THE EVALUATION OF DRY MASS YIELD OF NEW ENERGY CROPS AND THEIR ENERGETIC PARAMETERS

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Abstract

The investigations of local as well as introduced tall perennial grasses for biofuel production is an important object in agronomical science. In order to determine the effect of lime and nitrogen fertilisation on new unconventional energy plants (virginia mallow (*Sida hermaphrodita* L. Rusby), cup plant (*Silphium perfoliatum* L.) and common mugwort (*Artemisia vulgaris* L.), the investigations were carried out in Vėžaičiai branch of the Lithuanian Research Centre for Agriculture and Forestry in 2009 - 2011. The field experiments comprised of 3 levels of liming (i.e. not limed, limed at 0.5 rate, limed at 1.0 rate) and 3 levels of nitrogen rate (i.e. 0, 60 and 120 kg ha^{-1}).

Both liming and nitrogen application were two factors which positively affected the increase of cup plant, common mugwort and virginia mallow above-ground dry mass yields, although not statistically reliable (at a 95% probability level) in some treatments. Liming had no significant influence on common mugwort productivity. Out of three species, cup plant accumulated a substantially higher dry mass amount. The calculated data of the energy balance parameters shows that the share of energy bounded in lime and nitrogen fertilizers comprised a most substantial part of the energy expenses. Cup plant accumulated the highest amount of total energy and achieved the highest net energy balance (energy output - energy input ratio). The increase of the liming and nitrogen rates frequently caused the decrease of net energy balance.

Key words: lime, nitrogen, cup plant, common mugwort, virginia mallow, energetic evaluation.

Introduction

The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in the chemical bonds. Commonly, the „ideal“ energy plants species have the following attributes: 1) high productivity (maximum dry mass production); 2) low energy input to produce; 3) low cost; 4) composition with the least contaminants; 5) low nutrient requirements. These characteristics also depend on the soil and climatic conditions (McKendry, 2002). Some authors emphasize the superiority of perennial crops over annuals due to higher cultivation profitability.

In recent years, a fair amount of attention has been focused on the investigation of local and introduced species that are potentially relevant for energy purposes.

Some introduced species, belonging to *Miscanthus* as well as *Polygonum* genus, produce high above-ground biomass yield, and were grown as ornamental species. The expansion of *Miscanthus* genus to the north is restricted by its low resistance to negative temperatures (Clifton-Brown et. al., 2003). Virginia mallow (*Sida hermaphrodita* L. Rusby) and Cup plant (*Silphium perfoliatum* L.) are from North America. The sparse available data indicates that both plants accumulate high amounts of biomass and thus could be cultivated and utilized for various kinds of energy purposes, i.e. direct combustion, pellets or biogas production (Borkovska and Wardzinska, 2003; Kovalski, 2004; Heneman and Červinka, 2007; Kovalski, 2007).

Artemisia genus species is widely prevalent throughout the Northern Hemisphere and characterized as high as 18.83 KJ kg^{-1} energy value (Van Epps and Barker, 1982; Barney and DiTommaso, 2002). In Lithuania, the investigation of *Artemisia* genus, and other tall grassy species for bioenergy purposes are still in the initial stages (Kryževičienė et al., 2010).

Naturally acidic *Albeluvisols* and *Fluvisols* contain high amounts of toxic for plants' mobile aluminium (Plesevičius, 1995), and the soil acidification process is in progress due to a high annual amount of precipitation (Mažvila et al., 2004). In this respect, Western Lithuania region is less favorable for profitable farming. It is supposed that energy plants could occupy the area of approx. 10-15% of all abandoned areas (Jasinskas et al., 2003). Thus, in the near future, a part of agricultural land could be used for energy crop cultivation. Special attention should be given to the species that can tolerate low soil pH.

Research aim – the productivity evaluation of unconventional agricultural plant species as well as the energetic assessment of growing technology.

Materials and Methods

The trials were set up in Vėžaičiai branch of the Lithuanian Research Centre for Agriculture And Forestry, Western Lithuania (55º43´N, 21º27´E) during 2009 – 2011. Prior to establishing the experiments, the site was occupied by black shallow. The soil of the experimental site is Dystric Albeluvisol (FAO, 1998), moraine loam. The upper soil layer (0-20 cm) contained pH KCl – 4.2-4.8, mobile P_2O_5 – 35-120 mg kg^{-1}, mobile K_2O – 140-209 mg kg^{-1}, hidrolytic acidity – 21.9-62.1 mekv kg^{-1}, mobile Al – 10.7-50.9 mg kg^{-1}.

An experimental scheme was composed of two factors: lime rates (not limed, 0.5 liming rate (3.0 t ha^{-1} $CaCO_3$), and 1.0 liming rate (6.0 t ha^{-1} $CaCO_3$)) – thus, forming three different pH strips, and nitrogen rates (0, 60, and 120 kg ha^{-1}). The liming was done just before the establishing on the experiments, particularly on the 20th of April.

Mugwort and cup plant were planted in 2008, and virginia mallow – in 2009. Cup plant and virginia mallow were planted in 10 metre length rows with 1 m spacing between them and 0.5 m between plants in rows. Thus, 1 ha was comprised of 20,000 plants. Each mugwort treatment comprised three 10 metre length rows. The distance between the rows – 0.75 m, and 0.5 m between each plant.

Ammonium nitrate was used as a source of nitrogen. A 60 kg ha^{-1} nitrogen rate was broadcasted prior to the beginning of vegetation. The rest of the 60 kg ha^{-1} nitrogen fertilisation was done at the beginning of July (3rd treatment). Phosphorus (single superphosphate) and potassium (potassium chloride) were applied just prior to the beginning of vegetation. The rates of phosphorus and potassium fertilisation were equal for all the treatments - 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O.

The harvesting of cup plant and mugwort was done at the last stages of vegetation, particularly in 2009 on 16th of September, in 2010 on 30th of September, and in 2011 on 22nd of September. To determine the dry mass productivity, plant samples were dried to air-dried moisture content, and were later on recalculated to t ha^{-1}.

The biomass energy value (MJ kg^{-1}) for all investigated plants (except the treatments applied at the 60 kg ha^{-1} nitrogen rate) was evaluated according to the chemical tests executed at the Agricultural Institute's of the Lithuanian Research Centre for Agriculture and Forestry Chemical Research Laboratory in 2010.

The significance of liming and nitrogen fertilization was analyzed using analysis of variance (ANOVA), by choosing LSD_{05} to assess the significance (Tarakanovas, Raudonius, 2003).

By calculating the total energy expenses (GJ ha^{-1}), we included the direct energy expenses (ploughing, cultivation, protection from weeds, biomass harvesting, and transportation), indirect energy expenses (share of energy in fertilisers and herbicides), machinery energy consumption, and human labour input.

Energy output (GJ ha^{-1}) was calculated by multiplying dry mass yield (t ha^{-1}) by energy value of the plants (MJ ha^{-1}). Net energy ratio (or energy balance) (NER) was calculated by the equation (acc. to Shahin et al., 2008).:

NER = energy output (GJ ha^{-1}) - energy input (GJ ha^{-1}) (1)

Weather conditions. In 2009, the weather was cooler, meanwhile the temperature from the end of June until the middle of September was slightly higher. The amount of precipitation during vegetation was 437 mm and comparable to annual average; the sum of active temperatures - 2064 ºC. The 2010 growing season was uneven with periodical heavy rainfalls with two hot and dry weather periods in between them. During the April – September period, the amount of precipitation was 620 mm, the sum of active temperatures - 2246 ºC. Overall in 2011, the weather was warmer in compare with previous vegetations; the higher amount of precipitation felled in the second half of vegetation and amounted to 540 mm; the sum of active temperatures – 2400 ºC.

Results and Discussion

The data of cup plant dry mass productivity is presented in Fig.1. In all the experimental years, the effect of liming and nitrogen application was similar. With reference to average data, the application of the highest lime rate had a positive effect on dry mass increment by 15.5% (in 2009), 44.2% (in 2010) and 22.9% (in 2011). In turn, the application of 120 kg ha^{-1} nitrogen rate caused the increase of dry mass yield by 41.1% (in 2009), 20.1% (in 2010) and 20.0% (in 2011). Thus, the application of highest lime and nitrogen rates caused the highest dry mass productivity. In both the subsequent years, the cup plant productivity increased sharply and outweighed the first year's dry mass

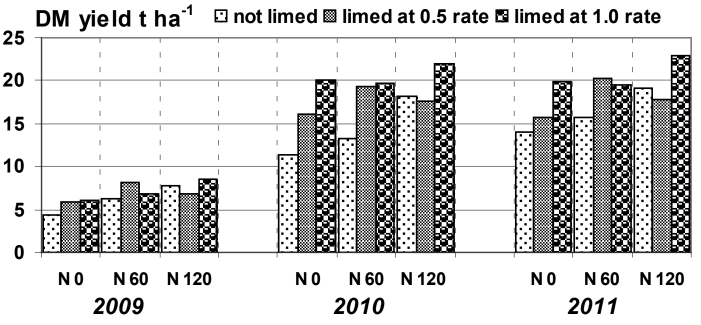

Figure 1. **The productivity of cup plant (t ha^{-1}) as influenced by liming and nitrogen fertilisation (kg ha^{-1})**

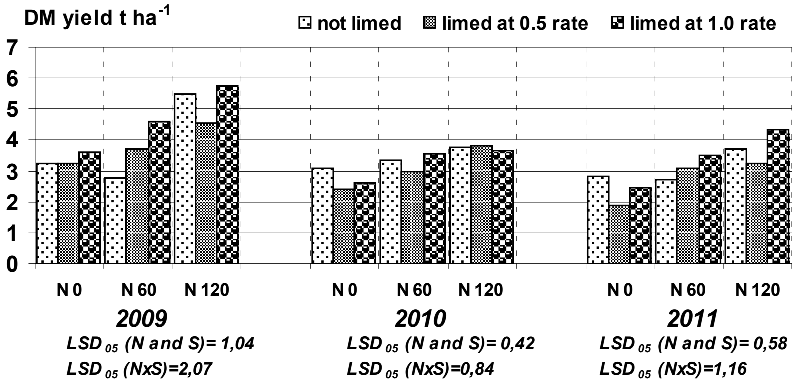

Figure 2. **The productivity of common mugwort (t ha^{-1}) as influenced by liming and nitrogen fertilisation (kg ha^{-1})**

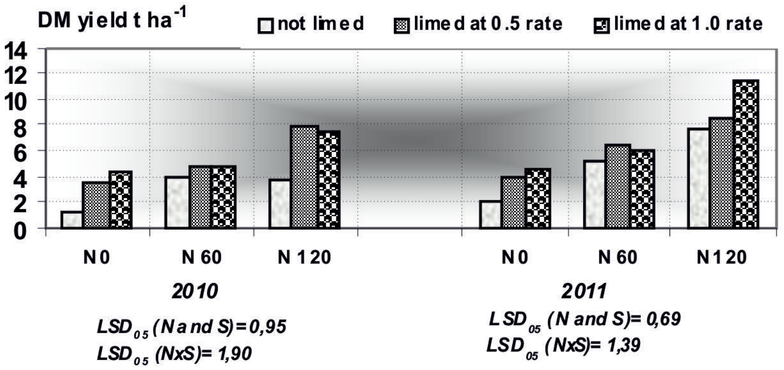

Figure 3. **The productivity of virginia mallow (t ha^{-1}) as influenced by liming and nitrogen fertilisation (kg ha^{-1})**

productivity by 259% (in 2010) and 267% (in 2011). These results correspond with other reports that the first year's yield is poor, but it increases in subsequent years (Filatov et al., 1986).

It is noted that the application of lime only (without nitrogen) showed that the cup plant productivity was fairly high and was equal to the impact of nitrogen fertilisation in many treatments. In this respect, cup plant has a well developed root system and ability to utilize a substantial part of nitrogen from deeper soil layers. It seems that drought periods during vegetation had no substantial effect for productivity. Cup plant has a well developed root system. Some roots grow down (roots penetrate to 30-150 cm), others spread radially under the soil surface (Stanford, 1990).

Thus, the cup plant dry mass productivity was far superior to other investigated species.

In 2009, the application of highest – 120 kg ha^{-1} nitrogen rate had the highest importance for common mugwort dry mass productivity in all pH strips (Fig. 2). The liming influence was less noticeable and less significant than the 95% probability level. The common mugwort above-ground dry mass productivity was substantially reduced in both the subsequent years and was lower by 19.7% (in 2010) and 24.8% (in 2011) in comparison with the 2009 vegetation results. As in the first year of vegetation, liming had no significant influence to the dry mass increment. The optimal rate of nitrogen fertilisation was 60 kg ha^{-1} (in 2010) and 120 kg ha^{-1} (in 2011). The decrease of dry mass increment and herewith the inferior affect of nitrogen fertilisation could happen as a result of rainless periods during the stage of intense growing.

According to the reports of other authors, meteorological conditions (moisture and temperature) can cause substantial variation of common mugwort dry mass yield – from 5.55 to 8.00 t ha^{-1} (Kryževičienė et al., 2010).

Fig.3 represents the data of virginia mallow productivity of both successive years. In the first year of growth (i.e. 2010), the significant influence of liming was observed by application of the average 3.0 t ha^{-1} rate. The application of highest liming rate had no significant effect on dry mass yield. In many treatments, the application of nitrogen fertilisers was favorable for dry mass productivity. In addition, positive and reliable interaction was observed between liming and the 120 kg ha of nitrogen rates.

In 2011, virginia mallow dry mass yield was 33.5% higher than in previous vegetation. In all the cases,

Table 1.

Energetic evaluation of common mugwort, cup plant and virginia mallow in 2010

Treatments	Total energy expenses for cultivation GJ ha^{-1}	Total accumulated energy in biomass, GJ ha^{-1}			Net energy ratio (NER)		
		Common mugwort	Cup plant	Virginia mallow	Common mugwort	Cup plant	Virginia mallow
N0 (not limed)	7.5	51.6	186	22.7	44.1	178.5	15.2
N120 (not limed)	11.0	65.6	289	67.7	54.6	278	56.7
N0 + 0.5 liming rate)	13.0	47.6	248	61.6	34.6	235	48.6
N120 + 0.5 liming rate	16.4	68.4	295	140	52.0	278.6	123.6
N0 + 1.0 liming rate	18.4	49.0	335	75.7	30.6	316.6	57.3
N120 + 1.0 liming rate	21.9	63.5	374	131	41.6	352.1	109.1

virginia mallow dry mass yield responded positively to liming as well as the application of 120 kg ha^{-1} nitrogen rate. Thus, the combination of highest liming and nitrogen rates as well as their interaction was the cause of highest dry mass productivity during the experiment – 11.5 t ha^{-1}.

In comparison with other investigated species, the use of liming and nitrogen fertilisation had the greatest effect on virginia mallow dry mass productivity. In 2010, by the application of the highest 1.0 liming rate, the average dry mass yield increased by 84.0% and the 120 kg ha^{-1} nitrogen rate – by 108.5%; meanwhile according to the 2011 vegetation results, liming and nitrogen fertilisation caused the increase of dry mass yield by 36.5% and 263.1%, respectively.

The report of other authors shows that virginia mallow productivity was low at first two growing years, but increased by approximately 3 times in subsequent years (Borkowska et. al., 2001). It is observed that virginia mallow productivity is sensitive to unfavourable soil physical-chemical properties (Borkowska et. al., 2009).

Energetic evaluation. The data of the energy parameters (in 2010) are presented in Table 1. Since the technological operations are the same for all three plants, the energy expenses for cultivation as presented in the Table 1. are equal.

Depending on the treatment, the total energy expenses for cultivation varied 7.5 to 21.9 GJ ha^{-1}. These wide differences were determined by the different fertilisation, particularly of the liming and nitrogen application. The share of energy in lime and mineral fertilisers (especially ammonium nitrate) comprised 32.8 to 76.1% of all the consumed energy expenses. Out of all the energy expenses, the energy for different agricultural operations comprised a mere 0.26–0.28 GJ ha^{-1}

Liming and nitrogen application highly affected the amount of total accumulated energy (GJ ha^{-1}) in cup plant and virginia mallow biomass and had a less influence on energy accumulation in common mugwort biomass. Out of three species, the highest amount of total accumulated energy was observed in cup plant biomass (from 186 to 374 GJ ha^{-1}).

The net energy ratio (energy output - input or NER) varied on a high scale: from 30.6 to 54.6 (for mugwort) and from 17.04 to 26.36 (for cup plant). It is noticed that the decrease of common mugwort and cup plant NER was highly influenced by the high 1.0 liming rate (or 6.0 t ha^{-1} $CaCO_3$). The share of the accumulated energy was higher than the additional share of energy obtained by the effect of liming (especially inherent for mugwort). The influence of nitrogen fertilisation (120 kg ha^{-1}) was less evident. Contrarily, the virginia mallow NER was substantially increased by the application of 120 kg ha^{-1} nitrogen and liming by 0.5 rate (or 3.0 t ha^{-1} $CaCO_3$). The NER slightly decreased by the application of 1.0 liming rate.

Commonly, the positive NER balance is receivable due to photosynthetic active radiation, which inspires the accumulation of solar energy in plants. Other means, such as fertilisers, pesticides, soil cultivation, etc. only enable plants to accumulate a higher amount of energy in plants (Aleksynas, 1990).

Conclusions

Liming and nitrogen application caused a significant increase of cup plant and virginia mallow above-ground dry mass productivity in all the years of the experiment. The mugwort productivity was affected only by nitrogen application; liming did not have a substantial effect. In comparison with mugwort and virginia mallow, cup plant productivity and the amount of total accumulated energy in biomass was substantially higher.

The indirect energy consumption (especially the share of energy bounded in lime and nitrogen fertilisers) comprised a substantial part of the energy input. High rates of liming and nitrogen application highly affected energy accumulation in cup plant and virginia mallow above-ground biomass and had a lesser effect on common mugwort. The net energy ratio (NER) for common mugwort and cup plant frequently decreased as the result of liming and nitrogen fertilization (except for virginia mallow).

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