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Relation between Growth and Nutrient Content of Field-grown Tree Nursery Crops

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Summary

The concept of deducing nutrient uptake from shoot fresh or dry matter (ALT 1990) was reassessed for *Acer pseudoplatanus* and *Sorbus aucuparia*. These species are representatives of stress tolerator resp. competitor species, which differ in their allocation of biomass and nutrients to aboveground and belowground biomass. Competitor plants allocate more resources to the shoots, while stress tolerators invest more in root growth.

The experiment was carried out in a partly randomized block design with eight replications. One year old seedlings were planted in autumn 2003. Sampling took place in autumn 2004, 2005, and 2006. Fertilization was carried out with 'Entec blue special' (12+12+17) each May after an Nmin-analysis of the soil (0–60 cm) to give 60 kg N ha^{-1}. At sampling, plants were divided into this year's shoots, old shoots and into roots. Dry matter and N-, P-, and K-concentrations were determined in the different plant parts.

Sorbus a. had a higher shoot-to-root ratio than *Acer p*.. This is consistent with the growth habit of a competitor resp. stress tolerator species. In the shoot the concentration and content of N and K in most cases was higher in *Acer p*. than in *Sorbus a*., for P the differences were not as frequently. In the roots *Acer p*. always had a higher N-, P-, and K-concentration than *Sorbus a*., the fertilized *Acer p*. also had a higher content of these nutrients than *Sorbus a*..

The proportion of nutrients contained in this year's shoot decreased from 70–80 % for the two years old seedlings to approx. 48 % in the four years old tress. The proportion of N, P, and K stored in the roots differed widely. The N-content of this year's shoot in most cases was underestimated when deducing it from its dry matter. This was more pronounced for *Acer p*. compared to *Sorbus a*.

Key words. biomass partitioning – competitor species – nutrient partitioning – stress tolerator species

Introduction

For field grown tree nursery plants nutrient uptake and fertilization are based on the fresh or dry matter production of the total shoot or this year's shoot (ALT 1990; OBERMAYR and ALT 1992). The assumption is that nutrient concentrations are similar for different species and hence facilitates the calculation of nutrient contents. An addition is made for the roots independent from species. This addition amounts to 30 % for N, 70 % for P, and 65 % for K (P and K: seedlings older than one year) of the respective amount in the total shoot (ALT 1990).

Production of tree nursery plants covers a broad range of species and cultivars. In their natural habitats growth of trees and shrubs varies in relation to their position in the ecological succession. Competitor species are the first to colonize a site following disturbance. They rapidly respond to changing environmental conditions and try to maximize their shoot growth. Stress tolerator species are later successional species and invest more in root growth (GRIME 1979).

Fertilization in the tree nursery might result in different plant responses depending on the adaption of the plants to their habitats. Furthermore, root losses due to uprooting might affect tree species differently depending on the proportion of biomass and nutrients allocated to shoots and roots. From this, tree nutrition and fertilization is not only a topic of interest for nursery producers but also with regard to the transplanting success in the post-tree-nursery time (WATSON and HIMELICK 1982).

Considering species dependent growth reactions the following questions have to be answered:

- Is there a difference between a competitor and a stress tolerator species concerning their allocation of biomass to shoots and roots?
- Are there species related differences concerning their N-, P-, and K-concentrations in the shoot and in the roots?
- Is it possible to deduce nutrient contents from the above- and belowground biomass irrespectively of the species?

Materials and methods

Experimental design

The experiment was carried out with *Sorbus aucuparia* as a competitor and *Acer pseudoplatanus* as a stress tolerator

species. They were planted as one year old seedlings in autumn 2003. The factors were "species", "time" and "fertilization resp. no fertilization". A combination of species and fertilization was allocated to a block, which was replicated eight times and randomized on the experimental area. The blocks contained five trees. Within the blocks trees "two", "three" and "four" were randomized with regard to sampling date, while trees "one" and "five" were border trees.

Soil, fertilization, irrigation

The soil was a sandy soil with an organic matter content of 4.5–4.7 % in 0–30 cm depth and a pH of 6.5–6.7. Fertilization was carried out with 'Entec blue special' (12+12+17) each May after an Nmin-analysis of the soil to give 60 kg N ha^{-1}. During the experimental period of three years the mineral N-content in May ranged between 25 and 30 kg ha^{-1} (0–60 cm). The content of K_2O was in the category 'medium' (6–10 mg 100 g^{-1} soil), P_2O_5 was 'high' (11–20 mg 100 g^{-1} soil). Irrigation was carried out as drip irrigation starting at −150 hPa. The space between the plants was kept weed-free.

Plant measurements and analyses

At planting five plants per species were divided into shoots and roots and analysed for dry matter and N-, P-, K-concentrations. Shortly after planting the root neck diameter was marked with a permanent colour, root neck diameter and height of all plants were measured.

Sampling was carried out in October 2004, 2005, and 2006. At sampling root neck diameter and longest shoot of the respective plants were measured. The plants were carefully uprooted, extracting as much roots as possible. The trees were divided into this year's shoot and older shoot parts, depending on the year of sampling, and into roots. The leaves were analysed together with this year's shoots. The roots were carefully washed. Dry matter of the shoot parts and roots was determined after drying at 105 °C for each plant.

The dry matter of the shoot parts and of the roots was analyzed for N, P, and K. At the start (2003) and at the end (2006) of the experiment the analyses were carried out for each plant (five in 2003, eight per treatment in 2006), while in 2004 and 2005 mixed samples from identical plant parts of the eight replications were used. Nitrogen was analyzed by controlled burning with oxygen (Dumas method) and was measured in the form of originating gas (VarioMAX CN). To measure phosphorous and potassium the powdered plant material was ashed and then dissolved in 0.5 M HCl. Potassium was measured using the flame photometer, phosphorous was measured at 470 nm with a photometer.

Statistical evaluation

Statistical evaluation was carried out with the statistical software R 2.8 (2008) separately for the different sampling dates. This means that there is no multiplicity adjustment for the number of different sampling dates. All data were assumed to be normally distributed and showing homoscedasticity for each sampling date. Except for the plants at planting, an ANOVA was carried out to test for the influences of the factors "species" and "fertilization", and their interactions. Afterwards plant species were tested separately for the two fertilization levels with t-tests, and p-values were adjusted according to Holm (Holm 1979).

Table 1. Dry matter (g $plant^{-1}$) of shoots and roots and shoot-to-root ratio of fertilized (f.) and not fertilized (n. f.) *Acer pseudoplatanus* and *Sorbus aucuparia* at planting and at the end of three growing seasons. Means and standard deviations are presented. Different letters indicate statistical differences for P < 0.05. Upper and lower case letters refer to separate tests.

Time	Treatment		Dry matter shoots (g $plant^{-1}$)	Dry matter roots (g $plant^{-1}$)	Ratio shoot : root
2003	*Sorbus a.*		8.96 ± 3.4 a	6.0 ± 2.0 a	1.5 a
	Acer p.		3.65 ± 0.5 b	8.2 ± 2.0 a	0.5 b
2004	*Sorbus a.*	f.	172.3 ± 60.4 a	56.4 ± 14.3 a	3.1 a
		n. f.	163.0 ± 79.4 A	60.2 ± 25.5 A	2.7 A
	Acer p.	f.	120.3 ± 57.0 a	70.1 ± 28.5 a	1.7 b
		n. f.	135.0 ± 45.0 A	74.4 ± 15.2 A	1.8 B
2005	*Sorbus a.*	f.	821.5 ± 286.3 a	245.1 ± 71.4 a*	3.4 a
		n. f.	869.5 ± 216.5 A	289.9 ± 73.5 A*	3.0 A
	Acer p.	f.	918.0 ± 325.1 a	346.6 ± 100.4 a*	2.7 b
		n. f.	841.9 ± 231.1 A	351.5 ± 105.7 A*	2.4 B
2006	*Sorbus a.*	f.	1250.5 ± 462.6 a	517.4 ± 188.7 b	2.4 a
		n. f.	1141.9 ± 471.9 A	552.6 ± 197.4 A	2.1 A
	Acer p.	f.	1305.5 ± 411.7 a	796.0 ± 189.6 a	1.6 b
		n. f.	1081.4 ± 621.3 A	470.6 ± 229.2 A	2.3 A

f. = fertilized; n. f. = not fertilized; *significant for P < 0.1

Results

Plant growth

At planting (2003) and in the first year after planting (2004) *Sorbus aucuparia* was bigger than *Acer pseudoplatanus*. During the second and third year after planting (2005 and 2006) the differences between the species did not persist. The height of the plants was never influenced by fertilization. Root neck diameter was neither influenced by species nor by fertilization (data not shown).

Similar results were found for the dry matter of shoots. Only at planting *Sorbus a*. had more dry matter than *Acer p*. (Table 1). While for the shoot growth the differences between the species disappeared in the course of time, the opposite was the case for the roots. There were no differences in root dry matter between the species in 2003 and 2004. However, in 2005 *Acer p*. produced more root dry matter than *Sorbus a*. irrespective of fertilization (significant for $P < 0.1$). In 2006 the fertilized plants showed differences with *Acer p*. having a bigger root dry mass compared to *Sorbus a.*. Except for the not fertilized plants in 2006 the shoot-to-root ratio was significantly higher for *Sorbus a*. compared to *Acer p*. (Table 1).

N-, P-, K-concentration and content

For both species the nutrient concentrations decreased from the one to the four years old shoots. In most cases the roots showed the second highest nutrient concentrations (Table 2).

During the whole experimental period there was a trend for *Acer p*. having higher % N in all plant parts compared to *Sorbus a*. This was confirmed statistically at the last sampling date (2006) except for the two years old shoots. For P there was no clear distinction between *Acer p*. and *Sorbus a*. in the shoot, but in 2006 the concentration in the roots was higher for *Acer p*. compared to *Sorbus a*. (Table 2). The same applied to K in the roots, whereas in the shoot only the three and four years old shoots showed higher concentrations for *Acer p*. than for *Sorbus a*..

The N-, P-, K-content in this year's shoot always was higher than in single older shoot parts. The proportion contained in this year's shoot decreased with age of the trees from 75 % in two years old trees to 50 % in four years old trees (data averaged). There is no influence of species or fertilization. In this year's shoot the N- content was higher for *Acer p*. compared to *Sorbus a*., but this was significant in 2006 only for $P < 0.1$. The same applied for K in 2006, but without being significant. In contrast to N and K there is a trend for a higher P content in this year's shoot of *Sorbus a*. (Table 3).

In the roots *Acer p*. had higher N-, P-, and K-contents than *Sorbus a*.. This was significant for the fertilized *Acer p*. in 2006 (Table 3).

The fraction of nutrients stored in the roots related to the amount in the total shoot highly varied and was slightly different for the two species. Concerning N the range was 28–52 % for *Sorbus a*. and 34–56 % for *Acer p*. For P the variation was between 18 and 63 % for *Sorbus* and 35–91 % for *Acer*, and for K between 22 and 45 % for *Sorbus* and 33–85 % for *Acer* (Table 3).

Discussion

Plant growth

According to German quality regulations for tree nursery crops both the four years old *Sorbus aucupari*a and *Acer pseudoplatanus* achieved the standards for trees of this age (Gütebestimmungen für Baumschulpflanzen 2004).

Plant growth was not influenced by fertilization. Similar results were already found by Dierend (1992). Nutrient uptake by woody plants is small and often met by the supply of the soil.

For *Sorbus a.* and *Acer p.* a different partition of biomass between aboveground and belowground parts was expected according to their characterization as competitor resp. stress tolerator species. Competitor species (here *Sorbus a*.) invest more in the aboveground biomass especially under high fertility levels as opposed to stress tolerator species (here *Acer p*.), which direct more resources to the roots (Canham et al. 1996).

Concerning the aboveground growth expected differences between the species were found only in the first two years of the experimental period. However, differences between the species appeared with time in root growth. Non-fertilized three years old *Acer p*. and fertilized four years old *Acer p*. had a higher root dry matter than *Sorbus a*. and hence behaved as stress tolerator species. This is also reflected in the shoot-to-root ratio, which always was bigger for *Sorbus a*. compared to *Acer p*.. Similar results were found by Larimer and Struve (2002) for *Quercus rubra* (stress tolerator) and *Acer rubrum* (competitor). Fertilization slightly increased the shoot-to-root ratio for *Sorbus a*., a typical reaction of a competitor species. High shoot-to-root ratios potentially lower plant quality (Harris 1992).

Hence under the prevailing circumstances in the tree nursery the allocation of biomass still showed the adaption of the trees to different habitats. Similar results were found by Rincón and Huante (1994), who investigated pioneer species and mature forest species in silica sand with different nutrient regimes.

If species dependant responses are neglected, the significance of root growth can be underestimated for those species which direct more resources to the roots. Roots remain in the soil due to uprooting for transplanting. The implication of this root loss for the transplanting success will be more severe for trees with a higher proportion of roots in relation to their shoot, particularly if fine roots are left in the soil. Gordon and Jackson (2000) found for N, P, and Mg, but not for K, a significant inverse relationship between root diameter and nutrient concentration. Also Rademacher (2005) reported high nutrient concentrations in fine roots. The root system is a very important factor for successful establishment after transplanting (Grossnickle 2005) to minimize water stress (South and Zwolinski 1996), to retranslocate stored nutrients for shoot growth and to use stored carbohydrates for energy demand when photosynthesis is still restricted (Davis and Jacobs 2005; Wilson and Jacobs 2006).

N-, P-, K-concentration and content

Nutrient concentrations and contents are difficult to compare with data from literature since the results even for a specific species depend on site, plant age, and analysed

Table 2. N, P, K (%) in shoots and roots of fertilized (f.) and not fertilized (n. f.) *Acer pseudoplatanus* and *Sorbus aucuparia* at planting and at the end of three growing seasons. Means and standard deviations are presented. Different letters indicate statistical differences for $P < 0.05$. Upper and lower case letters refer to separate tests.

Time	Treatment		Part of the plant				
			Shoot				Root
			One year	Two years	Three years	Four years	
			% N in dry matter				
2003	*Sorbus a.*		1.72 ± 0.14 a				2.4 ± 0.22 a
	Acer p.		1.84 ± 0.13 a				2.0 ± 0.43 a
2004	*Sorbus a.*	f.	1.63	0.63			1.4
		n. f.	1.72	0.69			1.7
	Acer p.	f.	2.49	1.31			2.0
		n. f.	2.45	1.37			2.0
2005	*Sorbus a.*	f.	1.02	0.39	0.35		0.6
		n. f.	1.12	0.48	0.41		0.8
	Acer p.	f.	1.85	1.14	1.18		1.3
		n. f.	1.34	0.44	0.61		1.0
2006	*Sorbus a.*	f.	1.59 ± 0.30 b	0.69 ± 0.08 a	0.39 ± 0.05 b	0.43 ± 0.11 a	0.6 ± 0.18 b
		n. f.	1.46 ± 0.22 B	0.71 ± 0.13 A	0.36 ± 0.08 B	0.29 ± 0.05 B	0.6 ± 0.15 B
	Acer p.	f.	1.92 ± 0.23 a	0.84 ± 0.29 a	0.52 ± 0.09 a	0.48 ± 0.06 a	0.8 ± 0.13 a
		n. f.	1.91 ± 0.20 A	0.78 ± 0.10 A	0.57 ± 0.06 A	0.53 ± 0.09 A	0.9 ± 0.19 A
			% P in dry matter				
2003	*Sorbus a.*		0.22 ± 0.02 a				0.3 ± 0.06 a
	Acer p.		0.20 ± 0.02 a				0.3 ± 0.02 a
2004	*Sorbus a.*	f.	0.19	0.09			0.3
		n. f.	0.22	0.16			0.3
	Acer p.	f.	0.22	0.15			0.3
		n. f.	0.22	0.16			0.3
2005	*Sorbus a.*	f.	0.40	0.08	0.06		0.1
		n. f.	0.37	0.09	0.07		0.2
	Acer p.	f.	0.33	0.09	0.07		0.1
		n. f.	0.23	0.07	0.06		0.1
2006	*Sorbus a.*	f.	0.35 ± 0.12 a	0.13 ± 0.02 a	0.06 ± 0.01 a	0.05 ± 0.04 b	0.1 ± 0.03 b
		n. f.	0.28 ± 0.09 A	0.13 ± 0.02 A	0.07 ± 0.02 A	0.04 ± 0.05 B	0.1 ± 0.02 B
	Acer p.	f.	0.20 ± 0.03 b	0.11 ± 0.03 a	0.08 ± 0.01 a	0.08 ± 0.08 a	0.2 ± 0.02 a
		n. f.	0.22 ± 0.04 A	0.11 ± 0.02 B	0.08 ± 0.01 A	0.08 ± 0.08 A	0.2 ± 0.02 A
			% K in dry matter				
2003	*Sorbus a.*		0.59 ± 0.04 a				1.0 ± 0.17 a
	Acer p.		0.43 ± 0.08 b				0.5 ± 0.10 b
2004	*Sorbus a.*	f.	0.68	0.25			0.5
		n. f.	0.74	0.29			0.6
	Acer p.	f.	0.64	0.40			0.8
		n. f.	0.60	0.41			0.8
2005	*Sorbus a.*	f.	0.57	0.18	0.17		0.2
		n. f.	0.61	0.20	0.18		0.3
	Acer p.	f.	0.98	0.44	0.41		0.5
		n. f.	0.64	0.30	0.33		0.6
2006	*Sorbus a.*	f.	0.78 ± 0.15 a	0.30 ± 0.05 a	0.17 ± 0.04 b	0.15 ± 0.01 b	0.3 ± 0.05 b
		n. f.	0.70 ± 0.11 A	0.30 ± 0.03 A	0.19 ± 0.04 B	0.14 ± 0.01 B	0.3 ± 0.03 B
	Acer p.	f.	0.88 ± 0.15 a	0.38 ± 0.11 a	0.31 ± 0.10 a	0.33 ± 0.08 a	0.5 ± 0.02 a
		n. f.	0.80 ± 0.19 A	0.37 ± 0.15 A	0.35 ± 0.11 A	0.33 ± 0.06 A	0.5 ± 0.04 A

f. = fertilized; n. f. = not fertilized

Table 3. Amount (g plant^{-1}) of N, P, K in shoots and roots of fertilized and not fertilized *Acer pseudoplatanus* and *Sorbus aucuparia* at planting and at the end of three growing seasons. Means and standard deviations are presented. Different letters indicate statistical differences for $P < 0.05$. Upper and lower case letters refer to separate tests.

Time	Treatment		Part of the plant						One year old shoot	Roots
			Shoot					Roots		
			One year	Two years	Three years	Four years	Total shoot		(% of total shoot)	
			N in dry matter (g plant^{-1})							Fraction of N
2003	*Sorbus a.*		0.16 ± 0.06 a				0.16	0.14 ± 0.05 a		93
	Acer p.		0.07 ± 0.01 b				0.07	0.16 ± 0.03 a		239
2004	*Sorbus a.*	f.	1.37	0.56			1.93	0.77	71	40
	Sorbus a.	n. f..	1.41	0.56			1.97	1.02	72	52
	Acer p.	f.	1.92	0.56			2.48	1.37	77	55
	Acer p.	n.f.	2.26	0.59			2.84	1.49	80	52
2005	*Sorbus a.*	f.	3.36	0.95	0.87		5.18	1.45	65	28
	Sorbus a.	n. f..	3.91	1.11	1.18		6.20	2.35	63	38
	Acer p.	f.	6.61	3.71	2.78		13.09	4.51	50	34
	Acer p.	n.f.	3.99	1.28	1.54		6.81	3.62	59	53
2006	*Sorbus a.*	f.	3.93 ± 1.62 a*	1.55 ± 0.48 a	1.27 ± 0.59 a	1.66 ± 0.71 a	8.66 a^{+}	3.26 ± 2.01 b	45	38
	Sorbus a.	n. f..	3.49 ± 1.40 A*	1.49 ± 0.57 A	0.87 ± 0.57 A	1.18 ± 0.46 A	8.03 A^{+}	3.19 ± 1.48 A	43	40
	Acer p.	f.	6.56 ± 3.37 a*	1.26 ± 0.70 a	2.30 ± 1.13 a	1.55 ± 0.51 a	11.67 a	6.49 ± 1.88 a	56	56
	Acer p.	n.f.	5.47 ± 2.42 A*	1.41 ± 1.12 A	1.98 ± 1.53 A	1.23 ± 0.53 A	10.07 A	4.00 ± 1.77 A	54	40
			P in dry matter (g plant^{-1})							Fraction of P
2003	*Sorbus a.*		0.02 ± 0.01 a				0.02	0.02 ± 0.01 a		100
	Acer p.		0.01 ± 0.07 b				0.01	0.02 ± 0.01 a		200
2004	*Sorbus a.*	f.	0.16	0.08			0.24	0.15	67	63
	Sorbus a.	n. f..	0.18	0.09			0.27	0.17	67	63
	Acer p.	f.	0.17	0.06			0.23	0.21	74	91
	Acer p.	n.f.	0.20	0.07			0.27	0.23	74	85
2005	*Sorbus a.*	f.	1.30	0.19	0.16		1.65	0.29	79	18
	Sorbus a.	n. f..	1.29	0.20	0.22		1.70	0.48	76	28
	Acer p.	f.	0.80	0.28	0.18		1.26	0.44	63	35
	Acer p.	n.f.	0.68	0.21	0.17		1.06	0.45	64	42
2006	*Sorbus a.*	f.	0.97 ± 0.67 a	0.30 ± 0.09 a	0.23 ± 0.11 a	0.19 ± 0.07 a	1.75 a^{+}	0.67 ± 0.35 b	55	38
	Sorbus a.	n. f..	0.73 ± 0.41 A	0.28 ± 0.11 A	0.16 ± 0.11 A	0.18 ± 0.08 A	1.61 A^{+}	0.62 ± 0.29 A	45	39
	Acer p.	f.	0.71 ± 0.45 a	0.17 ± 0.10 b	0.32 ± 0.15 a	0.25 ± 0.11 a	1.46 a	1.29 ± 0.36 a	49	88
	Acer p.	n.f.	0.65 ± 0.33 A	0.19 ± 0.13 A	0.27 ± 0.21 A	0.18 ± 0.09 A	1.29 A	0.79 ± 0.39 A	50	61
			K in dry matter (g plant^{-1})							Fraction of K
2003	*Sorbus a.*		0.05 ± 0.02 a				0.11	0.06 ± 0.02 a		120
	Acer p.		0.02 ± 0.02 b				0.07	0.04 ± 0.01 a		200
2004	*Sorbus a.*	f.	0.57	0.21			0.80	0.28	71	36
	Sorbus a.	n. f..	0.60	0.23			0.84	0.37	71	45
	Acer p.	f.	0.49	0.17			0.66	0.55	57	83
	Acer p.	n.f.	0.55	0.18			0.73	0.62	75	85
2005	*Sorbus a.*	f.	1.87	0.46	0.42		2.75	0.60	68	22
	Sorbus a.	n. f..	2.14	0.46	0.53		3.13	0.89	68	28
	Acer p.	f.	3.06	1.45	0.96		5.46	1.80	56	33
	Acer p.	n.f.	1.62	0.86	0.84		3.33	2.02	49	61
2006	*Sorbus a.*	f.	1.96 ± 0.83 a	0.68 ± 0.24 a	0.61 ± 0.24 b	0.60 ± 0.22 a	4.29 a^{+}	0.95 ± 0.80 b	46	25
	Sorbus a.	n. f..	1.77 ± 0.94 A	0.64 ± 0.24 A	0.47 ± 0.28 A	0.57 ± 0.19 A	5.17 A^{+}	1.38 ± 0.52 A	34	40
	Acer p.	f.	3.04 ± 1.58 a	0.62 ± 0.38 a	1.25 ± 0.49 a	1.10 ± 0.54 a	6.01 a	4.17 ± 1.03 a	51	69
	Acer p.	n.f.	2.38 ± 1.40 A	0.66 ± 0.50 A	1.27 ± 1.19 A	0.85 ± 0.55 A	5.16 A	2.47 ± 1.35 A	46	48

f. = fertilized; n. f. = not fertilized; * = significant for $P < 0.1$; $^{+}$ = fruits included

plant part (Rademacher 2005). Rauch (1998) found for *Acer pseudoplatanus* of similar age (five years old) but different growth conditions in this year's shoots 0.72–0.81 % N, 0.09–0.10 % P, and 0.58–0.70 % K. The corresponding data for two years old shoots are 0.6 % N, 0.08 % P, and 0.05–0.08 % K. In the roots he recorded 0.86–1.13 % N, 0.15–0.17 % P, and 0.56–0.59 % K. While the nutrient concentrations in the roots were similar to those presented here, the shoots had lower concentrations, especially in this year's shoot. This might indicate that environmental conditions influence the various tree components differently with highest impact on the currently growing shoot (Augusto et al. 2000).

With few exceptions the N-, P-, K-concentration in the shoot was higher in *Acer p*. than in *Sorbus a*.. In the roots *Acer p*. always showed higher N-, P-, K-concentrations than *Sorbus a.*. Species related differences in nutrient concentration were also reported for *Quercus petraea* and *Carpinus betulus* (André and Ponette 2003) and for *Quercus rubra* and *Acer rubrum* (Larimer and Struwe 2002). Rademacher (2005) found decreasing nutrient contents for pine < spruce < oak < beech. Species related nutrient concentrations question if nutrient contents can be deduced from fresh resp. dry matter as proposed by Alt (1990) and Obermayr and Alt (1992).

Total shoot (Alt 1990) resp. this year's shoot (Obermayr and Alt 1992) is the base for estimating nutrient uptake and fertilization. Looking at nutrient contents in this year's shoot, species related differences were measured for N with *Acer p*. showing a higher N-content than *Sorbus a*. In some cases differences occurred in older shoot parts with the same relation between *Acer p*. and *Sorbus a*.. K behaved similar to N while for P the trend was converse, *Sorbus a*. showing a higher amount than *Acer p*..

Table 4 compares the nutrient content in the total shoot according to Alt (1990) with results from this experiment. For N the content according to Alt in most cases is underestimated. This underestimation increased with time. It was more pronounced for *Acer p*. compared to *Sorbus a*., which is in accordance with the higher N-concentration and -content especially in this year's shoot of *Acer p*. (Table 2 and 3). Concerning P calculated data tend to underestimate measured ones for *Sorbus a*. which also agrees with data in Table 2 and 3, and overestimate P-contents in the four years old *Acer p*.. For K both over- and underestimation of measured compared to calculated data exists, but without a clear distinction between the species. In contrast to Alt (1990) P- and K-content of the shoots were calculated including leaves.

Relationships between total aerial biomass and nutrient content were also given by Augusto et al. (2000). For European beech there were significant relations for N, K, and Mg, but not for P and Ca. According to Alban (1979) tree species is a parameter which directly influences this relation.

In the two years old trees with few exceptions the proportion of N, P, and K contained in this year's shoot is between 70–80 %. For transplanting, the shoot grown in this vegetation period partly is pruned back. Removal of a fraction with a high nutrient content reduces the nutrient reservoir for new growth (Rytter 2002). The fraction of N, P, and K in this year's shoot decreased with age of

Table 4. Comparison of the N, P, and K content (kg ha^{-1}) of the shoot calculated according to Alt (1990) and measured in the experiment.

Time	Treatment		Dry matter		N-content (kg ha^{-1})		P_2O_5-content (kg ha^{-1})		K_2O-content (kg ha^{-1})	
			(g plant^{-1})	(kg ha^{-1})#	Alt[1)]	meas.	Alt[2)]	meas.	Alt[3)]	meas.
2003	*Sorbus a.*		9	99	1					
	Acer p.		4	41	1					
2004	*Sorbus a.*	f.	172	1912	25	21	6	6	9	11
	Sorbus a.	n. f.	163	1809	23	22	6	7	9	11
	Acer p.	f.	120	1335	17	27	4	6	6	9
	Acer p.	n. f.	135	1498	19	31	5	7	7	10
2005	*Sorbus a.*	f.	821	9118	49	57	28	42	44	37
	Sorbus a.	n. f.	870	9652	52	69	30	43	46	42
	Acer p.	f.	918	10189	55	145	32	32	49	73
	Acer p.	n. f.	842	9345	50	76	29	27	45	44
2006	*Sorbus a.*	f.	1251	13881	75	96	43	45	67	57
	Sorbus a.	n. f.	1142	12675	68	89	39	41	61	69
	Acer p.	f.	1306	14491	78	129	45	37	70	80
	Acer p.	n. f.	1081	12004	65	112	37	33	58	69

f. = fertilized; n.f. = not fertilized

11100 plants ha^{-1}

1) 1000 kg ha^{-1} dry matter ~ 12.9 kg N ha^{-1} for 1 to 2 years old plants, ~ 5.4 kg N ha^{-1} for 4 years old plants

2) 1000 kg ha^{-1} dry matter ~ 3.1 kg P_2O_5 ha^{-1}

3) 1000 kg ha^{-1} dry matter ~ 4.8 kg K_2O ha^{-1}

trees. For the four years old trees this proportion was only 48 % (averaged for nutrients and species). However, fertilization must not be based solely on the nutrient demand of this year's shoot but take into account N storage in older tree compartments (GESSLER et al. 2004). N-storage and remobilization processes from the whole tree N-pool are important strategies for trees with their long life span in changing environments (MILLARD 1996) and favour the transplanting success.

Concerning the roots there is a trend for *Acer p*. having higher amounts of N, P, and K than *Sorbus a*.. At the end of three years this was statistically significant for the fertilized *Acer p*.. *Acer p.* allocated more biomass and more nutrients to its roots compared to *Sorbus a*. This is consistent with a stress tolerator species growth habit.

The fraction of N contained in the roots in most cases was higher than 30 %, which was given by ALT (1990). The fraction of P and K in the roots varied widely. For P the range was between 18 % and 88 % (average 54 %), for K a range between 22 % and 85 % (average 48 %) was found. The corresponding average data given by ALT (1990) are 70 % for P and 65 % for K (seedlings older than one year). The results presented here confirm Alt's statement concerning the high variability even for one species and a specific age.

Conclusions

The growth habit of *Acer pseudoplatanus* and *Sorbus aucuparia* as a stress tolerator resp. a competitor species has been retained unchanged when growing under tree nursery conditions. This had consequences for their allocation of shoot and root biomass. The stress tolerator species had a lower shoot- to- root ratio than the competitor species. Moreover, *Acer p*. always had higher N-, P-, and K-concentrations in its roots than *Sorbus a*.. Due to the function of roots as reservoir for nutrients and carbohydrates root losses in the course of transplanting will affect the stress tolerator species to a bigger degree than the competitor species.

Deducing the nutrient content from fresh or dry matter of this year's shoot in most cases underestimated their N-content. Due to its higher N-concentration this was more pronounced for *Acer p*. compared to *Sorbus a*. For P and K both under- and overestimation was found but without a specific trend. Hence Alt's method can be considered suitable for P and K. For N, however, species related differences in the nutrient concentration question if the nutrient content can be calculated from their fresh or dry matter.

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