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***Artemisia dubia* growth, yield and biomass characteristics for combustion**

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Abstract

In recent years, there has been increasing interest in the use of agricultural biomass for energy purpose in many northern countries. This has created demand for novel, high biomass yielding, specific quality crops for sustainable use. The aim of the current study was to examine *Artemisia dubia* Wall. for biomass yield and biomass characteristics important for combustion in the temperate climate conditions. The crops were grown on an *Endocalcaris-Epithypogleyic Cambisol (CMg-p-w-can)* without fertilization and with mineral nitrogen fertilization at 90 and 170 kg ha⁻¹ N rates. Nitrogen fertilization slightly increased plant height and accumulation of biomass. Moisture content in the biomass of swards applied with a higher rate of mineral N decreased more slowly compared with the lower rate. Biomass annual yield in the second and third years ranged from 15.8 to 17.1 t ha⁻¹; however, significant effect of nitrogen fertilization was not observed. Nitrogen fertilization had a significant influence on N content and lignin in the biomass. The variation of values of the elements relevant for combustion (carbon and sulphur) in the biomass was negligibly influenced by nitrogen fertilization. The relatively low ash content and heating value, amounting to 8.5 MJ kg⁻¹ achieved even without nitrogen fertilization, makes *A. dubia* a promising energy crop in the northern part of the temperate climate zone. More studies and analyses on *A. dubia* are needed to ascertain the fertilization effect on biomass yield, biomass quality and biomass properties for combustion in senescent plants.

Key words: ash, energy crops, fibre components, heating value, nitrogen fertilization.

Introduction

The development of bio-based economy is increasingly focusing on biomass supply and conversion to energy. On a global scale, there has been observed a significant increase in the demand of biomass supply in conversion chain (Scarlat et al., 2015). The composition of biomass as feedstock for combustion needs to be harmonized with technological processes, considering the whole chain sustainability (Yılmaz, Selim, 2013; Seay, Badurdeen, 2014).

The use of biomass and conversion to energy should be cost-effective, reliable and contribute to the mutual benefit of the biomass supplier and processor. Combustion is prevalent conversion pathway for the lignocellulosic biomass (Prochnow et al., 2009; Tonn et al., 2010) and for energy; however, biomass has some limitation (Williams et al., 2012). High biomass productivity and suitable quality are needed for any energy purpose (Searle, Malins, 2014) and there always exist requirements for sustainably produced biomass (Robbins et al., 2012). Different species of energy crops

(Laurent et al., 2015) or low input high diversity biomass (Van Meerbeek et al., 2015; Corton et al., 2016) or wild plant mixtures (Von Cossel, Lewandowski, 2016) have been identified as biomass feedstocks for bioenergy. Naturally, the choice of plant species varies depending on the conversion pathway. Reed canary grass is usually referred to as a potential crop for combustion (Jasinskas et al., 2008; Heinsoo et al., 2011; Lord, 2015), while for other energy purposes more traditional grasses have been identified (Tilvikiene et al., 2016). Perennial grasses show considerable potential for bioenergy production; however, these crops can vary in regional adaptability and yield in different environments and year to year, and optimizing the nutrient efficiency and the potential for suitable conversion to energy are important components in bioenergy pathway (Palmer et al., 2014). Some energy crops are criticized (Naik et al., 2010; Pedroli et al., 2013) because their biomass production requires high-inputs of fertilizers and pesticides, and this poses a threat to the environment and food security (Tilman et al.,

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2009; Dauber et al., 2010). On the other hand integration of bioenergy systems into the agricultural landscape can contribute positively to increased N recirculation and to mitigation of environmental impacts associated with N losses, while at the same time providing renewable energy for society (Skenhall et al., 2013). The acceptable solution, often discussed by researchers would be to use non-food plant biomass for energy and to avoid competition for land (Robbins et al., 2012; Tanger et al., 2013).

Not only high yield but also appropriate composition of biomass of energy crops is important in the conversion processes. Biomass qualitative composition varies depending on plant species and even variety, specific growing conditions that can lead to an increase or depletion of different elements in certain growth stages (Vassilev et al., 2015). Many types of agricultural biomass contain undesirable chemical elements such as S, Cl, Si, P, K and Na. As a result, appropriate combustion-related biomass properties should be a deciding factor when choosing species for combustion (Fournel et al., 2015). Crop species, harvest timing and nitrogen rate most frequently affected the measured parameters and indicators of combustion (Kludze et al., 2013).

Most herbaceous plants positively respond to nitrogen fertilization (King et al., 2012; Muylle et al., 2015; Pocienė, Kadžiulienė, 2016; Tilvikiene et al., 2016). Lesser reliance on N fertilizer for plant biomass accumulation is an important agronomic and economic advantage. While analysing non-traditional energy crops, attention was drawn to *Artemisia dubia*, which distinguished itself among other energy crops by a rapid growth rate and high biomass productivity. In Nordic countries, this species has been little studied; and generally there is very little published data on *A. dubia* as an energy crop. Because little is known about the plant growth, development, biomass production and composition, the aim of the study was to investigate *A. dubia* growth, evaluate the productivity and chemical composition as influenced by management in the northern part of the temperate climate zone.

Material and methods

Experimentalsiteanddesign. Fieldandlaboratory experiments were carried out in Central Lithuania (55°23'50" N, 23°51'40" E) at Institute of Agriculture, Lithuanian Research Centre for Agriculture, *Artemisia dubia* Wall. was grown on an *Endocalcari-Epihyopogleyic Cambisol (CMg-p-w-can)*. Soil characteristics: pH_{KCl} 6.5, K_2O 300 mg kg⁻¹ and P_2O_5 75 mg kg⁻¹. The experiment was laid out in a randomized complete block design with four replicates. The year 2013 was *A. dubia* planting year and the first year of growing. The crop was planted by chopped roots, two roots per square meter. In the second year of growing, to ascertain the dynamics of plant height assessments were made once a month. Three treatments (not fertilized, fertilized with mineral nitrogen fertilizers 90 and 170 kg ha⁻¹ N) were tested. Nitrogen fertilizer rate 90 kg ha⁻¹ N was applied once at the beginning of vegetation. The rate 170 kg ha⁻¹ N was split-applied: 90 kg ha⁻¹ N at the beginning of vegetation and 80 kg ha⁻¹ approximately a month after the first application. The fertilizers were used in the second and third years.

Estimation of biomass yield and composition. Dry matter (DM) yield was determined from the plots

harvested at the beginning of December (after the first frosts). The study was conducted in 2013, 2014 and 2015. All of the collected biomass samples were weighed on site to measure the moisture content and dried for 12 h at 105°C in a laboratory to assess dry matter content.

For chemical analyses the samples were dried at 65 ± 5°C. Before analysing, the samples were ground by an ultra centrifugal mill ZM 200 ("Retch", Germany) using sieves of 2 mm mesh size. Prior to analyses, the samples prepared in the following way were assessed for dry matter. The content of nitrogen (N), carbon (C) and sulphur (S) was determined by dry combustion method in an oxygen atmosphere at 1145 ± 5°C temperature according to the Dumas method (König, Fortman, 1996) using a fully automatic analyser Vario EL III ("Elementar", Germany). After the samples had been wet digested with sulphuric acid, the content of phosphorus (P) was determined by a spectrophotometric procedure at the wavelength of 430 nm, and the content of potassium (K) was measured by atomo-absorciometric procedure after wet digestion with sulphuric acid. Chemical analyses were done at the Chemical Research Laboratory of the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. The content of structural carbohydrates was calculated as differences: cellulose (Cell) = ADF – ADL, and hemicellulose (HCell) = NDF – ADF (Hindrichsen et al., 2006). Heating value was measured with a bomb calorimeter C 200 (IKA, Germany) by the 25°C dynamic calorific test method and expressed as MJ kg⁻¹ DM.

Meteorological data. The weather conditions in 2013–2015 are presented in Table 1. Temperatures were consistently above multi-annual average from May through September of 2013. In 2014, temperatures from spring to autumn were also higher than average, except in June, when the temperature was 1.3°C lower than monthly average. Temperatures in early spring of 2015 were higher, while from May till August temperatures were lower and in August and September again higher than multi-annual average.

In the spring of 2013, establishment year of *A. dubia*, and at the beginning of summer precipitation was normal and in July even higher than average, but August was dry. In 2014, the rate of precipitation in spring and summer was close to the long-term average. However, August was rainy and autumn was dry. Below normal precipitation rate was in 2015, except for September. Overall, the growing seasons for biomass accumulation were changeable in terms of temperature and moisture conditions.

Statistical analysis. The obtained results were analysed using analysis of variance (ANOVA) and Fisher protected least significant difference (LSD) test ($p \leq 0.05$).

Results and discussion

Artemisia dubia growth and biomass yield.

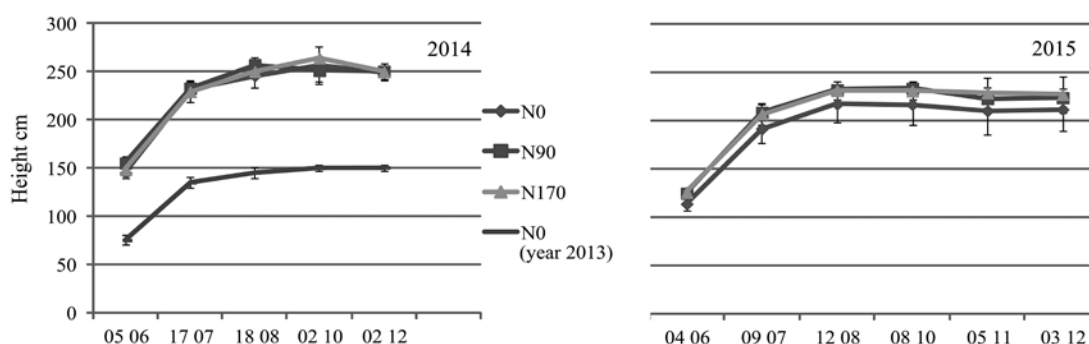
The growing season in the first growing year of *A. dubia* was favourable and plant establishment was successful. The average plant height at the end of the growing season was 149 cm. In a northern climate, the *A. dubia* lifecycle begins in May. In the second year of cultivation, in spring *A. dubia* resumed vegetation early and plant growth was rapid in the spring. The fast growth and the ability to accumulate biomass are important features of *A. dubia* distinguishing this plant from many traditional

Table 1. The average monthly air temperature and precipitation

Month	Average air temperature °C				Precipitation sum mm			
	Year							
	2013	2014	2015	multi-annual average	2013	2014	2015	multi-annual average
January	-7.0	5.7	-0.6	-4.7	35.5	36.6	72.6	31.1
February	-1.7	0.2	0.1	-4.4	42.9	27.4	4.6	25.5
March	-4.8	4.8	4.4	-0.7	8.6	31.4	48.7	28.1
April	4.8	8.9	7.0	5.9	46.2	27.1	51.5	37.0
May	16.0	13.0	11.4	12.3	49.6	76.8	50.4	52.3
June	18.6	14.4	15.1	15.7	46.4	65.8	26.3	61.9
July	18.5	20.0	17.1	17.8	104.3	69.1	57.6	75.3
August	18.0	17.6	19.7	16.8	42.4	111.2	5.6	73.4
September	12.6	13.3	14.0	12.1	77.8	21.7	66.0	51.3
October	8.5	7.1	5.2	6.8	28.9	38.9	6.7	49.1
November	4.8	2.7	4.7	1.9	46.7	31.9	71.3	45.0
December	1.8	-1.1	2.3	-2.3	36.9	52.4	41.8	37.6

grasses discussed as energy plants. At the beginning of June, the average height of plants was 145–155 cm (Fig. 1); however, the height was not affected by nitrogen treatment. Intensive plant growth continued until mid-summer, but nitrogen fertilization had no apparent impact. Plant height increased until the second half of August and was greater than at the beginning of the summer, but no significant fertilization effect was observed. In the third year of cultivation plant growth was slower. At the

beginning of June, plant height was 114–126 cm and the maximum height was reached at the beginning of August, but it was smaller than in the second year. Differences in the plant height between years were caused by the effect of weather conditions. In the third year of cultivation, there was observed negligible influence of fertilization on plant height. Plants without nitrogen fertilization were shorter till the end of the growing season.

**Figure 1.** Dynamics of *Artemisia dubia* growth in the second and third year of cultivation

A. dubia biomass in early October (at the early end of vegetation season) was characterized by a high moisture content, around 70% with slight variations between fertilization treatments (Fig. 2). Subsequently, the moisture content decreases, as plant senescence begins (at the end of October). At the beginning of December, moisture content was nearly 35% in the second year of *A. dubia* cultivation. The differences between fertilization treatments were very small; however, the moisture content in fertilized treatments decreased more slowly. In the third year of cultivation, moisture content of *A. dubia* varied in a similar range as in the second year of cultivation and before harvest it was about 40% and fertilization treatments had no noticeable effect. From October to December, the moisture content of the crops consistently decreased and the decline indicated the need to delay the harvesting time, which would reduce transportation and storage costs. It is considered that the

efficient combustion process requires moisture content of biomass to be below 50% (McKendry, 2002).

Biomass grower or the user selecting a particular technological solution requires a wide range of knowledge, but above all, it is vital to know the yielding potential and optimal harvesting time. The aboveground biomass yield of *A. dubia* varied ($LSD_{05} = 4.6$) from 4.64 to 5.07 t ha⁻¹ DM in the first year of cultivation and from 15.8 to 17.1 t ha⁻¹ DM in the second year (Fig. 3). Naturally, that the yield in the second year of *A. dubia* growing increased compared with the first year. The highest yield of *A. dubia* biomass was produced in the swards with mineral nitrogen fertilization at a rate of 170 kg ha⁻¹ N; however, it was insignificantly higher compared to the yield reached not only at a rate of 90 kg ha⁻¹ N but without fertilization also. Our results indicate a high potential yield of *A. dubia* with and without nitrogen fertilization when compared, for example, with tall

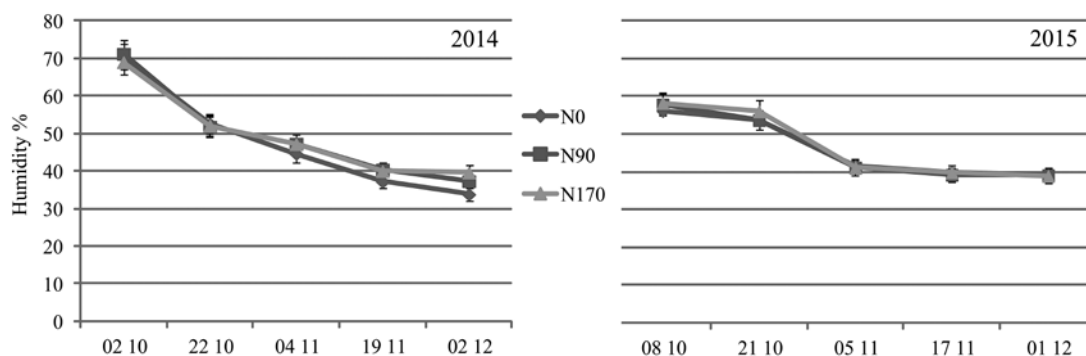


Figure 2. The change of moisture content of *Artemisia dubia* biomass during October–December

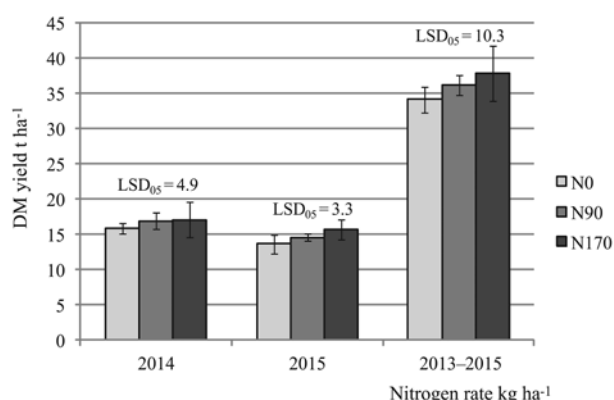


Figure 3. Biomass yield of *Artemisia dubia* from establishment year till the third growing year (2013–2015)

fescue or reed canary grass at the same location (Pocienė, Kadžiulienė, 2016) or investigated related species *A. vulgaris* (Siaudinis et al., 2015), or intensively cropped maize (Povilaitis et al., 2016). More studies were carried out on reed canary grass in Northern European countries, the estimated dry matter yields ranged between 5–10 t ha⁻¹ depending on management (Kukk et al., 2011; Tilvikiene et al., 2016). In the present study, *A. dubia* yielded more biomass than the above-mentioned crops. This positive feature of the plant has already been observed in previous studies (Kryževičienė et al., 2010).

The aboveground biomass yield of *Artemisia dubia* in the third year of cultivation was lower than that in the second year. In both years, nitrogen fertilization did not have significant influence on the biomass yield of *A. dubia* (Fig. 3). As the biomass yield even without N fertilization was relatively higher than that of previously

evaluated traditional energy grasses, *A. dubia* was found to be a potential energy crop. However, it is not known how long *A. dubia* can be grown and produce high biomass yield in the same site without being re-established. It has already been documented that this crop can perform well for at least 4–5 years (Kadžiulienė et al., 2013). It is important to assess the yields of a few years because the plants are exposed not only to the management measures, but also the soil, weather and crop conditions (Kludze et al., 2013; López-Bellido et al., 2014). Although *A. dubia* does not need nitrogen fertilization to achieve high yields, N fertilization might influence biomass quality.

The analysis of biomass characteristics relevant for combustion. For any energy conversion system biochemical and elemental properties of biomass are relevant (Nhuchhen, 2016) and end-use efficiency could be affected. The concentration of fibre components (cellulose, hemicellulose and lignin) in the biomass is important for combustion. The results show that N treatment had effect on the fibre composition during both years (Table 2); however, the results are still inconsistent. Cellulose content was the highest in the second year of *A. dubia* growth without nitrogen fertilization, while in the third year of growth it was the lowest. Even though some differences were detected among cellulose and hemicellulose, there was no consistent pattern across years as a result of the N treatments. In the second year of *A. dubia* growing, lignin content in the biomass was significantly highest when nitrogen fertilization at a rate of 170 kg ha⁻¹ had been used. Significantly higher lignin content was accumulated in *A. dubia* fertilized at a rate of 90 kg ha⁻¹ N compared to treatment without fertilization.

Table 2. Cellulose, hemicellulose and lignin content in *Artemisia dubia* biomass as influenced by nitrogen fertilization

N-fertilizer rate kg ha ⁻¹	Fibre components g kg ⁻¹ DM					
	cellulose		hemicellulose		lignin	
	2014	2015	2014	2015	2014	2015
0	538.8	483.0	87.3	55.9	165.4	156.2
90	529.0	502.4	75.5	78.4	170.2	153.3
170	519.1	498.1	72.7	88.4	177.0	152.6
LSD ₀₅	66.5	46.9	17.8	12.6	3.7	1.3

However, the same effect was not obtained in the third year of *A. dubia* cultivation and nitrogen treatment did not alter its content. Lignin content is important for combustion (McKendry, 2002), although part of lignin in the biomass was significantly lower than that of cellulose, lignin depending on its content, or more precisely on its ratio with cellulose in combustion process may not have the same influence on the properties. Thus, the low lignin content fibres are those having the best fire behaviour; however, heating value of a lignocellulosic fuel is a function of its lignin content and it increases with increasing lignin content in biomass (Demirbas, 2004).

Many chemical elements of biomass are potential contributors to pollution during combustion process (Williams et al., 2012). The biomass of most agricultural crops can contain relatively high levels of N, Cl and S, which can contribute to high emissions of NO_x, HCl and SO₂ and boiler corrosion during combustion

(Oberberger et al., 2006; Fournel et al., 2015). Nitrogen fertilization in most cases is required for improvement of biomass productivity; however, it may have a negative influence on the quality parameters of the biomass and combustion process (Kludze et al., 2013). The analysis of chemical elements in the biomass of *A. dubia* in the second and third year of cultivation showed that they varied depending on fertilization (Table 3); however, the greatest differences were not obtained either for C, S, P or K content. Nitrogen concentration in the biomass was influenced by N rates, but only 170 kg ha⁻¹ N had significant effect on nitrogen content in *A. dubia* biomass in both years of growing. Even not very high from the agronomic point of view N fertilization at 80 kg ha⁻¹ tended to increase fouling and slagging; therefore some results suggest that combustion quality could be improved by agronomic management consisting of little or no nitrogen fertilization (Kludze et al., 2013).

Table 3. Chemical elements and heating value of the *Artemisia dubia* biomass

N-fertilizer rate kg ha ⁻¹	% in DM						Heating value MJ kg ⁻¹
	N	S	C	P	K	Ash	
2014							
0	0.457	0.087	49.11	0.052	0.526	3.20	–
90	0.485	0.080	48.81	0.053	0.563	3.27	–
170	0.597	0.080	48.81	0.071	0.593	3.30	–
LSD ₀₅	0.028	0.015	0.585	0.026	0.188	0.712	–
2015							
0	0.349	0.091	49.3	0.040	0.459	3.57	18.50 ± 0.662
90	0.476	0.077	49.3	0.036	0.391	3.11	18.53 ± 0.116
170	0.559	0.075	49.7	0.038	0.394	3.47	18.78 ± 0.185
LSD ₀₅	0.161	0.022	0.902	0.033	0.142	0.339	

Application of nitrogen fertilizers did not have significant effect on ash concentration in the biomass in the second and third year of *A. dubia* cultivation (Table 3). Our scarce research on *A. dubia* suggests that this plant could be a useful energy plant for combustion. Nitrogen fertilization does not cause such a major change in the elemental composition of biomass, and as previous studies (Kadziulienė et al., 2013) have shown ash content was considerably lower than in other herbaceous plants. Such a low ash value is important because, as noted by other researchers, biomass from agricultural crops is usually characterised by high ash content (Oberberger et al., 2006). The ash content has the greatest role in differentiating biomass energy properties and fuel energy content between species and between varieties (Tao et al., 2012). Through knowledge of the chemical composition and physical properties of ash, it is possible to predict the tendency to form deposits in the boiler components, as well as their potential to cause corrosion, erosion and abrasion (Nunes et al., 2016). The high ash content in biomass reduces the energy available in the material, and thus reduces the conversion efficiency; therefore efficient energy in combustion could be expected from *A. dubia* biomass with low content of ash.

Heating value is considered to be an important fuel parameter in the combustion chain, therefore it

is necessary to analyse it (Nhuchhen, Salam, 2012), especially of less known crops. Heating value of *A. dubia* with fertilization (Table 3) or without differed negligibly and this value is in good agreement reported for other crops (Jasinskas et al., 2008; Siaudinis et al., 2015; Povilaitis et al., 2016).

Many different crops could be used for energy purposes; however, the cultivation of perennial crops as *A. dubia* with lower nutrient demand and other inputs provides advantages in choosing plants to use.

Conclusions

1. The ability to accumulate high biomass yield during the first three growing years is an important feature of *Artemisia dubia* Wall. The moisture content of *A. dubia* biomass decreased consistently from October to December and reached the optimal level for combustion at the end of November and beginning of December. In the second and third growing year of *A. dubia*, the annual dry matter yield ranged from 15.8 to 17.1 t ha⁻¹ and the biomass yield of not fertilized swards was as high as that of swards fertilized with mineral nitrogen.

2. Results indicated that chemical characteristics of *A. dubia* biomass are suitable for combustion. The most

marked response to nitrogen fertilization was observed in nitrogen content and lignin in the biomass. The biomass of *A. dubia* exhibited a relatively small ash content, which is an advantage when burning the biomass and showed higher heating value, although application of nitrogen fertilizers did not improve these characteristics.

3. The relatively low ash content and a heating value of 18.5 MJ kg⁻¹ even without nitrogen fertilization makes *A. dubia* a promising energy crop in the northern part of a temperate climate zone. Nevertheless, further investigation and analyses on *A. dubia* are needed to validate biomass productivity, quality and energy potential in senescent crops.

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***Artemisia dubia* augimas, derlius ir biomasės tinkamumas deginti**

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Santrauka

Daugelyje šiauresnių šalių padidėjo susidomėjimas žemės ūkio augalų biomasės naudojimu energijos tikslais, o tvariam naudojimui reikalingi kuo didesnio derlingumo ir tinkamos kokybės nauji augalai. Tyrimo tikslas – nustatyti *Artemisia dubia* Wall. biomasės derlių auginant vidutinio klimato sąlygomis ir biomasės savybes deginant. Augalai auginti giliau karbonatingame sekliai glėjiškame rudžemyje (RDg8-k2) netrešiant ir trešiant mineralinėmis azoto trąšomis 90 ir 170 kg ha⁻¹ N. Augalų augimas, derlius ir deginimui svarbios biomasės savybės vertinta antraisiais ir trečiaisiais augalų auginimo metais. Azoto trąšos šiek tiek didino augalų aukštį ir biomasės kaupimą, tačiau drėgmės kiekis biomasėje mažėjo lėčiau. Trešiant azotu augalų biomasės antrųjų ar trečiųjų auginimo metų metinio derliaus esminio padidėjimo negauta, tačiau ir be trešimo azotu gautas 15,8 iki 17,1 t ha⁻¹ sausųjų medžiagų derlius lenkia vidutinius kitų augalų biomasės derlius. Trešimas azotu esmingai didino azoto ir lignino kiekius biomasėje. Nepriklausomai nuo trešimo, degimo proceso svarbių cheminių elementų anglies ir sieros vertės biomasėje kito nežymiai. Augalų netrešiant gautas gana nedidelis kiekis pelenų, o šilumingumas siekė 18,5 MJ kg⁻¹. Siekiant išsamiau įvertinti daugiamečių kiečių biomasės derlių bei kokybinės sudėties vertes ir trešimo įtaką, reikia papildomų tyrimų.

Reikšminiai žodžiai: energiniai augalai, ląstelienos komponentai, pelenai, trešimas azotu, šilumingumas.