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The effect of fertiliser type on hybrid aspen increment and seed yield of perennial grass cultivated in the agroforestry system

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Abstract. Agroforestry is a perspective way of biomass production which combines simultaneous growing of woody plants with agricultural crops on the same area for different purposes. The advantage of agroforestry lies in the improved efficiency of resource utilisation and smaller competition of plants for nutrients. In this system the woody plants are less influenced by lasting periods of drought, and a stable annual increase in biomass is ensured. Accordingly, agroforestry is biologically more productive, economically – more favourable, and it is more sustainable than the monocultures of forestry or agriculture separately.
The work was done to test the effect of fertiliser type on the increment of two clones of hybrid aspen (*Populus tremuloides x Populus tremula*) and the seed yield of perennial grasses (*Phalaris arundinacea* L.*, x Festulolium pabulare*) and legumes (*Lupinus polyphyllus* L.*, Galega orientalis* Lam.) cultivated in the agroforestry system on loam/sandy soils. Fertilisers used at the planting were wastewater sludge (dose 10 t_{DM} ha^{-1}) and wood ash (dose 6 t_{DM} ha^{-1}). Wastewater sludge fertilisation increased the stem length of hybrid aspen by 20% after the first growing season. The effect of wastewater sludge fertilisation on stem length was still significant after the second growing season. Soil and soil solution analysis indicated that the main Hybrid aspen growth response was due to the P and N supplied by fertiliser.
Reed canary grass (RCG), festulolium and fodder galega can be successfully cultivated for seeds in the first year of use, locating the crop fields in the plantations of energy plants interchangeably with trees. The use of wastewater sludge provided an essential increase in seed yields for all species of herbaceous plants. However, the influence of fertilisers on the grass species was different: the greatest increase in seed yields was established by the use of wastewater sludge in RCG, mineral fertiliser in festulolium, and ash in galega, and the fertilisation provided the seed yield increase of 136%, 31% and 163%, respectively.

Key words: agroforestry, hybrid aspen, perennial grasses, fertilisers.

INTRODUCTION

Silvoarable agroforestry has been recently proposed as an alternative land-use system for Europe (Torquebiau, 2000; Reisner et al., 2007). Agroforestry in general is defined as a land-use system in which two or more plant species interact, one of the species being perennial and having a woody consistency (Somarriba, 1992). Silvoarable agroforestry comprises agricultural systems where trees and crops are cultivated on the same land area (Reisner et al., 2007). Agroforestry practices have been shown to improve soil quality, carbon sequestration, and water quality in cropping systems. Also, these practices are believed to reduce nonpoint source pollution from row-crop areas by improving soil hydraulic properties and reducing surface runoff (Paudel et al., 2011).

Populus species and their hybrids have been extensively studied in short rotation woody biomass production for multiple uses such as fibre, fuel and environmental benefits in many countries (Zalesny et al., 2007). Hybrid aspen has been grown and studied most intensively in Sweden, Finland and the Great Lakes Region in the USA (Tullus et al., 2007). Hybrid poplar (*Populus* spp.) plantations are economically attractive to the forest industry, even in the boreal forest, because of their fast growth rates and high yield potential (Guillemette & DesRochers, 2008). The predicted rotation period for hybrid aspen in boreal conditions is 20–30 years for the production of pulpwood (Tullus et al., 2007). Since 2009 in Latvia there has been accepted the establishment of short rotation plantations of willow, aspen, grey alder with a rotation period of no more than 5 years on agricultural land as agroforestry, and these areas are accepted for payment as agriculture procedure is regulated by the rules of the Cabinet of Ministers of the Republic of Latvia (Lazdina et al., 2011). Hybrid of American aspen (*Populus tremuloides* Mich.) and common aspen (*Populus tremula* L.) demonstrate that the heterosis effect in the first generation is most appropriate for conditions in Latvia (Zeps et al., 2008). Growing poplars in plantations is challenging, and good establishment in the first year is critical to long-term success (Stanturf et al., 2001). Hybrid poplars have high nutrient requirements and the establishment of new plantations can be improved by fertilising at the time of planting, to increase early growth rates across a wide range of site conditions, allowing the trees to overtop competing vegetation and form established stands sooner, ultimately reducing the time period between planting and harvest (van den Driessche et al., 2003; DesRochers et al., 2006; Guillemette & DesRochers, 2008). Reisner et al. (2007) has integrated data on soil, climate, topography, and land cover in a geographic information system to identify agroforestry target regions where productive growth of trees in silvoarable agroforestry systems could be expected and where silvoarable agroforestry systems could potentially reduce the risk of soil erosion, nitrate leaching and increase landscape diversity. The analysis shows that poplar (*Populus* spp.) hybrids could grow productively in silvoarable agroforestry systems on 33.6% of the arable land (547,054 km^2) throughout Europe (Reisner et al., 2007).

In the system of agroforestry along with fast-growing trees the herbaceous plants can be successfully cultivated for different purposes. Perennial grasses and legumes have been widely used as fodder crops for centuries and there has been an increasing interest in the use of them as energy crops in the US and Europe since the mid-1980s (Lewandowski et al., 2003). Tall-growing perennial grasses have several advantages in fuel production, since the grass biomass can be used as fuel the year after sowing. To minimise competition with food production energy crops must be able to produce high yields on poorer soils and sites that are not ideal for food production (Allison et al., 2012). Perennial grasses are high yielding, pest resistant and less demanding in terms of soil conditions compared to other crops (Peeters, 2008; Rancane et al., 2012). There are many ecological benefits expected from the production and use of perennial grasses (Sanderson and Adler, 2008; Rösch et al., 2009). They can produce for about 10 years without reseeding and protect hilly soils from erosion and maintain soil fertility (Jasinskas et al., 2008).

Reed canary grass (RCG) is a promising bio-energy crop and a potential non-wood crop for industrial uses (e.g., papermaking) in Northern Europe (Saijonkari–Pahkala, 2001; Lewandowski et al., 2003; Kukk et al., 2011). RCG is a persistent species, which grows well on most kinds of soil. It responds well to flooding, and at the same time it is more drought resistant than many other grass species (Ostrem, 1987; Tahir et al, 2011). Festulolium is a cross between fescue and perennial ryegrass. Theoretically, it should have the winter-hardiness and persistence of fescue and the digestibility of perennial ryegrass. However, festulolium varieties exhibit considerable variability, with some varieties behaving more like fescue and others more like ryegrass (Thomas & Humphreys, 1991**)**. The fodder galega possesses all the best qualities of grasses – the ability to grow in one place without reseeding and the ability to fix atmospheric nitrogen. It has a high harvesting rate and can ensure dry matter harvests for many years without reseeding and nitrogen fertilising (9–16 t ha^{-1}) (Adamovičs, 2007). The perennial lupine has a highly developed root system that reaches deep into the soil. For the cultivation of this species the most suitable are sandy loam and light loam soils with acid soil reaction (pH KCl about 4 to 5). It grows well in sandy soil as well, if during the first year the plants are sufficiently provided with humidity. The perennial lupine is not demanding in terms of nutrition, because it has the possibility to fix nitrogen from the atmosphere with the help of N-fixing bacteria, but it extracts potassium and phosphorus from the deeper layers of soil and uses less soluble compounds with the help of its strong root system (Dubrovskis et al., 2011). The above mentioned species herbaceous plants grow very well in a cool temperate climate. They have good winter hardiness and they survive well in Latvia's conditions. Also the fact is important that a successful seed production for propagation of further varieties is possible.

The investigation was done on the seed production of legume and grass cultivars grown in columns alternated with aspen rows and fertilised with residual materials - wood ash and wastewater sludge that contain chemical elements with considerable fertilising value. Some studies have shown that grate (bottom) ashes may be successfully used as a fertiliser in agriculture and forestry (Fritze et al., 2000). In Latvia and worldwide the research has been done on the usage of sewage sludge for fertilisation of energy plants.

MATERIALS AND METHODS

Study site

An experimental plot was established on agricultural land in the central part of Latvia (56°41 N and 25°08 E) in the spring of 2011. The experimental plot is part of the large scale multifunctional plantation of short rotation energy crops and deciduous trees with the total area of 16 ha. The mean annual temperature in 2012 was 6.1 °C at the study site, the mean annual rainfall in 2012–928 mm (it is 139% of long-time average rates in Latvia). The characterisation of chemical composition of wet precipitation in 2012 is presented in Table 1. The type of soil is classified as *Phaeozems/ Stagnosols* with the dominant loam (at 0–20 cm depth) and sandy loam (at 20–80 cm depth) soil texture. The plantation was fenced in the autumn of 2012.

Table 1. Characterisation of chemical composition of wet precipitation at the study site in 2012

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Precipitation, mm	61	40	32	59	121	91	163	45	63	111	94	48
pH	4.7	4.7	6.3	5.6	6.1	8.3	7.4	7.5	6.2	6.4	4.1	4.5
Conductivity, $\mu S\ cm^{-1}$	22.6	12.4	61.6	12.8	12.4	10.0	13.5	32.2	13.0	8.3	12.7	14.3
Total alkalinity, $mmol\ L^{-1}$	0.01	0.01	0.14	0.05	0.06	0.08	0.08	0.20	0.08	0.06	0.00	0.01
$N\text{-}NO_3^-$, $mg\ L^{-1}$	0.66	0.30	1.83	0.14	0.72	0.10	0.18	0.69	0.17	0.39	0.74	1.18
$N\text{-}NH_4^+$, $mg\ L^{-1}$	0.54	0.28	2.44	0.51	0.36	0.15	0.72	0.39	0.18	0.12	0.36	0.43
$P\text{-}PO_4^{3-}$, $mg\ L^{-1}$	0.01	0.01	0.01	0.02	0.01	0.04	0.07	0.35	0.03	0.01	0.01	0.01
K, $mg\ L^{-1}$	0.25	0.06	0.35	0.16	0.12	0.35	0.39	1.23	0.09	0.05	0.07	0.16
Ca, $mg\ L^{-1}$	0.32	0.24	1.91	0.50	0.47	0.49	0.33	0.75	0.93	0.51	0.27	0.36
Na, $mg\ L^{-1}$	0.26	0.08	1.36	0.19	0.13	0.14	0.10	0.41	0.33	0.14	0.26	0.34
Mg, $mg\ L^{-1}$	0.09	0.05	0.72	0.12	0.14	0.21	0.11	0.27	0.32	0.11	0.06	0.12

Design and planting material

Two different clones (4 and 28) of hybrid aspen (*Populus tremuloides x Populus tremula*) were planted in the agroforestry system, the planting material originated from JSC 'Latvijas valsts meži' *(Latvia's State Forests),* Latvia. The average spacing between the trees was 2.5 x 5.0 m and the planting density – 850 trees per ha.

Between the 5 m tree rows two legume and two perennial grass cultivars were sown for the seed production: fodder galega (*Galega orientalis* Lam.) 'Gale', poor-alkoloid lupine (*Lupinus polyphyllus* L.) 'Valfrids', reed canary grass (RCG) (*Phalaris arundinacea* L.) 'Bamse' and festulolium (*x Festulolium pabulare*) 'Felina'. The grasses and the legumes were placed in 2.5 m wide columns and the size of one plot was 60 m^2. A free space of 1.25 m between the trees and grass lines was provided. The sowing was carried out in mid-June of 2011 in three replications, using the seeders 'Nordsten NS-1025'. Grasses and legumes were sown without a cover crop using narrow row spacing for RCG and festulolium, and broad row spacing (36 cm) for galega and lupine. Seeding rates: galega 12 kg ha^{-1}; lupine 30 kg ha^{-1}; reed canary grass 10 kg ha^{-1} and festulolium 12 kg ha^{-1} germinating seeds. Legume seeds were treated with nodule bacteria preparations before the sowing; wet Nitragin grown on agar was used for galega and peat powder mixed with Nitragin – for lupine.

Treatments

Four replications of three different fertilisation subplots – control (no fertilisation), wastewater sludge and wood ash, the size of each – 30 x 24 m, were established in the spring of 2011. I class (according to regulations of the Cabinet of Ministers of the Republic of Latvia No. 362) wastewater sludge (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 hybrid aspen and sowing of legumes and perennial grasses (Table 2). Heavy metals target values and precautionary limits are not exceeded in fertilised soils according to legislative regulation for soil and ground quality (regulations of the Cabinet of Ministers of the Republic of Latvia No. 804). For comparative evaluation of grasses and legume seed yields along with the mentioned fertilisers there was also a mineral fertiliser option included: N25:P50:K125 for the legumes and N60:P50:K125 for the grasses.

Table 2. Chemical composition (content of elements, g kg^{-1}) of wastewater sludge and wood ash

Fertiliser	N	P	K	Ca	Mg	Mn	Fe	Na
Wood ash	0.40	10.9	31.6	224.8	30.9	3.1	4.6	1.6
Wastewater sludge	25.9	16.3	2.2	10.9	11.3	0.3	23.4	0.2

Measurements

The height of trees was measured right after the planting and at the end of the first and the second growing seasons. Galega and grasses seeds were collected by using a small experimental harvesting Wintersteiger. Seed yield, seed germination and weight of 1,000 seeds were tested. In the autumn of 2012 sward samples were removed from the field for RCG and festulolium and the stem, flowerhead and leaves ratio, and flowerhead length for each fertiliser variant in 4 replications were tested in the laboratory.

Soil analysis

Soils were sampled at 0–20 cm, 20–40 cm, 40–60 cm and 60–80 cm depth in each subplot after the planting. Soil samples were prepared for analyses according to LVS ISO 11464 (2005) standard, fine earth fraction of soil ($D < 2$ mm) was used for chemical analysis. The following parameters were determined in the soil samples: soil exchangeable acidity (pH) in calcium chloride suspension was measured according to LVS ISO 10390 (2002); total nitrogen (N) content was determined using modified Kjeldahl method according to LVS ISO 11261 (2002); available phosphorus ($P\text{-}PO_4^{3-}$) content was determined according to LVS 398 (2002); exchangeable potassium (K) was extracted with ammonium acetate and determined by flame atomic emission spectroscopy; nitrate nitrogen ($N\text{-}NO_3^-$) and ammonium nitrogen ($N\text{-}NH_4^+$) content was determined by spectrophotometry; particle size distribution was determined using wet sieving and sedimentation method according to LVS ISO 11277 (2000); carbonate content was determined using volumetric method according to LVS ISO 10693:1995; organic and total carbon content was determined using elementary analysis according to LVS ISO 10694 (2006); total content of sulfur was determined using an ELTRA elemental analyser and soil bulk density according to LVS ISO 11272:1998.

Soil solution analysis

Soil solution was sampled in 6 subplots with soil solution samplers (suction tube lysimeters, Eijkelkamp), soil solution sampler cup made of porous ceramic (92% pure Al_2O_3) and body of trace metal free PVC. Two soil solution samplers were installed vertically into the soil in each subplot at 30 and 60 cm depth in the summer of 2011. Soil solution was sampled twice a month from May 2012 to November 2012. The following parameters were determined in soil solution samples: pH determined according to LVS ISO 10523; electrical conductivity determined according to LVS EN 27888:1993; total alkalinity determined according to LVS EN ISO 9963-1:1995; ammonium ($N\text{-}NH_4^+$) determined using manual spectrometric method according to LVS ISO 7150/1:1984; nitrate ($N\text{-}NO_3^-$) determined using Visocolor ECO Test 5–41 manual spectrometric method; phosphorus (P-PO_4^{3-}) determined using ammonium molybdate spectrometric method according to LVS EN ISO 6878; calcium (Ca) and magnesium (Mg) determined using atomic absorption spectrometric method according to LVS EN ISO 7980 (2000); sodium (Na) and potassium (K) determined using flame emission spectrometric method according to LVS ISO 9964-3:2000.

Statistical analysis

The experimental data of Hybrid aspen length and annual increment, grasses and legumes seed yield and yield structural elements were statistically analysed by applying the OpenOfficeCalc and analysis of variance (ANOVA). Pearson correlation analysis was also used.

RESULTS AND DISCUSSION

Characteristics of Hybrid aspen growing

According to literature, hybrid aspen clones have shown a high level of variability in phenological, physiological, growth and wood properties (Yu, 2001; van den Driessche et al., 2003). Seedlings of Hybrid aspen clones were of relatively uniform size at planting, but according to one-way ANOVA the length of stems after the first and the second growing season were significantly different among the replicates of experimental subplots. Over all fertiliser subplots and across sites, the height of clone 4 was significantly bigger than that of clone 28 both at the planting and after the first and the second growing season (Table 3). Comparison of increment of Hybrid aspen in the first and the second growing season is shown in Fig. 1. The analysis showed that there was a statistically significant effect of wastewater sludge fertilisation at the planting on the stem height of both clones. The stem height increased by 20% in the wastewater sludge fertilisation subplots after the first growing season. The effect of wastewater sludge fertilisation on the stem height was still significant after the second growing season, the stem height increased above control from 34 to 44%, depending on the clone. According to literature, the most limiting nutrient of Hybrid aspen growth is phosphorus (van den Driessche et al., 2003; van den Driessche et al., 2005). Wastewater sludge is characterised by high concentrations of macro- and microelements, including a high concentration of mobile forms of N, P, K. An average phosphorus (P_2O_5) content in untreated wastewater sludge is 0.8–2.8%, but an average phosphorus (P_2O_5) content in digested wastewater sludge is 1.5–4.0% (Fytili & Zabaniotou, 2008). There were no statistically significant differences in stem height between the control and wood ash fertilisation subplots after the first growing season. The stem height increased by 19% in Hybrid aspen clone 28 wood ash fertilisation subplots after the second growing season. The most abundant elements in wood ash are Ca and K, followed by Mg, Al, Fe and P. Micronutrients potentially toxic in high concentrations, such as Cd, Cu, Zn, Pb, As, and Cr may also be present. Nitrogen is low in wood ash because most of it is volatilised during combustion (Park et al., 2005). Scientific literature presented either positive, not significant or negative effects of wood ash on seedling growth and survival rate (Augusto et al., 2008). Some experiments showed some complex interactions of seedling response to ash application relative to ash dose, tree species, time span between ash application and seedling establishment and probably with soil type (Augusto et al., 2008).

Table 3. Effects of fertiliser and clone on the stem height. Values of mean stem height (cm) with one standard error are represented

Fertilisation subplots	Measurement dates		
	Spring 2011	Autumn 2011	Autumn 2012
	Stem height (cm) of Hybrid aspen clone 4		
Control	22 ± 1	69 ± 2	142 ± 5
Wastewater sludge	25 ± 1	83 ± 2	190 ± 5
Wood ash	21 ± 1	68 ± 3	143 ± 6
	Stem height (cm) of Hybrid aspen clone 28		
Control	16 ± 1	45 ± 3	88 ± 6
Wastewater sludge	17 ± 1	54 ± 3	127 ± 8
Wood ash	17 ± 1	46 ± 3	105 ± 6

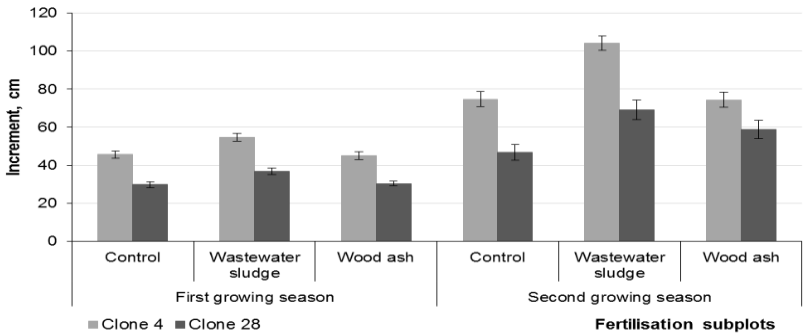

Figure 1. Effects of fertiliser and clone on the increment of Hybrid aspen; error bars indicate standard errors.

Seed yield of perennial grass

The average seed yields of the herbaceous plants species obtained in the study are estimated as good for festulolium and moderate for reed canary grass, because RCG reaches its yield capacity potential only in the 3rd or 4th year of growing. In general the seed production of RCG is complicated due to the fact that seeds often shatter from the upper branches while seeds at the base are still immature (Baltensperger, & Kalton, 1959). Numerous rainy days during the vegetation period did not allow the pollination of galega flowers and made a negative effect on the seed yield, therefore the obtained galega seed yields were quite poor. The sowings of perennial lupine were rather thinned out in the first year, and there were quite a few generative sprouts, therefore the seed yield has not been evaluated.

The results of the first production year indicate that in general the use of fertilisers in the plantation facilitated higher yields of seeds. An essential increase of seed yield for all grass species was provided by applying wastewater sludge (Table 4). The highest increase of seed yield by applying the sludge was observed for RCG (+175 kg ha^{-1} or 136% more in comparison with control variant). The increase of festulolium seed yield was 275 kg ha^{-1} or 23%, but for galega it was respectively 134 kg ha^{-1} or 95% more in comparison with the control. The greatest increase of seed yield (363 kg ha^{-1} or 31%) for the quick-growing festulolium was provided by the use of mineral fertilisers. As to galega being a nitrogen fixing papilionaceous plant the greatest increase of seed yield (230 kg ha^{-1} or 163%) was provided by the use of ash.

Table 4. Seed yield in the first year of sward use (kg ha^{-1})

Fertiliser	Phalaris arundinacea	Festulolium	Galega orientalis
Control	128.9	1176.0	141.7
Mineral fertiliser	225.3	1539.0	184.7
Wastewater sludge	303.9	1451.0	275.8
Wood ash	241.1	1296.0	371.9
Mean	303.9	1366.0	243.6
$LSD_{0.05}$	153.2	254.0	123.1

Morphological and agronomical features of grasses are important factors in producing seed yields, in general, greater production of biomass can also provide for higher seed yields. Therefore a wider analysis of seed yield elements was performed on the grasses (Table 5).

Table 5. Seed yield formative indices

Species	Traits	Fertiliser				Mean	$LSD_{0.05}$
		Control	Mineral fertiliser	Wastewater sludge	Wood ash		
Ph. arundinacea	Flowerhead length, cm	7.0	8.5	7.1	8.3	7.7	1.1
	Plant length, cm	131.8	152.5	136.8	144.3	141.3	16.7
	Overground biomass, t ha^{-1}	5.85	10.68	6.34	7.00	7.47	2.03
	Content in overground biomass, %						
	Stem	75.9	77.6	75.7	78.7	77.0	4.0
	Flowerhead	2.1	1.8	1.7	2.3	2.0	0.9
	Leaves	22.0	20.6	22.6	19.0	21.1	3.9
Festulolium	Plant length, cm	127.5	128.3	134.0	125.8	128.9	15.3
	Flowerhead length, cm	16.8	15.9	16.6	18.4	16.9	1.9
	Overground biomass, t ha^{-1}	6.43	11.41	7.25	10.15	8.81	1.94
	Content in overground biomass, %						
	Stem	71.0	56.7	65.7	65.8	64.8	11.6
	Flowerhead	4.7	6.2	5.6	4.7	5.3	5.7
	Leaves	24.3	37.1	28.8	29.6	29.9	13.8

The biggest average height of plant (141.3 cm) was that of a reed canary grass. Analysis of fertiliser effect on the height of RCG showed that the greatest increase in plant length (+20.7 cm compared with the control) was provided by using mineral fertilisers, but for the variants of wastewater sludge and wood ash the increase of height was not essential. The greatest increase of DM yield (4.83 t ha^{-1}) for overground biomass was also obtained by using mineral fertiliser, but for the variants of using ash and sludge the increase of DM yield was not significant. The use of mineral fertiliser and sludge also provided for a significant increase of flowerhead length (1.6 cm and 1.3 cm respectively) for the RCG. The analysis of content percentage of stems, flowerheads and leaves in the overground biomass yield showed that most of the DM yield (77%) of the RCG was stems. There was not found any significant influence of fertiliser on the changes of stems, flowerheads or leaves for the RCG.

The average length of festulolium was 128.9 cm, but there was not any significant influence of fertiliser on the length of plant established. The greatest increase of DM yield of overground biomass (4.98 t ha^{-1} more) of festulolium, similar to RCG, was obtained by using mineral fertilisers. The use of sludge also gave an essential increase of DM yield (3.72 t ha^{-1} more) but the use of ash did not give any important increase of the DM yield. Festulolium had the biggest average flowerhead length (16.9 cm), but there was not stated any essential influence of fertiliser on the length of flowerhead. The analysis of content percentage of stems, flowerheads and leaves in the overground biomass yield showed that most of the DM yield (65%) of festulolium was also stems. Though, in comparison to the RCG, festulolium had greater proportion of leaves and flowerheads. There was not found any significant effect of fertiliser on the changes of stems, flowerheads or leaves for festulolium.

For the most part the seed quality parameters of the grasses were not influenced by the type of fertiliser applied. For galega the weight of 1,000 seeds was bigger in the variant of wastewater sludge applied but it was not so essential. Bigger seeds of grasses were gathered in the variant of mineral fertiliser applied, and in this case the difference between the use of mineral fertiliser and other variants is credible (Table 6). Germination parameters of festulolium seeds did not differ essentially among the variants but it is symptomatic that in the mineral variant mould was formed during the seed germination, which was not observed in the other treatments. Galega seeds gathered in the variant of mineral fertiliser applied showed lower germination, they had more defective seeds because mould appeared during the germination there. In the variant of sludge galega had more hard seeds which is a characteristic feature of seeds of papilionaceous plants. These seeds are live, but they germinate more slowly therefore there is a limiting number of hard seeds (40 pieces) that are counted to the germinating ones. Due to that the germination of galega in the variant of sludge applied was essential lower.

Table 6. Seed quality parameters

		Control	Mineral fertiliser	Wastewater sludge	Wood ash	$LSD_{0.05}$
1,000 seeds weight, g	Ph. arundinacea	0.99	1.14	0.97	0.97	0.15
	Festulolium	2.51	2.72	2.51	2.45	0.15
	Galega	7.95	8.00	8.21	7.93	0.36
Germination (total), %	Festulolium	89	89	88	87	9
	Galega	100	97	91	100	3
Hard seeds, %	Galega	37	38	49	37	8

Soil and soil solution properties

The results of statistical analysis of soil chemical analysis show high variability in the concentration of nutrients in topsoil horizons of the study field soils. This could be explained by different fertilising practices during the previous use. The soil is not homogenous due to the recent re-cultivation of topsoil: about 20 years ago the levelling of the field was performed and peat was worked in, which is proved by a peat layer visible in some places of the soil profile. The remains of completely decomposed organic residues are found in the soil. Only concentration of $N\text{-}NO_3^-$ significantly affected mean increment of Hybrid aspen in the first growing season ($r = 0.75$). No other significant correlation at $P < 0.05$ was observed on the studied soils. In the previous studies performed in Latvia it has been found that in the first growing season the increment of Hybrid aspen depends mainly on the concentration of soluble N forms in soils (Lazdina et al., 2011). It has also been stated in the research performed in Finland that nitrogen fertilisation improved the height and diameter growth and above-ground dry mass yield (Ferm & Hytonen, 1989).

Chemical content of the soil solution in the study field one year after fertilisation is reported in Table 7. The relation between the mean chemical properties of soil solution in 2012 and subplots mean increment of Hybrid aspen in the second growing season were studied for 2 replicates of experimental plots. The concentration of $P\text{-}PO_4^{3-}$ in soil solution significantly affected the mean increment of Hybrid aspen in the second growing season ($r = 0.88$). The concentration of $N\text{-}NO_3^-$, $N\text{-}NH_4^+$ and Ca in soil solution also related to the mean increment of Hybrid aspen in the second growing season (respectively, $r = 0.62$, $r = 0.55$, $r = 0.59$), no significant correlation was found for K, Mg, conductivity and pH in soil solution.

Table 7. Effects of fertilisation on soil solution chemical content in 2012. Mean values with one standard error are represented

Soil solution chemical parameters	Fertilisation subplots					
	Control 1	Wastewater sludge 1	Wood ash 1	Control 2	Wastewater sludge 2	Wood ash 2
pH	7.8 ± 0.1	7.9 ± 0.1	7.7 ± 0.1	7.7 ± 0.1	8.0 ± 0.1	8.1 ± 0.1
Conductivity, $\mu S\ cm^{-1}$	413 ± 18	508 ± 75	572 ± 32	232 ± 49	449 ± 41	443 ± 57
Total alkalinity, mmol L^{-1}	4.8 ± 0.2	6.9 ± 0.4	6.2 ±0.5	1.7 ± 0.4	3.6 ± 1.2	6.1 ± 0.1
$N\text{-}NO_3^-$, mg L^{-1}	0.2 ± 0.1	1.9 ± 1.0	0.3 ± 0.1	0.7 ± 0.2	0.9 ± 0.2	1.3 ± 0.6
$N\text{-}NH_4^+$, mg L^{-1}	0.02 ± 0.01	0.05 ± 0.02	0.05 ± 0.01	0.05 ± 0.01	0.04 ± 0.01	0.03 ± 0.01
$P\text{-}PO_4^{3-}$, mg L^{-1}	0.03 ± 0.01	0.12 ± 0.04	0.06 ± 0.03	0.04 ± 0.02	0.13 ± 0.05	0.03 ± 0.02
K, mg L^{-1}	0.6 ± 0.1	0.9 ± 0.2	3.7 ± 0.5	2.1 ± 0.3	3.8 ± 0.3	10.9 ± 2.4
Ca, mg L^{-1}	53 ± 4	105 ± 9	76 ± 9	11 ± 1	61 ± 8	70 ± 2
Na, mg L^{-1}	8.6 ± 1.2	5.7 ± 0.6	6.4 ± 0.2	15.7 ± 2.1	5.7 ± 0.4	12.2 ± 2.0
Mg, mg L^{-1}	13.6 ± 0.5	9.6 ± 0.8	18.1 ± 0.7	3.3 ± 0.2	15.2 ± 1.3	12.6 ± 1.2

CONCLUSIONS

The combined growing of agricultural crops and woody plants in plantations provides for a sustainable management system, it increases the efficiency of natural resource utilisation, it extends the range of obtainable produce and also squares the movement of financial resources.

Growth dynamics of Hybrid aspen affects both the clone and the use of fertilisers at planting. Wastewater sludge fertilisation increases stem height by 20% after the first growing season. The effect of wastewater sludge fertilisation on stem height was still significant after the second growing season, the stem height increased above control from 34 to 44%, depending on the clone.

Reed canary grass, festulolium and fodder galega can be successfully cultivated for seeds in the first year of use locating the crop fields in the plantations of energy plants interchangeably with trees.

The use of wastewater sludge provided an essential increase in seed yields for all the grass species. Still the influence of fertilisers under research on the grass species was different. The greatest increase in seed yields of the RCG was established with the use of sludge, for festulolium it was the use of mineral fertilisers, but for fodder galega it was the applying of ash.

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