Evaluation of Common Osier (*Salix viminalis* L.) and Black Poplar (*Populus nigra* L.) Biomass Productivity and Determination of Chemical and Energetic Properties of Chopped Plants Produced for Biofuel

ALGIRDAS JASINSKAS [a*], GINTARAS ŠIAUDINIS [b], MINDAUGAS MARTINKUS [a], DANUTĖ KARČAUSKIENĖ [b], REGINA REPŠIENĖ [b], NERIJUS PEDIŠIUS [c] AND TOMAS VONŽODAS [c]

[a] *Institute of Agricultural Engineering and Safety, Faculty of Agricultural Engineering, Aleksandras Stulginskis University, Studentu str. 15, Akademija, LT-53362 Kaunas distr., Lithuania*

[b] *Vėžaičiai Branch of the Lithuanian Research Centre for Agriculture and Forestry, Gargždų str. 29, Vėžaičiai, LT-96216 Klaipėda distr., Lithuania*

[c] *Laboratory of heat equipment research and testing, Lithuanian Energy institute, Breslaujos 3, LT-44403 Kaunas, Lithuania*

**Corresponding author E-mail: algirdas.jasinskas@asu.lt*

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Abstract

Two energy plants – common osier (*Salix viminalis* L.) and black poplar (*Populus nigra* L.) – were investigated in order to evaluate their productivity, to perform an energy growing analysis and to investigate plant physical-mechanical and energetic properties of chopped plants for biofuel production. The field experiments were conducted at the Vėžaičiai branch of the Lithuanian Research Centre for Agriculture and Forestry (Western Lithuania, 55°432 N, 21°282 E). The average common osier's yield was 7720 t ha^{-1} of dry matter (DM), and that of black poplar was 4228 t ha^{-1} DM. A 3.0 t ha^{-1} liming rate and 60 kg ha^{-1} N rate was optimal for both crops growth and DM productivity.

Common osier and black poplar chaff's elemental composition analysis showed a similar C (carbon) content of 49.1–49.7%, H (hydrogen) content of 5.6–5.8%, N (nitrogen) and S (sulphur) in small volume %. The estimated ash content of the investigated plants was relatively low – from 1.44% for willows to 2.52% for poplars. The lower calorific value of these plants' dry chaff was relatively high (18.49–18.62 MJ/kg). Depending on the different liming and nitrogen fertilization rates, the total energy input (including direct and indirect inputs) to the growing process constituted 8.41–29.21 GJ ha^{-1}. Common osier had the highest energy output (from 1030 to 1639 GJ ha^{-1}) and the highest energy use efficiency (46.01–122.47).

Keywords: black poplar, biofuel, elemental analysis, calorific value, common osier, energetic evaluation

Introduction

According the proposition of the European Commission, the share of renewable energy sources in EU-27 countries should be at least 20% of total energy consumption (European Commission 2007). Currently, each EU country has deployed its own strategy to increase the share of renewable energy sources in the primary energy production of electricity (Haas 2011). In Lithuania, the major types of renewable energy sources that are a key component of indigenous fuels are wood fuel, straw and fast-growing energy plants (Katinas et al. 2007).

In many European Union countries, the area of different energy crops is gradually increasing. Researchers notice that perennial energy crops have superiority over annual crops due to fewer requirements for land cultivation and pesticides (Lewandowski et al. 2003). Of these, short rotation forest (SRF) species have gained attention as an important renewable energy source in many European countries over the past few decades, including Lithuania (Heinsoo et al. 2002, Bakšienė at al. 2012, Toilon et al. 2013).

Special attention is being paid to the newly selected common osier (*Salix viminalis* L.) species. Altogether, to avoid competition with food crops, alternative energy plantations should be established in less productive soils, especially those that are economically not suitable for traditional farming. The region of Western Lithuania is characterized by the variability of different soil types. Of these, naturally acidic *Retisols* and *Fluvisols* occupy a large area. The high amount of precipitation enforces the leaching of nutrients to deeper soil layers. To improve crop productivity, liming is a traditional means to control soil acidity level (Tang et al. 2003, Repšienė et al. 2013). Due to the increasing of biomass demands, part of the agricultural area less suitable for traditional crops should be designed for energy crop cultivation.

It is known that different *Salix* species are adapted to grow under certain ecological conditions. The objects of our investigations were two energy crops: common osier (*Salix viminalis* L.) and black poplar (*Populus nigra* L. var. fastigiata). The role of nitrogen as a major nutrient for both species is well described by many Lithuanian and foreign investigators (Cooke et al. 2010). Some articles give information that the use of wood and peat ash (as liming material) has a substantial and positive effect to some of short rotation forest crops (*Betula*, *Salix*) productivity (Hytönen 1988, Hytönen and Kaunisto 1999). The use of dolomite lime significantly affected *Salix viminalis* and *Salix purpurea* biomass yield by growing them in naturally acid peatland (Hytönen, and Yrk 2005). The experiments done in vegetative pots also revealed the positive effect of limestone to biomass production of willow (Trakal et al. 2011). Other experiments did not reveal a significant effect of wood ash to plant (*Salix purpurea*) growth or plot biomass production (Park et al. 2005). Besides, there are many varieties in *Salix* genus. In addition, according the detailed overview of Kuzovkina and Volk (2009), the information on different *Salix* species variability to tolerate low pH is still limited.

The European Union (EU) is being approached in 2020 for the realization of the 20-20-20 targets, but they began to prepare the draft for the new policy for climate and energy issues for years 2020-2030. EU has proposed a new target in 2030, including a 40% decrease in greenhouse gas emissions, a 30% decrease in energy consumption, and a 27% increase for the use of renewable energy (Biomass Industrial…2016). History shows how biomass policies are the main driver for the development of various sorts of biofuel in the market in Europe. It is also widely used as a model for a particular region or country to implement renewable energy policies, especially in the biomass sector (Biomass Industrial…2016).

Plant biomass for energy purposes is a major source of renewable energy. Currently, biomass accounts for about half of the renewable energy used in the European Union (Blumberga et al. 2008, Šateikis 2006, Matias and Devezas 2007, Schaumann 2007). In European Union countries, the estimated volume of biomass energy by 2020 will increase to 3-3.5 times, and it will increase 3.5-4.5 times by 2030. The target shares of energy from renewable sources in the final consumption of energy in 2020 for Lithuania is equal to 23% according to the proposed directive on renewable energy sources (RES). People in many countries of the world are growing and using for biofuel many different sorts of short rotation trees – willows, poplar, short rotation aspen etc. (Schaumann 2007, Jasinskas and Liubarskis, 2005).

The government of Saskatchewan is evaluating whether biomass crops can be successfully used as an affordable, reliable, and environmentally sustainable bioenergy source. The objective of this study was to determine the first 3-year-rotation biomass yields of 30 willow cultivars planted in central Saskatchewan. Annual willow morphological data were collected throughout the first rotation, and stem biomass equations were developed. A willow yield map was produced for these willow cultivars across climates and soils of Saskatchewan (Amichev et al. 2015). The use of willow as a bioenergy source appears promising but further research is needed.

Green biomass energy stock includes quick-growing trees and bushes, willow, and a tall perennial grass. There are more than 500 ha of cultivated willow (*Salix viminalis*) plantations in Lithuania, which has been used as a hard biofuel. Therefore, with increasing uptake of renewable energy sources new technologies, research and development work are necessary.

Cultivation of energy plants and their usage for fuel contribute to solving a number of environmental problems: vegetation improves the environmental climate, improves soil structure, allows for a smaller demand for chemical fertilizer, and burning of plant biomass reduces environmental pollution by harmful substances (Filho and Badr 2004, Kryževičienė 2003, Vares et al. 2007 Pienkowski 2010).

The aim of these experiments is to evaluate and compare the effect of liming and nitrogen fertilization on *Salix viminalis* L and *Populus nigra* L. productivity in Western Lithuania *Retisol* and to determine the chemical and energetic properties of chopped plants produced for biofuel.

Materials and Methods

The experiments with two short forest rotation crops – common osier (*Salix viminalis* L.) and black poplar

(*Populus nigra* L.) – were held at the Vėžaičiai branch of the Lithuanian Research Centre for Agriculture and Forestry (LAMMC). The preceding crop was bare fallow. The experiment was established in a naturally acidic moraine loam, *Bathygleyic Dystric Glossic Retisol*. Prior to establishing the experiment, the following upper soil layer chemical parameters were determined: pH_{KCl} was 4.31-4.64, mobile P_2O_5 was 57-120 mg kg^{-1}, K_2O was 144-225 mg kg^{-1}, hydrolytic acidity was 46.84-60.37 mequiv kg^{-1}, and mobile Al was 5.19-13.15 mg kg^{-1}.

The experiments were composed of two factors. Factor A was liming: 1) not limed (natural soil acidity); 2) limed by 3.0 t ha^{-1} $CaCO_3$ rate; 3) limed by 6.0 t ha^{-1} $CaCO_3$ rate. Factor B was nitrogen fertilization (60 and 120 kg ha^{-1}). Thus, the experiment was divided into 3 strips with different liming rates. Nitrogen treatments with 3 replications were randomly performed per each liming strip.

The experiment was established in 2008. The liming (that is the forming of different pH levels) was performed on 20th April 2008. The cuttings of both crops (0.30 m size) were planted directly in the soil on 29th April 2008. Each treatment was composed of two rows. The distance between plants in each row was 0.50 m, the distance between two rows was 0.75 m, and the distance between each treatment was 1.25 m. The following year (on 6th April 2009), both plants' stems were cut at 5 cm height to increase their branching ability.

The application of 60 kg ha^{-1} N rate was performed just before the beginning of spring vegetation in 2009. The highest N rate (120 kg ha^{-1}) was split and applied two times (60 and 60 kg ha^{-1}) in April and at the beginning of July. Prior to planting, phosphorus and potassium fertilizers were applied at the rate of 60 kg ha^{-1} P_2O_5 and K_2O. Ammonium nitrate, single superphosphate and potassium chloride were used as nitrogen, phosphorus and potassium sources, correspondingly.

To protect the newly planted crops against weeds, the herbicide Roundup (3.0 l ha^{-1}) was applied two times at the first season and once at the second growing season.

Both plants were harvested on 28th September 2012. The biomass yield was recalculated into the air-dry mass (DM).

The experimental analysis of willows and poplar yield, harvesting and chopping was performed in 2013-2015 at the base of the Institute of Agricultural Engineering and Safety, Aleksandras Stulginskis University (ASU), and in the plantations of common osier (*Salix viminalis* L.) and black poplar (*Populus nigra* L.) belonging to the LRCAF.

The stems of short rotation energy plants of 4 years of growth and of various diameters (biggest and smallest stems) were cut down in the early spring. The stems of plants were chopped with the stationary conical screw chopper *Laimet-21,* mounted to the tractor. The biometric characteristics of energy plants' elemental composition, ash content, and the calorific value.

Determination of common osier and black poplar elemental composition, ash content and calorific value

The research of the produced energy plant chips' quality indicators – elemental composition, ash content and heat parameters (calorific value) – is performed in the Laboratory of Heat Equipment Research and Testing, Lithuanian Energy Institute (LEI), according to the standard methodology used in Lithuania and in other European countries:

- in the experimental mechanism of moisture No. 8B/1 according to LST EN 14774-1:2010 standard;
- in the experimental mechanism of ash content No. 8B/5 according to LST EN 14775:2010 standard;
- in the experimental mechanism of heating No. 8B/2 according to LST EN 14918:2010 standard.

One of the most important quality indicators of the chips is their calorific value. To determine this index, the succinct 'IKA C5000' was used. To make the experiment more accurate, the chip samples of unconventional energy plants were dried. The experiment was repeated 5 times with each type of chips. The measurement deviation was 0.02%. The experiment deviation was evaluated by estimating the arithmetic average of the data of every repeated experiment.

The indirect energy expenses were calculated by using the following equivalents: 6.4 for single superphosphate, 5.3 for potassium chloride, 27.6 for ammonium nitrate, 1.79 for lime material (Opokos), and 288 for pesticides (Roundup) (Alrikson et al. 1997, Afas et al. 2008).

To determine the significance of the results, a three-way analysis of variance was performed on the data of the liming and N fertilization, using analysis of variance (ANOVA) at 0.05 (95%) probability level (Tarakanovas and Raudonius 2003).

Results

Common osier and black poplar fertilization and productivity

The mean values of the effects of liming and nitrogen fertilization on common osier DM yield during the 2009-2012 growing seasons are presented in Figure 1.

On average for 2009-2012 (or during 4 growing seasons), common osier accumulated 7,720 kg ha^{-1} DM (Table 2). However, the cultivation of common osier under different liming levels had no effect on growing intensity or the total DM yield. The significant was the effect of 60 kg ha^{-1} N rate application – DM yield increased by 25.46% (up to 8195 kg ha^{-1}). The further increase of the nitrogen rate up to 120 kg ha^{-1} had no significant effect on DM accumulation.

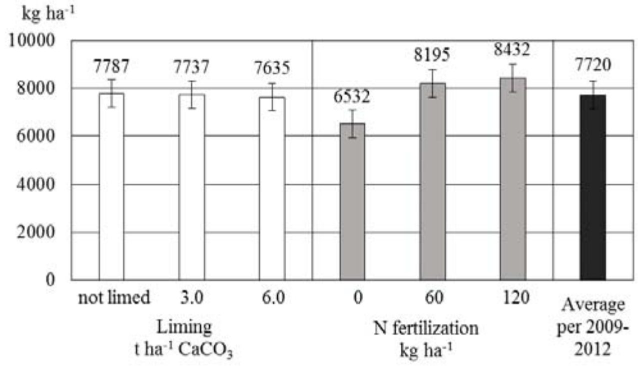

Figure 1. The effects of liming and nitrogen fertilization on common osier DM yield (kg ha^{-1}) during 2009-2012

The mean values of the effects of liming and nitrogen fertilization on black poplar DM yield during the 2009-2012 growing seasons are presented in Figure 2.

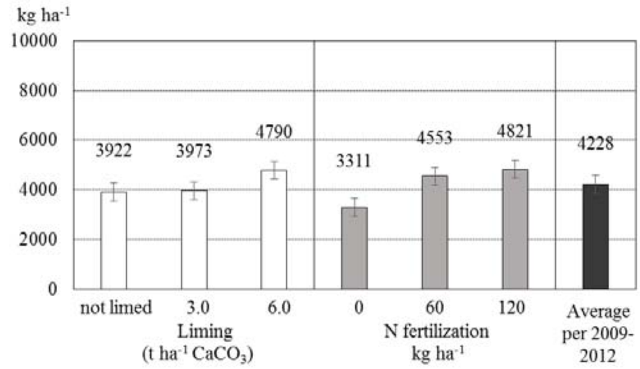

Figure 2. The effects of liming and nitrogen fertilization on black poplar DM yield (kg ha^{-1}) during 2009-2012

On average, black poplar accumulated 3,922 kg ha^{-1} DM during 4 growing years. In comparison with the control treatment (without liming or growing under natural pH level), the application of 6.0 t ha^{-1} $CaCO_3$ rate significantly increased the DM yield by 22.13% (up to 4790 kg ha^{-1}). It is already known that black poplar as a species is susceptible to soil acidity levels (Isebrands et al. 2007). The optimal level was 60 kg ha^{-1} N rate, which caused an increase in the DM yield by 37.51% (up to 4553 kg ha^{-1}). The application of 120 kg ha^{-1} N rate and the subsequent increase in the DM yield was statistically insignificant.

Plant chaff elemental composition, ash content and calorific value

The experimental research results of common osier and black poplar chaff elemental composition, ash content and heat properties (calorific value) are presented in Table 1.

In the Table 1, the results show that common osier and black poplar chaff elemental composition analysis showed a similar C (carbon) content of 49.1–49.7%, O (oxygen) content of 42.6–42.9%, H (hydrogen) content of 5.6–5.8%, and other chemicals composition was in small volumes, N (nitrogen) content of 0.22–0.23% and S (sulphur) content of <0.01%. Plant chaff was dried before these experiments, and the determined chaff moisture contents ranged from 9.8% to 10.4%. The estimated ash content of investigated plants was relatively low and reached only 1.44% for common osier and 2.52% for black poplars. The lower calorific value of these plants as dry fuel is relatively high – 18.49-18.62 MJ/kg (Table 1).

Table 1. Plant chaff elemental composition, ash content and calorific value

Parameters	Value	Deviation, ± %
Common osier		
C (carbon) content, %	49.67	1.19
H (hydrogen) content, %	5.79	0.44
N (nitrogen) content, %	0.23	0.03
S (sulphur) content, %	<0.01	0.00
O (oxygen) content, %	42.87	2.10
Ash content, %	1.44	0.10
Moisture content, %	9.84	0.07
Wet fuel upper calorific value, MJ/kg	17.86	0.36
Wet fuel lower calorific value, MJ/kg	16.56	0.41
Dry fuel upper calorific value, MJ/kg	19.81	0.36
Dry fuel lower calorific value, MJ/kg	18.62	0.40
Black poplar		
C (carbon) content, %	49.06	1.20
H (hydrogen) content, %	5.59	0.44
N (nitrogen) content, %	0.22	0.02
S (sulphur) content, %	<0.01	0.00
O (oxygen) content, %	42.61	1.90
Ash content, %	2.52	0.28
Moisture content, %	10.36	0.07
Wet fuel upper calorific value, MJ/kg	17.61	0.29
Wet fuel lower calorific value, MJ/kg	16.34	0.34
Dry fuel upper calorific value, MJ/kg	19.65	0.29
Dry fuel lower calorific value, MJ/kg	18.49	0.33

Efficiency and energy evaluation of technologies

While evaluating the investigated technologies, the indirect energy inputs were calculated, which include the amount of energy attributable to liming material, mineral fertilizers and pesticides (Table 2). Energy equivalents were used to express the energy consumption used in the manufacturing of particular chemical substances (Afas et al. 2008). Since ammonium nitrate contains 34% N, the application rates were 176 and 353 kg ha^{-1} (in dependence on N fertilization rate). Each treatment plot received 100 kg ha^{-1} of potassium chloride (60 % K_2O) and 300 kg ha^{-1} of single superphosphate (20% P_2O_5). Of these substances, the highest energy value fell to ammonium nitrate and lime material (Opokos). The share of other substances (potassium and phosphorus fertilizers, pesticides) was notably lower.

Table 2. Indirect energy inputs for mineral fertilizers, pesticides, and lime material

Substances	Application rate, ha^{-1}	Energy equivalent, $MJ\ ha^{-1}$	Energy value, $MJ\ ha^{-1}$
Ammonium nitrate	176 kg 353 kg	27.6	4871 9743
Potassium chloride	100 kg	5.3	530
Single superphosphate	300 kg	6.4	1920
Lime material	3.0 t 6.0 t	17.9	5346 10726
Roundup	3 l	288	864

In addition to the direct expenses, the following indirect energy expenses were included. Common osier and black poplar production technology energetic assessment was performed based on practical works already performed and described by (Jasinskas et al. 2008a, Jasinskas et al. 2008b, Šarauskis et al. 2014). These data are presented in Table 3.

Table 3. The energetic evaluation of technological operations for common osier and black poplar cultivation in 2009-2012

Technological operations	Direct energy input $MJ\ ha^{-1}$	Machinery for particular operation $MJ\ ha^{-1}$	Energy input of human labour $MJ\ ha^{-1}$
Soil ploughing	575.6	77.1+27.8	1.8
Soil cultivation	217.8	77.1+24.1	0.6
Plant protection	43.2x2	(10.6+13.1)x2	0.6
Planting of cuttings	392.8	200	1.8
Distribution of liming material and fertilizers*,**,***	60-240*	21.85-87.40*	0.4-1.6*
Interrow cultivation	256	77.1+48.9	0.6
Growing expenses	1376-1616	452-539	6.4-8.0
Self-propelled crushing	606.3	395	1.3
Stems transportation	1394	77.1+280	16.6
Stems loading into storage place	342	77.1+70.5	4.0
Total	3718-3958	1352-1439	28.3-29.9

* – without liming + 0 kg ha^{-1} N (control treatment); ** – 1) without liming + 120 kg ha^{-1} N, 2) liming + without N fertilization; *** – liming + 120 kg ha^{-1} N

By calculating growing direct energy inputs, the following operating processes were included: soil ploughing (in the previous year before establishing of the experiment), soil cultivation (in spring prior to establishing the experiment), liming, planting of cuttings, 3 inter-row applications by herbicides (2 sprays in the 1st year and 1 spray in the 2nd year of growth), and biomass harvesting (including self-propelled crushing, stem transportation and the following transportation to production storage). The unevenness in energy input was determined by the fact that different application rates of liming material and mineral fertilizers were applied in the experiment. Therefore, energy input varied depending on the different liming and nitrogen fertilization rates. In this way, the overall technology energy input ranged between the plantation installations cutting the stems by 1,376 – 1,616 MJ ha^{-1} (from 37.01 to 40.83%) of all technological operations for the divestment of energy. The energy input for harvesting, transportation and storage operations comprises 2,735 MJ ha^{-1} (or 59.17 to 62.99% of all direct energy inputs into the growing technology) and accounted for a higher proportion of energy content insertion.

Energy output of common osier growing and harvesting machinery and production amounted 1,352 – 1,439 MJ ha^{-1}, and human labour costs ranged from 28.3 to 29.9 MJ ha^{-1}. Again, the higher the cost of removal the more work was required.

Depending on the particular treatment, the energy expenses (or total energy input) varied from 8.41 to 29.21 GJ ha^{-1} (Table 4). It is worth noting that the indirect energy inputs, i.e., liming material and mineral fertilizers, amounted 28.23 – 78.20% of all energy input. It indicates that a huge amount of energy is bounded in agrochemical substances.

After 4 years of growth cycle, the total energy output (or energy accumulated in the osier aboveground biomass per 4 growing years) reached 1,030-1,469 GJ ha^{-1}, and that of black poplar was 492-947 GJ ha^{-1} (Table 4). The liming material (or growing under a different soil pH level) did not significantly affect osier and poplar energy output. A more substantial increase in energy output was obtained in the case of 60 kg ha^{-1} N application rate.

Table 4. Energy evaluation of common osier and black poplar growing technology per 2008-2012 seasons

Treatment	Indirect energy input $GJ\ ha^{-1}$	Total energy input $GJ\ ha^{-1}$	Share of lime and mineral fertilizers (%)	Total energy output $GJ\ ha^{-1}$		Energy use efficiency	
				Common osier	Black poplar	Common osier	Black poplar
Not limed and 0 kg ha^{-1} N	3.31	8.41	39.36	1030	492	122.47	58.50
Not limed and 60 kg ha^{-1} N	8.18	13.36	54.79	1442	751	107.93	56.21
Not limed and 120 kg ha^{-1} N	13.06	18.38	66.32	1639	875	89.17	47.61
3.0 t ha^{-1} $CaCO_3$ and 0 kg ha^{-1} N	8.66	13.84	56.36	1191	674	86.05	48.70
3.0 t ha^{-1} $CaCO_3$ and 60 kg ha^{-1} N	13.53	18.85	67.21	1424	966	75.54	51.25
3.0 t ha^{-1} $CaCO_3$ and 120 kg ha^{-1} N	18.40	23.83	73.60	1469	947	61.64	39.74
6.0 t ha^{-1} $CaCO_3$ and 0 kg ha^{-1} N	14.04	19.22	54.40	1227	622	63.84	32.36
6.0 t ha^{-1} $CaCO_3$ and 60 kg ha^{-1} N	18.91	24.23	74.49	1460	742	60.26	30.62

The relationship between the accumulated and consumed energy is expressed as energy use efficiency. Energy use efficiency values for the common osier ranged from 46.01 to 122.47 GJ ha^{-1}, meanwhile black poplar energy efficiency ranged from 26.77 to 58.50 GJ ha^{-1}. For both of the crops, energy use efficiency was the highest in the non-limed and nitrogen free treatment. However, it gradually decreased as the liming and nitrogen fertilization rates increased. Subsequently, the lowest energy efficiency was obtained in the treatment by the application of the highest liming (6.0 t ha^{-1} $CaCO_3$) rate and nitrogen (120 kg ha^{-1}) rates. According to the point of view of energy balance, high lime and nitrogen fertilization rates are impractical.

Discussion and Conclusions

Based on the presented data, we could conclude that from the point of view of both biomass and energetic productivity, the application of 60 kg ha^{-1} N rate (DM yield increase by 37.51%) is sufficient for common osier even if the use of liming material causes energetic loses. This means that when growing in *Retisol*, common osier is not susceptible to different soil pH levels. According to the results of other investigations performed in the LAMMC, the highest efficiency was obtained by the application of 90 kg ha^{-1} nitrogen rate. In that case, common osier DM yield was 8,700 – 9,070 kg ha^{-1} (Bakšienė et al., 2012). Swedish research suggests that the highest effect of nitrogen fertilization falls in the 2nd and 3rd growing seasons; meanwhile, the rates of nitrogen fertilizers as a factor have a lesser effect (Alriksson et al. 1997).

Concerning black poplar, the optimal condition was the application of 6.0 t ha^{-1} $CaCO_3$ liming material According the survey of 10 years experiments with hybrid poplar (*Populus trichocarpa*× *Populus deltoides*) in the Northern US, liming was highly efficient mean to increase poplar productivity (Czapowskyj and Safford 1993). Optimal N rate for black poplar is 60 kg ha^{-1} (DM yield increased by 22.13%). The use of higher lime and nitrogen fertilization rates is highly unprofitable.

Common osier and black poplar chaff elemental composition analysis showed a similar C (carbon) content of 49.1–49.7%, H (hydrogen) content of 5.6–5.8%, and other chemical compositions of N (nitrogen) and S (sulphur) were small in volume %. Estimated ash content of the investigated plants was relatively low and reached from 1.44% for willows to 2.52% for poplars. The lower calorific value of dry chaff of these plants was relatively high (18.49-18.62 MJ/kg).

The small amount of ash shows that the chaff of such energy plants as both species burns relatively well in comparison with other energy plants without a high calorific value (Šiaudinis et al. 2015).

The determined total energy input (depending on the different liming and nitrogen fertilization rates) to the growing process constituted 8.41 to 29.21 GJ ha^{-1}. Common osier and black poplar had the highest energy output (from 1,030 to 1,639 GJ ha^{-1}) and the highest energy use efficiency (46.01–122.47).

Depending on crop species and the application of 150 kg ha^{-1} of nitrogen rate, the energy consumption of all technological operations may reach 9.40 GJ ha^{-1}; meanwhile, in the case of no N fertilization, energy inputs range from 0.50 to 4.50 GJ ha^{-1} (Faber et al. 2007).

The positive balance for the production of agricultural crops is achievable due to the capture and accumulation of solar energy in plants. All the means used by humankind (fertilizers, machinery, and chemical agents) just allow plants to accumulate more energy.

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