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Wood ash and wastewater sludge recycling success in fast-growing deciduous tree – birch and alder plantations

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Abstract. Due to the increasing of wood as energy renewable resource in power and heat plants the amount of wood ash as waste will increase. Wood ash contains plant macronutrient elements P, K and different elements as micronutrients, only organic and nitrogen are missing. Wastewater sludge from small municipalities is usually clean, first-class material and contains a lot of nitrogen and phosphorus. Wood ash can be a good fertiliser and a liming material not only for acid organic soils, but also for mineral soils, but with a less significant effect on the tree growth in first seasons than a nitrogen rich fertiliser wastewater sludge.

The effects that wood ash and wastewater sludge have on the increment and survival of trees were tested during the years 2011 and 2012 on loam and loamy soils at plantations of black alder, birch and grey alder, and they were compared with the results collected in the previous research started in 2005. It was observed that wood ash in the first two seasons did not significantly increase the growth of silver birch, as wastewater sludge did, but it had a positive effect on the annual increment of grey alder. Fertilisation of the whole field decreased the survival of trees because of weed competition and different injuries.

The aim of the study was to evaluate the growth of fast-growing deciduous trees seedlings as short rotation crop under fertilisation of wood ash, and wastewater sludge on former agricultural land.

Key words: silver birch, black alder, grey alder, fertilisers, wood ash, wastewater sludge.

INTRODUCTION

Trees of the Betulacea family are more recent species in natural afforestation and forest regeneration in the Baltic States and Scandinavia, because their growth is more active at the juvenile stage. The Latvia State Forest Research Institute Silava since 1999 has tested wastewater sludge effects on soils at plantations of birch, black alder, pine, aspen and willows and forest sites (Kāposts et al 2000; Lazdina et al 2006; Lazdina, 2009), wood ash as a fertiliser for tree plantings and forests on peat and mineral soils (Indriksons et al 2003; Indriksons, 2010). Birch is the most recent of the pioneer species on abandoned agricultural lands in Latvia, alder is the second (respectively, 39.4% and 20.4%). The majority of the increment is located in birch stands, grey alder is in the second position, the third position belongs to other species (mostly, *Salix* sp.) (Daugaviete et al 2007, Lazdiņš, 2011). Grey alder stands up to the age of 40, maintains a high yield and a large annual current volume increment, which is higher than the average volume increment of other tree species (Daugavietis et al 2011). In the scope of the State Research Program 2005–2009 it was observed that grey alder stands could reach growing stock from 170–410 m^3 ha^{-1} at the age of twenty years; after that the annual increment reduces (Miezīte & Dreimanis, 2009). The amount of naturally moist biomass in one-to-five-year old untended grey alder stands is uneven with the variations depending on stand age and stem dimensions. The amount of biomass in untended grey alder stands depending on the stand density varies in a fairly wide range (Daugaviete, 2011). Young grey alder stands of the age up to ten years four, six, seven, and nine-year old stands on the sites of the Dm *Hylocomiosa* and Vr *Oxalidosa* growing conditions, the average number of stems was 7,300 trees ha^{-1}. On average the mean biomass of freshly harvested sample tree comprised 4.6 ± 1.5 kg of stemwood, 1.5 ± 0.5 kg of branchwood, 1.2 ± 0.4 kg of foliage, and 2.6 ± 0.6 kg of roots and stumpwood (stumpwood 0.8 ± 0.4; coarse roots 1.7 ± 0.4 kg) (Bārdulis et al 2011). Biomass of young grey alder stands aged one to five years varies from 0.9–7.7 t ha^{-1} ha in one-year old stands; from 2.2–23.6 t ha^{-1} in two-year old stands; from 5.2–28.9 t ha^{-1} in three-year old stands; from 7.3–57.4 t ha^{-1} four-year old stands; from 15.2 t ha^{-1} to 64.4 t ha^{-1} per ha in five-year old stands Daugaviete, 2011. The main market of fast-growing deciduous trees is energy wood (Miezīte & Dreimanis, 2009, Lazdiņš, 2011), but the formerly undervalued alder and birch called forest weeds, are not only suitable as firewood trees but are suitable for higher value products by using modern technologies (Andersons et al 2009).

Figures achieved from the research plots indicate that cultivated plantations and well-managed stands could be more productive than natural forest stands at the same age. Scientists from Baltic States and Scandinavia have observed that birch and alder planted on former agricultural land are more productive (Niemisto, 1996; Jõgiste et al 2003; Uri et al 2003; Wall & Hytönen, 2005; Aosaar & Uri, 2008, Liepiņš & Liepiņš, 2010). Liepiņš, in 2011 observed that in Latvia the same quality class stands in first years grow shorter as forest stands, one of the possible reasons could be the quality of seedlings and usage of inadequate planting material at first trials (Liepiņš, 2007).

To follow up the course of growth and biomass increment in originally different density silver birch plantations on farmlands, demonstration and trial plots were accordingly established in 1997. The field data after 15 years show that the diameter growth significantly differs depending on the density of plantations. The growth in height at the age of 15 years at different density birch plantations show no significant differences. Overstocked tree plantations containing 10,000 trees ha^{-1}; 5,000 trees ha^{-1} show significantly higher volume growth – 153.9 m^3 ha^{-1} and 131.9 m^3 ha^{-1}, respectively, compared to 99.3 m^3 ha^{-1}, 63.7 m^3 ha^{-1}, and 65.3 m^3 ha^{-1} for the density of 2,500 trees ha^{-1}, 1,600 trees ha^{-1}, and 1,100 trees ha^{-1}, respectively (Daugaviete et al 2011).

The growth in height of analysed birch plantations (plantation-cultivated forest crops) substantially exceeds the growth of natural birch stands following the existing yield tables. Thus, the tables for predicting the growth of regular forest stands appear to be unsuitable for modelling the growth of intensively managed stands of birch in plantation cultivation. The height of the most productive birch plantations in Latvia can exceed the site index H50 = 30 indicated for the growth of most productive birch plantations in Finland (Liepiņš, 2011).

All studies show that not only grey alder, but also silver birch and black alder are economically valuable trees and could be used as forest crop on agricultural land with a significantly shorter rotation period than ordinary forest stands; that study investigated one of the possible addition treatments to make the rotation period shorter – addition of fertilisation as a start for increasing growth at an early development stage, simultaneously solving the problem of plant macronutrient saturated municipal residues – by-product utilisation in an environmentally safe way.

The aim of study was to evaluate the growth of fast-growing deciduous tree seedlings as a short rotation crop under fertilisation of wood ash, and wastewater sludge on former agricultural land.

MATERIALS AND METHODS

Study sites

Two experiments are analysed. The first plot, established in April 2005, birch and grey alder together with pine and willows were planted on former peatland, silt mineral soil in Mārupe (56°51 N and 23° 58 E).

The second experimental plot was established on agricultural land in the central part of Latvia – Skrīveri (56°41 N and 25°08 E) in the late spring of 2011. The type of soil in Skrīveri is classified as *Phaeozems/ Stagnosols* with dominant loam (at 0–20 cm depth) and sandy loam (at 20–80 cm depth) soil texture.

Mārupe (2005–2008) foto A.Bardulis

Skrīveri (2011–2012) foto D.Lazdina

Figure 1. Experimental fields.

The birch and alder experimental plots were a part of the large-scale multifunctional plantation of short rotation energy crops, planted as agroforestry systems with a total area of 16 ha.

Design and planting material

Three fast-growing deciduous tree species – silver birch, grey alder and black alder were planted in April 2005 and 2011, the planting material originated from JSC 'Latvijas finieris' *(forest nursery 'Zābaki'),* Latvia. The spacing between trees was 2.5 x 2.5 m, which corresponded to planting density – 2,500 trees per ha. Trials are placed side by side to each other as rectangles, only the buffer zones, at least six metres wide, were left between treatments.

Treatments

The first experimental trial in 2005 was established to test the possibilities of municipal Ltd. company Rīgas ūdens wastewater sludge (WWS) utilisation for former peatland re-cultivation using the most recent used dosage of 10 t_{DM} ha^{-1}. According to regulations of the Cabinet of Ministers of the Republic of Latvia No. 362 first class wastewater sludge was used in Skrīveri (dose 10 t_{DM} ha^{-1}) from Ltd. Aizkraukles ūdens (*Aizkraukle Water*) and stabilised wood ash from the boiler house in Sigulda (dose 6 t_{DM} ha^{-1}) were spread mechanically before the planting of trees in the spring of 2011. The target amounts of NPK calculated trying to reach recommended fertilisation for fast-growing tree plantations (Uri et al 2003; Kāposts 2005; Lazdina et al 2011) are shown in Table 1.

Table 1. Amounts of main nutrients applied by fertilisers

Amount of fertiliser	N, kg ha^{-1}	P, kg ha^{-1}	K, kg ha^{-1}
wood ash 6 t_{DM} ha^{-1}	1.4	38.6	329.4
WWS 10 t_{DM} ha^{-1}	324.80	136.00	19.60
optimum	100–200	20–40	100–200

The heavy metal content of soil after the application of fertiliser did not exceed the limits corresponding to regulations of the Cabinet of Ministers of the Republic of Latvia No. 804. Amounts of the applied fertilisers were calculated to use more or less similar concentrations of at least one of the nutrient elements, in that case phosphorus. Four replications of fertilisation rectangle shaped subplots – control (no fertilisation), wastewater sludge and wood ash were established.

Statistical analysis

The experimental data of birch and alder height and annual increment were statistically analysed by statistical tools of the OpenOfficeCalc, to calculate values of mean, standard deviation and standard error. TTEST used to determinate significance of difference of tree growth between groups and fertilisers.

RESULTS AND DISCUSSION

Characteristics of the growth of trees and effect of fertilisers

Former investigations did not show a greater effect of wastewater sludge (WWS) fertiliser in the first two seasons, and the height of birches and alders planted in 2005 at the same age as planted in 2011 were significantly different (Table 2, 3).

Birch has shown a height level of variability in phenological, physiological, growth depending on the seedling growing technology, soil properties and management (Liepiņš, 2007), that are well reflected in data collected in 2005 and 2011 plantings to analysing increments, that increments relative to initial height were higher on fertilised plots just of trees planted in the last experiment (Fig. 1).

Table 2. Effects of fertiliser on average stem height in (cm)

Season	Fertiliser	Grey alder	Silver birch		Black alder	
		2011	2005	2011	2005	2012
first	control	46.24 ± 0.91	70.25 ± 2.79	61.59 ± 0.78	36.15 ± 2.72	48.96 ± 0.68
	WWS 10 t_{DM} ha^{-1}	47.99 ± 1.35	77.07 ± 2.32	67.2 ± 0.88	103.93 ± 2.83	49.68 ± 1.05
	wood ash 6 t_{DM} ha^{-1}	41.19 ± 1.2		63.04 ± 1.05		45.01 ± 0.91
second	control	112.59 ± 2.25	133.78 ± 4.77	85.02 ± 1.13	145.56 ± 4.75	
	WWS 10 t_{DM} ha^{-1}	115.36 ± 3.21	157.83 ± 4.44	91.42 ± 1.91	177.77 ± 4.29	
	wood ash 6 t_{DM} ha^{-1}	110.38 ± 3.15		81.08 ± 1.5		

Table 3. Effects of fertiliser on the annual increment (cm)

Season	Fertilisers	Grey alder	Silver birch		Black alder	
		2011	2005	2011	2005	2012
first	control	26.34 ± 0.68	28.41 ± 1.62	16.95 ± 0.33	16.36 ± 0.81	12.31 ± 0.47
	WWS 10 t_{DM} ha^{-1}	25.67 ± 0.85	25.52 ± 1.56	19.42 ± 0.48	21.34 ± 0.95	12.43 ± 0.79
	wood ash 6 t_{DM} ha^{-1}	23.41 ± 0.99		17.47 ± 0.5		11.29 ± 0.59
second	control	63.18 ± 1.6	71.08 ± 2.42	40.52 ± 0.93	64.71 ± 2.52	
	WWS 10 t_{DM} ha^{-1}	65.22 ± 2.24	71.3 ± 2.81	44.64 ± 1.49	72.9 ± 2.47	
	wood ash 6 t_{DM} ha^{-1}	67.39 ± 2.54		32.32 ± 1.05		

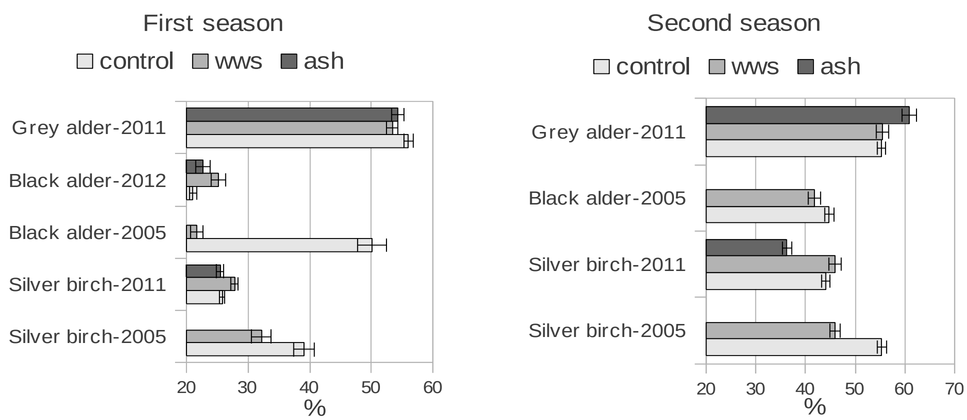

Figure 1. Effects of fertiliser on first two season increment in % to tree height at season beginning of silver birch, grey alder and black alder plants.

According to the findings of Daugaviete, 2011, an equation for estimating the amount of naturally moist biomass in one-to-five-year old grey alder growth, when biomass (M) is calculated as a function of the average stem height (HV) and the number of stems (N) per ha: M = 0.0536 HV2.2516 N, ($R^2 = 0.905$; $P < 0.05$), our experimental plot average for grey alder biomass in the second season was 30.1 t ha^{-1}. The highest estimated fresh biomass could be harvested from control plots 31.9 t ha^{-1}, wastewater sludge – 28.39 t ha^{-1} and wood ash – 29.97 t ha^{-1}, because of higher mortality of plants on fertilised plots, but data are higher as from Daugaviete, 2011 and Bārdulis et al 2011 reported from natural stands at that age.

Container type and nursery growing media

Seedlings of silver birch and grey alder planted in 2011 were cultivated in the same conditions, in the same peat substrate, in containers Lannen Plantek 35 F (LP 35 F), additionally half of silver birch were cultivated in smaller containers Rootraines Sherwood (RS) (Table 4).

Table 4. Effects of container type and specie on the annual increment (cm)

Season	Fertiliser	Control	Wastewater sludge 10 t_{DM} ha^{-1}	Wood ash 6 t_{DM} ha^{-1}
first	Grey alder LP 35 F	56.04 ± 0.71	53.39 ± 0.92	54.28 ± 1.03
	Birch LP 35F	27.18 ± 0.51	29.75 ± 0.73	27.69 ± 0.74
	Birch RS	24.44 ± 0.67	26.00 ± 0.91	23.12 ± 0.79
second	Grey alder LP 35 F	55.35 ± 0.85	55.48 ± 1.31	60.83 ± 1.45
	Birch LP 35F	46.93 ± 1.05	46.70 ± 1.68	38.37 ± 1.21
	Birch RS	40.53 ± 1.31	44.7 5± 1.87	33.78 ± 1.26

By comparing the results of the growth of trees cultivated in the same substrate, greenhouse and containers and testing the impact of container size on birch, it was observed that there were relatively larger increments in the first season for trees from larger containers, and on plots fertilised with wastewater sludge in the case of birch, and no positive, but rather negative effect of fertilisers on the development of increments of grey alder. The birch grown in smaller containers started to grow faster in the second season, because of the development of the root system.

Planted seedlings of grey alder were shorter than silver birch, but during the second season grey alder overgrew both birches formerly cultivated in different containers (Fig. 2). As it was researched by Liepiņš in 2007 for an afforestation grown on a former farmland, silver birches from smaller containers at control plots grew slower, but fertilisers, especially nitrogen-rich wastewater sludge, increased the growth of seedlings cultivated in *Rootrainer Sherwoods* containers and the impact of containers on the tree height grows decreases (Fig. 2).

These data allow for assuming that in the next seasons the impact of container size on the tree growth will decrease more on fertilised plots. Smaller containers allow growing more seedlings per area, but seedlings have a risk to spindle and suffer from lack of nutrients because of a smaller volume of substrate (Liepiņš, 2007).

A bigger survival rate of grey alders was observed at plots not treated and fertilised with wood ash, during the second growing season the number of survived plants decreased by 4% only on control plots.

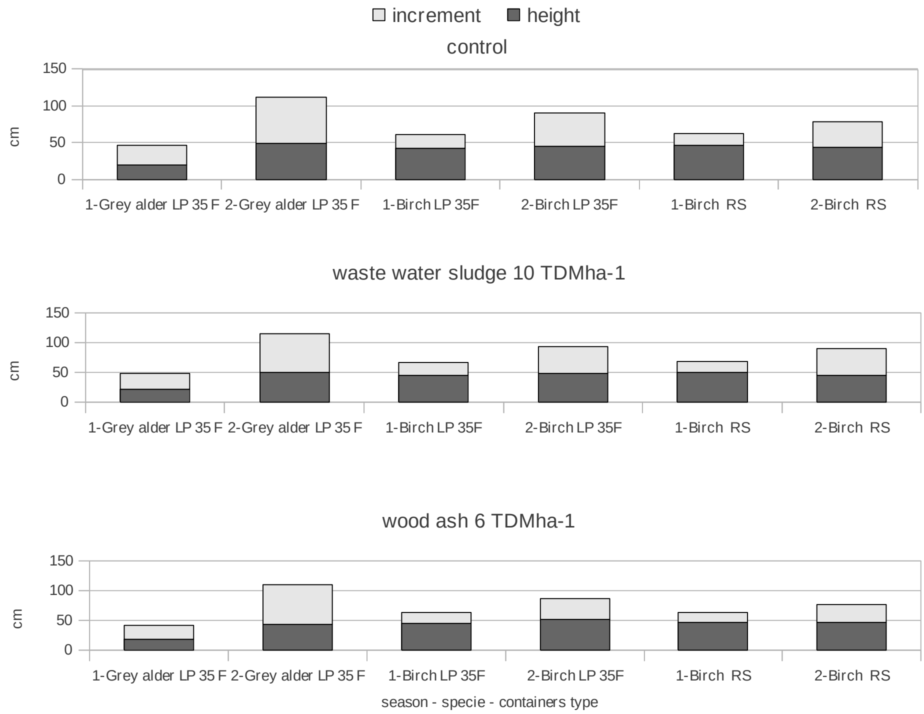

Figure 2. Height and annual increments of silver birch and grey alder seedlings grown in the same substrate and container and effects of container on growth of silver birch under different fertilisers – first two seasons.

Silver birch grown in larger containers showed similar surviving results to others in the first season, just 3–4% mortified plants. The survival rate of birch in the second season decreased 22–42%. Trees from *Rootrainers Sherwood* containers in the second season had a higher mortality rate because fresh plants, fertilised with wastewater sludge, had more animal damage (Table 5).

Table 5. Impact of fertilisers on tree survival (%)

Species, year	Containers	Control		Wastewater sludge		Wood ash	
		vigorous	sprouts	vigorous	sprouts	vigorous	sprouts
Grey alder 2011	LP 35 F	95	3	76	6	85	5
Grey alder 2012	LP 35 F	94	0	82	0	90	0
Silver birch 2011	LP 35 F	87	10	90	6	91	5
	RS	85	9	93	3	83	13
Silver birch 2012	LP 35 F	78	0	75	0	77	0
	RS	66	0	56	1	66	3
Black alder 2012	LP 35 F	55	4	41	1	44	3

The significantly lower survival rate of black alder is the result of spring frosts at the nursery plant-storing polygon on top of the hill.

CONCLUSIONS

The growth of the fast-growing trees in plantations provides for a sustainable management system, it increases the efficiency of plant nutrient elements from municipal waste products – wastewater sludge and wood ash resource utilisation.

The growth dynamics and survival of silver birch are affected by both the container and the use of fertilisers upon planting. Wastewater sludge fertilisation increases stem height in both seasons more than control and wood ash application. Stem heights in the first season increased from 29.75 to 26.00% in comparison to the beginning of season – 20.88 and 17.99 cm, depending on the container. Growth in the second season was respectively 46.70–44.75% and 44.44–44.91 cm, which for larger containers is close to control, but for smaller containers even 10 cm more than control and 15 cm more than fertilised wood ash. Even though, numerically increments of trees from smaller containers were less, the effect of fertiliser is more significant on seedlings grown in smaller containers, and by usage of start fertilisers trees during the second season reached dimensions close to plants grown in larger containers. Better vitality results in the last season were observed for trees on control and wood ash fertilised plots, vigorous, non-damaged trees 77% for larger containers and 66% for smaller containers. On plots fertilised with wastewater sludge there were vigorous 75 and 56% of birch trees. After the first season the survival rate of trees ranged from 83–93%. Total mortality ranged from 11–3% and birches from smaller containers under wastewater sludge fertilisation in the second season had a higher mortality rate.

The grey alder growth rate in the nursery and on fields in the first season was lower than that of silver birch grown in both types of containers, which allowed for estimating that silver birch seedling growth technology is not optimal for grey alder. The average height of plants grown on plots fertilised with wastewater sludge is higher than control and wood ash fertilised, which is the effect of initial tree height in 2011. In the first season no fertiliser had a more positive effect on the annual increment as control, but in the second season, when the root system started to develop, wood ash had a more positive effect on increments 67.39 cm or 60.83% in comparison to the beginning of the season (in comparison to control 4.21 cm or 5.48% more), while wastewater sludge fertilised alders had increments 65.22 cm or 55.48% similar to control 63.18 cm or 55.35%. The survival rate of seedlings after the second season was 82% for the ones fertilised with wastewater sludge, 90% – wood ash and 94% with wood ash.

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