POSSIBILITIES OF USING FODDER GALEGA IN THE ENERGY SECTOR AND AGRICULTURE

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(Received 22nd Nov 2018; accepted 25th Jan 2019)

Abstract. This paper presents changes in basic energy parameters of fodder galega (*Galega orientalis* Lam.) cultivated for five years as a potential energy crop under the effect of mineral fertilization. Additionally, the chemical composition of ash obtained after burning the fodder galega biomass was examined for its possible use as a liming agent. The field experiment was conducted between 2005 and 2009 in the experimental plots of the Soil Science and Plant Nutrition Department at the Siedlce University of Natural Sciences and Humanities, Poland (52º17´N and 22º28´E). Five levels of fertilization were included in the study: without fertilization, NP, NK, PK, NPKCa (0 – control, N–20, P–50, K–150, Ca–150 kg·ha^{-1}). Significantly highest values of heat of combustion (18.95 MJ·kg^{-1}) and calorific value were found for galega fertilized with nitrogen (20 kg·ha^{-1}) and potassium (150 kg·ha^{-1}). The highest dry matter yields and the highest yield energy value, as well as the most amount of ash obtained from biomass combusting were found for galega harvested from objects fertilized with NPKCa (20; 50; 150; 150 kg·ha^{-1}). The content of macroelements in galega ash followed a decreasing sequence of: Ca > K > P >Mg > S > Na.
Keywords: *Galega orientalis Lam., heat of combustion, calorific value, ash, macroelements*

Introduction

In recent years, a great interest in new species of energy crops has been observed all over Europe (An et al., 2018; Drazic et al., 2017; Haines et al., 2015; Jureková et al., 2015; Kalembasa and Symanowicz, 2003; Maw et al., 2017; Tumminello et al., 2018; Wang et al., 2018).

According to the EU Climate and Energy Package of 17.12.2008, by 2020, Member States should reach the level where 20-30% of all energy obtained is from renewable energy sources (Zegada-Lizarazu et al., 2010). The research conducted in central-eastern Poland, concerning adaptation of fodder galega (*Galega orientalis* Lam.), a plant originating from the Caucasus, demonstrated the multi-directionality of its cultivation. It can be cultivated for animal fodder in the form of green forage, silage, dried feed, hay or protein concentrate. This is a perennial, leguminous plant (cultivation for even 16-18 years), rich in macro- and microelements. Biomass of the species can also be co-fired with coal (Brodowska et al., 2018).

The research conducted in the Podlasie region (Kalembasa and Symanowicz, 2003), with the application of ^{15}N isotope, proved the high possibilities demonstrated by fodder galega to biologically reduce atmospheric nitrogen (380 kg·ha^{-1}). Preliminary research

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1702_26772687

also showed the possibilities of cultivating fodder galega as an energy crop. Therefore, the introduction of an additional plant, apart from *Miscanthus sacchariflorus, Miscanthus x giganteus* (Jeżowski et al., 2011; Maksimović et al., 2016); *Sweet Sorghum, Maize, HBS* (Maw et al., 2017); *Sorghum hybrids* (Pannacii and Bartolini, 2016); *Salix spp*., (Stolarski, 2008) and *Sida hermaphrodita* (Krzyżaniak et al., 2015) is recommended and related to the possibility of increasing biomass production, with a view to binding atmospheric N_2. An additional benefit is the possibility of using ash from biomass combustion as a liming agent in agriculture. To evaluate the usefulness of biomass for energy purposes, the following values must be examined: moisture, ash content, sulphur content, heat of combustion and calorific value coal (Brodowska et al., 2018). The calorific value of biofuels is 5-8 $MJ \cdot kg^{-1}$ for biomass of 50-60% moisture content, 15-17 $MJ \cdot kg^{-1}$ for pre-dried biomass (15-20% moisture content) and about 20 $MJ \cdot kg^{-1}$ for completely dried biomass.

The potential of biomass production is enormous and is of importance for bioenergy in the future. Eastern galega provide a relatively anknown input feedstock for conversion of biomass into biofuel especially when grown on marginal lands. Field studies carried out 10 years ago are still valid. The search for new potential energy crops, especially perennial with low crop costs, continues (Foster et al., 2017).

The aim of this paper was to determine the optimum conditions for cultivating fodder galega in terms of usefulness for energy purposes and the fertilizing value of ash obtained after biomass combustion.

Material and methods

In the years between 2005 and 2009 the field experiment was set up with a completely randomized method in three replications, on the experimental plots of the Soil Science and Plant Nutrition Department at the Siedlce University of Natural Sciences and Humanities, Poland - 52°17′N, 22°28′E (*Figure 1*).

Figure 1. *Location of the study area [https://contour maps.com.pl] in the own modification*

Five levels of fertilization were included in the study: without fertilization, NP, NK, PK, NPKCa. The field experiment was conducted on loamy sand soil containing 31.5 $g \cdot kg^{-1}$ of carbon compounds, 1.66 $g \cdot kg^{-1}$ of total nitrogen, and pH in KCl $mol \cdot dm^{-3}$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1702_26772687

– 6.6. The content of available forms of phosphorus and potassium in soil determined with the Egner-Riehm's method was high (80 mg·kg^{-1} P and 140 mg·kg^{-1} K) and the content of magnesium determined with the Schachtschabel's method was average (50 mg·kg^{-1} Mg). According to the IUSS World Reference of Soil resources (2014), the soil on which the field experiment was carried out was classified as *Hortic Anthrosol*. The fodder galega seeds was sown in the amount of 24 kg·ha^{-1} (300-500 plants per 1 m^2). The germination was 45-60% and the 2.4 grams was TGW. Mechanically scarified seeds were sown into soil inoculated with *Rhizobium galegae* bacteria. In the subsequent years, the following fertilization scheme was implemented: N – 20 kg·ha^{-1} as 34% ammomium nitrate applied in early spring; P – 50 kg·ha^{-1} as triple superphosphate applied in autumn; K – 150 kg·ha^{-1} as 60% potassium salt at two doses: dose I (100 kg·ha^{-1} K) applied in early spring, dose II (50 kg·ha^{-1} K) applied after the first swath; Ca – 150 kg·ha^{-1} as dolomite calcium applied in autumn. During vegetation, agricultural procedures such as weeding were performed. The three swaths of fodder galega were harvested at budding in each,subsequent crop year (*Figure 2*).

Figure 2. *Fodder galega (Galega orientalis Lam.) – budding phase*

In the samples marked plant analytical moisture, ash and combustion heat in accordance with Polish Norm PN-81/G-04513. The calorific value (according to Szyszlak-Bargłowicz and Piekarski, 2009) and energy value were calculated.

$$H_c = \frac{h_{cc}(t_h - t_l) - h_{rw} \cdot w_{rw}}{m_p} \quad \text{(Eq.1)}$$

H_c – heat of combustion value (MJ·kg^{-1});
h_{cc} – heat capacity of the calorimeter;
t_h – highest temperature of the main measurement period;
t_l – lowest temperature of the main measurement period;
h_{rw} – heat of burning the resistance wire;
w_{rw} – weight of the resistance wire;
m_p – mass of the plant sample.

$$C_v = H_c - h_{vw} \cdot (m_a + f_{h/w} \cdot h_c) \quad \text{(Eq.2)}$$

C_v – caloric value ($MJ \cdot kg^{-1}$);
H_{vw} – heat of vaporization of water at 25°C;
m_a – analytical moisture;
$f_{h/w}$ – conversion factor of hydrogen to water (8.94);
h_c – hydrogen content in the analytical sample.

$$E_v = Y_b \cdot C_v \quad \text{(Eq.3)}$$

E_v – energy value ($MJ \cdot ha^{-1}$);
Y_b – yield of biomass;
C_v – caloric value.

The content of total macronutrients was determined with the ICP-AES method (Spectrometer Optima 3200RL, Perkin Elmer, Waltham, USA) in plant material after drying, comminution and dry mineralization (550°C).

The results obtained were subjected to statistical analysis using the analysis of variance ANOVA (Statistica 12 PL, Statsoft, Inc., 2018). The least significant difference (LSD) determined by the Tukey's test. The criterion for significance was set at $P \leq 0.05$. The linear regression equations and correlation coefficients between selected features were determined (Statistica 12 PL, Statsoft Inc., 2018).

The atmospheric conditions in the year 2005-2009 exerted a large impact on the content of total NPKCa in the sub-surface horizon (Ap) of the soil profile and on its uptake by the test plant (*Table 1*). Excessively high temperatures limited the uptake of macroelements whereas a large volume of precipitation caused extensive washing-out of these elements deep into the soil profile.

Table 1. *Meteorological conditions during the studies in 2005-2009 years. Reported by the measurement centre in Siedlce*

Years	**Months**												**Mean/ Sum**
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
Means monthly air temperature (°C)													
2005	0.3	-4.0	-0.7	8.6	13.0	15.9	20.2	17.5	15.0	8.5	2.7	-0.9	8.0
2006	-7.7	-2.4	1.1	8.4	13.6	17.2	22.3	18.0	15.4	9.9	5.0	3.2	8.7
2007	-4.5	-0.7	5.8	8.3	14.5	18.2	18.5	18.6	13.1	9.3	5.1	1.2	8.6
2008	0.6	-0.7	4.6	9.1	12.7	17.4	18.4	18.5	12.2	8.5	3.4	0.1	8.7
2009	-4.5	-2.5	3.5	10.0	12.8	15.8	19.3	17.3	14.3	6.5	4.7	3.7	8.4
Multiyear average 1987-2000	-9.8	-9.9	3.8	7.8	12.5	17.2	19.2	18.5	13.1	7.2	3.6	-2.8	6.7
Total monthly rainfalls (mm)													
2005	13.2	13.2	11.7	12.3	64.7	44.4	86.5	45.4	15.8	0.0	13.8	32.9	353.9
2006	39.0	30.0	34.0	29.8	39.6	24.0	16.2	227.6	22.0	15.1	10.5	20.8	862.5
2007	28.6	34.1	29.6	21.2	59.1	59.9	70.2	31.1	67.6	12.8	7.5	15.4	437.1
2008	51.4	0.7	53.1	28.2	85.6	49.0	69.8	75.4	63.4	18.6	5.3	30.4	530.9
2009	10.9	29.0	33.5	1.8	19.9	54.5	18.8	31.9	4.5	17.5	12.2	16.5	251.0
Multiyear average 1987-2000	45.7	32.4	29.5	38.6	44.1	52.4	49.8	43.0	47.3	36.1	27.9	41.3	488.1

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 17(2):2677-2687.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1702_26772687

Results and discussion

Changes in the basic energy parameters of fodder galega (a potential energy crop) are presented in *Table 2*. The determined analytical moisture of fodder galega harvested from fertilized objects ranged from 6.33 to 6.49%. Fertilization applied and years of research did not significantly differentiate this parameter.

Mineral fertilization and years of research significantly differentiated ash content in the fodder galega biomass. The significantly highest amount of ash in biomass was found for the galega harvested from the control object (without fertilization) as compared to the fertilized objects under analysis. The significantly highest ash content was found for the biomass of fodder galega harvested in the fourth year of the research. The energy value of 1 kg of dry matter of entire fodder galega plants, obtained according to PN-81/G-04513, designed to determine heat of combustion in the analytical state, ranged from 16.88 to 18.95 $MJ \cdot kg^{-1}$. The significantly highest values of heat of combustion were determined for fodder galega fertilized with nitrogen (20 $kg \cdot ha^{-1}$) and potassium (150 $kg \cdot ha^{-1}$). Similar values of heat of combustion (17.8-18.2 $MJ \cdot kg^{-1}$) were determined in studies on *Miscanthus* fertilized with sludge in the doses of 0, 10, 20, 40, 60 $Mg \cdot ha^{-1}$ dry matter (Kołodziej et al., 2016). In studies on sorghum hybrids fertilized 75 kg N and 75-80 kg K_2O the average values of HHV elevate 17.7-18.4 $MJ \cdot kg^{-1}$d.m. (Pannacci and Bartolini, 2016). According to Pilon and Lavoie (2013) switchgrass calorific value was on the level 18.0-19.5 $MJ \cdot kg^{-1}$. The amount of energy (higher and lower heating value) as well as the thermophysical and chemical composition of biomass (carbon, sulphur, hydrogen, nitrogen as well as ash and moisture content) are very important characteristics of biomass used for energy purpose and production of biomaterials. For example, ash formed in the process of biomass combustion (responsible for particulate emission and corrosion), affect the operation of boilers, installation safety and its later use or utilization. The composition of feedstock also influences the quality of bio-products obtained by thermochemical conversions (Wilson et al., 2013).

Table 2. *Energy parameters of the fodder galega (Galega orientalis Lam.)*

Treatment	Analytical moisture (%)	Ash (%)	Heat of combustion value ($MJ \cdot kg^{-1}$)	Calorific value ($MJ \cdot kg^{-1}$)	Yield of dry weight of biomass ($Mg \cdot ha^{-1}$)	Energy yields value ($MJ \cdot ha^{-1}$)
0[1]	6.33	5.82[b]	18.03[b]	17.88[b]	7.81[a]	139.64[a]
NP	6.47	4.57[a]	18.15[b]	17.99[b]	12.78[b]	229.91[b]
NK	6.36	4.40[a]	18.95[c]	18.79[c]	14.10[b]	264.94[c]
PK	6.49	4.94[a]	16.88[a]	16.72[a]	13.56[b]	226.72[b]
NPKCa	6.40	4.92[a]	18.80[c]	18.63[c]	16.25[c]	302.74[d]
P	ns	*	*	*	*	*
2005[2]	6.03	5.06[a]	18.13[b]	17.98[b]	7.19[a]	129.28[a]
2006	6.24	4.89[a]	18.26[b]	18.11[b]	12.22[c]	221.30[c]
2007	6.28	4.63[a]	17.56[a]	17.40[a]	11.40[b]	198.36[b]
2008	6.43	5.36[b]	18.62[b]	18.46[b]	16.92[d]	312.34[d]
2009	6.39	4.91[a]	18.93[b]	18.77[b]	16.78[d]	314.96[d]
P	ns		*	*	*	*
Fertilization/Years of research	ns	*	*	*	*	*

[1]0 – control, N–20, P–50, K–150, Ca–150 $kg \cdot ha^{-1}$; [2]1, 2, 3, 4, 5 – years of research; *significant at the $P \leq 0.05$; ns – non significant; values with the same letters are not different at the significance level of $P \leq 0.05$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1702_26772687

It should be assumed that for cultivation of leguminous plants intended for energy purposes, harvested in the budding phase, intensive fertilization with nitrogen and phosphorus is not necessary. Leguminous plants are able to biologically reduce atmospheric N_2 as a result of their symbiosis with bacteria of the *Rhizobium* genus. The highest values of combustion heat were obtained for fodder galega cultivated in the fifth year of research. The calorific value presented in *Table 2*, calculated on the basis of formulas (Szyszlak-Bargłowicz and Piekarski, 2009), was about 0.89% smaller than the heat of combustion determined. To obtain maximum total dry matter yield (3 crops during the vegetation period) of fodder galega (16.25 $Mg \cdot ha^{-1}$), it is necessary to supply soil with NPKCa. In the studies with *Miscanthus*, lower dry matter yields were obtained in the first year of research (Kohle et al., 2001; Jeżowski, 2008). The average dry weight of biomass sorghum was on the level 13.5-21.7 $t \cdot ha^{-1}$ after 141 days after emergence and 22.0-27.3 $t \cdot ha^{-1}$ after 127 days after emergence (Pannacci and Bartolini, 2016). In our own research conducted, the optimum balanced dose of mineral fertilizers was as follows: N-20, P-50, K-150, Ca-150 $kg \cdot ha^{-1}$. In subsequent years of cultivation, the dry matter yield of fodder galega significantly increased. It was related to a strongly developed root system, an increased process of biological reduction of molecular nitrogen due to soil infection with *Rhizobium galegae* bacteria and supplying basic nutrients to soil. Comparing the yield of fodder galega with its energy value in subsequent years demonstrates that the dry matter yield contained significant amounts of energy. The amount of energy obtained from 1 ha was directly proportional to the volume of the yield obtained. Total amount of energy obtained after five years of the experiment amounted to 1176.24 ($MJ \cdot ha^{-1}$). The energy value of the yield obtained under the effect of fertilization with NPKCa was over twice as high as the values obtained for the yield of fodder galega obtained in objects without fertilization. The energy value of the fodder galega yield under the effect of fertilization with NPKCa was 33% higher than the value obtained for *Miscanthus* fertilized with 20 $Mg \cdot ha^{-1}$ of dry matter sludge (Kołodziej et al., 2016). Based on the research conducted, significant relations were found between the calorific value (C_v) and heat of combustion (H_c) and between energy value (E_v) and dry matter yield of fodder galega (Y_b) for the fertilization applied (*Figure 3a and 3b*).

A statistical analysis also demonstrated a significant relation between dry matter yield (Y_b) of fodder galega and analytical moisture (M_a) for the years of research. The mean energy value (E_v) calculated for individual years of research was also correlated with analytical moisture (M_a). A positive correlation between heat of combustion (H_c) and calorific value (C_v) was demonstrated for the years of research and energy value (E_v) and dry matter yield of fodder galega (Y_b)obtained in subsequent years of research. The obtained results of our own research were at a similar level in comparison to the previous research carried out in the soil abundant in available nutrients (Kalembasa and Symanowicz, 2003).

The average content of macroelements in ash obtained after combusting fodder galega biomass followed a sequence of decreasing values: Ca > K > P > Mg > S >Na (*Table 3*). The fertilization applied and years of research significantly differentiated the content of phosphorus, potassium, calcium and sulphur in ash. Higher total amounts of macroelements were determined in ash obtained from fodder galega fertilized with NK and NPKCa and in the fourth year of research.

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DOI: http://dx.doi.org/10.15666/aeer/1702_26772687

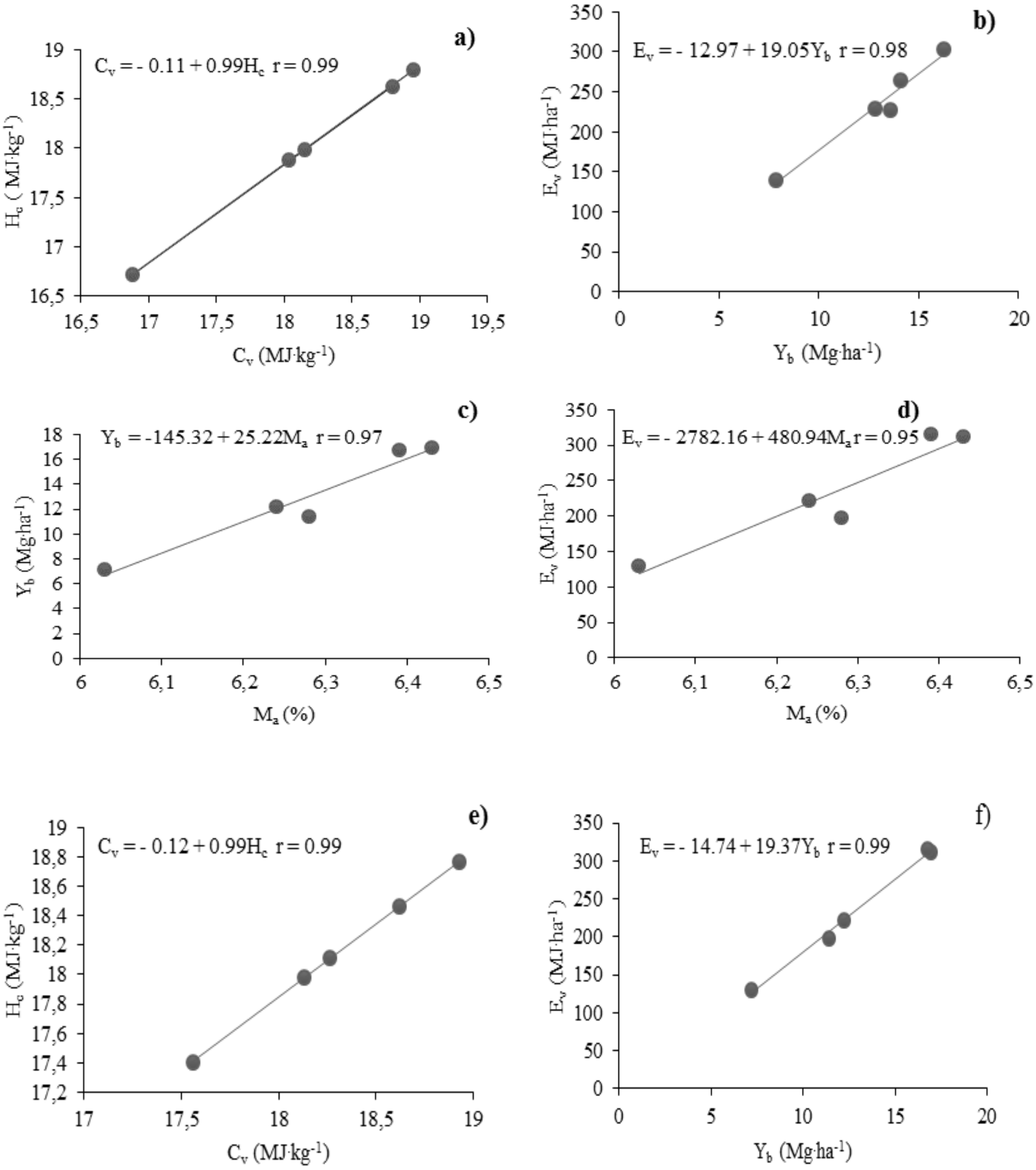

***Figure 3.** The relations between heat of combustion (H_c), calorific value C_v), energy value (E_v), dry matter yield of fodder galega (Y_b), analytical moisture (M_a) for the fertilization applied – Fig.1a,b and for the subsequent years of research – Fig. 1c,d,e,f*

The amount of ash obtained after the combustion of the total yield of fodder galega biomass, and the amount of phosphorus, potassium, calcium, magnesium and sulphur was significantly differentiated for fertilizing objects and years of research (*Table 4*). The significantly highest amounts of the analysed parameters (ash, phosphorus, potassium, calcium, magnesium, sulphur and sodium) were obtained for fodder galega fertilized with NPKCa. Similar values of ash were obtained in the research with sugar miscanthus, while the content of macroelements determined in ash obtained after combusting sugar miscanthus was at a low level (Borkowska and Lipiński, 2007). In examining subsequent years of research, the highest percentage share of calcium, potassium, phosphorus and magnesium was found in the fourth year of research, and the highest share of sulphur and sodium was found in the fifth year.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1702_26772687

Table 3. *The chemical composition of ash obtained from fodder galega (g·kg^{-1})*

Treatment	P	K	Ca	Mg	S	Na
0[1]	2.98[b]	13.47[b]	14.04[a]	2.56	2.36[b]	0.47
NP	2.60[a]	11.38[a]	17.89[c]	2.74	1.76[a]	0.41
NK	2.49[a]	13.06[b]	18.25[c]	2.56	1.53[a]	0.48
PK	2.41[a]	15.63[c]	16.60[b]	2.35	1.48[a]	0.48
NPKCa	2.79[a]	15.99[c]	17.78[c]	2.30	1.55[a]	0.43
P	*	*	*	ns	*	ns
2005[2]	2.64	17.09[d]	16.33[a]	2.42	2.08[b]	0.39
2006	2.53	12.22[b]	16.34[a]	2.15	1.49[a]	0.48
2007	2.73	13.97[b]	15.91[a]	2.57	1.55[a]	0.61
2008	2.96	15.40[c]	18.13[b]	2.96	1.73[a]	0.48
2009	2.41	10.85[a]	17.86[b]	2.41	1.83[a]	0.51
P	ns	*	*	ns	*	ns
Fertilization/Years of research	ns	*	*	ns	*	ns

[1]0 – control, N–20, P–50, K–150, Ca–150 kg·ha^{-1}; [2]1, 2, 3, 4, 5 – years of research; *significant at the $P \leq 0.05$; ns – non significant; values with the same letters are not different at the significance level of $P \leq 0.05$

Table 4. *The amount of ash and macronutrients obtained after burning the total biomass yield of the fodder galega per hectare (in kg)*

Treatment	Ash from biomass	P	K	Ca	Mg	S	Na
0[1]	454.5[a]	23.27[a]	105.2[a]	109.6[a]	20.00[a]	18.43[a]	3.67
NP	584.0[b]	33.23[b]	145.4[b]	228.6[b]	35.02[b]	22.49[b]	5.24
NK	620.4[c]	35.11[b]	184.1[c]	257.3[c]	36.10[b]	21.57[b]	6.77
PK	669.9[d]	32.68[b]	211.9[d]	225.1[b]	31.87[b]	20.07[b]	6.51
NPKCa	799.5[e]	45.34[c]	259.8[e]	288.9[d]	37.37[b]	25.19[b]	6.99
P	*	*	*	*	*	*	ns
2005[2]	363.8[a]	18.98[a]	122.9[a]	117.4[a]	17.40[a]	14.95[a]	1.37[a]
2006	597.5[c]	30.92[b]	149.3[b]	199.7[c]	26.27[b]	18.21[b]	5.86[b]
2007	527.8[b]	31.12[b]	159.2[c]	177.9[b]	29.30[b]	17.67[b]	6.95[b]
2008	906.9[e]	50.08[d]	260.6[e]	306.7[e]	50.08[d]	29.27[c]	8.12[b]
2009	823.9[d]	40.44[c]	182.1[d]	299.7[d]	40.44[c]	30.71[c]	8.56[b]
P	*	*	*	*	*	*	*
Fertilization/Years of research	*	*	*	*	*	*	ns

[1]0 – control, N–20, P–50, K–150, Ca–150 kg·ha^{-1}; [2]1, 2, 3, 4, 5 – years of research; *significant at the $P \leq 0.05$; ns – non significant; values with the same letters are not different at the significance level of $P \leq 0.05$

The results obtained were lower than those obtained in the research with other energy crops - miscanthus sinensis, virginia mallow, basket willow (Stolarski, 2008; Stypczyńska et al., 2017). The harvesting date of energy crops significantly affects the content of macroelements (in particular, of potassium) in biomass and ash. The diversified content of macroelements in energy crops is shown in studies, in which 5 times less sulphur was determined in the biomass of basket willows in comparison to our own research. The ash obtained from the combustion of fodder galega biomass, containing large amounts of alkaline elements, can be used for deacidification of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1702_26772687

medium and heavy soils (Regulation Commission UE, 2013). The possibility of using ashes to increase soil alkalinity, to improve the properties of heavy soils and to increase the content of macroelement in soils was indicated in the research by other authors (Kowalczyk, 2017; Stypczyńska et al., 2017; Symanowicz et al., 2018).

Conclusions

A strong interest in alternative energy sources indicates the possibility of using fodder galega biomass as a source of renewable energy which does not produce such high SO_2 and NO_x emissions, as is the case while combusting hard coal.

The calculated calorific value of 1 kg of fodder galega dry matter, ranging from 16.72 to 18.79 MJ, is comparable to the data concerning of sweet sorghum, switch grass, *Miscanthus*, straw, bark and lignite.

Additionally, the waste by-product created in the process (ash) can be used for agricultural purposes as a liming agent of balanced chemical composition.

The highest dry matter yields and the highest yield energy value, as well as the most amount of ash obtained from biomass combusting were found for galega harvested from objects fertilized with NPKCa (20; 50; 150; 150 $kg \cdot ha^{-1}$).

Acknowledgements. The results of the research carried out under the research theme No 315/12/S were financed from the science grant granted by the Ministry of Science and Higher Education.

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