Biomass, Nitrogen and Phosphorus Allocation in Above-ground Parts of Black Alder (*Alnus glutinosa* (L.) Gaertn.) Plantations

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Data for present study were collected in Estonia from three 21-year-old experimental plantations of black alder. One of the plantations was established on a periodically excessively moist meadow, the second on a spruce and grey alder clearing and the third on a wasteland produced as a result of oil-shale mining. Dimension analysis techniques were used to estimate the above-ground biomass of the plantations. The total amount of the above-ground biomass obtained from the experimental plots was 88.8 to 100.6 t ha^{-1}. Above-ground nitrogen supply in the plantations formed 442.6 to 500.8 kg ha^{-1} and phosphorus supply formed 28.5 to 102.9 kg ha^{-1}. The biggest amount of nitrogen (57.3 to 67.1 %) and phosphorus (71.1 to 83.0 %) was allocated in stems.

Key words: Estonia, *Alnus glutinosa*, biomass, nitrogen, phosphorus, plantation

Introduction

In recent decades problems concerning the growth of deciduous trees have become particularly urgent in Central and Northern Europe. Earlier establishment of conifer stands was widely recommended in these areas. Several changes have taken place in Estonian forestry policy where conifers are no longer given priority. Deciduous species have become to be valued in sustainable forestry which is aimed at maintaining already existing forests and promoting the development of deciduous forests or mixed deciduous-coniferous stands. The attention attracted by deciduous species is caused by increased energy needs as well as by the possibility to afforest abandoned agricultural areas. Besides, every year some wasteland is produced as a result of oil-shale mining in North-East Estonia where conditions for growth are extreme. Owing to its ability to fix atmospheric nitrogen in symbiosis with the genus *Frankia*, to enrich the soil with nitrogen, and at the same time to produce a considerable amount of biomass and high quality timber, black alder is a preferred species in afforestation activities on nutritionally poor soils.

Issues related to the development of energy plantations on the basis of grey alder (*Alnus incana* (L.) Moench.) and willows (*Salix* Spp.) and cultivation of birch and aspen on agricultural lands are quite topical in Estonia at present. Along with other tree species that have a relatively high growing rate one should not neglect high potential indigenous species, e.g. black alder (*Alnus glutinosa* (L.) Gaertn.). So far black alder has been cultivated in Estonia mainly for experimental purposes in quite small areas. However, there have been conducted no thorough investigations, focusing on the biomass, productivity and nutrient supply of black alder in Estonia.

The aim of the present study was to estimate the allocation and supply of above - ground biomass, major mineral nutrients (N,P) in 21-year-old black alder plantations located at different sites in Estonia.

Material and methods

Study sites

Data for the present study were collected from the experimental plantations of the black alder, developed in forest districts of Rimmu (Songa experimental site), Meeksi (Parapalu experimental site) and Sirgala (Sirgala experimental site) in the spring of 1978. The planting stock was grown in the greenhouse of the tree-nursery of the Estonian Forestry Institute in 1977. Cultivated seedlings were one year old, with an average height of 30 cm (Hainla, 1985; Tamm, Vares, 1996). The distance between planting rows was variable, 1 to 3 m in different plantations. The distance between the plants in a row was 1.25 m.

One of the plantations was established on a periodically excessively moist meadow (*Carex-Filipendula* site type on Eutri Histic Gleysol; 58°20'N 27°24'E), the second on a spruce and grey alder clearing (*Aegopodium-Dryopteris* site type on Calcari-Luvic Gleysol; 58°19'N 25°21'E) and the third on a wasteland produced as a result of oil-shale mining (59°17'N 27°44'E). The preliminary aim of the experimental plantations was to evaluate the possibilities of cultivating black alder and to identify the influence of mother trees on the growth and development of their offspring. The characteristics of the studied black alder plantations are presented in Table 1.

Table 1. Characteristics (± standard error) of the studied black alder plantations: mean age, dbh, basal area, stock and LAI (leaf area index).

Site	Age (yr)	Trees per ha	dbh (cm)	Height (m)	Basal area ($m^2\,ha^{-1}$)	Stock ($m^3\,ha^{-1}$)	LAI (m^2m^{-2})
Parapalu	21	2788	10.4±0.2	12.4±0.2	23.5	153	5.1
Songa	21	1530	13.9±0.3	15.1±0.2	23.2	172	4.0
Sirgala	21	2300	12.4±0.2	13.4±0.2	27.9	189	3.8

Biomass and nutrient estimation

Dimension analysis techniques (Borman and Gordon, 1984; Lõhmus et al., 1995) were used to estimate the above-ground biomass. In 1998 the diameter at breast height, tree height and height of the beginning of the living crown of trees were measured at study sites. The obtained data served as the basis for later selection of model trees. The trees were categorised into five diameter classes (the 1st diameter class – the smallest trees, the 5th diameter class – the largest trees). In early August one tree from each diameter class was felled for estimation of biomass and nutrient content. In Songa and Sirgala, one model tree was felled additionally from the average diameter class. The crowns of selected model trees were classified into five sections of which the first included the lowest, and the fifth the uppermost part of the crown. In each crown section, the length and the largest diameter as well as the fresh mass of all branches were measured, and one model branch from each section was chosen for further analysis. An important requirement in the selection of the model branch was that its parameters would be close to the average data of the respective section.

The stem was divided into 1 m sections whose weight was determined. Sample disks from five different heights (0 m, 1.3 m, ½ of the naturally pruned stem, beginning of the living crown and upper third of the crown) were taken to find the concentration of dry matter and nutrients in the stem. After Saarsalmi (1989), this number of samples allows to obtain nutrient concentration with sufficient accuracy.

The leaves and current year shoots of model branches were separated, and each branch was divided into three fractions (with bark) of a different diameter ($d < 5$ mm, 5 mm $\leq d <$ 10 mm and $d \geq$ 10 mm). The fresh mass of the samples was determined, and subsamples were taken for chemical analysis and for estimation of dry matter concentration. All subsamples were dried at 70°C until constant weight.

For estimation of the biomass of tree compartments, the following allometrical equation (1) was used:

$$\ln y = a + b \ln dbh \qquad (1)$$

where y is the dry mass of a biomass compartment (kg) and dbh is the overbark diameter at breast height.

Laboratory analysis

Plant samples were analysed for total Kjeldahl nitrogen (Tecator AN 300) and phosporus (Tecator ASTN 133/94) at the Laboratory of the Estonian Agricultural University.

Results and discussion

Several authors have found strong relationships between alder dimensions and dry mass (Bormann and Gordon, 1984; Helgerson et al., 1988; Luken and Fonda,1983; Lõhmus et al., 1995; Vares, 1999). In this study allometrical relationships between the biomass compartments of black alder (leaves, branches, stembark, stemwood) and the diameter at breast height were also strong. All equations had considerably high correlation coefficients and low levels of significance (Table 2).

The above-ground biomass of the studied 21-year-old black alder plantations was 88.8 to 100.6 t ha^{-1} (Table 3). Despite extremely different site conditions, differences in biomass between the stands were small. In accordance with literature data (Pregent and Camiré, 1985), black alder as a rapidly growing tree species is

Table 2. Parameters of regression equations used in dimension analysis for estimation of the mass of a tree compartment (kg); R^2 is the coefficient of determination, s.e.e. is the standard error of the estimate and p is the level of significance.

Site	Tree compartment mass (kg)	a	b	R^2	s.e.e.	p
Parapalu	Stemwood	-3.094	1.325	0.984	0.20	<0.001
	Stembark	-3.616	1.068	0.970	0.23	<0.002
	Branches	-5.579	1.400	0.920	0.49	<0.009
	Leaves	-4.855	1.114	0.978	0.20	<0.001
Songa	Stemwood	-2.313	1.590	0.996	0.05	<0.005
	Stembark	-3.200	0.998	0.995	0.05	<0.001
	Branches	-5.915	1.461	0.984	0.14	<0.001
	Leaves	-7.389	1.582	0.904	0.39	<0.004
Sirgala	Stemwood	-2.031	1.101	0.974	0.14	<0.001
	Stembark	-3.102	0.959	0.925	0.21	<0.002
	Branches	-6.786	1.549	0.938	0.30	<0.002
	Leaves	-6.090	1.246	0.908	0.35	<0.006

Table 3. Biomass, mineral nutrient concentration (% in dry matter) and supply in the studied plantations of black alder

		Biomass		Nitrogen		Phosphorus	
Site	Tree fraction	(t ha^{-1})	(kg tree^{-1})	(%)	(kg ha^{-1})	(%)	(kg ha^{-1})
Parapalu	**Stems,**	**76.9**	**27.6**		**309.6**		**20.3**
	wood	65.7	23.6	0.27	177.4	0.024	15.8
	bark	11.2	4.0	1.18	132.2	0.040	4.5
	Branches,	**7.9**	**2.8**		**63.5**		**3.7**
	primary growth	1.2	0.4	1.26	15.5	0.079	1.0
	secondary growth	6.7	2.4	0.72	48.0	0.041	2.7
	Leaves	**4.0**	**1.4**	3.14	**125.6**	0.114	**4.6**
	Total	**88.8**	**31.9**		**498.7**		**28.5**
Songa	**Stems,**	**80.2**	**52.4**		**187.2**		**80.6**
	wood	68.3	44.6	0.22	150.3	0.095	64.9
	bark	11.9	7.8	1.15	136.9	0.132	15.7
	Branches,	**1.5**	**6.3**		**94.4**		**13.5**
	primary growth	0.6	0.4	1.74	11.0	0.219	1.4
	secondary growth	9.0	5.9	0.93	83.4	0.135	12.1
	Leaves	**4.2**	**2.7**	2.84	**119.3**	0.211	**8.9**
	Total	**94.0**	**61.4**		**500.8**		**102.9**
Sirgala	**Stems,**	**90.8**	**39.5**		**196.9**		**84.9**
	wood	78.0	33.9	0.21	163.8	0.087	67.9
	bark	12.8	5.6	1.04	133.1	0.133	17.0
	Branches,	**7.0**	**3.0**		**57.2**		**10.8**
	primary growth	0.5	0.2	1.67	7.5	0.233	1.0
	secondary growth	6.5	2.8	0.77	49.7	0.152	9.8
	Leaves	**2.9**	**1.3**	3.05	**88.5**	0.223	**6.5**
	Total	**100.6**	**43.7**		**442.6**		**102.2**

able to produce a large amount of biomass; the above-ground biomass of a four-year-old black alder plantation can be as much as 15.8 t ha^{-1}. It can be concluded that black alder has high potential to produce biomass, while soils with a phosphorus and magnesium deficit are also suitable for cultivation of this species.

Considering the allocation of above-ground biomass in the studied plantations, the stemwood forms the biggest share, 72.8 to 77.4 %, while stembark makes up 12.4 to 12.9 % of total above-ground biomass. The proportion of branches in total above-ground biomass varies from 7.1 to 10.3 % and that of leaves from 2.9 to 4.5 % (Figure 1). Somewhat higher percentage of foliage can be noted in case of dominant trees. The share of stembark in dry mass of stems was 14.3 to 16.9 %, while it was higher in lower and upper stem parts. The proportion of stembark was higher in suppressed trees than in dominant trees. Stembark allocation trends in the studied black alder stands were similar to those observed in Finland (Björklund, 1984; Lehtonen et al., 1978).

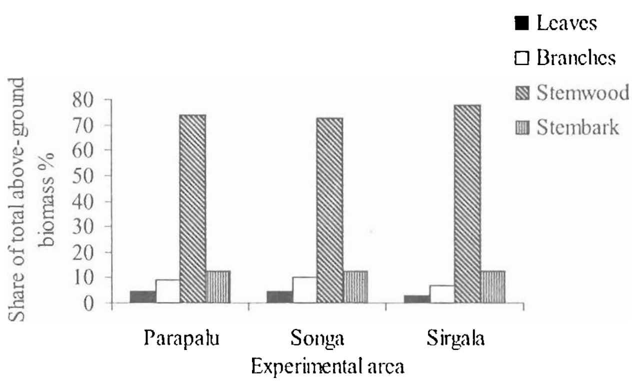

Figure 1. The allocation of above-ground biomass in the studied 21-year-old plantations of black alder.

When comparing different tree fractions, a significant characteristic is dry matter concentration which, after Wittwer and Immel (1978), averages 47 % for black alder. In the present study the average concentration (± standard error) of dry matter was estimated at 47.2±0.6 %, being the highest in stemwood, 54.2±0.7 %, and the lowest in leaves, 35.0±0.5 %.

Productivity of forest ecosystems is closely related to the availability of nutrients, particularly nitrogen and phosphorus. In experimental areas, nitrogen concentration in the leaves of black alder was 2.84 to 3.14 %, in current year shoots 1.26 to 1.74 %, in branches 0.72 to 0.93 %, and in stembark 1.04 to 1.15 % (Table 3). The lowest concentration of nitrogen (0.21 to 0.27 %) was measured in stemwood. In all cases the concentration of phosphorus was the highest in leaves (0.114 to 0.233 %) and the lowest in stemwood (0.024 to 0.095 %). Hence, the leaves of black alder contained over three times more nitrogen than branches and over twelve times more nitrogen compared with stemwood. The data of nitrogen concentration in alder leaves, provided by different researchers, vary a great deal, from 2.57 to 3.47 % (Coté and Dawson, 1986; Llinares et al., 1992; Tarrant and Trappe, 1971). The concentration of phosphorus varies from 0.207 to 0.231 %. After Mikola (1958) nitrogen concentration in alder leaves ranges usually from 2 to 3 %, which means that it is 2-3 times higher than in the leaves of the other European deciduous tree species. Besides, the nitrogen in the leaves of alder is easily mineralized (Mikola, 1958; Dawson and Funk, 1981). In accordance with literature data the concentration of phosphorus in the different parts of black alder trees is slightly higher than observed in the Parapalu plantation, which should be attributed to differences in growing conditions. In Songa and Sirgala the concentration of phosphorus was similar to that given in the literature data (Pregent and Camiré, 1985; Rodriques-Barrueco et al., 1984).

Variability of nitrogen and phosphorus concentrations was also analysed. Multifactorial analysis of variance revealed that the concentration of nutrients varied in different parts of model trees significantly. Hereby, the concentration of nutrients in the leaves, branches and current year shoots was not dependent on the crown section. The concentration of nutrients was significantly higher ($p<0.05$) in stembark than in stemwood, which is caused by the specific chemical composition of the latter. However, the concentration of nutrients in stemwood and stembark did not depend on the height of sample taking (0 m, 1.3 m, ½ of the naturally pruned stem, beginning of the living crown and upper third of the living crown).

The concentration of nutrients was investigated separately for different branch fractions. The results showed that the concentration of nitrogen and phosphorus was significantly different ($p<0.05$) in different fractions of branches, while within the branch it increased considerably in the direction of the top. After Miidla (1984), the concentration of phosphorus is highest in younger plant parts, which is also confirmed by my data. Moreover, nitrogen and phosphorus are able to retranslocate from older plant compartments to younger ones.

In general, nitrogen supply was quite similar in all three investigated plantations (Table 3). Still, the highest value was measured at Songa (500.8 kg ha^{-1}) and the lowest at Parapalu (442.6 kg ha^{-1}). Thus, black alder is able to assimilate and fix large amounts of nitrogen irrespective of different growing conditions in Estonia. The largest supply of nitrogen (57.3 to 67.1 %) was found in stems (wood+bark). Branches accounted for 12.7 to 18.8 % of total nitrogen supply, while leaves accounted for 20.0 to 25.2 % (Figure 2).

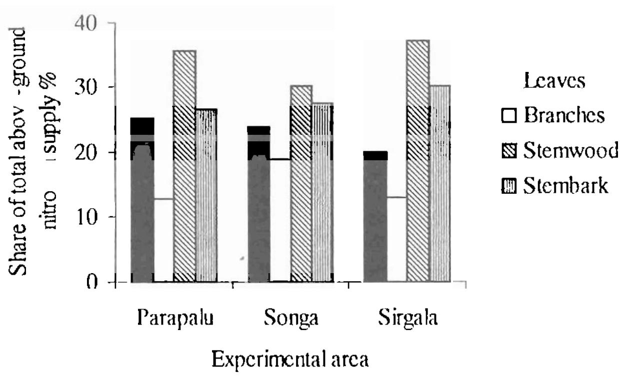

Figure 2. The allocation of above-ground nitrogen supply in the studied plantations of black alder

Since estimation of nitrogen supply does not yield information about derivation of nitrogen, this problem requires further investigation. Nitrogen fixing plants are thought to derive approximately half of required nitrogen from atmosphere (Lindblad and Guerrero, 1993). It has been shown that grey alder can cover up to 55 % of its nitrogen demand via biological fixation (Rytter et al., 1991), but this figure depends on environmental factors. In accordance with literature data, about 94 % of nitrogen in the leaves of black alder can be derived from atmosphere, while the tree is able to meet most of its nitrogen need through biological fixation (Beaupied et al., 1990).

The above-ground supply of phosphorus was similar at Songa and Sirgala but was different at Parapalu where it was seven times lower than in the other plantations (Table 3). The difference in phosphorus supply between Parapalu and other plantations may be caused by extremely different growing conditions. The highest supply of phosphorus was found in stems (wood+bark), 71.1 to 83.0 %. Only 10.6 to 13.1 % of phosphorus was found in branches and 6.3 to 16.0 % in leaves (Figure 3).

Conclusions

1. In Estonia, the most suitable areas for cultivation of black alder are forest lands and also periodically excessively moist lands no longer used in agricul-

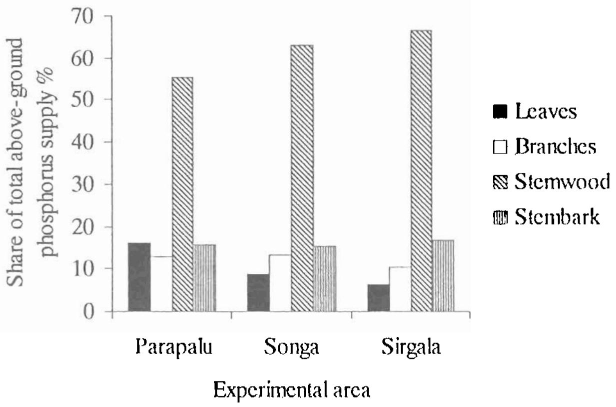

Figure 3. The allocation of above-ground phosphorus supply in the studied plantations of black alder

ture (meadows, etc.), where growth of many other species may tend to be poor or fail altogether. Black alder is also a suitable species for afforesting wastelands produced as a result of oil shale mining.

2. The total amount of the above-ground biomass obtained from the plantations was 88.8 to 100.6 t ha^{-1}. The biggest share of above-ground biomass (wood+bark) was allocated in stems (85.3 to 90.3 %).

3. The concentration of total nitrogen and phosphorus in branches in the studied black alder plantations increased in the direction to the top of branch, thus the younger compartments contained more of these elements. The concentration of total nitrogen and phosphorus was significantly higher in stembark than in stemwood, which is caused by the specific chemical composition of the latter.

4. The above-ground supply of total nitrogen in the black alder plantations formed 442.6 to 500.8 kg ha^{-1} and that of phosphorus, 28.5 to 102.9 kg ha^{-1}. The biggest share of total nitrogen (57.3 to 67.1 %) and phosphorus (71.1 to 83.0 %) supply was found in stems (wood+bark).

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РАСПРЕДЕЛЕНИЕ БИОМАССЫ АЗОТА И ФОСФОРА В НАДЗЕМНЫХ ЧАСТЯХ ДЕРЕВЬЕВ В КУЛЬТУРАХ ЧЁРНОЙ ОЛЬХИ (*ALNUS GLUTINOSA* (L.) GAERTN.)

А. Варес

Резюме

Данные для настоящей работы были собраны из трёх 21-летних опытных культур ольхи чёрной в Эстонии. Одна пробная площадь заложена на периодично увлажнённом сенокосе, вторая на вырубке ели и ольхи серой, а третья на залежи, возникшей на уравнённой площади, где раньше добывали сланец.

Для определения надземной биомассы в культурах использовали дименсионный анализ. Общее количество надземной биомассы на пробных площадях учитывали 88.8 до 100.6 т га$^{-1}$. Количество общего азота в надземных органах культур составило 442.6 до 500.8 кг га$^{-1}$ и количество фосфора 28.5 до 102.9 кг га$^{-1}$. Наивысшее количество общего азота (57.3 до 67,1%) и фосфора (71.1 до 83.0%) находилось в стволах.

Ключевые слова: Эстония, *Alnus glutinosa*, азот, фосфор, биомасса, культура.