Nutrient Allocation, Accumulation and Above-Ground Biomass in Grey Alder and Hybrid Alder Plantations

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The aim of the present work was to investigate the nutrient (N,P,K) allocation and accumulation in grey alder (*Alnus incana* (L.) Moench) and hybrid alder (*Alnus incana* (L.) Moench × *Alnus glutinosa* (L.) Gaertn.) plantations growing on former agricultural land and to estimate the above-ground biomass production during 4 years after establishment. In August of the 4th year, when leaf mass was at its maximum, the amount of nitrogen accumulated in above-ground biomass of grey alder stand was 142.0 kg ha^{-1}, the amount of phosphorus 16.3 kg ha^{-1} and the amount of potassium 49.5 kg ha^{-1}. The amount of nitrogen accumulated in a hybrid alder stand totalled 76.8 kg ha^{-1}, that of phosphorus 6.2 kg ha^{-1} and that of potassium 28.2 kg ha^{-1}. The smaller amounts of N,P and K bound in the hybrid alder plantation are related to the smaller biomass of the stand. Still, the amounts of N,P and K consumed for the production of one ton of biomass were similar in the case of up to 4-year-old grey alder and hybrid alder stands. In the 4th year, the amount of nutrients consumed in one ton of biomass produced were: 16.0 kg N, 1.6 kg P and 5.4 kg K for grey alder and 14.6 kg N, 1.1 kg P and 5.2 kg K for hybrid alder.

In the 4th year the total above-ground biomass (dry mass) of grey alder (15 750 plants ha^{-1}) amounted to 12.3 t ha^{-1}, current annual increment being 6.7 t ha^{-1}. In hybrid alder stands (6700 plants ha^{-1}), the respective figures were 6.1 t ha^{-1} and 4.5 t ha^{-1}. Comparison of the production capacity on the basis of mean stem mass in the 4th year revealed that the stem mass of grey alder exceeded that of hybrid alder (0.64 kg and 0.58 kg, respectively). Grey alder outpaced hybrid alder in height growth; in the 4th year after establishment, the mean height of the grey alder stand was 4.6 ± 0.9 m and that of the hybrid alder plantation 3.5 ± 0.9 m.

Keywords *Alnus incana*, *Alnus incana* × *Alnus glutinosa*, grey alder, hybrid alder, nutrient allocation, nutrient accumulation, biomass
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1 Introduction

Recent decades have witnessed a change in the economic situation of Estonia. Agricultural production has declined, and there are now about 223 000 ha of abandoned agricultural land (Meiner 1999). The prices of fossil fuel have soared, which has stimulated research into the application of wood and peat in power generation. Issues related to establishment and utilisation of energy forests have come to the foreground. As a rule, energy forests are defined as plantations of fast-growing short-rotation tree species that give as large biomass production as possible in the shortest period (Slapokas 1991, Hytönen et al. 1995).

In the nearest Nordic countries, Finland and Sweden, most studies have addressed the use of willows, birches and grey alders as energy forests both on mineral and organic soil (Granhall 1982, Elowson and Rytter 1988, Rytter et al. 1989, Slapokas 1991, Hytönen et al. 1995, Saarsalmi 1995, Rytter 1996), where willows are generally the most rapidly growing species (Saarsalmi 1995, Hytönen 1996). In Estonia, the first energy forests were established in collaboration with the Swedish University of Agricultural Sciences in 1993–1995 (Koppel 1996, Koppel et al. 1996).

Although the production capacity of grey alder is not as high as that of some willow species and its clones, grey alder has several advantages that make it a promising species for short-rotation forestry. It grows rapidly, is symbiotically N_2-fixing by the actinomycete *Frankia*, and has only a few pests and diseases. After cutting, a new alder generation emerges by coppicing from the root system, hence artificial reforestation is not needed. Grey alder seedlings also withstand direct sunlight and frost.

Alder forests are typical riparian ecosystems in Europe, which can retain and transform nutrient fluxes from adjacent intensively exploited territories. Therefore, riparian alder stands are commonly evaluated as buffer zones for protecting water-bodies against pollution (Mander et al. 1995, Lõhmus et al. 1996, Mander et al. 1997).

Up to quite recent time grey alder was not cultivated in Estonia. The first experimental plantation on former agricultural land was established in 1995 with the aim to study the possibilities of using this species in an energy forest as well as to estimate its impact on soil fertility on abandoned farmlands.

In Estonia as well as in the other Baltic countries, hybrid alder (*Alnus incana* (L.) Moench × *Alnus glutinosa* (L.) Gaertn.) is rather rare in nature. The study of hybrid alder shows that its growth in natural conditions can be more rapid than that of grey alder or black alder (Pirag 1962). Hybrid alders are as yet not well studied in Estonia. However, Granhall (1982) suggests that they can be considered promising species in short-rotation forestry. Hybrid alder may present interest also in the aspect of timber industry, because the quality of its wood is intermediate between that of grey alder and black alder, while wood increment is faster compared with black alder (Pirag 1962).

The working hypothesis of the present investigation was that both grey alder and hybrid alder are suitable species for afforestation of former agricultural land. Grey alder is primarily a promising short-rotation energy forest species, while hybrid alder can be considered for long rotation cultivation for timber industry. Since afforestation is usually practiced on less fertile arable land, the nutrient consumption and efficiency of these species present special interest. Alders are of perspective in afforestation of abandoned agricultural land, because they are very fast growing and enrich the soil with nitrogen. Since neither grey alder nor hybrid alder have been cultivated in Estonia earlier, this pilot study is expected to provide an assessment of their suitability in the given conditions.

The objectives of the present paper were the following:

1) to estimate nutrient (N,P,K) allocation, consumption and accumulation in the above-ground parts of grey alder and hybrid alder;
2) to estimate the above-ground biomass production and allocation dynamics in grey alder and hybrid alder plantations.

2 Material and Methods

2.1 Establishment and Management of the Experiments

The experimental plantation of grey alder was established in 1995 on former farmland. As grey alder had not been cultivated in Estonia, it was impossible to use a nursery-grown planting stock. 1–2-year-old natural plants of generative or vegetative origin were used (Uri and Tullus 1999). In the present study only seedlings of generative origin were used. The growth of plants of different origin has been discussed earlier (Uri and Tullus 1999). Planting density was 0.7×1.0 m and the total area of the plantation was 0.08 ha. The plantation was established with a high primary density proceeding from the high natural density of a grey alder stand and considering the experience of the Nordic countries energy forestry, where a stand density of up to 40 000 trees ha^{-1} was used (Elowson and Rytter 1988, Saarsalmi 1995).

The experimental plantation of hybrid alder was established next to the grey alder plantation in 1996. Two-year-old nursery-grown seedlings were used. Since according to literature the production of hybrid alder exceeds that of grey alder (Pirag 1962) and hybrid alder stands grow higher than grey alder stands, the planting density was 1.0×1.5 m, i.e. almost twice as low as in the case of grey alder. The area of the plantation was 0.2 ha. The established alder plantations were not tended. As both plantations grow on the same former field, their soil conditions are similar. According to FAO classification the soil in both grey alder and hybrid alder plantations was classified as Planosol. Concentrations of Kjeldahl nitrogen, phosphorus and available potassium in upper 20 cm soil layer were 1050, 22.5 and 212.5 mg kg^{-1}, respectively; percentage of organic matter and pH_{KCl} 2.40% and 5.9, respectively. Before afforestation the field had been out of agricultural use 1 year in the case of grey alder and 2 years in the case of hybrid alder.

2.2 Estimation of Nutrient Accumulation

The concentrations of major nutrients (N,P,K) were determined annually in different biomass compartments of the sample trees. In 1997–1998, the nutrient concentrations were analysed both in different height sections and in trees belonging to different height classes. The stem was divided into sections according to annual height increment so that the base as well as middle part and upper part of the tree were represented. For analysing nutrient concentration, the crown was divided into three sections and the stem into four sections. To estimate the impact of tree size (hierarchical position of a tree in the stand) on nutrient concentration, the lowest, medium and highest model tree were used. As the nutrient concentrations of different tree compartments change seasonally and dynamically, the present paper regards the accumulation of these nutrients in the above-ground parts of trees in the maximum leaf mass period in August.

Nutrient concentrations in different compartments of the sample trees were calculated as a weighted average, i.e. taking into account the section's share in the biomass of the respective compartment of the whole tree as well as the nutrient concentration of the respective section. On the basis of the concentrations of the chemical element in the compartment, accumulated nutrient content in the year concerned was calculated for the above-ground part. For estimating the amounts of the nutrients bound in annual biomass production, the annual production of a particular compartment was multiplied by the respective nutrient concentration.

The plant samples were analysed for total Kjeldahl nitrogen, total Kjeldahl phosphorus, potassium and ash content. Block digestion and steam destillation methods were used for measuring the nitrogen content of the plant material (Tecator AN 300). Digestion by flow injection analysis was used to analyse the plant material for Kjeldahl phosphorus content (Tecator ASTN 133/94). To analyse the plant material for potassium, flame photometric method was employed. The analyses were performed at the Biochemistry Laboratory of the Estonian Agricultural University.

2.3 Estimation of Above-Ground Biomass

The above-ground biomass of the plantations was determined annually in August when the formed leaf mass was the largest. Dimension analysis (Bormann and Gordon 1984, Lõhmus et al. 1996) was used to estimate above-ground biomass. In both plantations the height and the diameter of all trees were measured (the root collar diameter was measured in 1995 and 1996 and the breast height diameter in 1997–1999). On the basis of height (in 1995–1997) or diameter distribution (from 1998), 7 sample trees from each plantation were felled, except in the first year after planting when one medium sample tree from the grey alder plantation and three sample trees from the hybrid alder plantation were used for biomass determination. The trees were divided into five classes on the basis of the height or diameter and a model tree was selected randomly from each class. Additionally, a tree was felled from two classes with a larger number of trees. In all cases the sample trees were felled from the middle of the plantation to avoid the border effect. In the sections, the tree was divided into compartments: leaves, primary growth of branches, old branches and stem (wood+bark). From every compartment, a subsample was taken for the determination of dry matter content. The subsamples were weighed fresh, dried at 70ºC to constant weight and reweighed to 0.01 g. The proportion of the wood and bark of the stems was determined. The dry mass of different compartments was calculated for each sample tree by multiplying the respective fresh mass by the dry matter content.

In the first year after planting, the above-ground dry biomass of the plantations was calculated on the basis of an average sample tree because of the small dimensions of the planting stock. To estimate the biomass of the above-ground part of the plantation, (y), for the following years a regression equation (1) was used:

$$y = ax^b \tag{1}$$

Both for grey alder and hybrid alder the independent variables with the highest coefficient of determination, dh and d^2h, respectively, were used. The parameters of the regression equation are presented in Table 1. These parameters have been published earlier (Uri and Tullus 1999). The masses of different compartments were calculated using the percentage distribution of the fractions obtained on the basis of the sample trees.

Table 1. The parameters of the regression equation $y = ax^b$ for estimation of above ground biomass (from Uri and Tullus 1999). Probability level $p < 0.001$ in all cases. y – dry mass (g), d – diameter (cm), h – height (m), a and b – constants, R^2 – coefficient of determination, S.E. – standard error of estimate.

	x	*a*	*b*	R^2	S.E.
Grey alder					
2nd year	dh	3.059	1.406	0.991	0.12
3rd year	dh	3.791	1.252	0.960	0.17
4th year	dh	2.503	1.655	0.996	0.06
Hybrid alder					
2nd year	d^2h	3.331	0.881	0.976	0.20
3rd year	d^2h	4.838	0.633	0.906	0.34
4th year	d^2h	4.336	1.212	0.974	0.24

The annual production of the stemwood, bark and branches was calculated as the difference between the masses of the respective compartments for the year concerned and for the previous year.

2.4 Statistical Methods

Normality of the diameter and height distribution of all trees in the plantation was checked by χ^2 test. For the height, diameter and N,P,K concentrations of the model trees, the Kolmogorov – Smirnov test was used. To analyse the effect of the year, tree section or height class on N,P,K concentrations in the leaves, stemwood and stembark, one-way ANOVA was applied. When the data did not follow the normal distribution, or when there occurred an inhomogeneity of group variance the nonparametric Kruskal-Wallis analysis of variance was used. Linear and allometric models were employed for estimating the relationships. In all cases the level of significance $\alpha = 0.05$ was accepted.

3 Results

3.1 Nutrient Allocation in Above-Ground Biomass

In both grey alder and hybrid alder the highest nitrogen concentration was found in the leaves and the lowest in the stemwood (Table 2).

One-way ANOVA was applied to study the effect of tree section or tree height class (tree hierarchical position) on N,P,K concentrations in the leaves, stemwood and stembark. Analysis was made on the basis of the data of 1997 and 1998. Because in the first years the growth of the trees was low and the trees were weakly differentiated, the data of 1996 were excluded.

The impact of tree height class on N,P,K concentrations in the leaves, stemwood and stembark was insignificant in all cases. The impact of year and tree section on nutrient concentrations was significant (Tables 3 and 4).

In the third year after establishment (1997), the effect of section on the foliar nitrogen concentration of grey alder was statistically significant ($p<0.05$); nitrogen concentration was higher in the higher layers of the crown. However, this tendency was not revealed in 1998 when the nitrogen concentration of leaf mass was significantly higher than in 1997 ($p < 0.001$). Phosphorus and potassium concentrations in the leaves did not depend on section in either year. In the hybrid alder plantation, foliar nutrient concentrations were not significantly different in different tree sections ($p < 0.05$).

The impact of tree height section on N,P,K concentrations in the stemwood of grey alder was insignificant. For the stembark of grey alder, a significant difference was found for potassium ($p < 0.05$); the concentration of K was higher in the lower stem part.

Stemwood nitrogen concentration in hybrid alder was considerably higher in the upper part of the stemwood than in the lower part ($p<0.01$). Phosphorus and potassium concentrations in stemwood differed significantly in 1997 and 1998 ($p < 0.05$). Section had a significant effect on potassium concentration (the concentration

Table 2. Mean (± standard error) N,P,K concentrations (g kg^{-1}) in different tree compartments of grey alder and hybrid alder in fourth year after establishment.

	Grey alder			Hybrid alder		
	N	P	K	N	P	K
Leaves	39.0 ± 1.3	2.9 ± 0.4	12.0 ± 0.7	34.0 ± 1.1	3.3 ± 0.1	12.0 ± 0.5
Old branches	7.9 ± 0.5	1.1 ± 0.2	2.9 ± 0.1	8.3 ± 1.1	1.7 ± 0.7	3.4 ± 0.3
Stemwood	4.2 ± 0.3	1.0 ± 0.1	1.9 ± 0.2	4.4 ± 0.3	1.5 ± 0.1	3.0 ± 0.2
Stembark	16.0 ± 0.3	1.8 ± 0.2	4.7 ± 0.2	14.0 ± 0.3	2.1 ± 0.1	4.6 ± 0.3

Table 3. The effect of year and tree section on N,P,K concentrations in the leaves, stemwood and stembark in the grey alder plantation.

Fraction	Nutrient	Tree section 1997	Tree section 1998	Year
Foliage	N	p < 0.05	n.s	p < 0.001
n = 21	P	n.s	n.s	n.s
	K	n.s	n.s	p < 0.05
Stemwood	N	n.s	n.s	n.s
n = 24	P	n.s	n.s	n.s
	K	n.s	n.s	n.s
Stembark	N	n.s	n.s	n.s
n = 24	P	n.s	n.s	n.s
	K	n.s	p < 0.05	p < 0.001

Table 4. The effect of year and tree section on N,P,K concentrations in the leaves, stemwood and stembark in the hybrid alder plantation.

Fraction	Nutrient	Tree section 1997	Tree section 1998	Year
Foliage	N	n.s	n.s	p < 0.05
n = 18	P	n.s	n.s	p < 0.001
	K	n.s	n.s	p < 0.05
Stemwood	N	p < 0.01	p < 0.01	n.s
n = 18	P	n.s	n.s	p < 0.001
	K	n.s	p < 0.05	p < 0.01
Stembark	N	n.s	n.s	n.s
n = 18	P	n.s	n.s	p < 0.001
	K	n.s	n.s	p < 0.01

was higher in the upper sections) in 1998 but not in 1997.

For hybrid alder the phosphorus and potassium concentrations in the stembark were higher in 1998 than in 1997. The effect of section on the concentration of this nutrient in the stemwood was insignificant in both years.

3.2 N,P,K Accumulation in Above-Ground Biomass

By the fourth autumn after establishment the above-ground part of the grey alder stand had accumulated a total of 142.0 kg ha^{-1} nitrogen, of which 18.5% were located in the stemwood, 11.8% in the stembark and 54.6% in the leaves (Fig. 1). The above-ground compartments had accumulated 16.3 kg ha^{-1} of phosphorus and 49.5 kg ha^{-1} of potassium. The respective figure for hybrid alder was 76.8 kg ha^{-1}, of which 14.1% were located in the wood, 14.9% in the bark and 52.2% in the leaves. The above-ground compartments had accumulated 6.2 kg ha^{-1} of phosphorus and 28.2 kg ha^{-1} of potassium.

Comparison of the N:K:P ratios, which is one of the most important parameters in the analysis of nutrient concentration and consumption, is shown in Table 5.

Table 5. Amounts of nutrients consumed annually by grey alder and hybrid alder to produce one ton of biomass and the N:P:K ratios for annual biomass production.

		Grey alder kg t^{-1}	Grey alder N:P:K ratio	Hybrid alder kg t^{-1}	Hybrid alder N:P:K ratio
1st year	N	16.7	100	19.9	100
	P	1.5	9	1.1	5
	K	7.2	43	8.1	41
2nd year	N	13.4	100	15.5	100
	P	1.9	14	1.0	6
	K	5.0	38	4.5	29
3rd year	N	14.0	100	16.2	100
	P	1.0	7	2.2	13
	K	4.00	29	5.9	36
4th year	N	16.0	100	14.6	100
	P	1.6	10	1.1	8
	K	5.4	34	5.2	36

Table 6. The above-ground biomass and annual biomass production of grey alder and hybrid alder stands.

	Grey alder Total biomass t ha^{-1}	Grey alder Annual biomass production t ha^{-1}	Hybrid alder Total biomass t ha^{-1}	Hybrid alder Annual biomass production t ha^{-1}
1st year	0.37	0.28	0.16	0.14
2nd year	2.68	2.45	0.94	0.86
3rd year	7.61	5.80	2.72	2.20
4th year	12.27	6.74	6.15	4.53

3.3 Biomass and Production

In the fourth year after planting the above-ground biomass of the grey alder stand was 12.3 t ha^{-1} and the annual current increment 6.7 t ha^{-1} (15 750 plants ha^{-1}) (Table 6). In the hybrid alder stands the respective figures were 6.1 t ha^{-1} and 4.5 t ha^{-1} (6700 plants ha^{-1}).

As the plantations differed both in age and primary density, mean stem mass (total annual biomass of the stand divided by the number of the trees) was used to compare the production of the stands (Fig. 2). When comparing the stem masses of the two stands in the fourth year after establishment, the mean stem mass of grey alder exceeded that of hybrid alder.

The mean height of the grey alder stand was larger than that of the hybrid alder stand, 4.6 ± 0.9 m and 3.5 ± 0.9 m, respectively, in the fourth year after establishment. The difference in height growth between the stands decreases with age and, evidently, the growth of hybrid alder can surpass the growth of grey alder in the future.

Relative increment (Fig. 3), which expresses the proportion of annual production in the total biomass of hybrid alder stand during four years after establishment, can be described by the multiplicative function (2) (the data for the first year after establishment were excluded).

$$y = 1.12A^{-0.297} \quad (2)$$

$p < 0.01$, r^2 – 0.99, S.E – 0.004

where y – relative increment,
A – year after planting,
p – probability level,
r^2 – coefficient of determination,
S.E. – standard error of estimate

For grey alder stands, relative increment during the first five years can be represented by a linear model (3). The function of relative increment evidently changes with stand age and will also be replaced by the multiplicative function (Tullus et al. 1996).

$$y = 1.264 - 0.174A \quad (3)$$

$p < 0.01$, $r^2 - 0.99$, S.E. – 0.02

where y – relative increment,
A – year after planting

When comparing the proportion of the biomass of different compartments in the fourth year after establishment, it was found that in the grey alder stands the stems (wood + bark) accounted for 66% of total biomass, while in the hybrid alder stands the respective figure was 55%. Hence the branches (primary growth of branches + old branches) and the leaves (24% and 21%, respectively) formed a larger proportion in the hybrid alder stands than in the grey alder stands (18% and 16%, respectively).

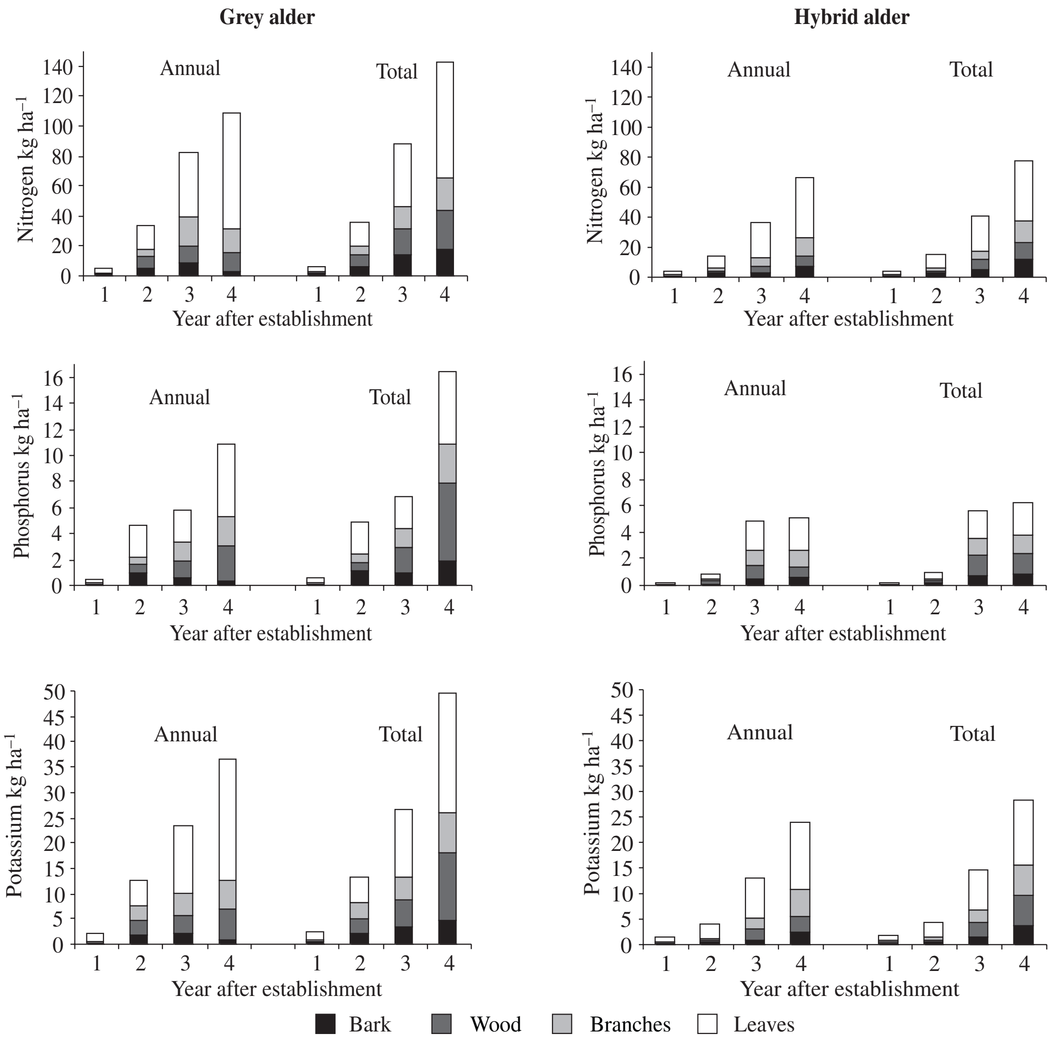

Fig. 1. N,P,K amounts (kg ha^{-1}) accumulated in total biomass and in annual biomass production in grey alder and hybrid alder plantations. Bark and wood indicate stembark and stemwood, respectively.

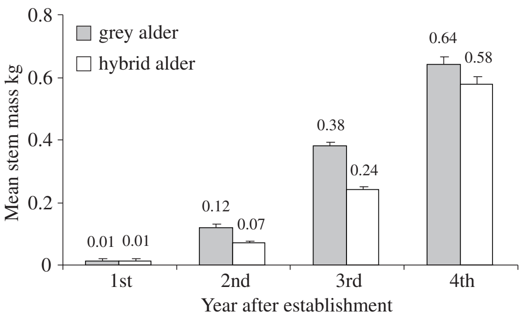

Fig. 2. Mean stem mass in grey alder and hybrid alder stands (means and their 95% confidence intervals).

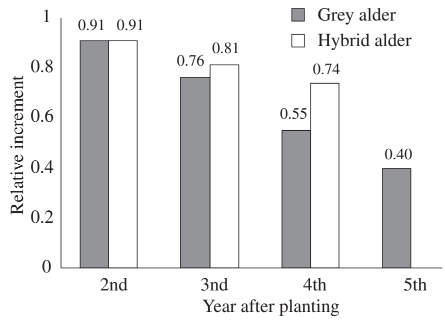

Fig. 3. The dynamics of the relative increment of the grey alder and hybrid alder plantations.

The potential efficiency of the leaf mass (above ground biomass per leaf mass unit) of the plantation in different years varied from 2.1 to 5.4 for the grey alder stand and from 2.0 to 3.5 for the hybrid alder stand.

4 Discussion

Different alder compartments are rich in nitrogen. The foliar nitrogen concentrations found in this study are in good accordance with the data of other studies. In Europe, the concentration of nitrogen in alder leaves is usually about 20–30 g kg^{-1} (Mikola 1958). On fertilised and irrigated peatlands leaf nitrogen concentration can be as high as 30–40 g kg^{-1} (Rytter 1990), both on fertilised and unfertilised mineral soils 33–38 g kg^{-1} (Saarsalmi 1995). The respective average figure for Estonian natural riparian grey alder stands is 32–33 g kg^{-1} (Lõhmus et al. 1996). In most deciduous trees, nutrients are transported from the leaves to the other compartments (branches, bark) before litterfall, where they are preserved until the following vegetation period. In alders, nitrogen concentration is also high in fallen leaves (Rytter et al. 1989, Saarsalmi 1995). During decomposition, nutrients are released, which results in increase in soil nitrogen concentration.

The study failed to demonstrate a steady tendency in nutrient distribution between the different sections or between the trees belonging to different height classes. Although differences in nutrient distribution between different compartments were evident in some years, general regularities concerning the effect of section or height class on the distribution of nutrients could not be established.

When comparing the amounts of nutrients accumulated per surface unit, grey alder surpasses hybrid alder, which can be ascribed to its higher primary density and larger biomass. On the other hand, the N,P,K amounts necessary for producing one ton of biomass of grey alder and hybrid alder were similar (Table 5). It can be concluded that in similar growing conditions the N,P,K consumption of both species are comparable. According to literature data a 3–5-year-old grey alder stand requires 11.8 kg N, 0.8 kg P and 3.9 kg K for producing one ton of biomass (Saarsalmi et al. 1985), while a 5–8-year-old coppiced alder stand requires 13.9 kg N, 1.2 kg P, and 6.0 kg K (Saarsalmi et al. 1991). The present study showed that the respective values for grey alder in the third growing season were comparable to those presented in literature.

One of the most important parameters in investigating nutrient concentration and consumption is the N:K:P ratio. According to hydroponic studies (Ingestad 1987) the optimum N:K:P ratio for grey alder is 100:50:18. It is evident from Table 5 that relative potassium and phosphorus concentration in annual production is lower than the optimum concentration. Still, our results agree with the findings by Saarsalmi et al. (1985) who claim that nitrogen, potassium and phosphorus would be required by a 3–5-year old grey alder stand according to the ratio 100:33:6.8.

In both plantations, majority of the nutrients accumulated in annual biomass was contained in the leaves. This is one of the reasons why the nutrients bound in annual production form the largest part of the nutrients bound in total biomass (for different nutrients 66–95% in grey alder stands and 74–98% in hybrid alder stands).

After the fourth year the above-ground biomass of grey alder amounted to 12 t ha^{-1}, current annual increment being 6.7 t ha^{-1}. According to literature data the maximum value of annual current increment for grey alder is attained at the age of 6–8 years (Rytter 1996) to 10 years (Tullus et al. 1998). In the most favourable site type in Estonia (*Aegopodium* site type), the above-ground biomass of a 6-year-old natural grey alder stand reached 51 t ha^{-1} and its annual production was 14.8 t ha^{-1} (Tullus et al. 1998). In 10-year-old natural stands of grey alder, annual biomass production amounted to 9.6 t ha^{-1}, while total biomass was 60 t ha^{-1} (Keedus and Uri 1997). In older grey alder stands, biomass increases, whereas current annual increment decreases: in a 20-year-old grey alder stand the above-ground biomass has been estimated at 83 t ha^{-1} and the annual production at 7.5 t ha^{-1} (Tullus et al. 1996). According to Saarsalmi (1995), the biomass production (without leaves) of the above-ground part of a 5-year-old grey alder plantation can be 5.8–6.1 t ha^{-1} yr^{-1}, depending on fertilisation, and total above-ground biomass can be 31 t ha^{-1}. Telenius (1999) found that in 6-year-old grey alder plantations total biomass was 27 t ha^{-1} and last year production 8.6 t ha^{-1}. In fertilised and irrigated experimental plantations on organic soils the current annual increment of above-ground leafless biomass in 4-year-old grey alder stands measured up to 8 t ha^{-1} and in 5-year-old stands up to 12 t ha^{-1} (Rytter 1996).

Far less information is available on the biomass production of hybrid alder, especially in younger stands. In the present study the mean height of grey alder exceeded that of hybrid alder. Pirag (1962), however, claims that the diameter increment of hybrid alder stands is 34–40% larger than that of grey alder or black alder stands of the same age (the relative increment of the diameter was the largest, 0.8–1.0 cm, in young stands under the age of 5 years). Depending on the site type the height growth the hybrid alder stand exceeded that of the grey alder stand in by 11–35%. The mean annual height growth in stands aged up to 15 years was 0.8 m. The annual height growth of two-year-old grey alders was 1.5m and that of hybrid alders 1.6 m (Pirag 1962). According to Granhall (1982), 5-year-old plants of *Alnus incana* in Sweden had a mean height of 3.3 m; the respective parameter for the hybrid alder triploid was 2.7 m and for the hybrid alder diploid 2.5 m.

In the present study the mean stem mass of grey alder exceeded that of hybrid alder. It should be borne in mind that the growing conditions of hybrid alder were more favourable owing to the lower density of the culture, which reduced competition between the trees and increased the amount of nutrients per tree. Fig. 2 shows that the difference in mean stem mass between grey alder and hybrid alder has decreased by the 4th year of planting. Still, this effect might also be associated with the weather conditions, as the 4th year of planting for grey alder was 1998 and for hybrid alder 1999. Both years were characterised by highly different amounts of rainfall: 378 mm from June to August 1998 and 134 mm in the same period in 1999 according to the data of the nearest meteorological station.

The branches and the leaves accounted for a larger proportion of total biomass in the hybrid alder stands than in the grey alder stands. The difference in primary density can obviously be attributed to the larger proportion of the branches and the lesser proportion of the stems in the hybrid alder stands. In Finland the proportion of the branches in the total biomass of an 8-year-old coppiced grey alder stand was found to be 6 to 13% (Saarsalmi et al. 1991) and in a young stand 18% (Simola 1977).

As in this study the proportion of the leaves was larger in the hybrid alder stands than in the grey alder stands, leaf mass efficiency (above-ground production per leaf mass unit) was proportionally lower. While in the grey alder stands leaf mass efficiency seemed to decrease with age, then in the hybrid alder stands it remained at a comparatively stable level, which is evidently caused also by the different densities of the plantations.

On the basis of the preliminary data, both grey alder and hybrid alder are characterised by high biomass production, which allows to evaluate them as perspective species for afforestation of abandoned agricultural land. Present investigations were pilot studies with no replications concerning afforestation of set-aside farmlands by grey alder and hybrid alder. Suitability of these species for different soil conditions in abandoned agricultural areas needs further investigations.

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