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EFFECT OF SEWAGE SLUDGE FERTILIZATION IN SHORT-ROTATION WILLOW PLANTATIONS

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Abstract. The aims of the research work were to evaluate increase of productivity of Salix energy crop and forest plantations by using sewage sludge fertilization, impact of sewage sludge on the environment, and to calculate economic income from plantations. The most important problem during the first rotation cycle in willow plantations was weed control. After using sludge weeds grew up, because sludge contains large amounts of nutrients. After cutting of sprouts in the second growth season willow plantations produce more sprout from stand, and productivity increases from 0,2–0,6 t to 4,6–5,5 t of dry mass/ha. Effect of sewage sludge fertilization is greater in the second season both in control plantations and fertilized plantations. Average biomass production in fertilized plantations was 5,5 t of dry mass/ha per year. Shoot wood from fertilized plantations contained on the average by 4–8 % more heavy metals than control plantation wood. The concentration of heavy metals in the top soil layer increased, but it did not exceed the Regulations issued by the Cabinet of Ministers of Latvia about the soil quality, and the soil cultivation in the first three years was 760 LVL/ha. If the distance were not longer than 40 km and a willow-cutting combine operated without pauses, costs for cutting, chip crushing and delivery to consumers would achieve 4 LVL/m^3.

Keywords: willows, plantations, energy wood, sewage sludge, fertilization.

1. Introduction

First plantations of energy crop in Europe were established in the seventies of the 20th century [13]. Plantations of poplars, alders, birches, but mainly willows are established as alternative of agricultural production, sewage treatment and utilization of sewage sludge for plantation forest fertilization. Productivity of intensive plantations is 30–40 m^3 of wood (10–12 t of dry mass) per year [5]. During the past few years interest in willow as an energy crop has been growing in Europe [1]. Willow production has a high net energy output compared, for example, to grain and oil seed production, and its biomass yield is relatively high [1]. In addition, Latvia is a natural habitat for willow. Substituting biomass for fossil fuels in the generation of energy is an important strategy for the EU in order to minify climate change and enhance security of supply. For this purpose bioenergy is promoted through several EU directives as well as national policies. Biomass-based electricity is promoted in the Renewable Electricity Directive which aims to increase the use of renewable energy sources (RES) to 22 % by 2010 [2].

Latvia, like most European countries, since 2005 had no laws of using sewage sludge in forestry, now we have regulations issued by the Cabinet of Ministers No 362 (since 2 May 2006). Now in compliance with the EU Soil Policy Directive working documents, plantation forests are one of the most perspective areas of using sewage sludge and wood ash as fertilizers which have not important effect on the environment and allow significant increase of forest stand productivity.

In 2004 in Latvia 36164 t of dry mass of sewage sludge were produced. Approximately 7684 t of sewage sludge were used in farming, the rest was stored [7]. If stored sewage sludge were used in forestry, especially for fertilization of plantation forests, almost 2 000 ha of plantation forests and willow crop plantations using such a sludge for fertilization could be established. In such plantations production of biomass could be 16–20 000 $t_{dry\ mass}$ per year and 60 000 $t_{dry\ mass}$ in energy crop plantations.

In Ireland if an irrigation rate of 150 kg ha^{-1} N is assumed, 1 ha will treat waste from 120 people. Thus to treat 10 % of waste water from Northern Ireland would require approximately 1250 ha of a coppice. This would reduce costs both for short-rotation willow coppice growing and their use as vegetation filters. Optimum proportion by weight of nutrients for a short-rotation willow coppice where N = 100, is N = 100, P = 14 and K = 72. Mean figures for wastewater show a similar proportional balance of N = 100, P = 18 and K = 64 [12].

In Sweden a recommended dose is 5 t of dry mass of sewage sludge per hectare per year, which should, if carefully managed, cause no adverse effects on the soil, groundwater or vegetation. It is assumed that sewage sludge meets the environmental requirements [4]. Willows from phytoremediation are a potential source of biomass for bioenergy [16], and ash from biomass production contains nutrients like calcium, potassium and phosphorus that ideally should be recycled for forest or agricultural soils, thus closing not only the carbon cycle but also the fluxes of mineral materials caused by these technologies [16].

Wood ash generated during the combustion of wood for energy contains both macro- and micronutrient elements required for plant growth. The most abundant elements include Ca and K with fair amounts of Mg, Al, Fe, P and small amounts of trace elements. Nitrogen, including organic and inorganic forms, is present only at low levels in wood ash because it is volatilized during combustion. Nitrification rates might increase in wood ash-treated soils, although wood ash itself does not supply significant amounts of N. Wood ash application increased soil pH, especially at a 0–10 cm depth. In a 0–10 cm soil layer, soil pH increased from 6,1 to 6,9 in control soils, and 7,1 in 10 and 20 Mg/ha treated plots. The increase in pH was smaller at a 10–20 cm depth, ranging from 6,3 in control soils to 6,5, and 6,7 in 10 and 20 Mg/ha treated plots. Extractable P, K, Ca, and Mg concentrations were higher in wood ash-amended soils than in control soils. Extractable P concentrations increased linearly with increasing ash application at a 0–10 cm depth [9].

Measurements of a courser ash fraction indicate that a large amount of Cd, Pb and Zn present in wood is volatilised during gasification. Optimization of the process parameters should aim at concentrating most of the heavy metals in a small ash fraction, achieving low metal levels in more voluminous ash fractions. Clean ashes then could be recycled on the soil, and disposal costs for contaminated ashes would be minimised [16].

Baseline values of metals in plants reported by Kabata–Pendias & Pendias (0,1–2,4 mg/kg Cd; 1–400 mg/kg Zn, 0,2–2,0 mg/kg Pb and 5–20 mg/kg Cu) [16]. These ranges represent normal values over a wide variety of plant species. More specific baseline metal concentration values in willow wood has rarely been reported for *Salix viminalis* of 4,5 mg/kg Cu and 23 mg/kg Zn [11]. Concentrations of several elements in branch wood Salix. *viminalis* from uncontaminated soil were reported to be 1,1 mg/kg Cd, 2 mg/kg Cr, 3,1 mg/kg Cu, 3,3 mg/kg Ni, 0,1 mg/kg Pb and 9,6 mg/kg Zn [3].

Reed canary grass and SRC were two of the few bioenergy crops that currently could potentially be grown north of latitude 65' N. Short-rotation coppices (SRC) were currently potentially widespread in Europe. They were predicted to decline from the most southern and western areas and increase further north, particularly in latitude 55'–64' N (north UK and Scandinavia), where they may be able to grow in a further 50 % of the land area. SRC were also predicted to approximately double their range in latitude 65'–71' N. SRC and reed canary grass have the same distribution as they have the same climate rules (600–2000 mm of rainfall with maximum temperatures of 38 °C) [15].

At the moment willow plantations in Latvia are established mainly for producing cuttings and shoots for fence production. These plantations were small and located around all Latvian farmers who produced fence and wattles but now are interested in growing willows for energy production.

Investigation object and methodology

Harvested shoots were planted in a mineral soil in May of 2004 and 2005. Plantation in Marupe located at

56 51 32, 76' N

23 58 39, 84' E

was established with *Salix viminalis* in 2004 and Sven in 2005.

Olaine plantation located at

56 49 24, 12'N

23 58 08, 76'E

was established with Sven, Tora, Tornhild in 2005.

The shoot length and diameter were measured in November of 2005 at the end of the vegetation season. Biomass was calculated as volume of conical frustum:

$$V = \frac{1}{3}\pi h\left(R_1{}^2 + R_1 R_2 + R_2{}^2\right),$$

where R_1 – top radii; R_2 – bottom radii; h – height.

The moisture content of wood was determined by drying in a forced air oven at 105 °C until reaching a constant weight (LVS ISO 11465:1993).

Ash content was determined by weighing after ashing at 550 °C during 4 hours in a muffle furnace.

Mobility of heavy metals in soil and above water was investigated in plantations fertilized with sewage sludge. Heavy metal content in soil and stems were determinated by atomic absorption spectrophotometry (AAS).

According to the data of measurement, economic effect and income from energy crop plantations fertilized with wastewater sewage sludge and wood ash were calculated.

2. Results and discussion

Site preparation was started in autumn prior to planting.

Vegetation was then killed by application of Roundup Eko, herbicide. Next spring, immediately before planting, the soil was harrowed and rolled. Planting was assumed to take place at an initial density of 12,000 cuttings per hectare (Fig 1).

In the spring of 2005 in Latvia prices were about 0,03 EUR per cutting for refined clones, including transport, but cuttings from Sweden were 0,06 EUR per cutting. A possible explanation of this is that the distribution system was less developed in Latvia than in Sweden.

In the first rotation cycle in willow plantations, like in birch, alder, pine plantations, the most important problem was the weed control. After using sludge weeds grew up double-quick because wastewater sewage sludge contains large amounts of plant nutrient elements.

Fig 1. Plantation planted in spring of 2004

Plots fertilized with sewage sludge were more grassed but shoots were healthful and green (Fig 2). It is recommended to fertilize plantations in the second year to reduce costs of weed control in the first year.

Fig 2. Control plot and fertilized plot after weed control

Weed control was necessary as weeds could overrun shoots [6]. Weeding of willows took more time than other species in a similar area (Fig 3).

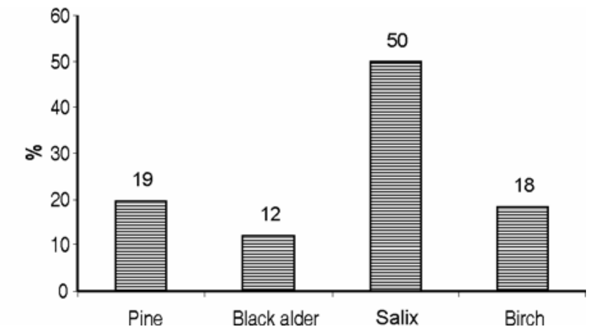

Fig 3. Weeding time for different species planted under similar growing conditions

In the second year after using sewage sludge fertilization deciduous plantations need less weed control and cultivation. During the next couple of years only mechanical weed control was applied. During the winter after planting the shoots were cut back in order to promote the growth of several vigorous shoots from each plant during the following spring. Subsequently, harvest to willows occurs every third year with a yield of 27 t/ha (9 $t_{dry\ mass}$/ha/yr).Yields are generally significantly lower during the first rotation period due to the plant's need to develop a root system [1].

In order to achieve the assumed yields, the plantation must generally be located on soils of an average quality. There were different amounts of nutrients in the top soil layer of willow plantations (Fig 4).

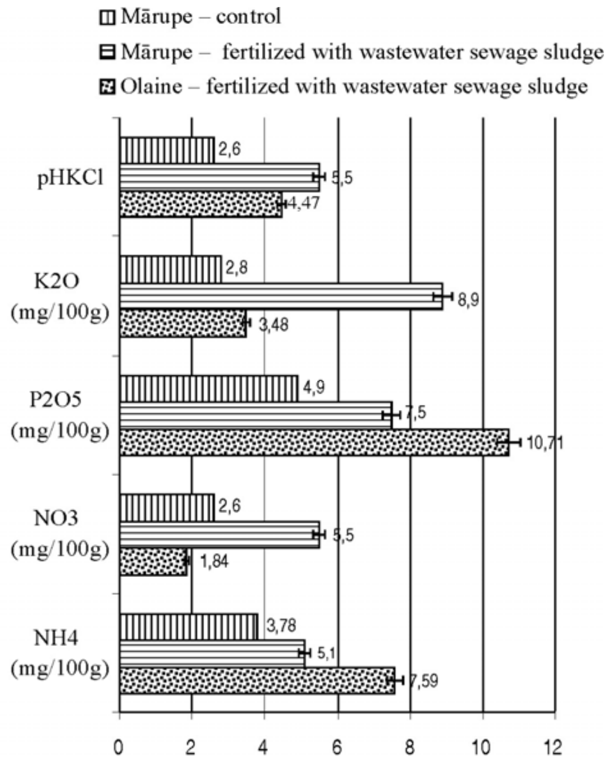

Fig 4. Amounts of main nutrient elements and pH value of top soil layer

Better growth conditions were in the plantations of Olaine and Marupe with sewage sludge fertilization (Fig 4).

Fig 5. Plantation established in 2004 after the first season in autumn

Willow plantations after cutting of sprouts in the second growth season produce more sprouts from stand (Fig 5, 6). Effect of sewage sludge fertilization is greater in the second season (Fig 7).

Fig 6. Sven, Tornhild and Tora in the second season (2005/06)

Fig 7. Control and fertilized *S. viminalis* in the second season (2005)

An average number of sprouts from sprout cutting in first and second seasons was: Tora – 1,5 and 4,3; Tornhild – 1,2 and 5,1; Sven – 1,5 and 4,9; Salix viminalis – 2,3 and 4,3 (Fig 8).

Productivity increases from 0,2–0,6 t of dry mass/ha to 4,6–5,5 t of dry mass/ha (Fig 9). In the first season Sven shows better growth results (1,3 m^3/ha), but Tornhild – only 0,3 m^3/ha. In the second season after fertilizing with sewage 14 t/ha stock of Tornhild is 9,5 m^3, while Sven produces less biomass than Tora and Tornhild (Fig 9). In the first season Sven shows better growth results (1,3 m^3/ha), but Tornhild – only 0,3 m^3/ha. In the second season after fertilizing with sewage 14 t/ha stock of Tornhild is 9,5 m^3, while Sven produces less biomass than Tora and Tornhild (Fig 9).

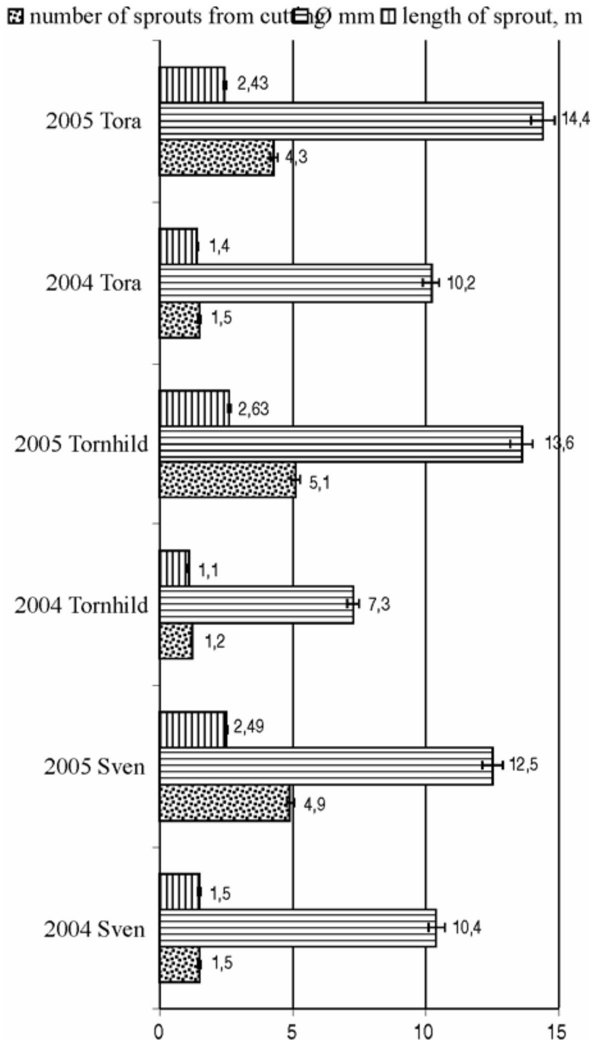

Fig 8. Wilow growth in the first and second seasons in Olaine

In Marupe *Salix viminalis* a control plantation produced one ton of dry mass from hectare ($t_{drymass}$/ha), a fertilized plantation – 5,5 t of dry mass/ha. In the first season (Sven) there was 0,8 t of dry mass/ha in control plantations, and 1,1 t dry mass/ha in fertilized plantations (Fig 10).

When excluding fertilization and reducing mechanical weed control, both costs and incomes decrease. In Poland calculations show that if low external input (LEI) management is employed, the farmer can afford a yield reduction of up to 2,3 t/ha/yr (7,5 EUR/MWh) and 1,3 t/ha/yr (11 EUR/MWh), without suffering negative economic consequences of that decision. The willow yield must exceed 5,8 t/ha/yr (7,5 EUR/MWh) and 3,3 t/ha/yr (11 EUR/MWh) for the farmer [1].

There was no observed increase in concentration of heavy metals above water during sewage sludge fertilization. Concentration of heavy metals in the top layer of soil increased, but it did not exceed the Regulations issued by the Cabinet of Ministers of Latvia on the soil quality standards [10, 11].

An average increment of concentration of heavy metals in the mineral soil top layer was 14 %.

Shoot wood from fertilized plantations contained averagely by 5–4 % more heavy metals than control plantation wood. Stems from control plots contained: Cd – 0,052 mg/kg; Cr and Cu – 0,024 mg/kg; Pb – 0,024 mg/kg; Zn – 11,20 mg/kg of dry mass. The content of Zn in stems from plots fertilized with sewage was greater by 5 %, for Cr, Pb and Cu – by 4 %.

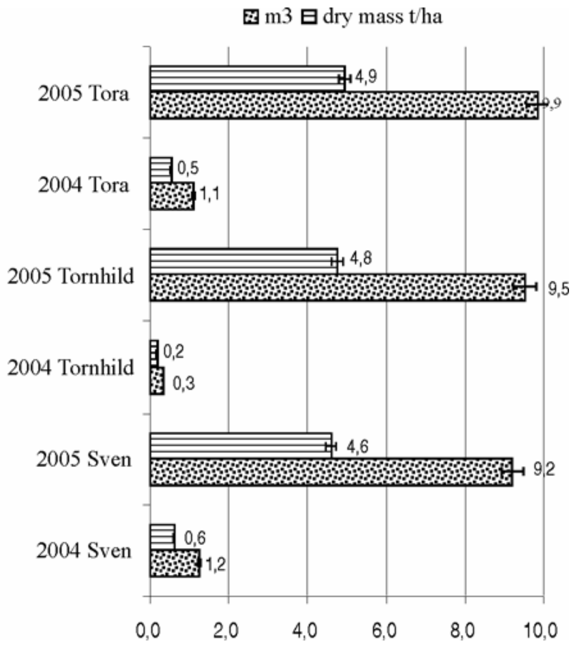

Fig 9. Productivity of willows in 2004–2005

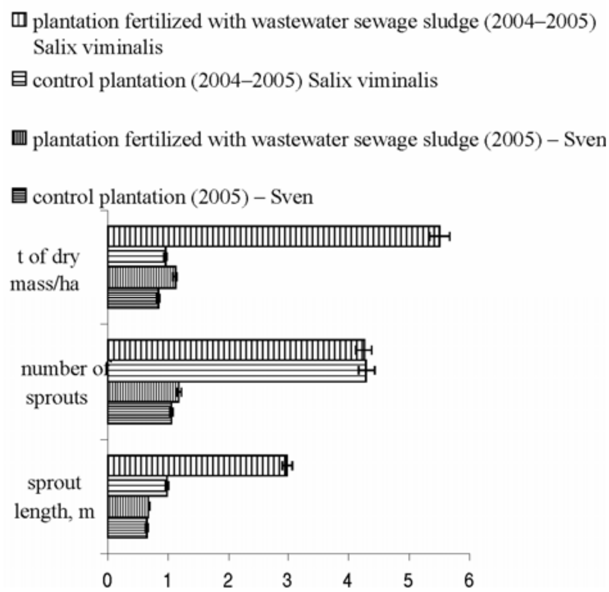

Fig 10. Effect of sewage sludge fertilization on Salix growth and productivity in Marupe

There are no huge willow plantations in Latvia, and costs are higher for pioneer growers. So far willow-for-energy is grown commercially only in Sweden, occupying a total area of 14 300 ha in 2003 [14].

Costs of plantation creation and cultivation during the first tree years in Latvia were 1 081 EUR/ha, including sewage diffusion and ploughing (Table). Costs of cutting, chip crushing and delivery to consumers reached 3,4 Ls/m^3 if the distance was not longer than 40 km, and a willow-cutting combine operated without pauses.

Costs of plantations established in Latvia during the first tree years

Year	Month	Activities	Costs per ha (EUR)
First	August–September	grass cutting	50,00
	September–October	analyses of soil	34,29
	October	diffusion of sewage sludge (70 t of undried sewage per ha)	150,00
	November	ploughing	60,00
	November	planting cuttings (12 000/ha)	342,86
		total	637,14
Second	April–May	herbicides (Basta) (6 l/ha)	95,71
	April–May	planting	92,86
	Juny–August	weed control	100,00
	July–August	grass cutting between rows	28,57
	November–February	cutting back of shoots	51,43
		total	368,57
Third	Juny–August	grass cutting between rows	28,57
	November–February	cutting back of shoots	51,43
		total	80,00
		total	1085,71

In 2004 the Polish farmers growing willows are thus eligible for a carbon credit of 11,25 EUR/ha. This subsidy reduces the wood chip price that is required for break even by 0,45 EUR/MWh, assuming a willow yield of 9 t/ha/yr [1]. But in Latvia there were no subsidies for willow plantation establishers.

At the moment (2005) wood chip prices are lower in Latvia than in most states of West Europe. Hence, in a short-term perspective it might be more profitable for willow farmers in Latvia to export their wood chips than to sell them to domestic consumers. Over time biofuel prices in Latvia are likely to increase, provided that policy measures are implemented in order to meet the RES targets for 2010 and 2020.

The costs of producing willow wood chips, including transport to the heating plant, amount to about 267 PLN/ha under the Polish conditions, excluding land rental costs and overheads. This cost is based on a yield of 9 t/ha/yr and corresponds to 8 EUR/MWh [1].

3. Conclusions

1. Fertilization with sewage has a positive effect on Salix growth, but it causes problems with weed control. The second season is optimal for fertilization to decrease problems with weeds.
2. In the first season the dry mass of control plantations without sewage was 0,2–0,6 t/ha, but in the second season after fertilization with sewage sludge 14 t/ha (700 kgN/ha) the dry mass of shoots reached 4,6–5,5 t/ha.
3. Shoot wood from fertilized plantations contained heavy metals averagely by 5–4 % more than control plantation wood.
4. The top soil layer in plots fertilized with sewage contained heavy metals averagely by 4–5 % more than that in control plots.
5. Costs of plantation creation and cultivation during the first tree years were 1 081 EUR/ha, and costs of cutting, chip crushing and delivering to consumers reached 4,8 EUR/m^3 if the distance was not longer than 40 km, and a willow-cutting combine operated without pauses.
6. If all costs covered by plantations owner willow chips cost price 2010 would be – 24 EUR/m^3, but if costs of sewage fertilization covered by producer – 121,4 EUR/m^3. Considering inflation, also wood-processing chip costs could achieve 21–23 EUR/m^3.

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TRĘŠIMO NUOTEKŲ DUMBLU ĮTAKA TRUMPOS ROTACIJOS KARKLŲ PLANTACIJOMS

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Santrauka

Mokslinio tiriamojo darbo tikslai yra įvertinti miško prieaugį ir *Salix* energinį pasėlių produktyvumą tręšimui naudojant nuotekų dumblą; nuotekų dumblo įtaką aplinkai ir apskaičiuoti plantacijų ekonominę naudą. Svarbiausia problema pirmosios rotacijos karklų plantacijose buvo piktžolės. Dumblą paskleidus piktžolės augo, nes jame buvo daug nitratų. Antrojo karklų augimo sezono metu jie duoda daugiau atžalų, todėl produktyvumas padidėjo nuo 0,2–0,6 t iki 4,6–5,5 t sausosios masės iš hektaro. Tręšimo nuotekų dumblu įtaka buvo didesnė kontrolinėse ir tręštose plantacijose antrojo augimo sezono metu. Vidutinis biomasės kiekis tręštose plantacijose buvo 5,5 t sausosios masės į hektarą per metus. Ūglių medienoje tręštose plantacijose buvo vidutiniškai 4–8 % daugiau sunkiųjų metalų nei kontrolinių plantacijų karklų medienoje. Sunkiųjų metalų koncentracija paviršiniame dirvožemio sluoksnyje padidėjo, bet neviršijo Latvijos ministrų kabineto nustatytų leidžiamųjų dirvožemio kokybės ribų, dirvožemio rekultivacija per pirmuosius trejus metus buvo 730 LVL/ha. Jei atstumas neviršytų 40 km ir karklų pjovimo kombainas dirbtų be pertraukų, pjovimo, smulkinimo ir pristatymo vartotojams išlaidos siektų 4 LVL/m^3.

Reikšminiai žodžiai: karklai, plantacijos, mediena energijai, nuotekų dumblas, tręšimas.

ВЛИЯНИЕ ИЛОВОГО УДОБРЕНИЯ НА ПЛАНТАЦИИ ИВНЯКА КОРОТКОЙ РОТАЦИИ

Д. Лаздина, А. Лаздинш, З. Каринш, В. Капостс

Резюме

Целью научного исследования было оценить прирост леса и энергетическую продуктивность посевов Salix в результате использования в качестве удобрения сточного ила; воздействие, оказываемое сточным илом на окружающую среду, и рассчитать экономическую пользу плантаций. Главной проблемой на плантациях ивняка первой ротации были сорняки. После попадания ила на плантации быстро росли сорняки из-за большого количества нитратов в нем. Во время второго сезона роста ивняка появлялось много отростков, продуктивность увеличивалась от 0,2–0,6 т до 4–5,5 т сухой массы с гектара. Влияние илового удобрения было большим на контрольных и удобренных плантациях во время второго сезона роста. Среднее количество биомассы на удобренных плантациях составило 5,5 т сухой массы за год. В ростках древесины с удобренных плантаций в среднем было на 4–8 % больше тяжелых металлов, чем в древесине ивняка с контрольных плантаций. Концентрация тяжелых металлов в поверхностном слое почвы увеличилась, хотя и не превысила установленных Правительством Латвии предельных величин. Рекультивация почвы в первые три года составила 730 латов/га. В случае, если расстояние не превышает 40 км и комбайн по срезке ивняка работает без перерывов, расходы на срезку, измельчение и доставку потребителям составят 4 лата/м^3.

Ключевые слова: ивняк, плантации, древесина, сточный ил, удобрение.

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