (19.9)	20.6 (3.5)
			S (<123.9)	44 (16%)	107.8 (15.3)	88.2	123.4 (25.6)	15.9 (3.1)
***Fraxinus excelsior* (2+0)**		69.6	L (>88.6)	7 (14%)	101.6 (7.4)	57	81.5 (10.6)	13.1 (2.2)
Stepin lug	50	(19)	M	33 (66%)	71 (9.1)	84.8	78.6 (19.6)	10.8 (1.8)
			S (<50.6)	10 (20%)	42.8 (6.1)	90	49.9 (19.2)	8 (1.7)
***Fraxinus excelsior*(1+0)**		34.5	L (>46.6)	16 (17%)	53.4 (5)	62.5	49.5 (17.9)	6.8 (1.7)
Senjski rudnik	92	(12.1)	M	60 (65%)	33.6 (7.3)	55	41.8 (13.6)	5.7 (1.7)
			S (<22.4)	16 (17%)	18.8 (2.5)	75	28.1 (5.3)	3.6 (0.7)
***Acer pseudoplatanus* (1+0)**		48.6	L (>70.1)	5 (17%)	86.2 (5.9)	100	98 (8.6)	17.2 (1.9)
Senjski rudnik	29	(21.5)	M	20 (69%)	44.2 (12)	95	50.3 (18.1)	7.9 (3.14)
			S (<27)	4 (14%)	23.2 (4.3)	100	36.7 (14.9)	5.3 (0.6)
***Quercus rubra* (1+0)**		35.3	L (>49.1)	6 (13%)	60.5 (7.6)	50	63.7 (7.6)	9.2 (0.4)
Senjski rudnik	46	(13.8)	M	33 (72%)	34.7 (7.7)	54.5	37.8 (12.1)	6.4 (1.2)
			S (<21.5)	7 (15%)	16.4 (2.4)	57	29.2 (6.5)	5.3 (1.4)

Seedlings were normally distributed in classes according to both classification systems, based on initial H and D, with ~70% of seedlings in medium class (M = MV±SD), and ~15% in classes L and S (Table 1 and 2). Seedlings of *R. pseudoacacia* showed a wider variation of H with mean value of seedlings height in class L six times bigger than those in class S.

Both initial height and diameter were poorly related to seedlings survival after the first growing season at field (Figure 1 and Tables 1 and 2). Smaller seedlings of *R. pseudoacacia*, *F. excelsior,* and *Q. rubra*, survived at higher rate than the largest seedlings from class L. Only the survival of *U. laevis* at both sites increased with seedling size. Survival of *F. sylvatica* increased with increase of initial height, but this trend was not followed by initial diameter.

Table 2. Survival and growth of seedling classes based on initial diameter.

Species, Stocktype and Locality	Nr. of samples	D mean value in mm and (standard deviation)	Class (limits)	Nr. (and percentage) of seedlings in class	D1 (standard deviation)	Survival (%)	D2 (standard deviation)	H2 (standard deviation)
***Fagus sylvatica* (1+0)**		5,4	L (>6,9)	16 (16%)	7,9 (0,8)	62,5	8,9 (0,9)	33,6 (7,6)
Bukovik	98	(1,5)	M	69 (70%)	5,2 (0,9)	42	6,1 (0,9)	23,7 (6,5)
			S (<3,9)	13 (13%)	3,2 (0,5)	61,5	4,6 (0,8)	20,2 (4,8)
***Robinia pseudoacacia* (1+0)**		6	L (>8,4)	25 (15%)	10,3 (1,4)	84	20,9 (4,4)	193,6 (45,2)
Subotica	163	(2,4)	M	111 (68%)	5,7 (1,3)	87,4	19,3 (4,9)	176 (49,4)
			S (<3,6)	27 (17%)	2,9 (0,4)	96,3	18,3 (3,1)	165,9 (30,1)
***Ulmus laevis* (1+2)**		13,1	L(>16,4)	123 (16%)	18,4 (1,4)	88,6	24,8 (4)	230 (54,6)
Veliko Ratno Ostrvo	770	(3,3)	M	526 (68%)	12,9 (1,8)	87,6	20,5 (4,1)	204,4 (47,5)
			S (<9,8)	121 (16%)	8,4 (1)	73,55	17,6 (4,7)	163,6 (42,8)
***Ulmus laevis* (1+2)**		16,1	L (>20,1)	45 (16%)	22,2 (1,8)	91,1	24,8 (3,1)	197,6 (27,4)
Bostanište	280	(4)	M	197 (70%)	16 (2,2)	89,3	20,4 (3,1)	168,2 (25,8)
			S (<12,1)	38 (14%)	9,6 (1,9)	89,5	14,7 (2,2)	133,8 (29,1)
***Fraxinus excelsior* (2+0)**		8,5	L (>10,3)	8 (16%)	12,4 (1,2)	87,5	13,2 (1,3)	81,9 (15,1)
Stepin lug	50	(2,3)	M	30 (60%)	8,6 (1,2)	76,7	10,3 (1,7)	76,6 (22,6)
			S (<6,2)	12 (24%)	5,7 (0,4)	91,6	8,9 (2,4)	58,4 (19,5)
***Fraxinus excelsior* (1+0)**		4,3	L (>6,4)	15 (16%)	7,9B(1,7)	53,3	8,4 (1,1)	58,5 (19,1)
Senjski rudnik	92	(2)	M	65 (71%)	3,9 (1)	58	5,3 (1,4)	39,1 (11,9)
			S (<2,3)	12 (13%)	2 (0,1)	75	3,4 (0,5)	28,5 (3,7)
***Acer pseudoplatanus* (1+0)**		7,7	L (>11,3)	6 (21%)	13,5 (1)	100	15,6 (1,4)	88,8 (18,5)
Senjski rudnik	29	(3,6)	M	19 (66%)	6,6 (1,8)	95	8 (3,8)	48,8 (21,2)
			S (<4,1)	4 (14%)	3,3 (0,7)	100	5 (1,5)	45,2 (13,2)
***Quercus rubra* (1+0)**		6,5	L (>7,7)	8 (17%)	8,4 (0,5)	25	9,6 (1,1)	41 (8,5)
Senjski rudnik	46	(1,5)	M	30 (65%)	6 (1)	56,7	6,7 (1,2)	42,6 (16,5)
			S (<4,4)	8 (17%)	3,8 (0,6)	75	5,2 (1,2)	30,3 (5,8)

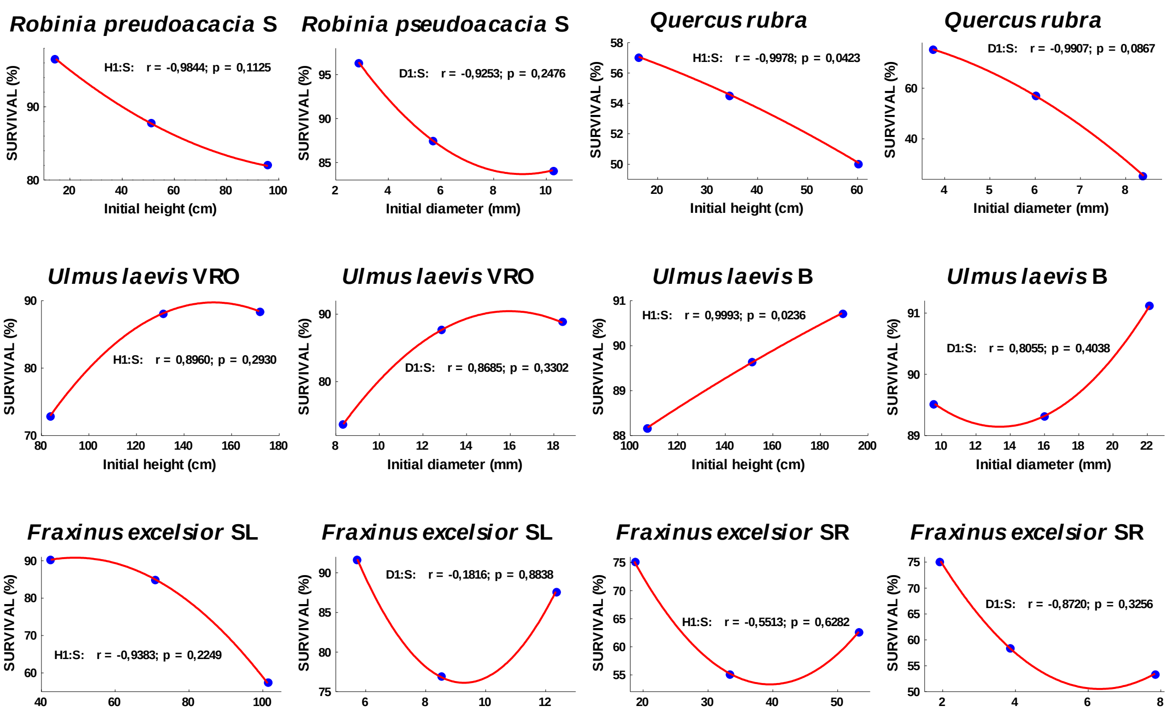

Figure 1. Relation between initial height and diameter and seedlings survival (only informative relations are shown).

Both initial height and diameter were equally good and better in forecasting of absolute growth than in forecasting survival after the first growing season on the field (Figures 2 to 7). Seedlings from class L based on both initial height and diameter kept their advantage and showed the largest absolute values of growth measured after the first growing season after planting on the field, even in the case of *F. excelsior* at both sites, where mean values of height decreased during growing season due to browsing.

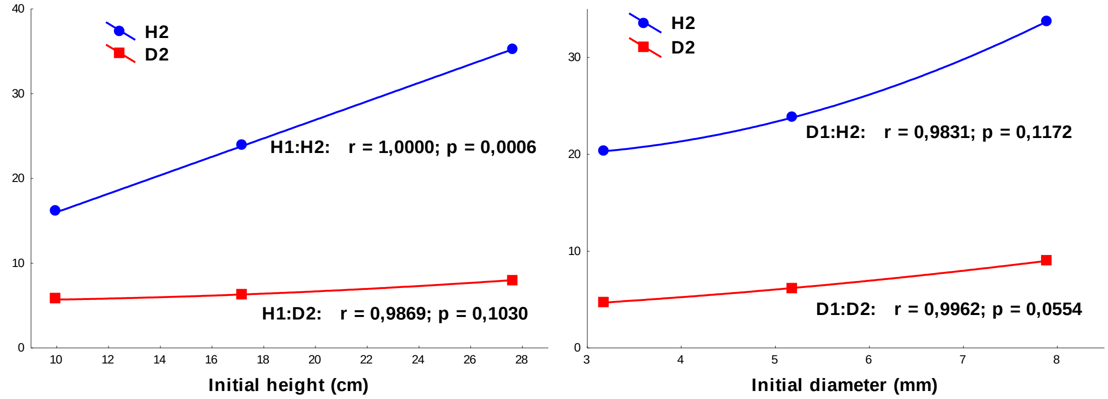

Figure 2. Relation between initial morphological attributes of *Fagus sylvatica* seedlings and absolute growth (H2 and D2) after the first growth season on the field.

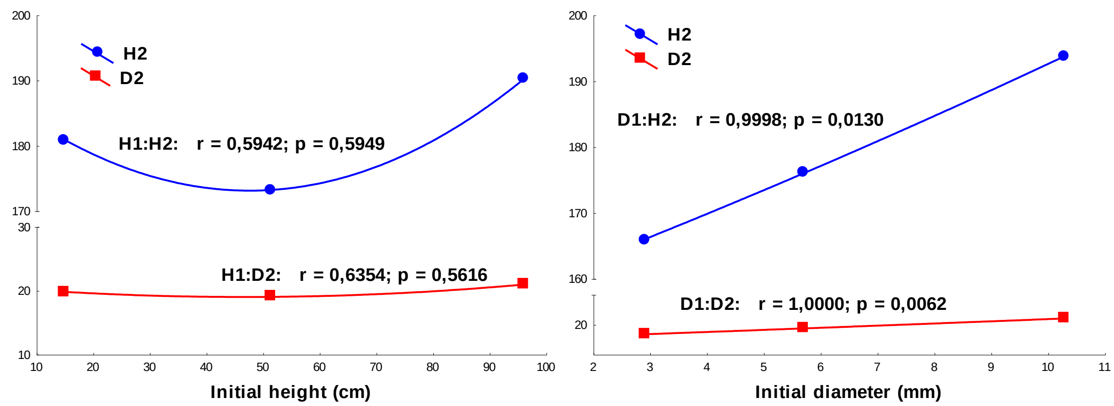

Figure 3. Relation between initial morphological attributes of *Robinia pseudoacacia* seedlings and absolute growth (H2 and D2) after the first growth season on the field.

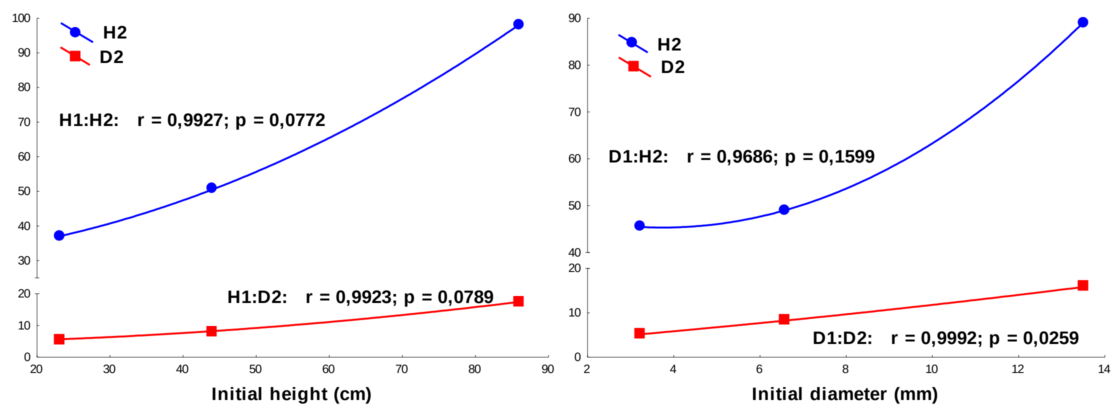

Figure 4. Relation between initial morphological attributes of *Acer pseudoplatanus* seedlings and absolute growth (H2 and D2) after the first growth season on the field.

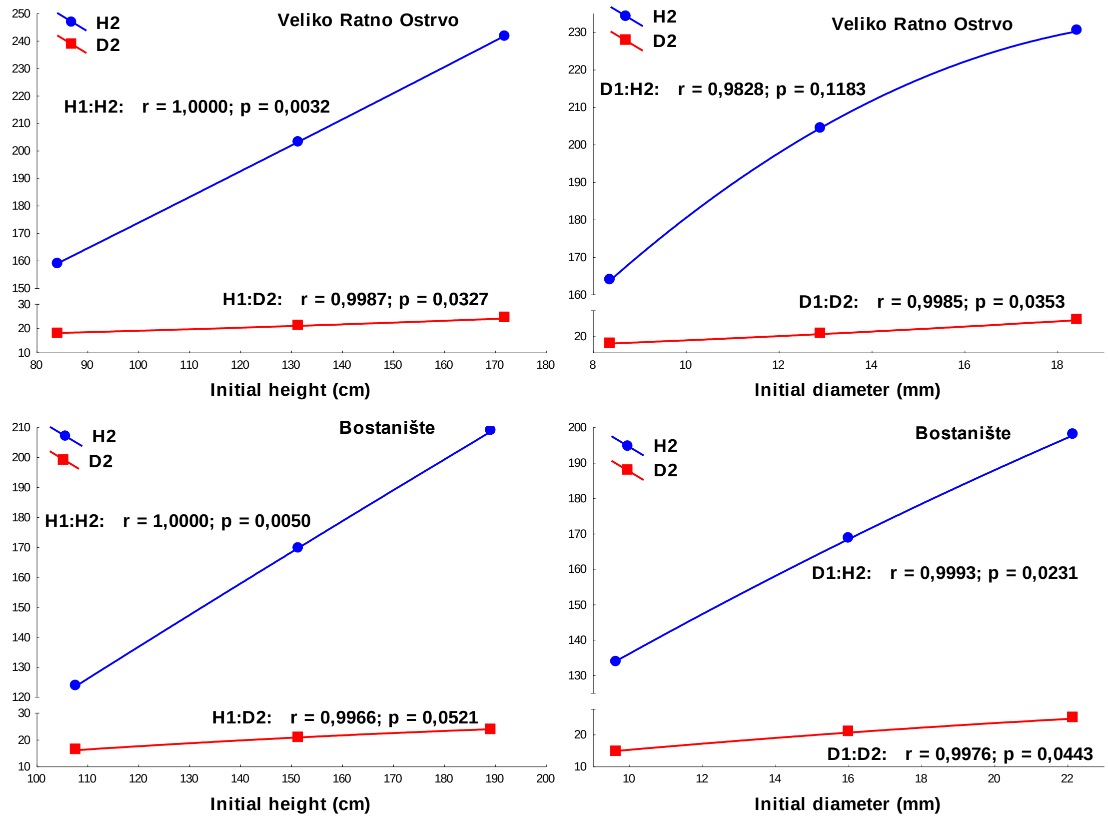

Figure 5. Relation between initial morphological attributes of *Ulmus laevis* seedlings and absolute growth (H2 and D2) after the first growth season on the field.

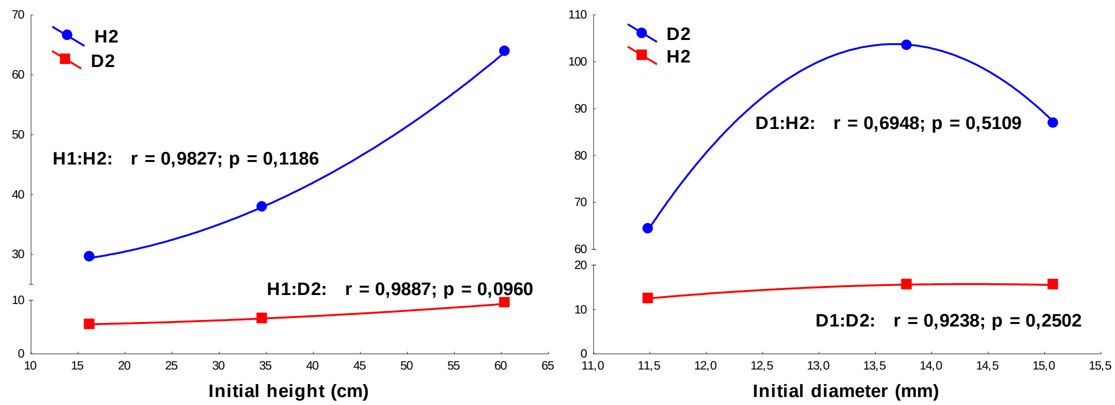

Figure 6. Relation between initial morphological attributes of *Quercus rubra* seedlings and absolute growth (H2 and D2) after the first growth season on the field.

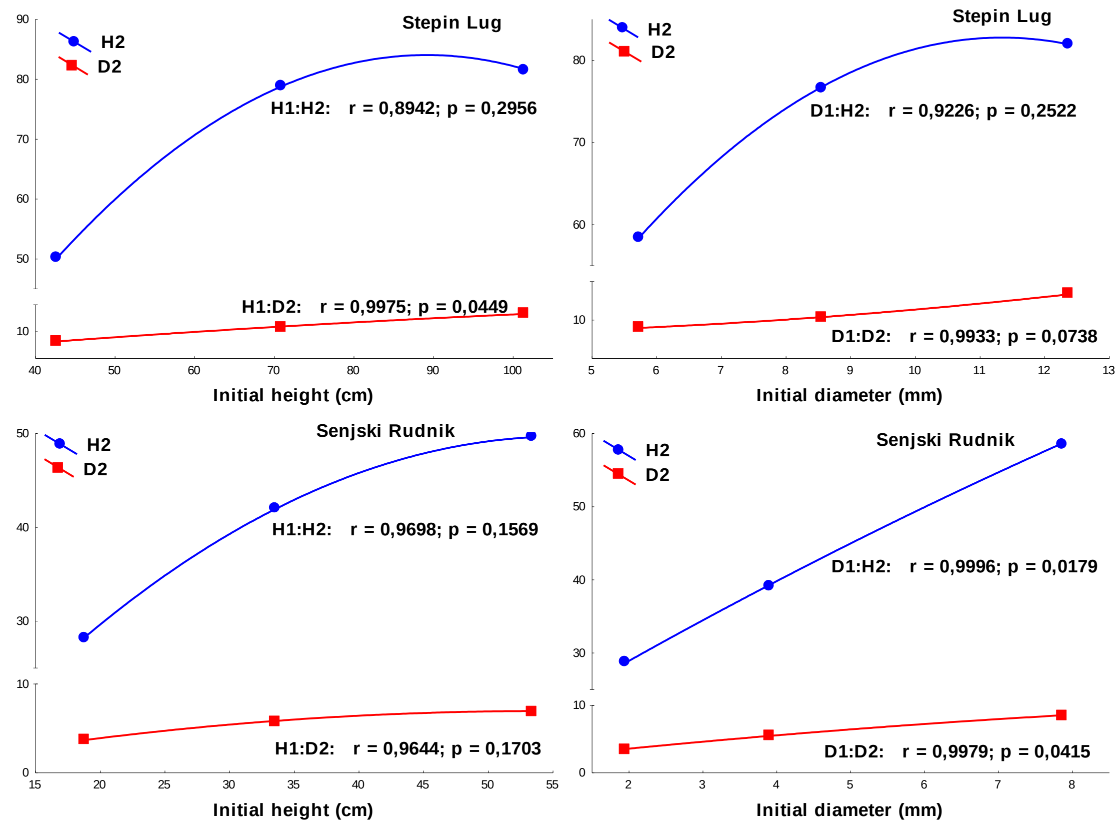

Figure 7. Relation between initial morphological attributes of *Fraxinus excelsior* seedlings and absolute growth (H2 and D2) after the first growth season on the field.

However, the smallest seedlings increased in both height and diameter at a much higher rate than larger seedlings (Figures 8 and 9). Seedlings from class S increased their height for 14% (*U. laevis* at site Bostanište) up to 1,109% (*R. pseudoacacia*), and diameter for 37% (*Q. rubra*) up to 529% (*R. pseudoacacia*). In the same time during the first growing season, seedlings from class L based on initial height increased their height for 5% (*Q. rubra*) up to 98% (*R. pseudoacacia*), with decreasing of height mean values of *F. excelsior* at both sites (-20% and -7% at Stepin Lug and Senjski rudnik, respectively). Seedlings from class L based on initial diameter increased diameter for 7% (*F. excelsior* at both sites) up to 104% (*R. pseudoacacia* at site Subotica).

4 Discussion

4.1 Seedlings initial size

There is a number of nursery cultural practices which influence bareroot seedling size (Duryea 1984; Thompson 1985; Mexal and South 1991; South et al. 2016). Seedlings used in this study were produced under standard nursery cultural practice in Serbian nurseries (Stilinović 1987), and they are used in regular reforestation programs. Seedlings of *F. sylvatica*, *R. pseudoacacia*, *F. excelsior*, and *A. pseudoplatanus* met all current acceptable standards for a 1st class plantable seedling for Serbian reforestation programs, as defined by The Serbian Standard for Hardwood Seedlings Quality SRPS D.Z2.112 (i.e., official document by Institute for Standardization of Serbia). *Ulmus laevis* and *Quercus rubra* are not part of this standard, but seedlings of *U. laevis* are comparable to sizes of seedling of the same stocktype reported by Cicek et al. (2007) and Devetaković et al. (2015). Seedlings of *Q. rubra* were much smaller than seedlings of the same stocktype reported by Franklin and Buckley (2006), but comparable to those reported by Ward et al. (2000). The fact that all seedlings met the minimal requirements for 1st class hardwood seedlings quality as defined by current standards, indicate the need for a revision. "Although designations for the primary types of seedlings have not changed much over the years, size and quality of most types have been improved significantly" (Owston 1990).

4.2 Seedlings initial size and survival

Larger seedlings grow better but often do not survive as well as smaller seedlings, if seedling physiological status is equal (Thompson 1985). In our study, smaller seedlings of *R. pseudoacacia*, *F. excelsior*, *A. pseudoplatanus*, and *Q. rubra* survived at higher rate, but this relation was not significant. Our results are consistent with negative correlation between initial H and survival after planting as previously reported for hardwoods (Rietveld and Van Sambeek 1989), but not consistent with previously reports for *Q. rubra* (Stilinović 1960; Franklin and Buckley 2006) with larger seedlings showing higher survival rate. In the same time, survival of *U. laevis* and *F. sylvatica* seedlings increased with size, consistent with evidence that larger seedlings survived better (Villar-Salvador et al. 2004; Tsakaldimi et al. 2005; Villar-Salvador et al. 2012). Hardwood seedlings with larger D survive better (Morrissey et al. 2010; Tsakaldimi et al. 2012), and additional ecophysiological research is required to explain reduced survival of seedlings with larger D in our study.

4.3 Seedlings initial size and growth

In many instances, initial seedling size affects field performance (as reviewed by Mexal and Landis 1990; Grossnickle 2012). In our study larger seedlings kept advantage in size after the first growing season in the field. Our results are consistent with previous reports on taller seedlings kept their height advantage over time after field planting (Schmidt-Vogt 1981; Thompson 1985; Grossnickle 2005; Anderson 2010) and positive correlation between initial seedling D and field growth of hardwood species (Rietveld and Van Sambeek 1989; Dey and Parker 1997; Aphalo and Rikala 2003; Jacobs et al. 2005; Bayala et al. 2009).

At the same time, smaller seedlings in our study grew at a higher rate. Similar results are reported for *F. excelsior* with the small tree transplants reached the height of the medium-sized transplants five years after planting, and for *A. pseudoplatanus*, with medium-sized tree transplants reached the height of the large transplants nine years after planting (Dostálek et al. 2014). Although shorter seedlings may have an advantage on droughty sites (Mexal and Landis 1990; Grossnickle 2012), we found the same relation for *U. laevis* at two sites flooded during the first growing season after field planting. The negative slope of a linear relationship between initial H and height growth increment indicate that seedlings were exposed to planting stress (South and Zwolinski 1997) as shown for all tested species in this study.

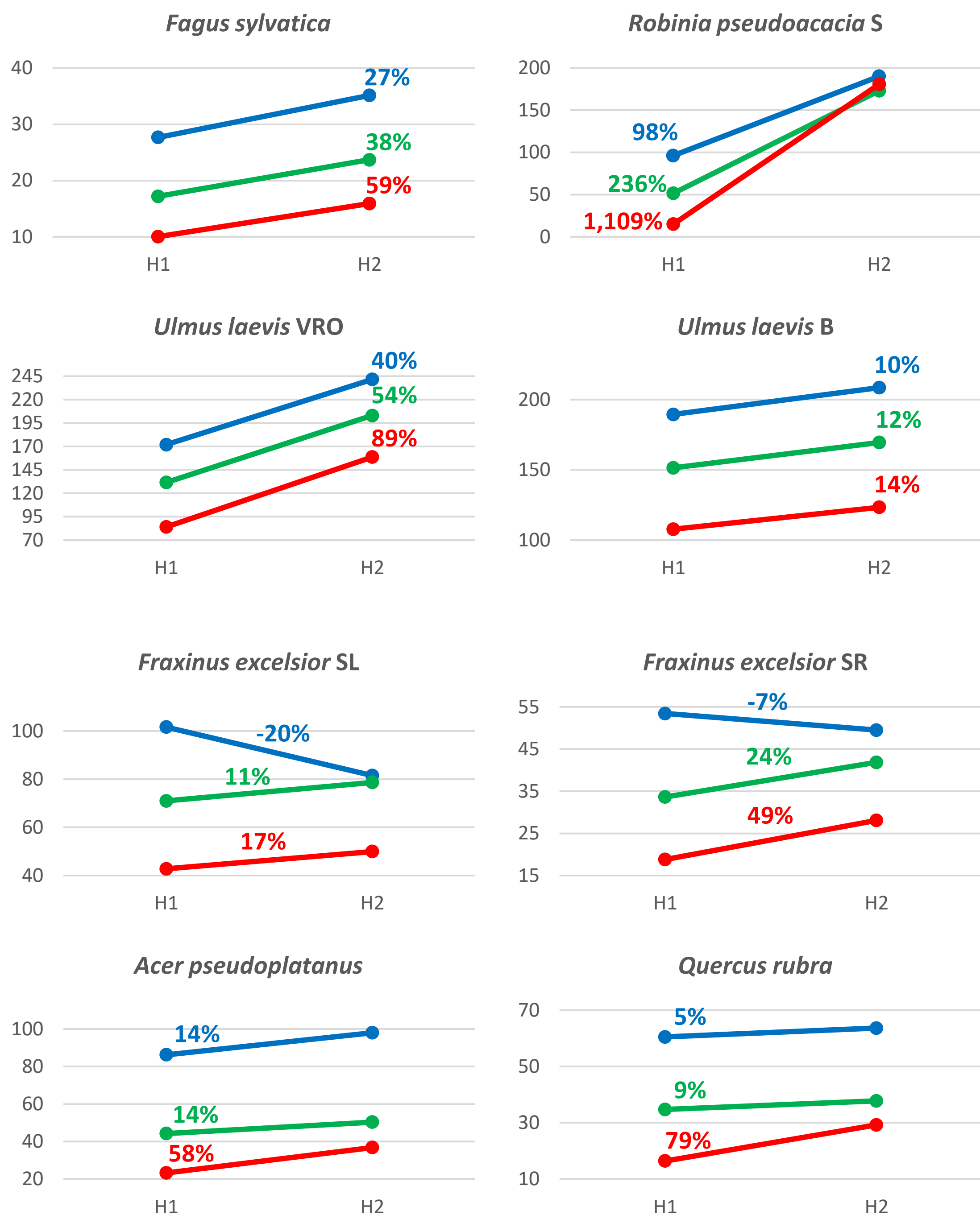

Figure 8. Height increment of class L (blue), M (green), and S (red) seedlings during the first growing season after planting on the field.

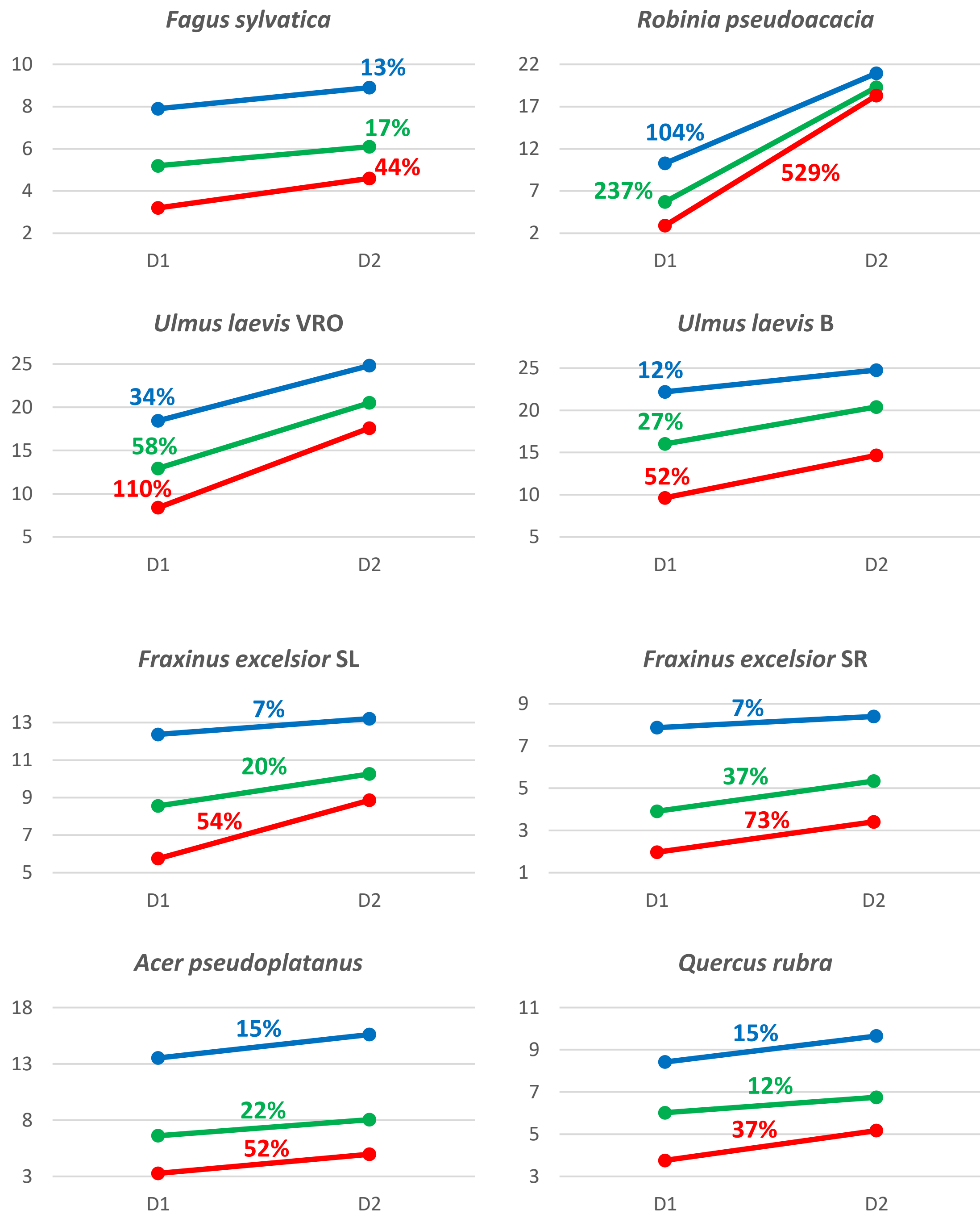

Figure 9. Diameter increment of class L (blue), M (green), and S (red) seedlings during the first growing season after planting on the field.

4.4 Height vs. Diameter

Initial seedling diameter is considered to be "the best predictor of survival, while height seems to predict height growth" (Mexal and Landis 1990). Diameter is reported as "the best single predictor of field survival and growth" (Thompson 1985) and considered as the single most useful morphological attribute to measure because it is a general measure of seedling sturdiness, root system size, and protection against drought and heat damage (Mexal and Landis 1990; Grossnickle 2012). Initial seedling D has provided consistent positive relationships with field performance in seedling quality tests with hardwoods (Wilson and Jacobs 2006), due to its strong correlation with many other important variables (Wilson and Jacobs 2006; Ivetić et al. 2013). Initial D of bareroot red oak seedlings was a better morphological indicator of height and diameter growth after field planting (Dey and Parker 1997). On the other side, for the one-year-old bareroot seedlings of *F. excelsior*, initial H (together with root morphology) is reported as the best criterion for selection of high quality seedlings (Maltoni et al. 2010). In our study we found that both initial H and D were better in forecasting growth than survival, and that both morphological attributes were equally related to field performance.

Simple, fast, and non-destructive measurements of aboveground morphological attributes are still best suited for most operational programs, especially if results are combined with knowledge about planting site conditions (Ivetić et al. 2016). Despite our findings that initial H and D were equal as indicators of after planting seedling performance, grading of seedlings only on a single morphological attribute should be avoided, since effects of initial morphological attributes on field survival and growth of hardwood seedlings were generally dependent on the other morphological parameters (Jacobs et al. 2012).

5 Conclusion

Initial seedling H and D were equally related to the field performance of six hardwood species and better in forecasting growth than survival. Relations between seedlings initial morphological attributes and survival was species specific, while for all tested species growth was positively correlated to seedling size at planting. Although large seedlings kept their advantage in size, smaller seedlings grow at higher rates. Both initial H and D should be considered equally important in operational programs for hardwoods seedling quality testing.

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