Use of waste water sludge and wood ash as fertiliser for Salix cultivation in acid peat soils

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Abstract: Two problems have become more topical in recent years – production of solid biofuel from wood and the utilisation of ash and organic waste, including waste water sludge. The purpose of this research is to model simultaneous solutions for both of these problems through their use as fertilizer and to identify useful indications for the use of waste water sludge and wood ash as fertilisers. Opportunities to boost the efficiency of the applications of waste water sludge by combined spreading with wood ash are addressed in this study. An experiment is carried out in vegetation pots with different proportions of peat, sludge and ash to determine the impact of stem and root system development related to chemical and nutrient availability. Due to these studies, it is determined that waste water sludge has a comparably small liming effect. The fertilising effect of sludge can be increased by the admixture of wood ash and dolomite. These materials reduce the acidity of the soil and provide additional nutrients. Using dolomite as a liming material in the amount of 10 t ha^{-1} secures a change in pH of 0.6–1.2 units in peat soil. Significant changes in pH were found just a few centimetres into the upper layer of the soil. The application of an equal amount of wood ash produces a faster effect in terms of neutralisation. The limiting element is phosphorus. However, the mineralisation of peat increases the percentile proportion of all mineral elements in substrates as well as heavy metals.

Key words: ash, biomass production, fertilisation, restoration, substrate & waste water sludge

INTRODUCTION

Utilisation of waste water sludge as a fertiliser for energy crops is a new use of sludge in Latvia, and as such there is insufficient information about its impact on the environment and timber quality and about the safest and economically most beneficial ways of utilising the fertilizer.

The rate of sequestration of carbon dioxide in biomass can be increased by expanding forest cover and increasing the productivity of existing forest. The establishment of plantations of fast-growing trees and shrubs meets both of these conditions. Despite this, there are now special state support mechanisms for the promotion of willow and other energy crop plantations in Latvia, as there are in the United Kingdom, Sweden, Ireland and Poland, and interest in these crops is growing in the same context as green energy factories and environmentally friendly waste management (Hasselgren, 2003; Mangalis, 2004; Smaliukas & Noreika, 2005; Park et al., 2005; Ericsson et al., 2006; Wisniewska et al., 2006; McCormick & Kåberger, 2007; Adler et al., 2008; Asamaa et al., 2010). The choice of hybrids in the genera osier

(*Salicaceae*), family willow (*Salix*) and aspen (*Populus*) was the result of their rapid rate of growth, ease of regeneration and tolerance to different climatic conditions. Willows can be used in different ways (depending on the market conditions) and have characteristics that improve the growing environment, including the soil (Saarsalmi, 1995; Weih & Nordh, 2002; Evarts-Bunders, 2005; Weih, 2004; Teece et al., 2008).

Increasing the welfare rate and improving the treatment efficiency of waste water secures the production of an increasing amount of considerably good-quality, environmentally safe waste water sludge, but the problem of utilising this material is therefore becoming more and more topical. This sludge, which contains different plant nutrients, can be used to improve growing conditions before the establishment of plantations, as well as to increase the growing rate of existing short rotation plantations. Local heating systems, which utilise different kinds of timber for energy, produce alkaline ash, which is rich in potassium and other elements and can be used in intensively managed forests, recultivated peat quarries and agricultural soils as a fertiliser and liming material (Jones et al., 1994; Uebel & Heinsdorf, 1997; Dilly, 1999; Hytonen, 1998; Kāposts et al., 2002; Schreffler & Sharpe, 2003; Jacobs et al., 2005; Huotari et al., 2007; Gemste & Vucāns, 2007).

Current conditions in Latvia promote increasing use of timber for energy and establishment as well as utilisation of short rotation plantations (Piebalgs, 2008), at the same time reducing the risk to supplies of timber for energy and providing favourable options for the use of waste water sludge and wood ash (Gemste & Vucāns, 2010).

The aim of this research is to produce an ecologically justifiable model for the use of waste water sludge by evaluating the environmental effects of sludge and ash applications and providing solutions for the environmentally safe use of sludge on peat land according to requirements.

MATERIALS AND METHODS

The research objectives are the modelling of the suitability of peat soils, fertiliser applications for the establishment of short rotation willow plantations in Latvian conditions and cut away peat land to reclaim used peat quarries by using wood ash and waste water sludge as fertilisers in an ecologically safe way.

Clones of *Torhild* willows originating in Sweden were used in the experiment. A vegetation experiment in partially controlled conditions was established to model the effect of different amounts of waste water sludge compost and wood ash on the chemical properties of the peat, including the leaching of heavy metals and the intensity of root development under the maximum load of compost and wood ash. Peat from a quarry was used to prepare mixtures of compost, wood ash and peat. The experiment was launched in May. Seven different samples by proportion of ash and compost substrates were prepared for the experiment. Pure peat was used as a control substance. The admixture of compost in different variants corresponded to 170 t_{dry} ha^{-1} (1:4) and 340 t_{dry} ha^{-1} (1:1) (Table 1).

The maximum amount can be used according to regulations on the recultivation of degraded areas in order to re-establish a fertile soil layer. The admixture of wood ash corresponded to 10 t ha^{-1} and 20 t ha^{-1}. 15–20 cm long cuttings planted in 25 cm pots with a 3-litre volume of substrate were used in the experiment. Four cuttings were planted in each pot. A total of 672 cuttings were planted in 168 pots.

Table 1. Substrates used in experiment.

Variant code	Description	Variant code	Description
T	control, peat	T	control, peat
T4Ko1	four parts peat to one part compost	T1Ko1	peat and compost in equivalent amounts
T4Ko1A10	four parts peat to one part compost with wood ash (10 g l^{-1}) equivalent to 10 T DM ha^{-1}	T1Ko1A10	peat and compost in equivalent amounts with wood ash (10 g l^{-1}) equivalent to 10 T DM ha^{-1}
T4Ko1A20	four parts peat to one part compost with wood ash (10 g l^{-1}) equivalent to 20 T DM ha^{-1}	T1Ko1A20	peat and compost in equivalent amounts with wood ash (10 g l^{-1}) equivalent to 20 t DM ha^{-1}

The height of the willow shoots in the pots was measured once every two weeks. Within the scope of the study, monitoring the development of the root system was done by weighing the roots and shoots of 12 willow cuttings every two weeks. The substrate was removed from the roots by washing; next, the roots were cut from the cutting. The roots and shoots were dried at 105°C until they became an unchanging mass. The dry biomass was then weighed using analytical scales. At the end of the vegetation season, the aboveground and belowground biomass of all residual willow cuttings was measured.

The reaction (pH_{KCl}) was estimated according to the requirements of the LVS ISO 10390 standard. Total carbon was estimated according to the requirements of the LVS ISO 10694 standard.

Exchangeable ammonia was estimated with a colorimeter using a Nesler reactive in 0.1 n NaCl extraction. Exchangeable phosphorus was estimated with a colorimeter using an ammonia molybdenite reactive in the presence of a reduction agent (0.1% $SnCl_2$ solution) in 0.2 n HCl extraction. Exchangeable potassium was estimated using a Perkin Elmer AAnalyst 200 flame photometer in 1 n sodium acetate extraction (Pāvule, 1978).

Statistical evaluation and graphical rendering of the data obtained was realised using SPSS, Microsoft Excel, OpenOffice.org Calc and Gretl software tools. The highest, smallest and average values, as well as standard error and measures of variation, were estimated using methods of describing statistics. The relations between different data were compared using T-test, variance and correlation analysis (Liepa, 1974; Arhipova & Bāliņa, 2003).

RESULTS AND DISCUSSION

Establishment of plantation type stands using different waste materials (wood ash, waste water sludge and composted biomass) as fertilisers is a new solution for Latvia not only in relation to the use of abandoned agricultural land, but also in relation to the recultivation of degraded areas (gravel and peat quarries), which have to be tested using economical and environmental criteria before broader industrial-scale implementation. Insufficient resources of potassium and phosphorus before fertilisation were found in all experimental plantations. Waste water sludge contains organic material, nitrogen, phosphorus and some potassium, which are all necessary for the rapid growth of energy crops. On average, waste water sludge produced in biological waste water treatment plant contains 51g kg^{-1} N,, 17 g kg^{-1} P and 65% of dry mass consists of organic substances (Gemste & Vucāns, 2007). Wood ash can be used as a source of mineral nutrients because it contains a significant amount of potassium (~30 g kg^{-1}), calcium (125 g kg^{-1}) and magnesium (20 g kg^{-1}) as well as phosphorus (10 g kg^{-1}) (Kudakas & Tamošauskas, 2005).

Of course, the simplest way to apply nutrients to soil is to use mineral fertilisers, because exact amounts of certain nutrients can be calculated according to the soil's properties. However, only mineral nutrients can be applied in this way, whereas using organic fertilisers enriches the soil with biologically active organics, which also play a significant role in the regulation of the water regime. Using waste water sludge and wood ash as a fertiliser for different crops ensures that the nutrients locked in these materials are returned to biological circulation.

Growth of shoots and roots and production of aboveground and belowground biomass are different, while the addition of ash stimulates production of the biomass of roots and sludge stimulates growth in shoots (Figs 1 and 2).

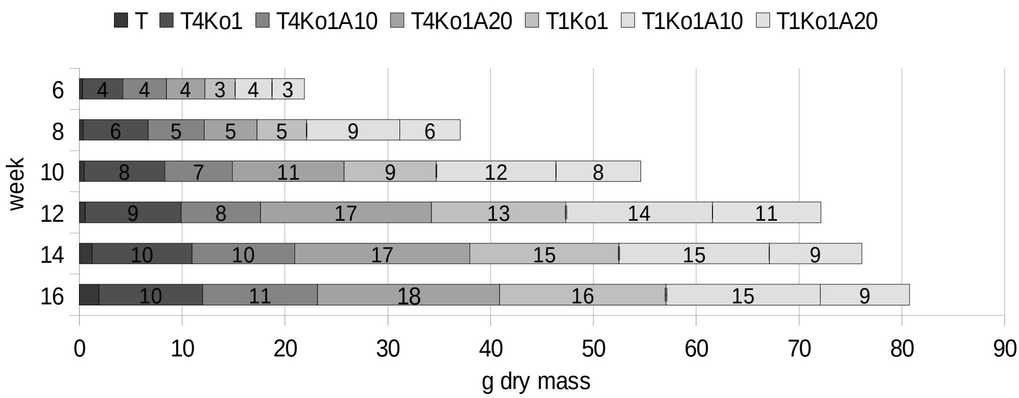

Figure 1. Biomass of roots (g DM) during vegetation season.

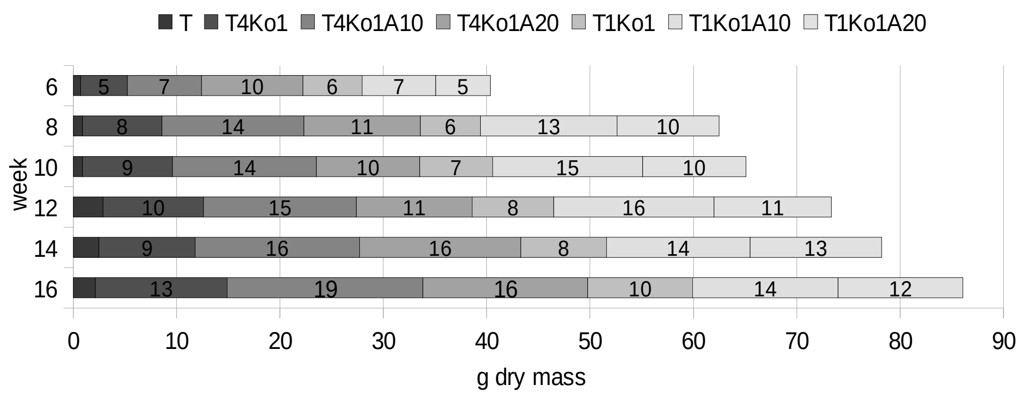

Figure 2. Biomass shoots (g DM) during vegetation season.

In previous studies, the acidity of topsoil on peat land does not differ significantly following the application of dolomite in comparison to areas where only sludge or mineral fertiliser is used (*P*<0.05; Lazdina & Lazdins, 2008). No significant difference was found between the acidity of the soil in the control area and areas treated with mineral fertiliser, except a small difference in the topsoil during the first year after application of the fertiliser. In later years this effect disappears (Lazdina, 2006; Lazdina et al., 2007a; Lazdina et al., 2007b). Experiments with dolomite applications demonstrate that even when considerably large amounts of this liming material are used on a surface they are not sufficient to secure proper growing conditions for willows (pH 5.5–6.5) on abandoned peat land. Waste water sludge is characterised by a neutralising effect which was not detected in mineral fertilisers. This neutralizing effect is described in studies by other authors (Kāposts & Kariņš, 1998; Kāposts et al., 2002; Hasselgren, 2003; Dimitriou & Aronsson, 2005; Vucans et al., 2005). In Finland and other countries, wood ash is tested as a good source of potassium and liming material (Hytonen, 2003; Leupold, 2006; Shen et al., 2008). Field experiments have demonstrated that in peat soils the surface spread of waste water sludge does not have a positive effect on the survival and development of willow shoots. The most common reason for willows dying out on peat soils is drying of the willow cuttings due to the lifting of the cuttings during winter and the acidic pH. In the vegetation experiment implemented as part of this study, a mix of waste water sludge compost, wood ash and peat produced the necessary liming effect. An amount corresponding to 10 t ha^{-1} of wood ash alkalised the substrate by 2.4 units, while an amount of wood ash corresponding to 20 t ha^{-1} alkalised the substrate by 2.8 units. Adding wood ash to a peat and compost mix in a proportional volume of 1:1 in its turn reduced acidity by 1.4 units and 1.9 units. The most significant alkalising of pH was found, if wood ash was added to the substrate, where the proportion of peat and compost by volume was 4:1. Optimal pH can be achieved by using an amount of wood ash corresponding to 10 t ha^{-1} (the substrate's pH_{KCl} at the end of the experiment was 6.5–7.0). Measurement of pH every second week demonstrated that fluctuations in pH during the vegetation period are not significant, except variants where the maximum amount of wood ash are applied (*P*>0.05). The pH_{KCl} of different substrates differs significantly at the end of the vegetation period (Table 2).

Table 2. Changes in substrate pH_{KCl} during vegetation season.

	Weeks after planting						
Variant	4	6	8	10	12	14	16
T	2.8	2.7	2.8	2.8	2.8	2.6	2.8
T_4Ko_1	4.2	4.1	4.2	4.2	4.3	4.4	4.7
$T4Ko_1A_{10}$	6.1	5.8	6.1	5.9	6.4	6.4	6.5
$T_4Ko_1A_{20}$	7.2	6.8	7.2	6.8	7.0	7.4	7.4
T_1Ko_1	5.3	5.4	5.3	5.6	6.1	6.3	6.3
$T_1Ko_1A_{10}$	6.7	6.5	6.7	6.4	6.2	7.0	6.7
$T_1Ko_1A_{20}$	7.2	6.8	7.2	6.9	6.9	7.4	7.2

Willow shoots are poorly developed in experimental plantations established in peat soil and are significantly smaller than in mineral soils (Lazdina, 2006; Lazdina et al., 2006; Lazdina et al., 2007a).

Wood ash and compost additions to the substrate in different proportions showed significantly different effects on the development of willow sprouts and roots. Correlation analysis of the concentration of nutrients in the substrates with aboveground and belowground biomass demonstrated significant relations between certain parameters. The number of shoots correlates with the concentration of all parameters except final nitrogen concentration (Table 3).

Table 3. Willow growth, substrate pH and macronutrients – Pearson correlations.

	Height in cm	Number of sprouts
Number of sprouts	-0.086	
Initially N g kg^{-1}	-0.058	-0.344**
Initially P g kg^{-1}	0.079	0.578**
Initially K g kg^{-1}	-0.010	-0.030
Initially pH KCl	0.016	0.591**
Final N g kg^{-1}	0.000	0.011
Final P g kg^{-1}	0.091	0.512**
Final K g kg^{-1}	0.008	-0.571**
Final pH_{KCl}	0.035	0.587**

*Correlation is significant at level of 0.05 (2-tailed) ** Correlation is significant at level of 0.01 (2-tailed)

There are no correlations between root biomass and nutrient concentrations in the substrate – only in the concentration of the phosphorus correlate with the biomass of shoots (Table 4).

Table 4. Willow biomass – Pearson correlations with growth media (substrate pH and macronutrients).

Parameter	Root DM, g	N, g kg^{-1}	P, g kg^{-1}	K, g kg^{-1}	pH_{KCl}	Compost addition	Wood ash addition
Aboveground biomass DM, g	0.284	-0.453	0.78*	-0.687	0.751	0.399	0.741
Root DM, g	1.000	-0.346	0.531	-0.208	0.402	0.517	0.198

*Correlation is significant at level of 0.05 (2-tailed)

Waste water sludge and wood ash, which were used in the experiments, contain not only nutrients but also an excessive amount of heavy metals, which are not used in biological processes. In the vegetation experiment, the amount of heavy metals applied by the compost and wood ash cumulate. This phenomenon, as in field experiments on peat soil, is associated with the decomposition of organic material and the increase of mineral fraction as a result. One of the factors that affects fluctuations in the concentration of heavy metals in a substrate is decomposition of organic substances. The amount of organics in different variants decreased by 4–40% compared to initial values (Fig. 3).

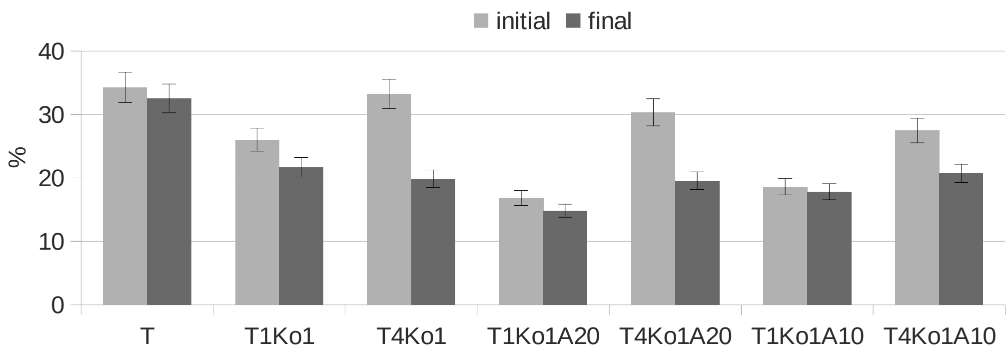

Figure 3. Concentration of carbon in substrates before and after experiment.

For the same reason, the concentration of heavy metals also increased by up to three times in the control variant. At the end of the experiment the concentration of heavy metals in the substrates with compost and wood ash admixtures decreased a little or was the same as in the initial stages, except for the substrate with the maximum amounts of wood ash and compost, where the concentration of all heavy metals increased by 7–24%.

CONCLUSIONS

Waste water sludge has a comparably small liming effect. The fertilising effect of sludge can be increased by the admixture of wood ash and dolomite. These materials reduce the acidity of soil and provide additional nutrients.

Use of dolomite as a liming material, at an amount of 10 t ha^{-1}, produces a change in pH of 0.6–1.2 units in peat soil. Significant changes in pH were found just a few centimetres below the upper layer of the soil. Application of an equal amount of wood ash provides a faster effect of neutralisation change in pH of 3.1–3.8.

Because of the correlation of concentration of exchangeable phosphorus in the substrate with all biological parameters, the phosphorus is a limited macro-element in peat soil.

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