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The assessment of common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.) productivity and technological preparation for solid biofuel

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Abstract

The research was carried out to determine the effects of soil pH (or liming) and nitrogen (N) fertilization on the common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.) dry mass (DM) yield, calorific value and mechanical properties. Field experiments were set up in 2008 in Western Lithuania on a naturally acid (pH 4.2–4.4) moraine loam.

According to the averaged data of four experimental years, the highest DM yield 4100 kg ha⁻¹ of common mugwort was established in 2009, which significantly decreased in the subsequent years. And, conversely, the highest cup plant DM yield 17980 kg ha⁻¹ was obtained in 2011. An increase in soil pH from 4.2–4.4 up to 5.6–5.7, resulting from 6.0 t ha⁻¹ CaCO₃ application, increased cup plant DM yield by 27.4%. Fertilization with 120 kg ha⁻¹ N significantly increased common mugwort and cup plant DM yield by 34.5% and 26.7% respectively, compared with the treatment without N fertilization. We also studied the chopping quality of common mugwort and cup plant and chaff fractional composition using sieves with different mesh sizes. The chaff of cup plant was finer and more even, and thus more suitable for use for energy purposes. Plant milling quality showed cup plant particles to be smaller and more even too, and thus better suited for pressing and combustion. The highest calorific value of common mugwort (17.97 MJ kg⁻¹) was obtained in 2010 and that of cup plant (17.48 MJ kg⁻¹) in 2012. The calorific values of common mugwort and cup plant were influenced most by the year of cultivation and 120 kg ha⁻¹ N application.

Key words: annual dynamics, calorific value, dry mass, fractional composition, liming, nitrogen, soil pH.

Introduction

Biomass is one of the basic renewable sources in energy systems. Compared with fossil fuel, the use of plant-based bio-fuel significantly reduces the “greenhouse” effect; CO₂ emission approximately equals zero, because the amount of CO₂, which is released during combustion, is used for the production of organic material during photosynthesis. Currently, much attention is being focused on identifying suitable plant species, which can provide high-energy outputs, and could replace fossil fuel energy sources (Forsberg, 2000; McKendry, 2002). In recent years, in Lithuania as well as abroad, a particular attention has been paid to the local and introduced plant

species with a high energy value, high terrestrial biomass productivity and high adaptation to growing under local soil and climate conditions (McKendry, 2002; Kryževičienė et al., 2010; Slepetyš et al., 2012).

Artemisia genus is one of the biggest among *Asteraceae* family and is wide-spread in many countries. Several species are found in Lithuania (Galiniš, 1980). Mostly mugwort has been studied as a medicinal plant and partly as a food plant. Due to a high essential oil concentration, calorific value of individual *Artemisia* species is quite high and can reach up to 4500 kcal kg⁻¹ (Frandsen, 1983; Judžentienė, Buzelytė, 2006). It has

been reported that common mugwort biomass structure and chemical composition are well suited for biofuel production and could be a reliable raw source for pellet and briquette production (Kryževičienė et al., 2010). However, the possible conversion of mugwort biomass to any sort of biofuel has not been investigated yet.

Cup plant (*Silphium perfoliatum* L.) as well as other *Silphium* genus species originates from Northern America (Huxley, 1992; Clevinger, Panero, 2000). Although it is listed as a potentially invasive species, some *Silphium* species (*S. perfoliatum* L., *S. integrifolium* Michx. and *S. laciniatum* L.) are characterised as high yielding crops (Margieva, 2006; Voigt et al., 2012); thus, have been broadly investigated as a potential source for animal nutrition (Kowalski, 2007; Lehmkuhler et al., 2007; Stepanov, Usenko, 2009). Yet, their prospects for animal feeding might be limited due to lower feeding value compared with maize, which is another traditional coarse stem species (Lehmkuhler et al., 2007). The recent focus has been targeted on a potential use of cup plant biomass for bio-fuel production. So far, such kind of experiments have been at initial stage and reliable data are scarce (Steininger, Holtinger, 2010; Frączek et al., 2011).

It is important to investigate not only cultivation peculiarities of these tall perennial grasses but also the technical measures of common mugwort and cup plant biomass preparation for biofuel, to assess quality indicators of these plants' chopping and milling, to determine the basic physical mechanical properties and calorific value of these plants biomass prepared for fuel. Some of these investigations have been done in other countries, but there is a lack of studies on these plants under Lithuanian climate conditions. The chaff quality of plant stems used for fuel has to meet the requirements of chaff burning chambers used in boiler-houses, chaff transportation equipment and storages (Vares et al., 2007). A high burning efficiency is produced in furnaces when chaff of required thinness is used.

The aim of this study was to assess the dependence of common mugwort and cup plant biomass productivity on soil pH and nitrogen fertilization and to evaluate physical-mechanical properties of the biomass.

Materials and methods

Research on common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.) was carried out at Vėžaičiai Branch of Lithuanian Research Centre for Agriculture and Forestry (55°43' N, 21°27' E on a naturally acid moraine loam (*Eutri-Hypostagnic Albelvisol*, *ABj-w-eu*) during 2008–2012. In the spring of 2008, before the establishment of the experiments, the following characteristics of upper soil layer (0–20 cm) were determined: pH_{KCl} 4.25–4.45, mobile P_2O_5 35–120 mg kg^{-1} , mobile K_2O 140–209 mg kg^{-1} , hydrolytic acidity 21.9–62.1 mequiv kg^{-1} and mobile Al 10.7–50.9 mg kg^{-1} .

Field experiments were laid out in two-factorial arrangement. Factor A – lime fertilizers (0, 3.0 and 6.0 t ha^{-1} CaCO_3). The whole research area was divided

into three different pH strips: 4.25–4.4 (natural acidity), 5.0–5.1 and 5.6–5.7. Factor B – nitrogen fertilization rates (0, 60 and 120 kg ha^{-1}). Nitrogen fertilization treatments were set out randomly with three replications in each pH strip. Lime material (“Opokos”, Lithuania) was spread in April 2008, before the setting up the trial. Nitrogen fertilization (ammonium nitrate) was performed each year of the studies. Phosphorus (single superphosphate) and potassium (potassium chloride) fertilizers were applied before the establishment of the field studies in 2008. The rates of phosphorus and potassium fertilizers were equal for all the treatments – 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O .

Naturally grown up sprouts of common mugwort were used as planting material. The sprouts were planted on the 27th of May in 2008. Cup plant seeds were sown in peat pots at the end of April. Cup plant seedlings at 2–3 leaf stage were planted in the trial site on the 3rd of June 2008. The distance between the rows of common mugwort was 0.75 m; the distance between plants in rows was 0.5 m. The distance between the rows of cup plant was 1.0 m; the distance between individual plants in each row was 0.5 m. The harvested area of each plot of both crops was 10 m^2 . The yield estimation started in 2009. Each year, in the second half of September, the biomass of common mugwort and cup plant was cut using a rotary reaper (“Claas”, Germany). The productivity of the above-ground biomass was recalculated into the air-dry mass (DM). For determination of plant chopping quality, common mugwort and cup plant biomass at first was chopped by a harvester’s “Maral 125” (“Fortschritt”, Germany) drum chopper with 8 blades at a speed of 913 revolutions per minute (Jasinskas et al., 2012). To prepare the mass for pellet production, the chaff was milled to small 1–2 mm particles by a mill “Retsch SM 200” (“Retsch”, Germany).

The fractional composition of chaff and mill was determined with the CEN/TS 15149-1:2006 system, commonly employed in the European Union, using a vibratory device and sieves with different mesh sizes (Jasinskas et al., 2012). 400 mm diameter sieves were used, where sieves with round pore are put one on other (in the order from the top sieve): diameter of 63, 45, 16, 8, 3.15 and 1 mm. For determination of mill fraction composition, we used sieves with meshes to 2 mm diameter. Screening 5 kg sample with a special sieve shaker, the set of sieves are being rotated in semicircle for 3 min in the horizontal plane. The rest of the mass on the sieve is weighted and each fraction's part in percentage is calculated. Each experiment is repeated five times.

Calorific value was measured by a calorimeter C 2000 (IKA, Germany). The analysis was performed by the standard methodology (Vares et al., 2007; BS EN 14918:2009).

A three-way analysis of variance with three replications design was performed on the data of the following factors: cultivation year, soil pH and nitrogen rate, using analysis of variance (*ANOVA*) to determine significance at 95% probability level (LSD_{05}) (Tarakanovas, Raudonius, 2003).

Results and discussion

Dry mass (DM) yield. According to average data of four years, the highest common mugwort above-ground dry mass yield was determined during the first harvest year (i.e. 2009) – on average 4100 kg ha⁻¹ DM (Fig. 1). In the next two years, DM productivity decreased signally and in 2011 was only 3084 kg ha⁻¹ (or 25% less than in the first year). Again in 2012, DM productivity increased substantially up to 3581 kg ha⁻¹. The DM yield strongly correlated with the number of stems per plant.

The decrease of DM yield in 2010 and 2011 growing seasons can be related to a higher air temperature and lack of moisture in the topsoil during the period of intensive growth in late May – early June, when a share of already synthesized DM could be utilized for more intense respiration. These tendencies agree with the observations of other trials that the lack of soil moisture could substantially retard mugwort development and DM accumulation. Due to different growth conditions, the increment of DM can vary up to 31% (Kryževičienė et al., 2010).

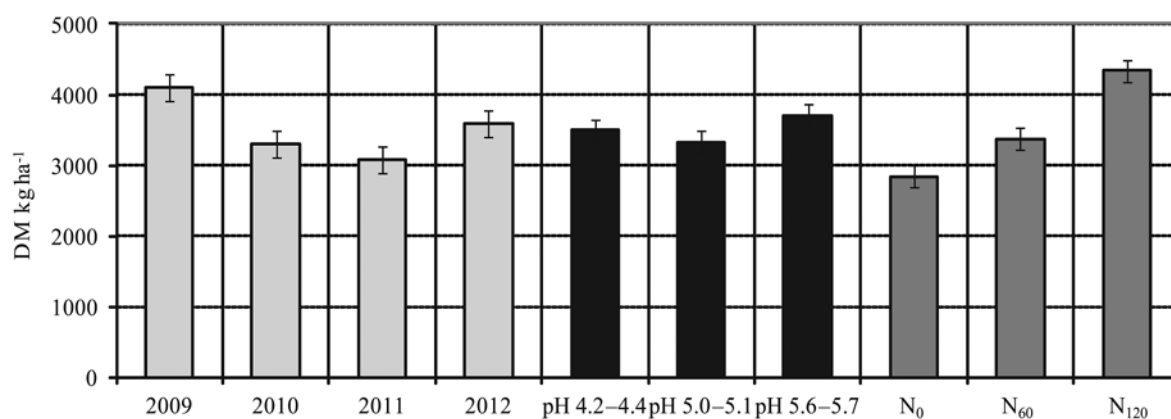


Figure 1. The influence of cultivation year, soil pH and nitrogen fertilizers on common mugwort (*Artemisia vulgaris*) dry mass (DM) yield

The cultivation of common mugwort under different soil pH (or liming) had no significant influence on biomass productivity. Common mugwort tolerates a wide range of soil types as well as soil acidity levels (Huxley, 1992). These studies also confirmed that liming of common mugwort crops is inexpedient. The common mugwort's DM yield, and at the same time the differences between particular treatments were determined by the nitrogen fertilization (especially 120 kg ha⁻¹ rate) – in this case, the DM increment was the highest and reached 4334 kg ha⁻¹, on average (or 34.5% more than without nitrogen fertilization). Similar tendencies were observed in parallel studies performed in Central Lithuania. By the application of 120 kg ha⁻¹ N rate, common mugwort

achieved the highest DM yield at the second harvest year – 9038 kg ha⁻¹, on average (Kryževičienė et al., 2010). However, common mugwort productivity in subsequent years decreased sharply to average annual DM yield of 3400 kg ha⁻¹ (Slepetys et al., 2012). The cup plant DM productivity increased from 6746 kg ha⁻¹ in 2009 to 17980 kg ha⁻¹ in 2011 (the increase was 266%) (Fig. 2). The use of lime fertilizers and the subsequent increase of soil pH to 5.6–5.7 positively influenced the increase of DM from 11778 to 15005 kg ha⁻¹ (or 27.4%). The application of nitrogen fertilizers had also a positive effect. Compared with the control treatment, 120 kg ha⁻¹ N fertilization significantly increased the DM yield from 11757 to 14897 kg ha⁻¹ (or 26.7%).

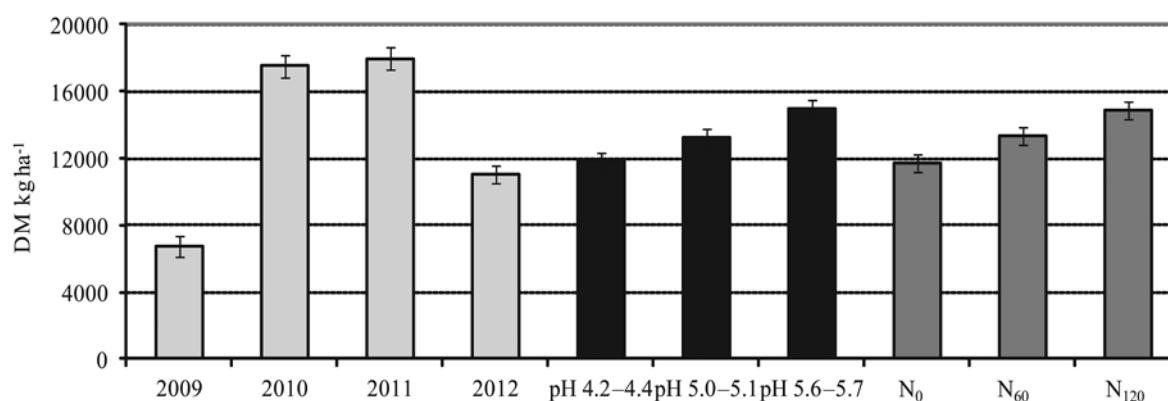


Figure 2. The influence of cultivation year, soil pH and nitrogen fertilizers on cup plant (*Silphium perfoliatum*) dry mass (DM) yield

Cup plant is characterized by the dynamics of growth, when in the first year the yield is not very high, but it increases rapidly during the later years of growth (Filatov et al., 1986). Cup plant has a well developed deep rooting system. The roots are 30–150 cm long. Some roots grow down, others spread radially under soil surface (Stanford, 1990). Thus in our experiments, cup plant dependence on atmospheric precipitation was less obvious compared to common mugwort. Though cup plant is a species which produces high biomass yield, its productivity might be influenced by other biotic factors. Similar studies in Central Lithuania revealed that on *Eutri-Cambic Arenosol* (ARb-eu), which is less suited for many plants growing, under the application of 60 kg ha⁻¹ N, the average annual cup plant productivity was 7290 kg DM ha⁻¹. Cup plant productivity was somewhat lower than that of other coarse-stemmed species – *Heliantus tuberosus*, *Sida hermaphrodita* or *Artemisia dubia* (Slepetys et al., 2012). Whereas under Central Poland's growing conditions, which are defined as having higher sum of active temperatures and longer vegetation period, each year different species of *Silphium* can produce 17800–28800 kg ha⁻¹ DM yield (by annual application of 100 kg ha⁻¹ N) (Kowalski, 2004; 2007). The increment of cup plant DM was far greater in comparison with common mugwort. In separate years of studies, cup plant DM yield exceeded common mugwort DM yield by on average 58–583%.

Chopping quality of energy plants. While assessing common mugwort and cup plant chopping quality we determined the fractional composition of chaff and mill. The dependence of plant chaff fractional composition (%) on the mesh diameter (mm) of sieves is presented in Figures 3 and 4.

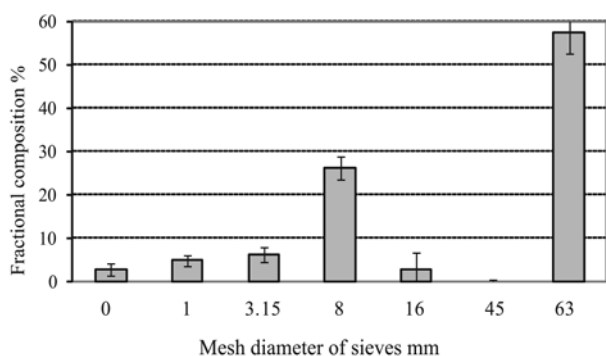


Figure 3. The dependence of common mugwort (*Artemisia vulgaris*) chaff fractional composition on the mesh diameter of sieves

The evaluation of plant stems chaff fractional composition according to the methodology applied in the EU countries, using sieves with different mesh diameters showed that the largest amount of cup plant chaff fraction accumulated on the sieve with round meshes of 8 mm diameter – 52.0 ± 2.9% of all chaff mass. The largest amount of common mugwort chaff fraction accumulated

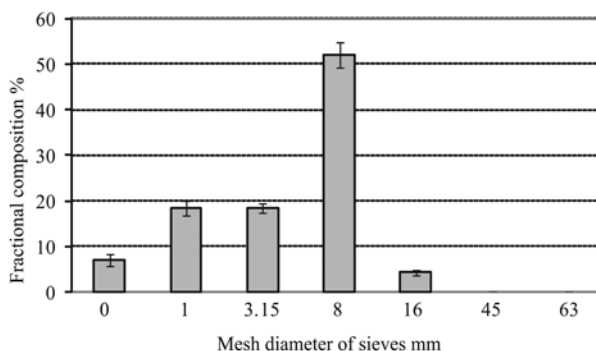


Figure 4. The dependence of cup plant (*Silphium perfoliatum*) chaff fractional composition on the mesh diameter of sieves

on the sieve with a mesh diameter of 63 mm – 57.3 ± 4.8%. Cup plant chaff was finer and more even, and thus more suitable for use for energy purposes. For the pellet production the chaff was milled by a hammer mill. Milling quality was found similar to that of a drum chopper, when the mass fractional composition was determined using sieves with different mesh sizes. The dependence of plant mill fractional composition (%) on the mesh diameter (mm) of sieves is presented in Figures 5 and 6.

The evaluation of cup plant mill fractional composition using sieves with different mesh diameters

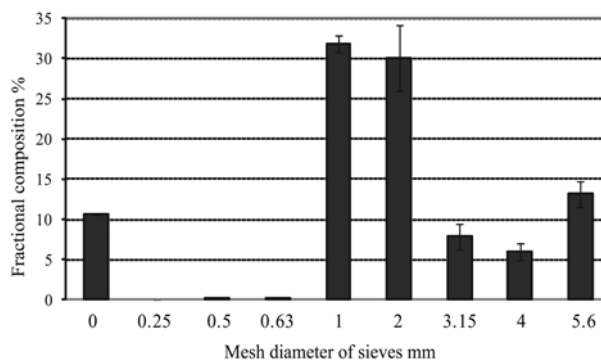


Figure 5. The dependence of common mugwort (*Artemisia vulgaris*) mill fractional composition on the mesh diameter of sieves

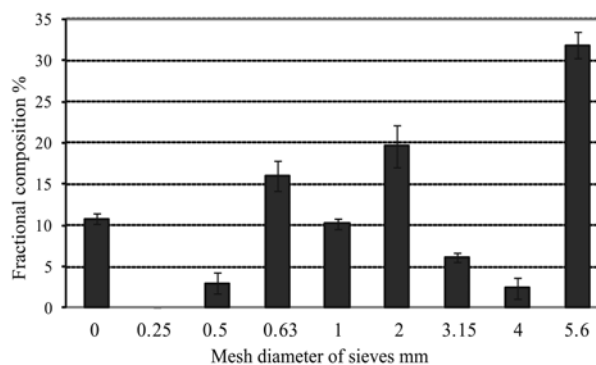


Figure 6. The dependence of cup plant (*Silphium perfoliatum*) mill fractional composition on the mesh diameter of sieves

shows that the largest fraction of cup plant chaff was accumulated on the sieve with 5.6 mm mesh diameter – by $31.8 \pm 1.6\%$ of all fractional part. The meal was not accumulated on the sieve with 0.25 mesh mm diameter. From the chart on common mugwort mill fractional composition we can see that the largest fraction of mill was accumulated on the sieve with 1 mm holes – $31.8 \pm 0.0\%$ of all fractional part, and a little less on the sieve with 2 mm holes – $30.1 \pm 4.1\%$ of all fractional part. The meal was not accumulated on the sieves with 0.25 and 0.5 mm mesh diameter. Cup plant particles were found to be smaller and more even, because of which they were better suited for pelleting and usage for burning. Research results

of common mugwort and cup plant pelleting and usage for energy purposes will be presented in a separate article.

Calorific value. Cultivation year was a significant factor for common mugwort calorific value, which ranged from 17.84 MJ kg^{-1} in 2011 to 17.97 MJ kg^{-1} in 2010 (Fig. 7). Cultivation in soil with different pH level did not have a vital influence on the common mugwort biomass calorific value. A substantial and positive impact was obtained by nitrogen 120 kg ha^{-1} fertilization – the biomass calorific value increased from 17.84 to 17.97 MJ kg^{-1} . Thus, nitrogen fertilizers may have had a positive impact on the chemical composition of biomass and herewith on the calorific value.

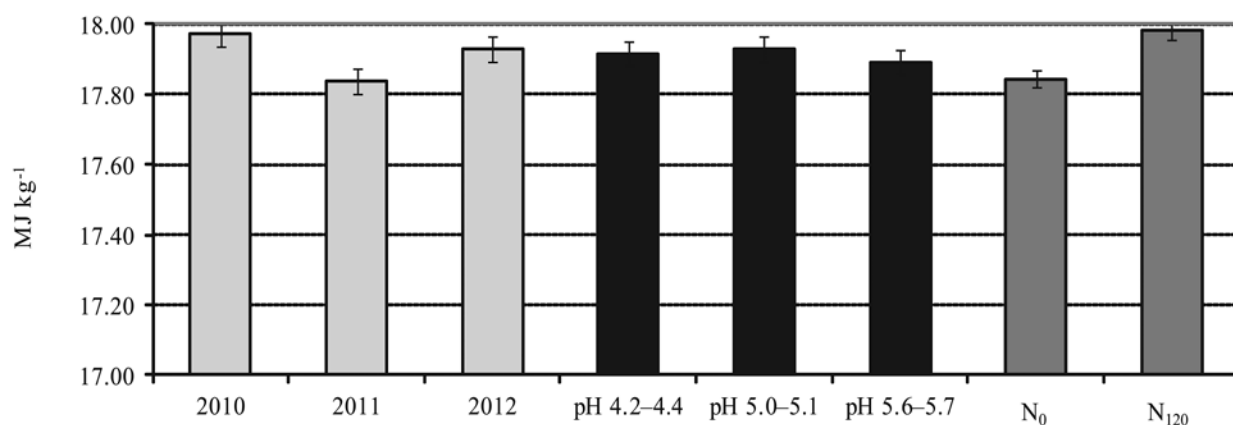


Figure 7. The influence of cultivation year, soil pH and nitrogen fertilizers on common mugwort (*Artemisia vulgaris*) calorific value

The growth conditions had a significant impact on cup plant calorific values (Fig. 8). In 2012, the average calorific value was 17.48 MJ kg^{-1} . Compared with the results of the previous two-years, the increase of calorific value was significant. The calorific value of cup plant, grown under different pH backgrounds, ranged from 17.26 to 17.35 MJ kg^{-1} . Although less notable, but there was observed a tendency that when growing cup plant

in limed site (or when pH $5.6\text{--}5.7$), its biomass calorific value was higher.

With liming, the nutrient stocks, soil pH, organic carbon content increase in the plant rooting zone, in turn, the resorption of individual nutrients (including nitrogen) increases (Repšienė, 2003; Karcauskiene, Repšienė, 2009). It follows thence that the changes of the ratio of chemical compounds in above-ground biomass may change calorific value as well.

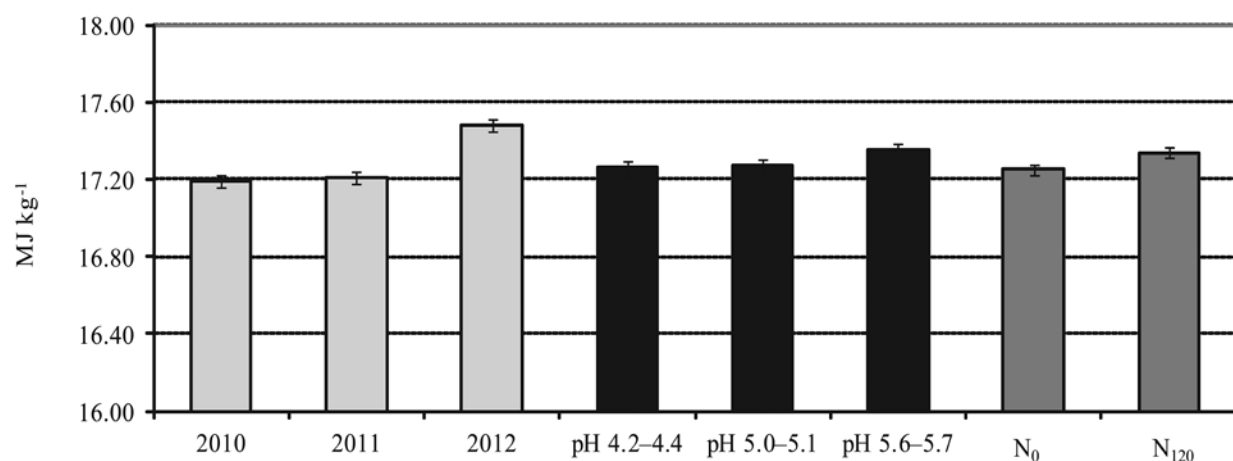


Figure 8. The influence of cultivation year, soil pH and nitrogen fertilizers on cup plant (*Silphium perfoliatum*) calorific value

The use of 120 kg ha⁻¹ N rate notably increased the calorific value in cup plant biomass from 17.25 to 17.34 MJ kg⁻¹. A positive influence of nitrogen fertilizers on calorific value was determined in all three experimental years. Nevertheless, our data do not agree with the conclusions of some authors, that nitrogen fertilizer does not affect the calorific value of biomass (Ercoli et al., 1999; Lemus et al., 2008). The data of other scientific investigations revealed that the average cup plant calorific value varied from 17.30 to 17.90 MJ kg⁻¹ (Heneman, Červinka, 2007; Frączek et al., 2011). The data presented in the article suggest that compared with common mugwort, cup plant biomass had a lower calorific value, and due to much higher annual DM yield and better measured technical properties, it seems that cup plant biomass is more suitable for biofuel manufacturing. The limited research data showed that briquettes manufactured from cup plant biomass are characterised by very good qualitative parameters (Frączek et al., 2011). These authors suggest that due to high biomass productivity, cup plant could be a relevant species for biogas production comparable with maize. However, the investigations concerned with cup plant biomass availability for biogas production are still in initial stage and no reliable results have been obtained so far (Steininger, Holtinger, 2010; Voigt et al., 2012).

Thus, the experiments with these energy crops must be continued by focusing on agronomical as well as biomass energy parameters. A special attention should be given to the suitability of energy crops biomass for particular type of biofuel.

Conclusions

1. According to the results of the four experimental years, the highest common mugwort dry mass (DM) yield averaging 4100 kg ha⁻¹ was obtained in 2009. The application of 120 kg ha⁻¹ N rate substantially increased DM yield by 34.5%. Soil pH (or liming) had no significant effect on DM increment of mugwort.

2. Cup plant reached the highest DM yield averaging 17980 kg ha⁻¹ in the third harvest year in 2011. The rise of soil pH from 4.2–4.4 to 5.6–5.7 (by application of 6.0 t ha⁻¹ CaCO₃) and application of 120 kg ha⁻¹ N rate significantly and positively increased cup plant DM yield by 34.5% and 26.7%, respectively.

3. Research results of plant chopping quality and chaff fractional composition showed that the largest amount of cup plant chaff fraction accumulated on the sieve with round meshes of 8 mm diameter – 52.0 ± 2.9% of all chaff mass. The largest amount of common mugwort chaff fraction accumulated on the sieve with the 63 mm mesh diameter – 57.3 ± 4.8%. Cup plant chaff was finer and more even and thus was more suitable for use for energy purposes.

4. Research results on the milling quality of the tested plants showed that the cup plant particles were smaller and more even and thus were better suited for pelleting and usage for burning.

5. The highest calorific value of common mugwort (17.97 MJ kg⁻¹) was obtained in 2010 and that of cup plant (17.48 MJ kg⁻¹) in 2012. The calorific values of both plants notably varied in response to cultivation year and 120 kg ha⁻¹ N application.

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Paprastojo kiekio (*Artemisia vulgaris* L.) bei geltonžiedžio legėsto (*Silphium perfoliatum* L.) produktyvumo ir kietojo kuro ruošimo technologinis vertinimas

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Santrauka

Tyrimai atlikti siekiant nustatyti dirvožemio pH (arba kalkinimo) ir tręšimo azoto trąšomis įtaką paprastojo kiekio (*Artemisia vulgaris* L.) ir geltonžiedžio legėsto (*Silphium perfoliatum* L.) sausosios masės (SM) derliui, šilumingumui ir mechaninėms savybėms. Lauko bandymai įrengti 2008 m. Vakarų Lietuvoje, natūraliai rūgščiame (pH 4,2–4,4) moreniniame priemolyje.

Remiantis vidutiniais ketverių metų tyrimų duomenimis, kiekį didžiausias SM derlius buvo nustatytas 2009 m. – 4100 kg ha⁻¹, kuris esmingai sumažėjo vėlesniais tyrimų metais, o legėstų didžiausias SM derlius buvo gautas 2011 m. – vidutiniškai 17980 kg ha⁻¹. Dirvožemio pH padidėjimas nuo 4,2–4,4 iki 5,6–5,7 (pakalkinus 6,0 t ha⁻¹ CaCO₃) legėstų SM prieaugį padidino 27,4 %. 120 kg ha⁻¹ N trąšų panaudojimas iš esmės padidino bendrą kiekį ir legėstų SM derlių – atitinkamai 34,5 ir 26,7 % daugiau nei netręšiant. Tirta paprastųjų kiekį ir geltonžiedžių legėstų smulkinimo kokybė bei pjaustinio frakcinė sudėtis pagal Europos Sąjungos šalyse taikomą metodiką, naudojant sietus su skirtingo skersmens skylutėmis. Nustatyta, kad geltonžiedžių legėstų pjaustinyse buvo smulkesnis ir tolygesnis, labiau tinkantis naudoti energetinėms reikmėms. Vertinant tirtų augalų malimo kokybę nustatyta, kad geltonžiedžių legėstų miltų dalelės buvo smulkesnės ir tolygesnės, todėl šie augalai labiau tinka presuoti ir naudoti deginimui. Didžiausias vidutinis paprastųjų kiekį biomasės šilumingumas siekė 17,97 MJ kg⁻¹ (2010 m.), o geltonžiedžių legėstų – 17,48 MJ kg⁻¹ (2012 m.). Abiejų augalų šilumingumo reikšmėms didžiausią įtaką turėjo augimo metai ir 120 kg ha⁻¹ azoto trąšų panaudojimas.

Reikšminiai žodžiai: azotas, dirvožemio pH, frakcinė sudėtis, kalkinimas, sausoji masė, šilumingumas, tręšimas.