REVIEW OF DIFFERENT TYPES OF FERTILIZERS FOR WILLOW PLANTATIONS

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Abstract. Willow (*Salix*) family is one of the fastest-growing woody energy crops. It·has been widely used for biomass energy production in short-rotation plantations, carbon storage in longer rotation, and as a phytoremediation plant in Northern Europe. Willows could be cultivated on a wide range of soils, including marginal land, and they are readily propagated by planting un-rooted cuttings. Soil fertilization is necessary for obtaining a higher biomass yield. Different side products of energy production and municipal waste could be used for soil improvement. The aim of this research is to review fertilization practices in short-rotation willow plantations and their impact on the biomass yield. The data from the literature were collected, and different doses of various fertilizers were compared. The response to fertilization is positive if fertilizer contains complex NPK macro elements. The most appropriate dose per hectare varies depending on the soil properties, soil types, willow varieties, weather conditions, water availability, and other factors. Wood ash and peat could be used for soil improvement to solve the main characteristic marginal soils problems in Latvia – low organic content and pH value. Wood ash has high concentrations of calcium (Ca) and magnesium (Mg) and already is widely used as a liming agent in organic farming. Less demanded peat fractions, dewatered wastewater sludge, and biogas fermentation leftover -digestate contain a high amount of organic matter and nitrogen, therefore, could be used as a replacement for previously used fertilizers such as cattle slurry. In addition, wastewater sludge, digestate, and wood ash are also sources of microelements. A mix of all listed products has a high potential to be used as a complex soil amendment.

Keywords: wood ash; digestate; fertilizer; nutrients; willows.

Introduction

According to the European Environmental Agency (EEA) definitions, marginal land is low-quality land (clay and sandy soil), where production barely covers cultivation costs [1]. In marginal land water holding capacity and risk of nitrogen leaching is high [2], but it is suitable for the creation of short rotation plantations which are a great resource for renewable energy sources [3; 4]. The fast-growing tree species: willow (*Salix* spp.), poplar (*Populus* spp.), eucalyptus (*Eucalyptus* spp.), and robinia (*Robinia pseudoacacia*) are mainly used as a renewable energy source [5]. The most suitable and widely grown tree species in northern Europe are willows. They grow well in different sites, but for the highest biomass production fertilization is necessary before every rotation, because after harvesting chemical elements are moved away from the soil [6]. To improve the soil quality and restore site productivity is necessary to use fertilizers with different compounds for nutrition compensation, especially in marginal conditions. Each element·has a different and significant role in the growing process. The most needed nutrition elements in tree plantations are nitrogen (N), phosphorus (P), and potassium (K). Other important macronutrients are calcium (Ca), magnesium (Mg), and sulfur (S). Micronutrition elements such as iron (Fe), boron (B), zinc (Zn), chlorine (Cl), manganese (Mn), copper (Cu), and molybdenum (Mo) are required for a smaller amount than macronutrient elements [7]. According to Adegbidi [8] annual willow dry biomass 15-22 $t \cdot ha^{-1}$ removed 75–86 $kg \cdot ha^{-1}$ of N, 10-11 $kg \cdot ha^{-1}$ of P, 27-32 $kg \cdot ha^{-1}$ of K, 52-79 $kg \cdot ha^{-1}$ of Ca and 4-5 $kg \cdot ha^{-1}$ of Mg in one year. Fertilizers for willow plantations can be divided into two large groups: the first group consists of mineral/chemical fertilizers including biological origin materials with burned organic, and the second group is organic fertilizers. For willow plantations, these elements are provided using fertilization with waste products (sewage sludge, wastewater, wood ash, manure, and slurry) thereby incorporating this process with the circular economy.

This literature review has three main objectives: (1) compare organic and inorganic fertilizer use for willow plantations from the peer-reviewed literature; (2) summarize data about the number of fertilizers from the peer-reviewed literature; and (3) from the available information, choose the most suitable fertilizers for white willow (*Salix alba* L.) in an agroforestry system in Latvia.

Materials and methods

Scientific data were collected from the 'Web of Science', 'ScienceDirect', and 'Google Scholar' databases, using the keywords *salix*, willow, short rotation coppice, short rotation plantation, fast-

growing trees, soil amendments, and fertilization. This literature review gathered information about what types of fertilizers are used for fertilizing willow plantations, compared the doses of fertilizers and their effect on the amount of biomass compared to unfertilized control fields.

Results and discussion

According to the Food and Agriculture Organization's checklist for cultivars of *Salix* L. (willow), there exist eight hundred and fifty-four cultivar epithets. *Salix triandra* and *S. alba* have the largest number of cultivars [9]. Both of these grow in the form of a large tree and they require a larger space between planted trees than shrub willows, and there is the possibility to make an agroforestry system from *S. alba* cultivars [10].

The cultivation of new planting material in containers may be based on an existing commercial substrate or a self-prepared complex substrate containing the necessary elements. Substrate and its physical (water-holding capacity, porosity, plasticity, and bulk density) and chemical (fertility, acidity, and buffer capacity) properties influence tree growth in containers. Commercially available substrates for container trees are mainly peat based [11]. Peat consists of 95% organic material which has a high water-holding capacity and it is commonly used for cultivation in agriculture [12]. The pores of peat supply oxygen to the root and provide drainage [13]. Commercially available peat substrate for tree/shrub nursery is made in most cases from medium-fibrous, coarse, and coarse-fibrous white peat. Some commercially available substrates have additional clay which makes the substrate strongly hydrophilous and provides more cation and anion exchange capacity than peat substrate without clay [14]. Willows grow in very varied soil conditions, but the optimal soil pH for willow tree growing ranges between 5.0-7.0 [15].

Marron (2015) reviewed 288 literature sources about different fertilizers for various fast-growing wood species and Fabio *et. al* (2018) analyzed literature sources mostly focused on N fertilizer in willow plantations, in a result they concluded that fertilization increases the amount of biomass by 40%. Existing fertilizers for willow plantation could be divided into large groups: mineral fertilizers and organic residues.

Wood ash is a by-product of the combustion process and it contains many nutrients, except N which is volatilized during combustion. In forestry, wood ash is commonly used as a fertilizer [16], especially in peatland [17-19]. Demeyera [19] has collected literature sources about the composition of wood ash, and the effect of using wood ash on soil fertility and plant growth, from which it can be concluded that properties of wood ash vary between combusted tree species, part of plant combustion (wood, bark, leaves) and between sources of waste (wood, pulp/paper, straw, peat). Wood ash consists of different macro- and micro-elements with a low level of nitrogen, and it acts as low-level N fertilizer (N:P:K, 1:10:50) [20; 21]. Applications of wood ash on willow plantations provide additional P, K, Ca, and Mg elements, as well as increase soil pH in the first 10 cm per unit [21]. Although in some studies no direct effect on the biomass of ash application has been observed, a positive effect·has been observed on the size of stems, but the number of steams decreases. Nevertheless, some studies observe increased biomass production after ash, and ash and sewage sludge mixture application [22–24]. But a higher increase in willow biomass was obtained using wood ash with nitrogen [25]. In European countries, the application of the amount of wood ash is determined by law.

Table 1

Wood ash as a fertilizer for willow plantations

Soil type	Fertilizer type	Applied dose	Biomass changes after fertilization	Reference
Silt loam	wood ash	10 and 20 $t \cdot ha^{-1} \cdot year^{-1}$ (3 year)	did not affect	[21]
Peat	wood ash	6, 12, 24 $t \cdot ha^{-1}$ (wood-ash treatments featured fertilization with 150 kg $N \cdot ha^{-1}$ as ammonium nitrate with lime)	increase	[17]

Table 1 (continued)

Soil type	Fertilizer type	Applied dose	Biomass changes after fertilization	Reference
Sandy soil	wood ash, straw ash with nitrogen 75 kg $N \cdot ha^{-1}$	ash 660 $kg \cdot ha^{-1}$ + different doses of N from 0 to 150 $kg \cdot ha^{-1}$	increase	[25]
Clay + silt + sand	wood ash, wood ash mixture with sewage sludge	5.5 $t \cdot ha^{-1}$ ash; 1.3 $t \cdot ha^{-1}$ sewage sludge + 2.8 $t \cdot ha^{-1}$ wood ash and 2x larger dose (2.6 $t \cdot ha^{-1}$ sewage sludge + 5.5 $t \cdot ha^{-1}$ wood ash)	increase	[26]

Commercial NPK fertilizers available on the market also belong to the group of mineral fertilizers. Mineral fertilizers are commonly used in willow plantations to gain more biomass Table 2. These fertilizers are easy to store and apply, but mineral fertilizers are costly and their transportation and extrication increase emissions. As well as there are problems with P which is obtained from mining phosphate rock. Raw phosphorus is a non-renewable resource and it is found only in a few places in the world [27], and in 2014 the European Commission listed phosphate rock as a critical raw material.

Table 2

Commercial mineral fertilizers for willow plantations

Soil type	Fertilizer type	Applied dose	Biomass changes after fertilization	Reference
Former mining land	N:P:K 6:20:12	annual 300 $kg \cdot ha^{-1}$ and 600 $kg \cdot ha^{-1}$	increase	[27]
Sandy loam	N:P:K 21:3:10	100 kg N, 14 kg P and 47 kg K ha^{-1} 3 year	increase	[28]
Clayey loam	N	100, 200, and 300 kg $N \cdot ha^{-1}$	increase	[29]
Sandy loamy soil	N:P:K 21:3:7	120, 240, 360 kg $N \cdot ha^{-1}$	increase	[30]
Coarse sandy soil	NPK 14:3:18	117 and 233 kg $N \cdot ha^{-1}$	increase	[31]
Panton silty clays, Basher silt loam, Hornell silt loam	Urea	150 and 200 kg $N \cdot ha^{-1}$	did not affect	[32]

According to several authors, the optimal dose of commercial N is 60 $kg \cdot ha^{-1}$ $year^{-1}$ [30; 33], the leaching amount is low and the biomass yield is similar to using a large fertilization dose of 240 and 360 kg $N \cdot ha^{-1}$. Increasing the fertilizers dose and adding the one-time application of 240 and 360 kg $N \cdot ha^{-1}$ per rotation, importantly increases nitrogen leaching [33], and overuse of fertilizers could cause contamination of surface water and groundwater.

The second large group is organic fertilizers, which are used for fertilizing willow plantations. Organic fertilizers are rich in organic matter and nutrition and they are sufficient resources for plant growth [34-36]. They are readily available from nearby livestock farms, biogas stations, and sewage sludge from wastewater treatment facilities. There are a large number of research papers on sewage sludge as a fertilizer in willow plantations [25; 34-42]. Sewage sludge is a wastewater treatment by-product, it contains organic matter, N, P, and a small number of trace elements such as Cd, Pb, and Cu [45]. In different Europe countries there are accepted regulations about the maximum application rate of sewage sludge and the acceptable level of macro-elements and trace elements. Physical-chemical properties, N content, and N mineralization of sewage sludge differ using various processing methods [35]. Also, the fraction size of sewage sludge has an impact on N and P content [43]. The use of sludge amendment changes soil physio-chemical properties and increases soil pH [45]. Most literature sources

report an increase in willow biomass amount when different types of treated sewage sludge are used, Table 3. Another type of biowaste organic fertilizer is irrigation wastewater, which improves willow growth [38]. Although wastewater and sewage sludge used as a fertilizer in willow plantations promote sustainability, there are studies that indicate that there is a risk of nutrient leaching into groundwater and contamination of plants by heavy metals [46]. But the good ability of willows to take up N and P elements indicates that the risk of polluting groundwater is low [38].

Table 3

Sewage sludge as a fertilizer for willow plantations

Soil type	Fertilizer type	Applied dose	Biomass changes after fertilization	Reference
Well-drained Palmyra gravelly silt loam	Lime-stabilized sewage sludge	129.5 t·ha^{-1} DM and 1200 kg·ha^{-1} of total N	increase	[37]
Light soil	compost from municipal sludge and enriched with mineral fertilizers	10 t·ha^{-1} DM and 10 t·ha^{-1} DM + Hydrofoska 16 (562.5 kg·ha^{-1} or 1125.0 kg·ha^{-1})	increase	[40]
Loamy fine sandy soil in the pot	municipal sewage sludge	36 kg (± 3%) fresh on each pot	increase	[47]
Mixed land (forest, agriculture, and wasteland)	sewage sludge in different sizes	3 and 9 t·ha^{-1}	increase	[43]
Well drained (sandy-loam), poorly drained (clay loam), poorly drained (clay loam, clayey)	dried and granulated sludge	150 kg·ha^{-1} of "available" N	increase	[48]
Sandy loamy soil	fresh digested sludge	12 t sewage sludge ha^{-1} (approximately 90 kg N·ha^{-1})	did not affect	[30]
Mineral soils	sewage sludge	14 t·ha^{-1}	increase	[41]
Sandy clay	composted sludge	100 kg N·ha^{-1}	increase	[50]

Explanation: DM-dry mass

Organic biowaste animal manure is commonly used for soil conditioning in agriculture to promote food production [49]. Only a few studies have been carried out about animal waste product recycling for willow plantation fertilization, Table 4. Animal manure has advantages in nutrient composition compared to other organic fertilizers, for example, it·has a higher level of macro-nutrients than paper sludge [51]. Pig slurry used as willow plantation fertilizer increases nitrate, copper, and zinc level in the soil [29]. Biogas production by-product digestate has a higher ammonium content than in pig slurry and cow manure and it can be used to fertilize willow plantations as well because it improves the soil properties [52; 53]. The content of slurry organic matter macroelements: N, P, and K, depends on the feedstock source [54]. The nitrogen in pig slurry is less effective than the nitrogen in commercial NPK fertilizer and composted poultry manure contains more nitrogen than composted sludge [35].

Table 4

Manure as a fertilizer for willow plantations

Soil type	Fertilizer type	Applied dose	Biomass changes after fertilization	Reference
Clay loam	pig slurry	from 148…590 kg·ha^{-1} of N	increase	[29]
Panton silty clays Basher silt loam Hornell silt loam	digested dairy manure, biosolid compost	150 and 200 kg total N ha^{-1}	did not affect	[32]
Palmyra series	manure and manure combination with paper sludge	manure 87 and 130 kg total N ha^{-1}; 250 kg total N ha^{-1} in combination	no significant differences between treatments	[51]
Coarse sandy soil	pig slurry	160 and 320 kg·ha^{-1} total N	increase	[31]
Heavy clay-loam soil	farmyard dirty water	90…250 kg N·ha^{-1} y^{-1}	no significant differences between treatments	[55]
Sandy loamy soil	dairy cattle manure	120 and 240 kg N·ha^{-1}	increase	[30]
Well-drained sandy site	manure	120 and 240 kg N·ha^{-1}	did not affect	[33]

Fertilization to increase willow biomass has shown different results from no effect to significantly increased biomass. The limited response can be explained by differences in the soil type [46; 52], availability of macro- and micro-elements in the soil, climate conditions, water availability, soil pH, willow species [28; 55; 57], plant density, and the plantation rotation length [58]. The difference between these factors limits direct comparison between studies about fertilizers. Wood ash provides additional P and K and peat is rich in organic matter and macro-elements, therefore, this mixture could be used as a self-made soil conditioner for fertilization of willow cutting during the early stages of tree growth.

Conclusions

1. Soil improvement is one of the prerequisites for obtaining a sufficient yield in willow plantations planted in marginal lands.
2. Various fertilizers are used for willow plantation fertilization: commercial, manure, digestate, sewage sludge, wood ash, and wastewater - more biomass amount from willows was obtained when they were fertilized with a fertilizer that contained macronutrients and various microelements.
3. The productivity of the plantation *Salix* spp. is increased by complex NPK fertilizers, which can be provided in different ways, fertilized with organic or inorganic fertilizers, and self-made fertilizers made by mixing peat and ash.
4. Mineral nitrogen or organic N-containing substance lacking fertilizer application does not increase willow yields in mineral soils.

Author contributions

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