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The evaluation of biomass and energy productivity of common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.) in *Albeluvisol*

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Abstract

Research on perennial coarse-stemmed herbaceous energy plants, common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.), was carried out in Vėžaičiai Branch of the Lithuanian Research Centre for Agriculture and Forestry in Western Lithuania. The soil of the experimental site is naturally acid moraine loam *Eutri-Hypostagnic Albeluvisol* (*ABj-w-eu*). Field experiments were established in 2008, according to a two-factor design including three levels of liming (not limed, limed with 3.0 and 6.0 t ha⁻¹ of CaCO₃) and three levels of nitrogen fertilization (0, 60 and 120 kg ha⁻¹).

Common mugwort accumulated 2.76–5.74 t ha⁻¹ of dry matter in 2009; the next year, however, the parameter decreased to 2.38–3.83 t ha⁻¹. In 2009, the cup plant dry matter productivity was 4.42–8.51 t ha⁻¹; while in 2010, it considerably increased and reached 11.37–21.94 t ha⁻¹. Liming positively influenced the cup plant dry matter productivity; however, there was no significant effect on the change in the common mugwort dry matter increase. The application of 120 kg ha⁻¹ nitrogen rate significantly enhanced dry matter increase of both species (although not always significantly at 95% probability level).

The energy analysis of the growing technology in 2010 indicates that the mineral and lime fertilizers as indirect energy costs accounted from 32.75% to 76.07% of the total energy input (including direct and indirect costs, machinery energy consumption and human labour input). The highest energy output (187.6–361.9 GJ ha⁻¹) as well as energy use efficiency (ratio of energy output to energy input) was determined for the cultivation of cup plant. However, the application of lime and nitrogen fertilizers caused a substantial decrease of energy output and energy use efficiency.

Key words: common mugwort, cup plant, nitrogen, liming, dry matter, energy evaluation of cultivation technology.

Introduction

The possibilities of using various woody and herbaceous species for cultivation and subsequent biomass utilization for energy purposes were broadly explored in all European Union countries. The basic feature of every energy crop species is high biomass (dry matter) and energy potential, achievable with relatively moderate economic and energy inputs. Positive results highly depend on individual species and their accommodation to local climatic and soil conditions (McKendry, 2002).

Some authors emphasize that perennial energy plant species are superior to annuals since they have higher energy potential, lower energy expenses for growing and thus higher production profitability (Lewandowski et al.,

2003; Jasinskas, Kryževičienė, 2006). In recent years, in the country as well as abroad, fair attention has been focused on the research of local and introduced varieties that are potentially relevant for energy purposes.

Artemisia genus plants are widely distributed throughout the entire Northern Hemisphere (Barney, DiTommaso, 2003). So far, common mugwort has been researched as a source of food and pharmaceuticals (Judžentienė, Buzelytė, 2006). Meanwhile, in agriculture it has been identified as a weed largely because of its persistence to propagate vigorously from small rhizome fragments (Barney, DiTommaso, 2002; Lauringson, Talgra, 2003). The substantial *Artemisia* genus attribute is

its insensitivity to moisture regime and high tolerance of different pH levels ranging from 4.8 to 8.2 (Huxley, 1992). The energy value of some naturally growing varieties is as high as 4500 kcal kg⁻¹ (Van Epps et al., 1982). The research on the *Artemisia* genus plant biomass increase as well as biomass utilization for biofuel purposes is still at the initial stage (Kryževičienė et al., 2010).

The cup plant (*Silphium perfoliatum* L.) species originated in North America (Huxley, 1992). Cup plant produces considerable amount of biomass and it has been found to be easy to cultivate and has versatile uses – as an ornamental, melliferous and fodder plant as well as a potential medical, reclamation, or energy plant (Kowalski, 2004; Емелин, 2010; Гимбатова, Алимирзаева, 2011). However, since the feeding value of this species is low, possibilities of its cultivation are limited (Lehmkuhler et al., 2007). Recent years, *Silphium* genus plants could be cultivated and their biomass used for energy purposes (Kowalski, 2004; 2007). Another research reveals that cup plant's biomass properties are satisfactory from the viewpoint of energy and briquettes are characterised by very good qualitative parameters (Frączek et al., 2011). It seems that cup plant, a coarse stemmed plant species, is a good material for biogas production. However, no reliable scientific articles on this subject have been found so far.

In Western Lithuania, the cultivation of traditional agricultural crops is often unprofitable because of relatively low soil productivity. It is dominated by naturally acid *Albeluvisols* and *Fluvisols* (Plesevičius, 1995). In the absence of the maintenance liming, the soil returns to its original condition it was in prior to liming, followed by deterioration of physical and chemical properties of soil and disrupted activities of micro-organisms (Mažvila et al., 2004). However, with the growing demand of biomass for energy purposes, some of the abandoned land might be used for energy crop cultivation. In this respect, there is a lack of data on the changes in the productivity and qualitative parameters of new energy crops depending on the different soil pH level as well as energy evaluation of growing technology.

The current study aims to investigate the dependence of the productivity of two unconventional plant species, common mugwort and perennial cup plant, on liming and nitrogen application and to perform the energy increase analysis.

Materials and methods

The experiments were carried out in Vėžaičiai Branch of the Lithuanian Research Centre for Agriculture and Forestry in Western Lithuania (55°43' N, 21°27' E) during 2008–2011. Bare fallow preceded the current experiments. The soil of the experimental site is naturally acid moraine loam, *Eutri-Hypostagnic Albeluvisol* (*ABj-w-eu*). The agrochemical characteristics of the upper soil layer: pH_{KCl} 4.25–4.85, mobile P₂O₅ 35–120 mg kg⁻¹, mobile K₂O 140–209 mg kg⁻¹, hydrolytic acidity 21.9–62.1 mequiv kg⁻¹, mobile Al 10.7–50.9 mg kg⁻¹. The objects of investigation were common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.).

The experiments were composed according to a two-factor design. Factor A – liming: 1) without liming, 2) limed at 0.5 rate (3.0 t ha⁻¹ CaCO₃) (to neutralize the effect of toxic aluminium), 3) limed at 1.0 rate (6.0 t ha⁻¹ CaCO₃). Thus, the experimental site was divided into

three strips with different soil pH. Factor B – nitrogen rates (0, 60 and 120 kg ha⁻¹). Nitrogen treatments were arranged randomly with three replications per each pH (different liming) background.

The experimental site was limed (except for the first pH strip) with Opokos fertilizer on 20th April 2008, just before the planting of sprouts. Both in 2009 and 2010, nitrogen fertilizer (60 kg ha⁻¹) was spread in April. The remaining nitrogen fertilization (60 kg ha⁻¹) (for the 3rd treatment) was done in July. Ammonium nitrate was applied as nitrogen fertilizer. Phosphorus (superphosphate) and potassium (potassium chloride) were applied each year before the beginning of vegetation. Potassium and phosphorus rates for all common mugwort and cup plant treatments were the same 60 kg ha⁻¹ P₂O₅ and 60 kg ha⁻¹ K₂O. Common mugwort seedlings were planted on 27th May 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 distances between the rows were 0.75 m, and between seedlings 0.50 m. Thus, the number of mugwort plants was 30.000 ha⁻¹. Cup plant sprouts were planted at the 2–3 leaf stage on 3rd June, 2008 in 10 m long rows, the distance between rows being 1 m, and distance between sprouts 0.5 m. Each row represented a separate treatment. Thereby, 1 ha area had 20000 plants. During the planting year, cup plant only grew a leaf rosette; meanwhile shoots started to grow in the second year. The research on both cup plant and common mugwort began in the growing season 2009.

The experimental plots were harvested at full maturity stage, on 16th September 2009 and on 30th September 2010, accordingly. Plant stems were mowed by a rotary mower.

The data of dry matter yield of the trial was processed using the analysis of variance (*ANOVA*) method by applying a two-factor randomised block variant, using LSD₀₅ (at 95% probability level) to assess the significance (Tarakanovas, Raudonius, 2003).

The evaluation of energy parameters of 2010 was performed (except for the treatments with 60 kg ha⁻¹ nitrogen application). Energy evaluation of technology per 1 hectare was carried out. When performing the energy evaluation, we included indirect (the share of fertilizer and pesticide energy), direct (fuel consumption), energy input of machinery, and energy input of human labour for each technological operation (Sirvydis, 2001; Jasinskas et al., 2008 a; b). The energy output (GJ ha⁻¹) was calculated by multiplying biomass energy value (MJ ha⁻¹) by biomass dry matter yield (kg ha⁻¹). Energy value for cup plant – 16.5 MJ kg⁻¹ and for common mugwort – 18.2 MJ kg⁻¹. The evaluation of energy value was assessed in Klaipėda University Maritime Institute Laboratory in 2010. When calculating the energy input, the following energy equivalents (MJ ha⁻¹) of mineral fertilizers were applied: for single superphosphate – 6.4, for potassium chloride – 5.3, for ammonium nitrate – 27.4, for lime (Opokos) – 17.9. Energy equivalent for herbicides – 288 (Green, 1987).

Energy use efficiency ratio was calculated according to the formula:

$$EUE = \frac{E_{out}}{E_{in}}$$

where EUE – energy use efficiency, E_{out} – energy output (GJ ha⁻¹), E_{in} – energy input (GJ ha⁻¹) (Shahin et al., 2008).

Cool weather prevailed in May and June 2009. The amount of precipitation was close to annual average while from the beginning of July until the middle of September was slightly over the annual average. During the vegetation period, the amount of precipitation was 437 mm (annual average 424.4 mm); the sum of active temperatures (above 10°C) was 2064°C. Changeable weather was prevailing during the vegetation in 2010. Dry and often warm weather was occurred at the beginning of July and in August. There was more rainfall in the second half of July and in September. Precipitation in April–September was 620.2 mm, the sum of active temperatures (above 10°C) was 2246°C.

Results and discussion

In 2009, the greatest impact on common mugwort dry matter was made by 120 kg ha⁻¹ of nitrogen rate – dry matter increment was determined in all pH backgrounds (Fig. 1). The influence of pH (liming) was less tangible and much lower than 95% probability level.

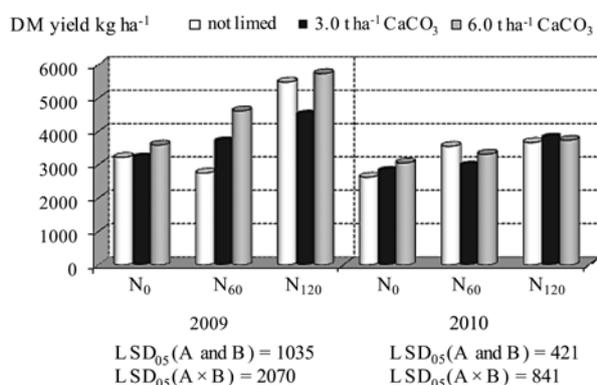


Figure 1. The effect of lime and nitrogen fertilization on common mugwort dry matter yield, in 2009 and 2010

In comparison to the data of the 2009 vegetation period, dry matter increase during the vegetation period of 2010 was lower by 5.20–36.03%. Again, the use of 120 kg ha⁻¹ nitrogen had the greatest impact on the yield. Actually, the effect of nitrogen was slightly lower than in previous years. Lower effect of nitrogen fertilization on the dry matter increase, and thus lower overall productivity could be due to two dry periods during the vegetation season. As a result, a significant portion of plant-synthesized organic compounds was depleted during respiration. The results of two years show that soil liming did not affect the productivity of common mugwort, thus, higher soil pH is not a stressor limiting mugwort ground biomass increase.

The ongoing studies in the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry in Central Lithuania revealed that depending on the seasonal weather conditions, mugwort dry matter yield ranged from 5.55 to 8.00 t ha⁻¹ (Kryževičienė et al., 2010).

Cup plant dry matter yield varied between 4.42–8.51 t ha⁻¹ (in 2009) and between 11.37–21.94 t ha⁻¹ (in 2010). The effect of liming and nitrogen fertilization was similar for both experimental years (Fig. 2). The effect of liming in many treatments significantly and positively influenced dry matter increment. Relatively the highest effect of nitrogen fertilizers was obtained

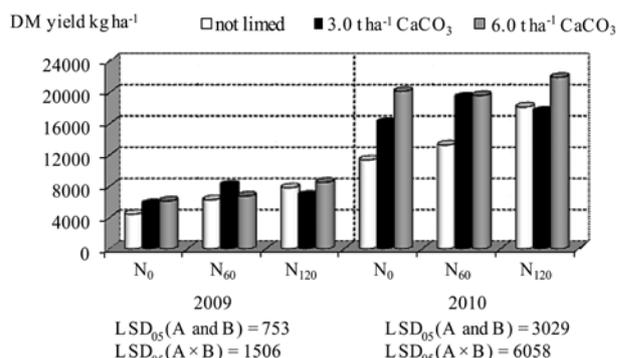


Figure 2. The effect of lime and nitrogen fertilization on cup plant dry matter yield, in 2009 and 2010

in the treatments, where plants were cultivated under naturally acid substratum (not limed). In comparison with control treatment (without nitrogen), the application of 120 kg ha⁻¹ nitrogen rate caused an increase in dry matter yield by 77.9% (in 2009) and 59.6% (in 2010). By cultivating cup plant in the strip limed with the highest rate (6.0 t ha⁻¹ CaCO₃), the impact of nitrogen fertilizers was less obvious; however, the application of the highest nitrogen rate (120 kg ha⁻¹) had the highest effect on dry matter increment in these experiments to 8.51 t ha⁻¹ (in 2009) and 21.94 t ha⁻¹ (in 2010), respectively.

In 2010, cup plant productivity was approximately 2.57 times higher compared with the first experimental year. The higher productivity was determined by significantly higher number of stems per plant and taller stems. Such growing dynamics corresponded with the data of other authors suggesting that the first-year yield is poor, but it increased quickly in subsequent years (Filatov et al., 1986). Similarly, other researchers indicated that under Western Siberia, Russia conditions cup plant has a productive lifespan of 10 years, and the average yield of dry mass is 15600 kg ha⁻¹. Biomass yield increased by 18–26% after application of mineral fertilizers (Степанов, Усенко, 2009). Other investigations in Northern Caucasus region revealed that when harvesting two biomass yields per vegetation, cup plant accumulated from 21700 to 27900 kg ha⁻¹ of dry matter (Гимбагов, Алимирзаева, 2011).

Commonly, cup plant dry matter productivity was far superior to that of common mugwort by 64.5% (in 2009) and 53.2% (in 2010), on average.

In the evaluation of technological operations we included the operations carried out during these field experiments: autumn ploughing, pre-sowing cultivation, distribution of fertilizers, sprout planting, plant protection, biomass harvesting, and transportation to the storage place (Table 1).

The energy share for harvesting and yield (biomass) transportation (7, 8 and 9 technological operations) comprised 2257 MJ ha⁻¹ or 57.66–59.47% of the total energy input. Actually, it is purposeful to use maize harvesters in spring for cutting the stems of coarse-stemmed plants that are left to dry out in the field until they reach 20–25% moisture content; to chop biomass and load it into a tractor trailer, afterwards transport to storage place and store the biofuel until consumption (burning in special furnaces) (Jasinskas et al., 2008 a; b).

Table 1. The evaluation of direct energy input, machinery energy consumption and human labour input for common mugwort and cup plant cultivation, in 2010

Technological operations	Tractor + implement	Direct energy input MJ ha ⁻¹	Machinery for particular operation MJ ha ⁻¹	Energy input of human labour MJ ha ⁻¹
1. Soil ploughing	TD 5030 + PN-3-35	576	77.1 + 27.8	1.8
2. Soil cultivation	TD 5030 + KRM-4.2	218	77.1 + 24.1	0.6
3. Plant protection against weeds (2 applications)	T-25 + Hardi	43 × 2	10.6 + 13.1 × 2	0.6
4. Distribution of fertilizers *, **, ***	T-25 + TB-0.5	60* (120)** (179)***	10.6 + 11.2* 10.6 + 11.2 × 2** 10.6 + 11.2 × 3***	0.4* (0.8)** (1.1)***
5. Planting	TD 5030 + Cramer	342	10.6 + 120	1.8
6. Interrow cultivation	Belarus 820 + KON-2.8PM	256	77.1 + 48.9	0.6
7. Harvesting (cutting and chopping)	E 281 C	521	243.1	1.8
8. Transportation	Belarus 820 + 2PTS-4	1394	77.1 + 280	8.4
9. Loading into storage place	Belarus 820 + PKU-0.8 A	342	77.1 + 4.4	2.7
Total		3795–3914	1203–1225	18.7–19.4

Notes. Recalculation of diesel into MJ coefficient $k = 42.7 \text{ MJ kg}^{-1}$ (Sirvydis, 2001). * – without liming and without N fertilization; ** – 1) without liming + 120 kg ha⁻¹ N, 2) liming and without N fertilization; *** – liming + 120 kg ha⁻¹ N.

Besides direct energy input, indirect energy input for fertilizers and herbicides was evaluated as well (3rd and 4th operations presented in Table 1). Energy equivalents are used to express the input of energy associated with the manufacture of production means in terms of primary energy input (Hulsbergen et al., 2001). The indirect energy costs (or energy input) are presented in Table 2.

Table 2. The indirect energy costs for herbicides and mineral fertilizers

Herbicides, fertilizers	Application rate ha ⁻¹	Energy equivalent MJ ha ⁻¹	Energy value MJ ha ⁻¹
Agil	1.0 l	288	288
Roundup	3.0 l	288	864
Liming fertilizer (Opokos)	3.0 t	17.9	5346
	6.0 t		10726
Ammonium nitrate	353 kg	27.6	9743
Single superphosphate	300 kg	6.4	1920
Potassium chloride	100 kg	5.3	530

In the above-mentioned technological variant all the technological operations could be fully mechanized with the minimum labour expenses (Jasinskis, 2003; Jasinskis et al., 2008 a).

Depending on the different options, the energy consumption for production was 7.40–27.98 GJ ha⁻¹ (Table 3). Phosphorus and potassium fertilizers alone represent 33.11% of total energy (direct and indirect) inputs. The use of liming and nitrogen fertilizer (ammonium nitrate) increased the proportion of energy consumption by 81.91%. In other words, a largest share of total energy input is used during the production process of mineral fertilizers.

With reference to the data of other investigations, with the annual rate of 150 kg ha⁻¹ of nitrogen fertilizers, the energy input makes about 9.4 GJ ha⁻¹, meanwhile without fertilization, the energy input ranged from 0.5 to 4.5 GJ ha⁻¹, depending on the species of different energy plants (Jasinskis, Scholz, 2008).

Table 3. Energy evaluation of common mugwort and cup plant cultivation technology, in 2010

Treatments	Energy input GJ ha ⁻¹	Share of mineral fertilizers %	Energy output GJ ha ⁻¹		Energy use efficiency	
			common mugwort	cup plant	common mugwort	cup plant
Without N and liming	7.40	33.11	47.9	187.6	6.47	25.35
120 kg ha ⁻¹ N (without liming)	17.20	70.89	66.8	299.4	3.88	17.41
Without N and 3.0 t ha ⁻¹ CaCO ₃	12.80	60.91	51.5	267.1	4.02	20.87
120 kg ha ⁻¹ and 3.0 t ha ⁻¹ CaCO ₃	22.60	77.61	69.7	290.5	3.08	12.85
Without N and 6.0 t ha ⁻¹ CaCO ₃	18.18	72.48	55.7	332.6	3.06	18.29
120 kg ha ⁻¹ and 6.0 t ha ⁻¹ CaCO ₃	27.98	81.91	68.1	361.9	2.43	12.93

Though common mugwort has a relatively higher energy value than common mugwort, due to low biomass yield the energy output (or the energy potential) per hectare was not high – 47.9–68.37 GJ ha⁻¹. The accumulated amount of energy only marginally depended on soil pH background. The application of N₁₂₀ nitrogen rate significantly increased the energy output in all three pH backgrounds. In comparison with common mugwort, cup plant produced substantially higher energy output in biomass which composed 187.6–361.9 GJ ha⁻¹. The application of high liming rate (6.0 kg ha⁻¹ of CaCO₃) caused a positive effect of energy output per hectare. Nitrogen fertilization (120 kg ha⁻¹) increased energy accumulation (or energy output) in cup plant biomass under all pH treatments.

Compared with the control treatment, the increasing energy input for growing particularly in the form of lime and nitrogen fertilizers, energy use efficiency decreased from 6.47 to 2.43 (for common mugwort) and from 25.35 to 12.93 (for cup plant). This suggests that additional energy content accumulated in biomass in most cases was less than the amount of energy consumed in the form of mineral fertilizers. Energy use efficiency was mostly reduced by using 120 kg ha⁻¹ nitrogen fertilizer. Slightly less, but unambiguous influence was made by using lime fertilizer. The regularity is characteristic of cup plant as well as of common mugwort.

According to other authors, in order to achieve a higher level of energy efficiency, fuel, fertilizer and machinery operations are the three major categories. Calculations show that the energy use efficiency is higher in large farms (Yilmaz et al., 2005; Shahin et al., 2008).

The energy evaluation in our experiments revealed, that the technology of cup plant cultivation for energy purposes is superior compared with common mugwort. The positive energy balance is obtainable due to the photosynthetic active radiation, which determines the accumulation of solar energy in plants. Other means, such as fertilizers, pesticides, soil management, etc. are just subsidiary means to accumulate higher amount of energy in plants (Aleksynas, 1990).

Conclusions

1. Research findings suggest that common mugwort productivity was substantially lower and totalled 2.76–5.74 ha⁻¹ (in 2009); meanwhile in 2010, it fell to 2.38–3.83 t ha⁻¹. Cup plant reached the highest dry matter productivity, which increased from 4.42–8.51 t ha⁻¹ (in 2009) to 11.37–21.94 t ha⁻¹ (in 2010).

2. In both experimental years, the use of lime and nitrogen fertilization had a positive effect on cup plant dry matter increase; common mugwort dry matter productivity depended entirely on nitrogen fertilization.

3. Energy evaluation of the growing technology revealed that indirect energy costs, particularly the share of mineral and lime fertilizers, constituted a considerable share (33.11–81.91%) of the total energy input.

4. Cup plant accumulated the highest energy output in the above-ground biomass (187.6–361.9 GJ ha⁻¹) and thus, achieved the highest energy use efficiency amounting to 12.85–25.35. Yet, the application of lime and nitrogen fertilizers caused a substantial reduction in energy use efficiency.

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Paprastojo kiekio (*Artemisia vulgaris* L.) bei geltonžiedžio legėsto (*Silphium perfoliatum* L.) biomasės ir energinis produktyvumas balkšvažemyje

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Santrauka

Lietuvos agrarinių ir miškų mokslų centro Vėžaičių filiale, Vakarų Lietuvoje, atlikti stambiasiebių žolinių energinių augalų – paprastojo kiekio (*Artemisia vulgaris* L.) ir geltonžiedžio legėsto (*Silphium perfoliatum* L.) – tyrimai. Tyrimų vieta – natūraliai rūgštus moreninis priemolis (J1j6-b). Lauko bandymai įrengti 2008 m. pagal dviejų veiksmų schemą: A veiksmas – kalkinimas (nekalkinta, kalkinta 3,0 ir 6,0 t ha⁻¹ CaCO₃), B veiksmas – tręšimas azotu (0, 60 ir 120 kg ha⁻¹).

Kiečiai 2009 m. sukauptė 2,76–5,74 t ha⁻¹ sausųjų medžiagų, tačiau 2010 m. šis rodiklis sumažėjo ir siekė 2,38–3,83 t ha⁻¹. Legėstų sausosios masės produktyvumas 2009 m. buvo 4,42–8,51 t ha⁻¹, o 2010 m. jis gerokai padidėjo ir siekė 11,37–21,94 t ha⁻¹. Kalkinimas turėjo teigiamos įtakos legėstų sausosios masės produktyvumui, tačiau neturėjo esminės įtakos kiekio sausųjų medžiagų prieaugio pokyčiui. Abiejų rūšių augalų sausosios masės prieaugį padidino (nors ne visada esmingai esant 95 % tikimybės lygiui) 120 kg ha⁻¹ azoto trąšų panaudojimas.

2010 m. auginimo technologijos energinė analizė parodė, kad mineralinių ir kalkinių trąšų kaip netiesioginių energijos šaltinių dalis sudarė 32,75–76,07 % visų bendrųjų energijos šaltinių (įskaitant tiesiogines bei netiesiogines išlaidas, mašinų energioimlumą ir žmogaus darbo sąnaudas). Didžiausia energijos išeiga (GJ ha⁻¹), taip pat ir energinis efektyvumas (energijos išeigos bei energijos šaltinių santykis) nustatytas auginant geltonžiedžius legėstus. Pastarųjų dviejų rodiklių sumažėjimą sąlygojo didelių normų kalkinių ir azoto trąšų panaudojimas.

Reikšminiai žodžiai: paprastasis kietis, geltonžiedis legėstas, azotas, kalkinimas, sausosios medžiagos, auginimo technologijos energinis įvertinimas.