THE INVESTIGATION OF THREE POTENTIAL ENERGY CROPS: COMMON MUGWORT, CUP PLANT AND VIRGINIA MALLOW ON WESTERN LITHUANIA'S ALBELUVISOL

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Abstract. Research on novel energy crops – common mugwort (*Artemisia vulgaris* L.), cup plant (*Silphium perfoliatum* L.) and Virginia mallow (*Sida hermaphrodita* Rusby) was set up on a naturally acid Albeluvisol in West Lithuania. The study was aimed to evaluate the effect of year (growing conditions), liming and nitrogen fertilization on biomass yield, its structure as well as lime and nitrogen use efficiency. In many cases, year (or growing conditions) and N fertilization were two determinant factors for all studied parameters (number of stems per plant, stem height, fresh (FM) and dry mass (DM) yield). Liming material had the biggest impact on the number of stems, stem height and biomass yield of Virginia mallow and less obvious for other two species. Among three crops, the highest productivity was recorded for cup plant in the 3rd harvest year – the average FM yield was 45.20 t ha^{-1} and that of DM – 13.45 t ha^{-1}. The highest lime use efficiency (LUE) values for all three crops obtained in the 2nd year of growing. The highest nitrogen use efficiency (NUE) was obtained in the 1st (for common mugwort - 30.71) and 2nd year of growing (for cup plant and Virginia mallow - 59.69 and 46.17, respectively).
Keywords: *energy crops, lime, nitrogen, yield parameters, NUE, LUE*

Introduction

Different kinds of woody and herbaceous plants are being widely investigated for bioenergy purposes in many European countries. The main characteristics of energy crops are high biomass (dry matter) yield and energy value, which is achievable with relatively small economic and energy inputs. A positive result is highly dependent on the adjustment of individual plant species to growing in certain areas of climate and soil conditions (McKendry, 2002).

The article presents the results of the study on three new but botanically very different perennial energy crops: common mugwort (*Artemisia vulgaris* L.), cup plant (*Silphium perfoliatum* L.) and Virginia mallow (*Sida hermaphrodita* Rusby).

Artemisia genus species are widespread in many countries around the world (Barney and DiTommaso, 2003). Out of them, common mugwort is being studied as a possible source for food and pharmaceutical industry in Lithuania and other countries (Judžentienė and Buzelytė, 2006). In traditional agriculture, mugwort is considered as a weed with the ability to propagate easily from small rhizome fragments (Barney and DiTommaso, 2003). It has been reported that Artemisia genus energy value can reach up to 4500 kcal kg^{-1} (Van Epps et al., 1982). However, there is very little information which is linked to Artemisia species cultivation and their biomass application for biofuel purposes (Kryževičienė et al., 2010).

A cup plant species is originally native to North Eastern US (Huxley, 1992; Clevinger and Panero, 2000). So far, the cup plant physiological and agronomical traits

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have been investigated in different countries (Wrobel et al., 2013; Franzaring et al., 2014). However, there are still many questions to be addressed with regard to its cultivation technology (Voigt et al., 2012; Gansberger et al., 2015).

Similarly, Virginia mallow originates from Northern America (Kujawski et al., 1997). However, many experiments were performed by European researches. Although biomass productivity varies depending on agroclimatic and growing conditions, the productivity of above-ground biomass is comparable with that of other high yielding energy crops – cup plant, basket willow or miscanthus (Borkowska and Molas, 2012; 2013). However, Virginia mallow is still a novel and little-known species in Lithuania and needs a further scientific investigation.

It is important to note that in order to avoid competition with traditional agricultural crops, it is advisable to cultivate energy crops in less fertile soils. For example, naturally acid Albeluvisols and Fluvisols are prevailing in Western Lithuania region. Without maintenance liming, soils return to their original state which leads to the deterioration of their physical, chemical and microbial properties (Mažvila et al., 2004). With increasing demand for biomass for bioenergy industry, a significant proportion of such soils could be used for the cultivation of energy crops. There are few data concerning energy crops productivity under different soil pH levels.

The current research was aimed to investigate the influence of the different liming (or soil pH) and N rates on the yield, yield structure, nitrogen use efficiency and liming use efficiency of common mugwort, cup plant and Virginia mallow in Albeluvisol.

Materials and methods

The experiments were performed at Vėžaičiai Branch of the Lithuanian Research Centre for Agriculture and Forestry (55º43´N, 21º27´E) on a naturally acid moraine loamy soil (Eutri-Hypostagnic Albeluvisol, ABj-w-eu). Before setting up the trials, the soil of the experimental site was under bare fallow. Agrochemical characteristics of the upper soil layer were as follows: pH_{KCl} – 4.25-4.85, mobile P_2O_5 (Egner-Riehm-Domingo (A-L)) – 35 – 120 mg kg^{-1}, mobile K_2O (A-L) – 140–209 mg kg^{-1}, hydrolytic soil acidity – 21.9-62.1 mequiv kg^{-1}, mobile Al – 10.7-50.9 mg kg^{-1}.

The subjects of the study were cup plant (*Silphium perfoliatum* L.), common mugwort (*Artemisia vulgaris* L.) and Virginia mallow (*Sida herhaphrodita* Rusby).

The experiments involved two factors. Factor 1 – liming: a) not limed; b) limed by 0.5 rate (3.0 t ha^{-1} $CaCO_3$) (to neutralize the effect of toxic aluminium); c) limed by 1.0 rate (6.0 t ha^{-1} $CaCO_3$). Factor 2 – nitrogen rates (0, 60 and 120 kg ha^{-1} N). Nitrogen treatments were arranged in a randomized block design with three replications in each pH (different liming) background.

The experimental site was limed (except for the control treatment) by OPOKOS lime material on April 20 in 2008, just before planting of seedlings. In both years (2009 and 2010), nitrogen fertilizers (60 kg ha^{-1}) were broadcast at the beginning of April. Treatment 3 was additionally fertilized with 60 kg ha^{-1} N at the beginning of July. Ammonium nitrate was applied as nitrogen fertilizer. Phosphorus was applied as single superphosphate and potassium – as potassium chloride. Both fertilizers were spread each year before the beginning of vegetation. Potassium and phosphorus rates for all treatments of common mugwort and cup plant were the same - 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O.

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Common mugwort seedlings were planted on May 27 in 2008. Naturally grown common mugwort plants were used as a planting material for the experiment. Each common mugwort treatment consisted of three 10-meter long rows. The distance between rows was 0.75 m^2, and between seedlings in rows – 0.50 m^2. The density of mugwort plants was 30.000 plants per ha.

Cup plant seedlings were planted at 2-3 leaf stage on June 3 in 2008 in 10 m long rows, by keeping 1m^2 distance between each row and 0.5 m between the seedlings in each row. Each row presents a separate treatment. Thus, the cup plant density was 20000 plants per ha. During planting year, cup plant grows a leaf rosette only; meanwhile shoots start growing from the second year. Both, cup plant and common mugwort investigations for biometrical parameters were started in the growing season 2009.

Virginia mallow seedlings were planted at 3-4 leaf stage on July 10 in 2009. Field parameters were the same as for cup plant. The assessments started from the 2010 growing season.

Nitrogen use efficiency was calculated by the following equation: (DM yield with N fertilization) − (DM yield without nitrogen fertilization (control))/ N rate, where N equals the amount of N from fertilizer added in kg ha^{-1} (Gan et al. 2008). Similarly, lime utilization efficiency (LUE) was calculated in the similar way (DM yield with lime application) − (DM yield liming (control))/ L rate (t ha^{-1} $CaCO_3$ rate) rate.

Each year, biomass of all three crops was harvested at the end of vegetation in the 3rd ten-day period of September, using a rotary cutter (Claas, Germany). The fresh (FM) mass yield (or above-ground biomass) was weighed and recalculated into the air-dry mass (DM).

The data of evaluated parameters were statistically processed using analysis of variance (Anova) as a three factorial randomized block variant to determine significant differences between means (*$P<0.05$ and **$P<0.01$), LSD_{05} and LSD_{01} (at 95% and 99% probability levels).

In 2009, in the first half of the vegetation season, conditions for plants growing were relatively cool and dry. From the beginning of July until the end of vegetation, the temperature and amount of precipitation were close to annual average. For 2009 growing period, the amount of precipitation was 437 mm. In general, for 2010, the warm and dry period alternated with humid and cool weather until the end of vegetation. The amount of precipitation was 620 mm. In 2011, the weather conditions and rainfall distribution were similar (540 mm per vegetation) throughout the whole vegetation. The moderately warm and dry weather was dominating at the beginning of 2012 growing season. The amount of precipitation gradually increased in the second half of vegetation and totalled 394 mm.

Results and discussion

The results of three factorial analysis (tear, liming rate, nitrogen rate and their interactions) are presented in *Table 1*. According to Fisher's criterion, year and nitrogen rate were determinant factors affecting the studied parameters for all three crops (at $P < 0.01$ and $P< 0.05$). For common mugwort, year significantly influenced the number of stems per plant, stem height, dry mass productivity ($p<0.01$) and fresh mass ($p<0.05$). In a similar way, nitrogen rate positively influenced all four yield parameters and nitrogen use efficiency (NUE) ($p<0.01$). However, the interaction of both parameters (Y x N)

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had a positive impact on the number of stems per plant and NUE (p<0.01). Although liming had no significant effect on yield parameters, liming rate (or growing under different soil pH levels) had a significant impact on NUE (p<0.01). Lime use efficiency (LUE) was not influenced by any of these three factors or their interactions.

Year as a factor had a significant impact on all parameters of cup plant (p<0.01). Nitrogen rate positively influenced the number of stems per plant, fresh and dry mass (p<0.01). Although liming had no statistically significant impact on individual yield parameters, it significantly influenced fresh mass (p<0.05) and dry mass (p<0.05) yield.

The impact of nitrogen rate and liming rate (L x N) (p<0.05) on stem height of cup plant was only statistically positive mutual interaction for cup plant.

Table 1. *Fisher criterion's mean squares for common mugwort, cup plant and Virginia mallow yield parameters, lime and nitrogen efficiency (LUE, NUE)*

Variable	Number of stems plant^{-1}	Stem height (cm)	Fresh mass (t ha^{-1})	Dry mass (t ha^{-1})	NUE (kg kg^{-1})	LUE (kg t^{-1})
Common mugwort						
Year	29.63**	10.32**	2.98*	4.11**	23.50**	0.51
Liming rate	1.87	0.01	0.44	0.99	5.57**	1.34
Nitrogen rate	4.52**	24.98**	25.00**	16.26**	0.02	0.12
Y x L	6.34**	0.57	0.64	0.65	4.91**	0.47
Y x N	2.13	0.99	0.69	0.57	0.65	0.91
L x N	1.42	0.81	0.62	0.10	2.01	0.23
Y x L x N	0.57	1.63	0.51	0.43	2.12	0.37
Cup plant						
Year	152.05**	138.24**	49.88**	55.90**	5.62**	6.32**
Liming rate	2.02	0.19	4.22*	5.82**	0.76	2,42
Nitrogen rate	9.70**	1.31	7.64**	5.43**	0.01	1,5
Y x L	0.74	1.35	1.02	1.50	1.95	1,62
Y x N	0.67	0.34	0.32	0.11	1.64	0,84
L x N	1.03	2.84*	2.36	1.16	1.67	1,36
Y x L x N	1.17	0.26	0.19	0.14	0.74	0,15
Virginia mallow						
Year	19.44**	17.52**	50.00**	9.69**	22.18**	4.51*
Liming rate	12.64**	3.36*	16.73**	15.69**	6.11**	0,25
Nitrogen rate	22.58**	4.27*	52.63**	48.71**	1.46	28.01**
Y x L	0.46	0.42	1.19	1.40	19.7**	2,39
Y x N	1.05	0.55	6.19**	3.69*	0.91	1,12
L x N	0.30	0.11	2.14	2.02	17.62**	1,79
Y x L x N	0.62	0.43	1.58	1.10	5.04**	0,39

*, ** - significant at P<0.05 and P<0.01 levels, respectively

As for Virginia mallow, all three investigated factors had a positive impact to all studied parameters (p<0.05 or P<0.01). However, both liming and nitrogen use efficiency (kg kg^{-1}) (or LUE and NUE) were not significantly affected by liming and nitrogen rates, respectively. In some cases, the interactions between the factors were

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statistically significant. Thus, nitrogen use efficiency was significantly affected by Y x L, L x N and Y x L x N interactions (P<0.01). The interaction Y x N positively influenced fresh (P<0.01) and dry mass (P<0.05) of Virginia mallow. These results suggest that compared with other investigated species, Virginia mallow is more susceptible to biotic and abiotic factors.

Yield and its structure

The smallest number of mugwort stems was observed in the first harvest year (in 2009) – 8.42 stems plant^{-1} (*Table 1*). In the next two years, the number of stems increased significantly up to 17.68 stems plant^{-1} (or 4.84 times) (in 2011). This indicates that with the increasing common mugwort age, its branching ability becomes stronger. The role of liming was less visible. On average, the application of 120 kg ha^{-1} N increased the number of mugwort stems up to 15.65 plant^{-1}.

Depending on the growing year, the average stem height varied from 82.47 to 90.73 cm. Although statistically significant, the effect of year on stem height was less noticeable than for other parameters. There was no significant effect of liming on stem height. There was a significant effect of 120 kg ha^{-1} N application – the average stem height increased up to 94.70 cm.

The highest common mugwort biomass productivity (both, FM and DM yield) was recorded in 2009. In this year, the average FM and DM yield was 6.93 and 4.10 t ha^{-1}, respectively. Herewith, the productivity significantly decreased in the following two years. It is probable that the decrease of common mugwort yield was determined by droughty periods in 2010 and 2011 seasons at the intensive growth stage of above-ground biomass, when significant parts of already synthesized DM are exhausted during the intense respiration. Besides, common mugwort might be more sensitive to water deficit in the upper soil layer due to a shallow root system. Statistical analysis showed that the application of 6.0 t ha^{-1} $CaCO_3$ rate significantly increased DM yield; however, the positive effect of liming was observed just in individual cases. The minor effect of liming material on mugwort productivity could be explained by the fact that the species is undemanding in terms of soils and soil pH levels (Barney and DiTomasso 2003). In all the treatments, the application of N fertilizers substantially increased mugwort FM as well as DM yield.

The correlation-regression analysis revealed that both the number of stems per plant and stem height strongly correlated with common mugwort FM and DM yield.

On the other hand, the relatively low common mugwort biomass productivity could be increased by increasing plant density per unit area. According to the results of other investigations conducted in Central Lithuania’s Arenosols, by application of 120 kg ha^{-1} N rate and plant density of 40 thousand ha^{-1} (twice more than in our experiment), the average common mugwort DM yield in the second growing season was 9.38 t ha^{-1} (Kryževičienė et al., 2010).

The lowest number of cup plant stems was observed in the first harvest year (in 2009) – 5.68 stems plant^{-1} (*Table 2*). In the subsequent two growing seasons, the number of stems significantly increased up to 12.18 stems plant^{-1} (in 2011) (or 214% higher compared with 2009 season’s results). Liming material had no statistically significant impact on the number of stems. However, the presented data revealed that there was a trend that nitrogen application significantly increased the number of stems. It is estimated by other experiments that depending on cup plant age, the number of stems per plant varied from 10 to 25 (Wrobel et al., 2013).

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Table 2. *The influence of liming and nitrogen rates on the mean values of common mugwort yield and yield components in 2009 – 2012*

Variable	Number of stems plant^{-1}	Stem height (cm)	Fresh mass (t ha^{-1})	Dry mass (t ha^{-1})
Cultivation year (Y)	Means			
2009	8.42	88.71	6.93	4.10
2010	15.46	82.47	5.72	3.29
2011	17.68	90.73	6.12	3.08
2012	14.94	75.40	6.97	3.58
LSD (for Y)$_{05/01}$	*1.26/1.68*	*3.72/4.94*	*0.62/0.82*	*0.38/0.50*
Liming rate (L)	Means			
Not limed	13.23	84.50	6.42	3.71
0.5 rate	14.19	84.41	6.24	3.33
1.0 rate	14.96	84.08	6.65	3.50
Nitrogen rate (N)	Means			
0 kg ha^{-1}	13.69	74.74	5.08	2.84
60 kg ha^{-1}	13.05	84.89	6.10	3.37
120 kg ha^{-1}	15.64	93.35	8.12	4.33
LSD (for L and N)$_{05/01}$	*1.03/1.37*	*3.04/4.03*	*0.50/0.67*	*0.31/0.41*

Likewise, stems were short in the 1st harvest year – 123 cm, on average. The next two years, the average stem height significantly increased and varied from 175 to 179 cm. The cultivation of cup plants under different soil pH (differing in liming level) had no impact on stem height. The application of N fertilizers had a slight, but at the same time insignificant effect on stem height.

Cup plant biomass productivity (FM and DM yield) was low in the first harvest year – 19.17 and 6.74 t ha^{-1}, respectively (*Table 3*). However, it substantially increased in the next two harvest years and reached the highest productivity in the third year of growing – 45.20 of FM yield and 13.48 t ha^{-1} of DM yield, on average. These results agree with other authors' observations that the cup plant yield in the first years is usually low; however it increases substantially in the following years (Filatov et al., 1986). However, based on the data of different authors, cup plant productivity is highly varied depending on agroclimatic conditions as well as cultivation technology (Kowalski, 2004, 2007; Voigt et al., 2013; Gangsberger et al., 2015).

The correlation-regression analysis revealed that both the number of stems per plant and stem height strongly correlated with common mugwort FM and DM yield.

However, there was no strong correlation between cup plant biomass yield (both FM and DM) and both number of stems and stem height. Therefore, it can be assumed that with increasing cup plant biomass yield, the mass of individual stems also tends to increase.

For the first two growing years, the number of stems and stem height of Virginia mallow were insignificant was similar. However, biomass productivity was significantly different. In the 2nd year of growing, the above-ground biomass reached its highest peak – 15.21 t ha^{-1} of FM and 6.24 t ha^{-1} of DM (*Table 4*). This suggests that in 2011, individual stems of Virginia mallow were thicker and heavier than in 2010. The highest number of stems (9.33 per plant) and the highest stem height (233 cm) was in 2012. However, biomass productivity was comparable to that in 2011 season.

The application of 1.0 liming rate substantially increased the productivity parameters as well as the biomass yield. A similar effect was exerted by the highest nitrogen rate (120 kg ha^{-1}) (at 99% probability level).

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Table 3. *The influence of liming and nitrogen rates on the mean values of cup plant yield and yield components in 2009 – 2012*

Variable	Number of stems plant^{-1}	Stem height (cm)	Fresh mass (t ha^{-1})	Dry mass (t ha^{-1})
Cultivation year (Y)	Means			
2009	11.35	123	19.17	6.74
2010	20.76	175	41.26	13.14
2011	12.18	179	45.20	13.48
2012	15.79	186	40.56	11.42
LSD (for Y)$_{05/01}$	*0.60/0.80*	*3.72/4.94*	*2.81/3.73*	*1.24/1.64*
Liming rate (L)	Means			
Not limed	14.51	165	31.19	11.21
0.5 rate	15.16	167	33.99	12.16
1.0 rate	15.38	156	36.97	13.76
Nitrogen rate (N)	Means			
0 kg ha^{-1}	11.35	163	30.15	10.99
60 kg ha^{-1}	15.60	167	34.05	12.47
120 kg ha^{-1}	15.99	167	37.94	13.67
LSD (for L and N)$_{05/01}$	*0.49/0.65*	*3.04/4.03*	*2.29/3.05*	*1.01/1.34*

Table 4. *The influence of liming and nitrogen rates on the mean values of Virginia mallow yield and yield components in 2010 – 2012*

Variable	Number of stems plant^{-1}	Stem height (cm)	Fresh mass (t ha^{-1})	Dry mass (t ha^{-1})
Cultivation year (Y)	Means			
2010	6.24	195	8.06	4.68
2011	6.41	192	15.21	6.24
2012	9.33	223	14.80	6.00
Liming rate (L)	Means			
Not limed	6.11	194	10.34	4.51
0.5 rate	7.01	207	12.74	5.75
1.0 rate	8.86	209	14.98	6.65
Nitrogen rate (N)	Means			
0 kg ha^{-1}	5.56	198	8.67	3.84
60 kg ha^{-1}	7.12	200	12.49	5.48
120 kg ha^{-1}	9.29	213	16.90	7.60
LSD (for Y, L and N)$_{05/01}$	*0.65/0.86*	*6.74/8.98*	*0.93/1.24*	*4.44/5.91*

The data of other researchers suggest that the productivity of Virginia mallow is not high in the 1st year of growing. It is substantially increasing in the subsequent growing years. Some authors have noted that the average annual yield per 4 years' cycle is not high – 6.85 t ha^{-1} (Borkowska et al., 2001). Other researches state that by growing mallow from seeds, the annual DM yield varies from 9 to 17 t ha^{-1}; meanwhile when mallow is planted by root cuttings, DM yield reaches up to 20 t ha^{-1} (Borkowska, 2007; Borkowska and Molas, 2012).

Lime use efficiency (LUE) and nitrogen use efficiency (NUE)

As it was mentioned, the liming was performed in 2008; thus, the highest soil pH rates were measured in the second half of 2010 (these data are not presented in the article). Herewith, for both crops - cup plant and Virginia mallow, the highest LUE

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values were obtained in 2010 season – 1103 and 620 kg t^{-1}, respectively (*Table 5*). In subsequent years, the effect of liming substantially decreased. For both crops, the liming rate had a significant and positive effect on LUE (at 99% probability level). As well, nitrogen rate significantly increased LUE values at 95% (for cup plant) and 99% (for Virginia mallow) probability level. Here we did not include LUE values of mugwort, since the species is not susceptible to the impact of liming.

Table 5. *LUE and NUE mean values of common mugwort, cup plant (in 2009-2012) and Virginia mallow (in 2010 – 2012)*

Variable	LUE (kg t^{-1})		NUE (kg kg^{-1})		
	Cup plant	Virginia mallow	Common mugwort	Cup plant	Virginia mallow
Cultivation year	Means				
2009	208	-	30.71	30.40	-
2010	1103	620	10.50	59.69	33.42
2011	480	251	11.14	53.07	46.17
2012	159	281	15.18	23.55	25.07
$LSD_{05/01}$	*301/402*	*160/215*	*3.40/4.53*	*12.82/17.12*	*3.74/5.03*
Liming rate	Means				
Not limed	-	-	21.48	44.14	21.48
0.5 rate	353	356	14.77	45.58	14.77
1.0 rate	622	412	14.41	35.31	14.41
$LSD_{05/01}$	*174/232*	*113/152*	*2.77/3.70*	*10.47/13.98*	*3.74/5.03*
Nitrogen rate	Means				
0 kg ha^{-1}	321	-48	-	-	-
60 kg ha^{-1}	459	251	17.03	42.02	17.03
120 kg ha^{-1}	683	949	16.75	41.33	16.75
$LSD_{05/01}$	*246/328*	*160/215*	*1.96/2.62*	*7.40/9.88*	*2.65/3.55*

Liming (or increasing soil pH) increases calcium (Ca) availability in plant rooting zone (rhizosphere), which, in turn, enhances the ability of plants to accumulate higher amounts of individual nutrients (including nitrogen (N)) and benefit high above ground biomass yields (Bailey, 1995; Hallbacken and Zhang, 1998, Karcauskiene and Repsiene, 2009).

The highest nitrogen use efficiency (NUE) values were obtained in the 1st (for common mugwort) and 2nd years of growing (for cup plant and virginia mallow) (*Table 4*). In the subsequent years, the efficiency of N fertilizers declined substantially. Out of the three species, depending on the growing season, the highest was cup plant nitrogen use efficiency which varied from 23.55 (in 2012) to 59.69 kg kg^{-1} (in 2010).

It is interesting to note that the highest nitrogen use efficiency was determined in the control treatments (without liming). Although it has been proven that common mugwort could grow well under a wide range of pH levels and liming has a negligible effect on species DM productivity, the use of nitrogen fertilizers was substantially higher (at 99% probability level) when cultivating in non-limed treatments (where soil pH was 4.2-4.4). A similar effect was noted for Virginia mallow. We presume that the application of nitrogen could to some extent reduce the negative effect of high soil acidity.

The application of two different nitrogen rates (60 and 120 kg ha^{-1}) had a similar effect on nitrogen efficiency. Thus, the application of the highest nitrogen rate (120 kg ha^{-1}) in two applications (60+60 kg ha^{-1}) was optimal for all three crops.

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These experiments produced some valuable material concerning agronomic traits and energy characteristics of the tested crops. Cup plant has already received a substantial interest as an energy crop in many countries. Our experimental results concerning high biomass yield are in agreement with the data of other authors (Kowalski, 2004; 2007). However, the expansion of cup plant is restricted by some factors. So far, another coarse stemmed crop - maize (*Zea mays* L.) has been much more frequently used for biogas production than cup plant. Besides, in the first year of growing, cup plant lacks harvestable biomass. Altogether, it is necessary to elaborate weed control technology in the first year of growing (Gangsberger et al., 2015).

Our experimental data corroborated what has also been established by other authors that Virginia mallow biomass could potentially be used for liquid and solid fuel production. As well, it is necessary to elaborate and improve agro-technical methods, since Virginia mallow has never been cultivated in large-area plantations (Borkowska, and Molas, 2012).

Concerning the common mugwort, the sparse experimental data indicate that mugwort biomass has good quality parameters and is suitable for solid biofuel production (Kryževičienė et al., 2010; Jasinskas et al., 2014). As it has already been mentioned, the species has a high tolerance of different soil conditions; however, in our trials mugwort biomass productivity and biomass potential were found to be low.

Currently, the investigation on these species is being continued with a primary focus on the energy parameters of biomass and its suitability for a specific biofuel type.

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