PERENNIAL GRASSES FOR BIOENERGY PRODUCTION: CHARACTERIZATION OF THE EXPERIMENTAL SITE

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Abstract
To promote the future of abandoned lands management and the reduction of fossil energy consumption in Latvia, the establishment of energy crops plantation facilities, including perennial grasses, was investigated. The objective – suitability of several perennial grasses for bio-energy production under condition of Latvia. The aim of the current research to evaluate the experimental field conditions for the cultivation of perennial grasses.
The perennial grasses are modest in terms of soil conditions, they are environmentally friendly, as well as provide high yields of biomass with adequate quality for bio-energy production without large investments. With increasing amounts of bio-energy production the amounts of various by-products which are profitable to utilize as energy crops fertiliser will also increase. It is essential that plant nutrients return back into circulation by creating a complete cycle. In order to test in practice the possibility of creating this complete cycle of growing perennial grasses, an experimental field was chosen at the Research Institute of Agriculture in Skriveri. In the summer of 2011, before trials establishment, the conditions of soil were examined at four depths: 0 – 20 cm; 20 – 40 cm; 40 – 60 cm and 60 – 80 cm. The analyses showed that the experimental field conditions were appropriate for growing of perennial grasses. The results of the soil agrochemical analysis will be a base for future studies of usage efficiency of different fertiliser types on perennial grass productivity and nutrient recycling opportunities in energy crop plantations.
Key words: bio-energy, digestate, perennial grasses, waste water sludge, wood ash.

Introduction

Bio-energy is important in the entire world, even at the moment it is the dominating source of renewable energy in Europe, and it is predicted that its production will grow significantly in the following decades. The European Union (EU) is committed to combat climate change and to increase the security of its energy supply. In 2009, the EU adopted Directive 2009/28/EC establishing the guidelines for the promotion of renewable energy. EU directives are binding for Latvia – we are bound by their commitment to the partial substitution of fossil fuels with renewable energy (Directive, 2009). Last year in the statement of Commission to the European Parliament on renewable energy sources (COM/2011/0031), a mandatory objective was suggested to ensure that 20% of the energy used in Europe will be provided by renewable sources of energy, including bio-energy, by the year 2020 (Agriculture and bioenergy, 2012).

Bio-energy is one form of renewable energy among many other sources (wind, solar, hydraulic, geothermal, etc.) which reduces greenhouse gas emissions. Bio-energy accounts for more than two thirds of total renewable energy in the EU. The share of agriculture – although still modest – but is growing fast (Donner and Kucharik, 2008; Agriculture and bioenergy, 2012).

Replacing fossil fuels by biomass reduces the accumulation of carbon dioxide into the atmosphere and a significant reducing of 'greenhouse effect' could be realized, thus preventing global climate change as by using biomass for energy production, the carbon cycle is closed. Plants during their growth cycle accumulate solar energy, a large amount of carbon dioxide (CO_2) is consumed during photosynthesis and a huge amount of oxygen is produced. Burning new biomass contributes no new carbon dioxide to the atmosphere, because replanting harvested biomass ensures that CO_2 is absorbed and returned for a cycle of new growth (McKendry, 2002).

Different raw materials can be used for the production of bio-energy: waste, woodchips, plant biomass, etc. Ways how to ensure the output of materials are searched for in the entire world; the possibilities of arranging the energetic plant plantations, including the growing of grasses, which have many advantages over other cultivated plants, are being studied. In the bio-based economy, renewable herbaceous biomass such as perennial grasses will become an important cellulosic feedstock for conversion to bio-fuels, electricity and heat (Bakker and Elbersen, 2005).

Perennial grasses are great for energy production, they are environmentally friendly, provide biomass of high energy and appropriate quality without large investments. There are suitable soil and climatic conditions in Latvia for the growing of perennial grasses. The amount of rainfall in Latvia's climatic zone is sufficient, and it is distributed so that high-quality biomass harvests from perennial grasses can be obtained during their vegetation period. Swards are not demanding in terms of soil, therefore for energy purposes it is expedient to establish them on less productive or abandoned land (Poiša et al., 2011; Kryževičiene, 2006). One of the opportunities for farmers is conversion from traditional farming and cultivation of fast growing plants for bio-fuel purposes, especially in the regions where cultivation of traditional crops is not profitable (Šiaudinis, 2010).

Grasses are relatively modest in terms of the soil condition, compared to other cultivated plants. Their strong root system provides the plants with necessary nutrients even from the deeper layers of the soil. Reed canary grass (*Phalaris arundinacea* L.) and tall fescue (*Festuca arundinacea* Schrab.) tolerate short flooding which occurs frequently in the countryside of Latvia in early spring or as a result of heavy rainstorms.

Perennial grasses are not endangered by diseases and pests as it is with other cultivated plants, and that is why the production of bio-energy from these plants is much 'greener'. There is no need for additional protection measurements saving resources and the environment, which is a significant argument in the context of climate change.

Bio-energy production from perennial herbaceous energy crops is promising because it alleviates the conflict of using food crops for bio-energy and because high biomass yields are produced annually for several years in succession before replanting (Tilvikiene et al., 2011). Perennial grasses are high yielding; moreover, they can produce for 10 or more years without reseeding, protect soils on slopes from erosion and maintain soil fertility. Unlike other cultivated plants, grasses can be grown in monoculture without any problems.

Research results in several countries confirm that native perennial rhizomatous grasses, including reed canary grass, show the greatest potential as bio-energy crops (McLaughlin et al., 1998; Saijonkari–Pahkala, 2001; Lewandowski et al., 2003). Reed canary grass likes wet soils, although it does not tolerate stagnant ground water in the upper layers. It grows well in humus and nutrient rich soils. Similarly to other runner top-grasses reed canary grass likes well aerated loose soils. In suitable conditions it ensures over 9 t ha^{-1} of dry matter annually. Acidic soils are not suitable for growing reed canary grass.

The tall fescue can be successfully used for the production of bio-energy, mainly of solid fuel. It is perennial and can grow for 8 – 15 years without reseeding, and can produce high dry matter harvests (12 – 14 t ha^{-1}). The tall fescue is resistant to frost, thus perspective for latitudes of Latvia. Due to its strong root system this species of grass tolerates drought. Soils with low fertility and newly cultivated soils are suitable for growing tall fescue, as it is a relatively modest grass crop (Adamovičs, 2007).

Whereas the fodder galega (*Galega orientalis* Lam.) possesses all the best characteristics of grasses – the ability to grow in one place without reseeding and ability to fix the 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}). The optimal conditions of soil for growing galega are: organic matter content 20 – 25 g kg^{-1}, soil reaction pH – 6 – 7, plant available P – 55 – 90, and K – 150 – 200 mg kg^{-1} soil. The fodder galega biomass is suitable for the production of biogas, as well as dry fuel – pellets and briquettes (Adamovičs, 2007).

The perennial lupine (*Lupinus polyphyllus* L.) 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 the terms of nutrition, because it has possibility of fixing nitrogen from the atmosphere with the help of the N-fixing bacteria, but it extracts potassium and phosphorus from the deeper layers of the soil and uses the less soluble compounds by help of its strong root system. The lupine grows intensely for 3 to 5 years, but afterwards the formation of N-fixing nodules decreases gradually. It grows rapidly after cutting, although frequent mowing causes the thinning of the sowings. The potential harvest for the lupine is about 12 t ha^{-1} dry matter (Jansone and Rancāne, 2011).

The perennial grasses used for bio-energy production do not require a large initial investment, and the future of this area of management costs is relatively low. Perennial grasses have been identified as the lowest cost dedicated agricultural feedstock for energy and agro-fibre markets. Lithuanian research evidence suggests that the energy potential of perennial grasses was up to 153 GJ ha^{-1}, and it was up to 19 times higher than the energy input for bio-fuel production (Kryževičiene, 2006; Navickas et al., 2003).

Several studies have shown that grass biomass qualitative features significantly affect the harvest time and soil conditions. Many previous studies (Burvall, 1997; Finell et al., 2002; Xiong et al., 2008) have confirmed that the delayed harvest system for grass crops in which the harvest of the previous year's crop is undertaken after it has over-wintered in the field significantly improves the fuel quality for both combustion and gasification.

A significant fraction – up to one-fifth – of herbaceous biomass consists of inorganic constituents, commonly referred to as ash that cannot be converted to energy. The quantity and quality of ash in herbaceous biomass depends on many factors including the plant type, growing conditions, fertilisation, choice of harvest date, etc. However, it is of paramount importance that the ash content of these feed-stocks should be reduced so as to facilitate their commercialization (Samson and Mehdi, 1998).

The critical elements that cause fouling and corrosion problems in boilers are alkali compounds and chlorine which are released during combustion. The concentrations of these are reduced by the delayed harvest system rather than harvesting at the end of the growing season (Xiong et al., 2008).

The loss of some leaf material and leaching of alkali compounds also contributes to an increase in the ash fusion temperature from 1070 °C to 1400 °C. Swedish research results indicate that ash content is influenced by the soil type as well. The most extreme variations were found between reed canary grass grown on clayey soils and those produced on very wet soils, with ash contents in grass of 101 g kg^{-1} and 22 g kg^{-1}, respectively (Burvall, 1997). Efforts should be made to integrate the approach with beneficial uses of ash derived from biomass, including the potential for recycling of nutrients to the field (Samson and Mehdi, 1998; Bakker and Elbersen, 2005).

In order to obtain high quality harvest, the grasses must be provided with all necessary nutrients. One of the most important elements that ensures the growth of harvest, increases winter-resistance and promotes sustained preservation in the sward is potassium. On average, with 1 t of grass dry matter, 21 kg of N, 2.3 – 2.8 kg of P and 20 kg of K are taken up from the soil (Kārkliņš and Līpenīte, 2011). Ash contains a lot of potassium (50 – 60 g kg^{-1}), thus it can be successfully used to fertilise the grass.

As a result of the anaerobic processing of the biomass, the by-product of the obtained gas is digestate, which contains all necessary plant nutrients. The presence of the nutrients in digestate varies depending on the contents of the fermentable biomass; usually digestate is a good source of phosphorus, potassium and nitrogen as well. Thus it can be successfully used as energy plants fertiliser, stimulating recirculation of the nutrients.

In Latvia and worldwide, research has been done about the usage of sewage sludge for the fertilisation of energetic plants, because often the sludge that comes from areas with bigger industrial centres contains more heavy metals, thus it is discussable whether it can be used to fertilise crops used as food or feed.

To promote the non-used and low-value land management and production of energy crops, growing conditions for perennial grasses were investigated. The objective – suitability of several perennial grasses for bio-energy production under condition of Latvia. The aim of the current research was to evaluate the experimental field conditions including soil parameters important for the cultivation of selected species of perennial grasses.

Materials and Methods

The experimental site is located at the LLU Research Institute of Agriculture in Skriveri. Four species of grasses are planned to be included in the test: reed canary grass (*Phalaris arundinacea* L.), tall fescue (*Festuca arundinacea* Schrab.), goats grass (*Galega orientalis* Lam.), and perennial poor-alkaloid lupine (*Lupinus polyphyllus* L.). Above mentioned crops will receive different kinds of fertilisers. The efficiency of these factors on grass productivity, yield quality, as well as time of grass harvesting will be studied. The proposed experimental scheme includes following treatments: 1) control (not fertilised); 2) mineral fertilisers; 3) wood ash; 4) digestate; 5) waste water sludge. The total area of the experimental field – 2 ha. The size of one experimental plot – 200 m^2. The variants of fertilisers will be arranged randomly in 4 replications.

Before the start of experiment (3rd decade of July, 2011), soil samples were taken from 20 places of the experimental field – 4 times for each plot at four different depths: 0 – 20 cm, 20 – 40 cm, 40 – 60 cm, and 60 – 80 cm. Two types of soil samples were taken: for agrochemical analysis and for bulk density determination.

The soil samples were prepared for the physical–chemical analyses in accordance with LVS ISO 11464 Standard (drying, crushing, sieving).

The following measurements were performed: bulk density, soil texture, pH $CaCl_2$, total carbon and sulphur, total nitrogen, and plant available P and K of the soil.

The bulk density of the soil (kg m^{-3}) was tested in accordance with LVS ISO 11272:1998, by placing a sample in a 100 cm^3 cylinder and drying it to an oven-dry condition in a laboratory at a 105 °C temperature. The exchangeable soil acidity was measured in a 0.01*M* $CaCl_2$ suspension potentiometrically (LVS ISO 10390/NAC). The total carbon and sulphur was analysed using an ELTRA CS 530 elementanalyzer. The soil texture was determined by dry sieving (LVS ISO 11277, 2000). The plant available phosphorus was extracted by 0.2*M* HCl, and phosphorous concentration was measured spectrophotometrically (LVS 398). Extraction of potassium was performed using 1.0*M* CH_3COONH_4, and atomic-absorption spectrometer was used for determination of potassium concentration in the extract. For determination of mineral nitrogen in soil (content of nitrate and ammonium ions), extraction using 0.1*M* NaCl was done, and a spectrophotometer for concentration measurements was employed. Statistical analysis of the obtained data was carried out – correlation analysis, and border differences and standard-deviations were calculated.

Results and Discussion

The test field is located in Skriveri – in the south-west part of Madliena tilt in Mid-Latvian lowlands. It is located on the border between the relatively cold north-west Vidzeme and the relatively warmer East-Latvian lowland. Consequently, the sum of annual average air temperatures is from 1800 to 2000 °C, and the sum of average soil temperatures ranges from 2000 to 2200 °C. It shows that the temperature conditions for the growth of the grasses are good. Also the average amount of rainfall is appropriate. The dominating humid sea air masses in Latvia provide a great amount of rainfall. In Latvia, and in Skriveri as well, the annual average rainfall is 600 – 700 mm (Nikodemus, 2009).

Topography of the experimental field is a slightly undulating plain. Soil cover is developed on glaciogenic sediments. The field is relatively well cultivated; for the past 10 – 15 years it was used for field crop rotation and is dominated by forage legumes and perennial grasses. The sampling scheme used for soil fertility evaluation enables the spatial (vertical and horizontal) variability of soil properties to be studied.

By evaluating the soil homogeneity in the top layer (at the 0 – 20 cm depth), it can be concluded that soil agrochemical indicators differed in different parts of the field. The bulk density of the topsoil layer was 1528 – 1618 kg m^{-3}, thus the topsoil layer can be evaluated as being medium loose, which will not restrict the primary development of the grass roots. After growing the perennial grasses for a longer period of time, their strong root system would have a favourable impact on the soil structure.

The soil reaction was weakly acidic – around neutral pH $CaCl_2$ 6.1 – 6.6, which is completely appropriate for the growing demands of the perennial grasses planned to be grown in the trial.

Carbon (C) content in the top layer of the soil ranged from 21.3 to 25.4 g kg^{-1}. This indicator is also sufficiently good for cultivation of these grasses for bio-energy production, as long-term studies show that in general grasses have a positive effect on the formation of soil organic matter.

In general, the experimental field has a good status of plant available phosphorus, its content in the top layer of the soil ranged from 106.73 to 142.35 mg kg^{-1} P_2O_5. The soil had less plant available potassium – from 85.66 to 129.02 mg kg^{-1} K_2O, which indicates that in this soil grasses could respond well to potassium fertiliser, including wood ash fertiliser, which has a high content of potassium.

As the area of the experimental field is 2 ha, the results in the topsoil varied quite a lot, but after carrying out a mathematical data processing it is clear that there are no significant differences between the soil agrochemical indicators of the planned test variants, which could not influence the experimental results.

After analysing the soil agrochemical indicators at different depths, several regularities were confirmed: by increasing the depth, also the soil bulk density increased, and there was a difference between the 1st and 2nd layer, but deeper – at 40 – 80 cm depth the difference practically disappeared. Although the correlation between the first and second depth was not observed, the intra-class correlation between the depths 2, 3 and 4 was significant $r=0.42>r_{0.05}=0.22$.

The average soil bulk density at the depth of 0 – 20 cm was 1570 kg m^{-3}, which means that the soil was sufficiently loose for the development of grasses in the soil top layer, which in its turn is important for the beginning of the growth. It allows grasses to develop rapidly, to create a dense sward and to compete with different weeds. The average soil bulk density at the

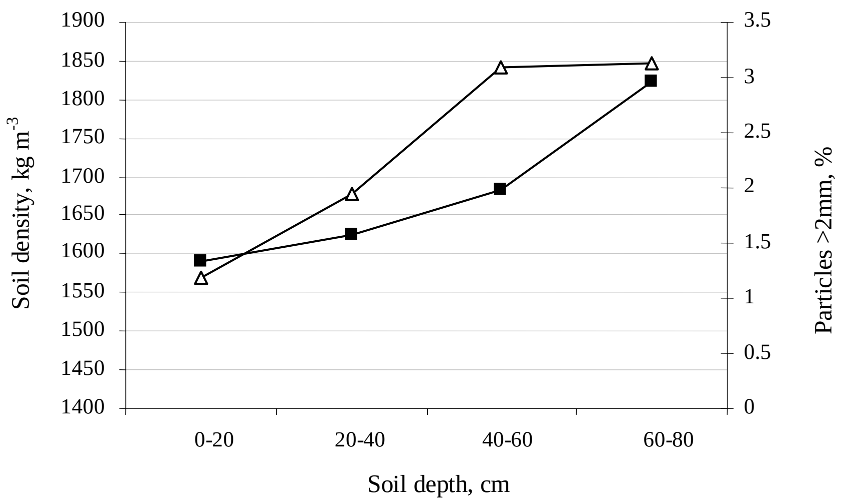

Figure 1. Soil physical properties of the four depths, cm: Δ - soil bulk density, kg m^{-3};
■ - soil particles >2 mm, %.

20 – 40 cm depth was 1679 kg m^{-3}, and deeper the bulk density increased rapidly, thus the development of root system will be obstructed at the depth of more than 40 cm. However when the depth is more than 40 cm. Although these soil conditions will not delay the development of the grasses, because the main root mass occupies the soil volume up to the depth of 30 – 40 cm (Figure 1).

When the depth increases, the proportion of the fine particles of the soil also increases – at up to 60 cm for every layer of 20 cm thickness it increased by 20% on average, but at the depth of 60 – 80 cm, the proportion of the fine particles increased by 50% compared to the adjacent depth of 40 – 60 cm. There was a closer correlation in the deeper layers of the soil: between depths 1 and 2, and between depths 1, 2, and 3 the correlation was not significant – respectively $r=0.04<r_{0.05}=0.36$ and $r=0.22\leq r_{0.05}=0.22$; when excluding the 0 – 20 cm depth, the correlation between the deeper layers increased to $r=0.49>r_{0.05}=0.22$.

The soil acidity in the deeper layers slightly decreases – the soil turns more neutral; however but those are not essential changes and there is a closer pair and intra-class correlation.

After observing the content of plant nutrients, it is obvious that their quantity increases when the depth increases. The content of carbon, consequently the organic matter as well, is concentrated in the soil upper layer. Even at the depth of 20 – 40 cm it decreases by half compared to the amount of C found in the plough layer, but in the deeper layer it increased even more rapidly (Table 1). There was a significant correlation between C content at the depths 1 and 2 ($r=0.44>r_{0.05}=0.36$).

Similar tendencies were observed also for the total sulphur content – its decrease by the depth was not so rapid, but it is obvious that the soil upper layers had more sulphur. The closest correlation of sulphur content was between the depths 1 and 2 ($r=0.42>r_{0.05}=0.36$), whereas the potassium content, which similarly decreases with depth, significantly correlated between the three deepest depths ($r=0.42>r_{0.05}=0.22$).

The above mentioned tendencies were not observed for phosphorus, which content was practically the same at all the depths. The amount of plant available P decreased only at the depth of 20 – 40 cm, but at the other three depths it was at equivalent amounts (within P_2O_5 127 – 143 mg kg^{-1}), and this indicator had a significant pair and intra-class correlation.

One of the most important elements for the growth of grasses, particularly for cereal grasses, is nitrogen.

Table 1

Agrochemical characteristics of four soil depths on average

Parameters	Soil depth, cm			
	0 – 20	20 – 40	40 – 60	60 – 80
Soil pH $CaCl_2$	6.40±0.38	6.50±0.36	6.60±0.35	6.80±0.32
C total, g kg^{-1}	23.95±4.40	12.40±8.27	4,40±3.18	6.95±6.04
S total, mg kg^{-1}	17.80±9.82	22.87±16.80	13.32±14.00	14.28±11.10
P, mg kg^{-1}	121.85±29.78	86.58±39.98	129.84±51.38	136.91±51.49
K, mg kg^{-1}	114.96±25.54	70.96±17.80	53.74±11.66	48.32±9.71
N-$NO_{3,}$ mg kg^{-1}	14.74±6.32	4.38±2.09	2.48±0.77	2.41±0.94
N-$NH_{4,}$ mg kg^{-1}	3.81±2.40	3.29±2.21	3.75±2.05	4.35±2.49

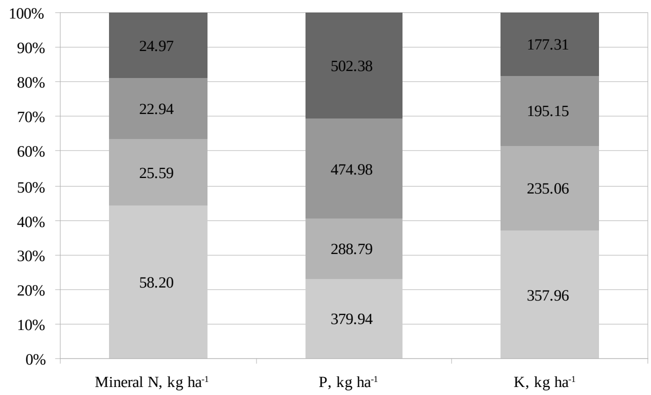

Figure 2. NPK content at different soil depths: 0-20 20-40 40-60 60-80.

$N–NO_3$ content significantly correlated between the three deeper depths ($r=0.50>r_{0.05}=0.22$), but nitrogen in the ammonium form $N\text{-}NH_4$ mostly remained at the same amount at all depths (Table 1).

The amount (kg ha^{-1}) of the main plant nutrients (NPK) in every soil layer was calculated. The amount of nitrogen in summer period, when all of microbiological processes actively took place, was sufficient – 58.2 kg ha^{-1} at the upper layer. At the depth of 20 – 40 cm, the N amount decreased approximately by half and remained practically the same up to the depth of 80 cm – on average 25 kg ha^{-1} (Figure 2).

The amount of plant available P was relatively high at all depths ranging from 288 to 502 kg ha^{-1}, and, unlike other elements, the highest P content was at the deepest soil layer. The average amount of potassium in the top layer was 357.96 kg ha^{-1}, and deeper it decreased sharply.

In general, it can be concluded that all the determined soil agrochemical indicators had a relatively close intra-class correlation between the deepest (2, 3 and 4) depths but, if we look at the all four depths, including the soil upper layer (0 – 20 cm) agrochemical indicators, the correlation decreased.

All the plant available nutrients, except phosphorus, were more concentrated in the soil upper layer because the microbiological processes occur most intensively there. At this soil depth, the plant roots have the easiest access to these nutrients, and can use them for root development, as the main grass root mass is located in the topsoil.

Conclusions

1. The perennial grasses are a perspective crop for the production of bio-energy in Latvia conditions, as they provide not only the production of biomass of high and appropriate quality but are modest in terms of growing conditions, their cultivation does not require large investments and they are environmentally friendly.
2. The soil agrochemical parameters of the experimental field were relatively good for the growth of the perennial grasses. The indicators were good not only in the soil upper layer, but at the depths of 20 – 40 cm as well, which allows grasses to form a deep root system.
3. The results of agrochemical analyses indicated that there was a certain spatial variability, but the statistical data processing demonstrated that the differences between the indicators of variants were not significant, which will allow obtaining objective results in the following research process.

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