The biogas production from lucerne biomass in relation to term of harvest

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ABSTRACT

The aim of this paper was to investigate the effect of delayed cut of lucerne on a biogas production in contrast to bud stage used for livestock feed. In 2009–2010, the dry matter (DM) yield, forage quality, substrate biogas yield (SBY, L/kg DM), and area biogas yield (ABY, m^3/ha) was assessed in the first and second cut in late bud and late bloom stage. Results show that ABY from lucerne could be significantly increased by change in harvest management towards to delayed cuts. The average increases of DM yield in late bloom stage achieved approximately 50 and 35% in the first and second cut, respectively, whilst the maximal significant decrease of SBY in bloom stage ranged from 25 to 30% in comparison with bud stage. This effect of strong SBY decrease was not consistent across years and was related to crude protein content in forage. Lucerne probably would not play a dominant role in biogas production but its growing could be a suitable supplement for field biogas production due to lucerne non-productive function.

Keywords: forage; alfalfa; bio energy; nitrogen

The generation of energy from biomass has a key role in current EU strategies to enhance energy security. Biomass can contribute to stabilise carbon dioxide concentrations in the atmosphere through biomass production for fossil fuel substitution and carbon dioxide storage in vegetation and soil (Ericsson and Nielson 2006). Currently, biogas production from energy crops in the arable land is mainly based on the anaerobic digestion of maize. The maize achieved the highest methane yield per hectare in comparison with cereal or sunflower (Amon et al. 2007). On the other hand, it must be noted that maize growing is limited in some areas and can have some negative impacts on environment as higher pesticide and fertilizes requirements. Maize fields are, in general, relatively vulnerable to both water and wind erosion (Graebig et al. 2010).

Legume crops could be also suitable source for biogas production and it is generally accepted that their growing significantly improve soil fertility in contrast to maize growing. According to Walla and Schneeberger (2006), lucerne grass mixture is more efficient energy crop than silage maize on organic farms. For conditions of the Czech Republic, the most important traditional forage legume crops are lucerne (*Medicago sativa* L.) and red clover (*Trifolium pratense* L.). These two crops have complementary production responses to climatic conditions, where lucerne is high yielding in dry whilst red clover in wet conditions (Peterson et al. 1992).

Lucerne's potential as a 'break crop' to improve soil fertility is well documented (Frame et al. 1997). One of the most important benefits is nitrogen

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fixation where Carlsson and Huss-Danell (2003) reported rate of N_2 fixation in the range of up to 350 kg N/ha per year. Another important benefit is high production of roots with positive effect on soil structure, fertility, content of organic matter, and also on stand productivity (Hakl et al. 2011). Light fraction of soil organic C, soil microbial mass C and microbial mass N increased with the number of growing years of lucerne (Jiang et al. 2006).

According to Frame et al. (1997) or Sheaffer et al. (2000), lucerne is considered as a bioenergy feedstock. Lucerne stands seem to be a suitable biomass source because of its persistency, high productivity, self-sufficiency of N_2 and positive impact on soil fertility. According to Amon et al. (2007), specific harvest and processing technologies are required when crops are used as a renewable energy source compared to growing them as a forage source for ruminants. The traditional harvest management for livestock feed recommends the cut term in the bud stage in relation to high quality of forage (Hakl et al. 2010). In contrast to it, suitable harvest managements of lucerne in a biogas production system are unknown. It must be taken into account that a two cut management system produced more total forage than a three- or four- cut management system harvested at early bud (Lamb et al. 2003). The impact of changes in lucerne biomass quantity and quality under different harvest management could be different for biogas production in comparison with animal utilization. The aim of this paper was therefore to answer the following question: can a delayed cut of lucerne increase a biogas production per area unit in contrast to recommended cut term in the bud stage for livestock feed? These results could be useful for optimizing the lucerne harvest management for biogas production.

MATERIAL AND METHODS

To test the biogas production from lucerne, we used a running experiment aimed at comparing 7 lucerne entries. In July 2004, the experiment was established by broadcast seeding with the seeding rate of 20 kg/ha at the experimental field station in Prague-Suchdol (286 m a.s.l., 50°08'N, 14°24'E). The long-term annual temperature is 9.3°C and precipitation 510 mm. The soil is a deep loamy degraded chernozem. The detailed subscription of site soil characteristic was presented by Černý et al. (2010).

The plot experiment was arranged in completely randomized blocks with four replicates for each lucerne entry. The plot size was 2 × 2 m. For biogas production assessment, the samples were taken at Jarka variety in 2009 and 2010. The samplings were realized in the late bud and late bloom stage in the first and second cuts (Table 1). Biomass was clipped in 4 cm height above the ground in the area 33 × 33 cm in four replicates and number of plants was counted. The fresh matter yield and stem length of the longest stem (MSL, cm) was assessed in the sample. The sample of fresh weight about 150 g was separated for dry matter content analyses and dry matter yield (DMY, t/ha) was calculated. These samples were analysed for crude protein (CP), neutral-detergent fibre (NDF), and acid-detergent fibre (ADF) content.

Table 1. The average value of dry matter content (DM), maximal stem length (MSL), crude protein (CP), neutro- (NDF) and acidodetergent fibre (ADF) in evaluated cuts and stages (n = 4)

Year	Cut	Stage	Date	DM (%)	MSL (cm)	CP (%)	NDF (%)	ADF (%)
2009	1	late bud	15 May	20.5^{b}	92^{a}	21.1^{a}	40.2^{a}	34.8^{ab}
		late bloom	4 June	26.2^{c}	123^{c}	16.4^{c}	47.4^{b}	39.3^{b}
	2	late bud	3 July	16.9^{a}	76^{b}	24.9^{b}	38.6^{a}	31.8^{a}
		late bloom	15 July	17.5^{a}	96^{a}	19.5^{a}	54.6^{c}	50.0^{c}
P				**< 0.000**	**< 0.000**	**< 0.000**	**< 0.000**	**< 0.000**
2010	1	late bud	20 May	15.7^{b}	89^{a}	21.8^{c}	37.9^{a}	35.1^{a}
		late bloom	7 June	23.1^{a}	127^{b}	19.4^{a}	45.1^{b}	41.9^{b}
	2	late bud	15 July	20.4^{a}	98^{a}	19.9^{a}	47.9^{bc}	40.6^{b}
		late bloom	4 August	23.0^{a}	124^{b}	17.6^{b}	51.3^{c}	46.5^{c}
P				**< 0.000**	**< 0.000**	**< 0.000**	**< 0.000**	**< 0.000**

One-way ANOVA, different letters document statistical differences for Tukey's HSD, α = 0.05

Within harvest terms, all fresh samples after separating subsamples created the mixed sample for substrate biogas yield (SBY, L/kg DM) assessment using laboratory batch test. Their basic principle was described by Straka et al. (2006). Biomass was tested in 120 mL bottles in five replications for each variant. After basic homogenization and grinding of fresh matter, two grams of tested biomass and 80 mL of inoculum were dosed into fermentors. Active mesophile anaerobic sediment from biogas plant was used as the inoculum. Cultivation took place in thermo box at 40°C for a period of 40 days. Production of biogas in laboratory tests of biomass was evaluated once a day, using gasmetric burette. Net substrate production of biogas was obtained after deduction of average production of blank bottle with inoculum. Area biogas yield (ABY, m^3/ha) was calculated from SBY and average DMY in the sampling date.

The effect of treatment on SBY, ABY, and DMY was statistically evaluated by a one-way ANOVA. The relations between the SBY and forage chemical composition or MSL were assessed by a partial linear correlation analyses. All statistical procedures were performed using Statistica 9.0 (StatSoft, Tulsa, USA).

RESULTS

Throughout the investigated period, the lucerne stand survived without any substantial damage. The average plant density of stand reached 73 and 60 plants/m^2 in 2009 and 2010, respectively. Due to the inconsistent effect of year on SBY, year 2009 and 2010 was evaluated separately in all following analyses.

The differences in dry matter content and MSL between cuts and stages (Table 1) are in accordance with expected stand development over first and second cut period. Similarly, a significant decrease of forage quality between bud and bloom stage was evident and expected.

The DMY significantly increased in a bloom stage in comparison with bud stage in all cuts and year (Figure 1) with exception for second cut in 2009 where this difference was not significant (P = 0.099). The SBY significantly decreased in the late bloom stage but this trend was observed only in 2009. In 2010, no significant changes in this parameter were assessed. The ABY also significantly increased in the bloom stage as DMY with the same exception for the second cut in 2009.

The dynamics of SBY over 40 day period in evaluated cuts and stages are given in Table 2. Due to high range of absolute values of SBY among the term of harvest, the relative cumulative percentage values were used which expressed the relative cumulative rate of biomass degradation. In 2009, this rate was significantly slowed down in late bloom stages of first cut over 10 and 5-day period, respectively. In contrast to it, the rate was significantly reduced in the second cut in comparison with the first cut over 20-day period in 2010.

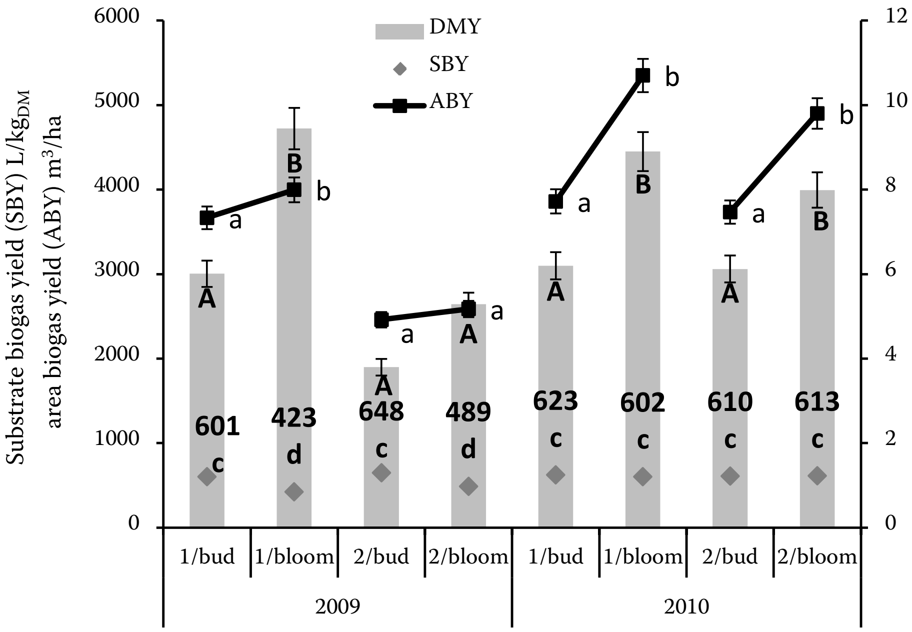

Figure 1. Dry matter yield (DMY; t/ha; n = 4), substrate biogas yield (SBY; L/kg DM; n = 5), and area biogas yield (ABY; m^3/ha; n = 5) in different cut and developmental stages of lucerne (vertical bars denote standard error of mean, different letters document statistical differences between stages within cut and year for Tukey's HSD, α = 0.05)

Table 2. The relative cumulative dynamic of substrate biogas yield (%) of lucerne forage over 40-day period of batch test in evaluated cuts and stages (n = 5; substrate biogas yield in 40th day = 100%)

Year	Cut	Stage	5th day	10th day	15th day	20th day	30th day	40th day
2009	1	late bud	60^{ab}	78^{a}	84	88	94	100
		late bloom	16^{c}	60^{b}	85	91	98	100
	2	late bud	63^{b}	82^{a}	86	89	95	100
		late bloom	51^{a}	73^{a}	82	88	95	100
P			**< 0.000**	**0.001**	0.831	0.926	0.793	–
2010	1	late bud	71^{b}	86^{a}	92^{a}	96^{a}	99^{a}	100
		late bloom	61^{ab}	82^{ab}	91^{a}	95^{a}	98^{a}	100
	2	late bud	53^{a}	69^{bc}	71^{b}	82^{b}	92^{b}	100
		late bloom	51^{a}	66^{c}	75^{b}	81^{b}	95^{ab}	100
P			**< 0.000**	**0.001**	**0.000**	**0.001**	**0.014**	–

One-way ANOVA, different letters document statistical differences for Tukey's HSD, α = 0.05

Due to inconsistent effect of year, the partial correlation analyses between forage quality and SBY and its dynamic were used (n = 8) when year was included as covariate. From evaluated nutrients, only CP was significantly related to SBY (r = 0.88) and also to relative cumulative rate of degradation at 5th (r = 0.87) and 10th day (r = 0.84). This cumulative dynamic of SBY at 5th day was significantly correlated with maximal stem length (r = –0.77) and SBY at 40th day (r = 0.88).

DISCUSSION

Substrate biogas yield. Assessment of SBY from harvested biomass represents basic qualitative characteristic in this process of energy production (Fuksa et al. 2012). In our experiment, values of SBY were in a wide range of 423 to 648 L/kg DM (Figure 1). Ratio of CH_4 in biogas usually varied from 60 to 65% (Straka et al. 2006) which represented substrate methane yield in our experiment approximately from 250 to 390 L CH_4/kg DM of lucerne forage. Similarly, when 10% as average ash content in lucerne forage is considered, methane yield from 280 to 430 L CH_4/kg OM could be obtained. This range corresponds with results published by Amon et al. (2007) about methane yield from other energy crops. The average methane yield 398 L CH_4/kg OM was obtained from maize silage whilst from wheat ranged between 140 and 343, from sunflower between 154 and 454, and from grassland between 128 and 392 L CH_4/kg OM. According to Amon et al. (2007), the important factor for methane substrate production is the nutrient composition of the energy crop. In spite of it, the nutrient content of lucerne was not closely related to SBY across the year in our experiment, except of CP. Late bloom stage with lower forage quality significantly reduced SBY in comparison with late bud stage, however, this effect of developmental stage was recorded only in 2009. It seems that only nutrient content of lucerne may not to be an effective predictor of SBY across years. Also the ratio of plant tissue could affect the SBY which could be expressed by leaf stem ratio. This ratio is closely connected with CP content in the aboveground biomass and varied among terms of harvest, used variety (Sheaffer et al. 2000) or stand structure (Hakl et al. 2009). For investigation of these relations, the assessment of SBY from separated leaf and stems in different cuts and stages should be recommended.

The rate of biomass fermentation plays an important role in optimization of degradation process in biogas plant. Based on the results in Table 2, it seems that this rate of lucerne forage degradation could be decreased in late bloom stage, as well as in the second cut. The dynamics of degradation through anaerobic digestion was also significantly positively related to the content of crude protein and negatively to stem length. This rate of degradation is also closely connected with technical equipment for fermentation such as liquid recirculation (Nordberg et al. 2007).

Area biogas yield. As was noted by Prochnow et al. (2009), the aim of energy crop for biogas production is to achieve the highest possible methane yields per hectare. Presented results (Figure 1) show that ABY from lucerne forage could be significantly increased by change in harvest management towards to delayed cuts. It is in accordance with Lamb et al. (2003), that harvesting twice per season at a later maturity stage would be an effective management strategy for maximizing yield in a lucerne biomass energy production system. In our study with biogas production, the average increase of DMY in late bloom stage was relatively stable across year and achieved approximately 50 and 35% in the first and second cut, respectively. In spite of SBY higher about 25% in the bud stage in 2009, the higher ABY was produced in late bloom stage. The increase of DMY was showed as more important than the decrease of SBY, except of the second cut in 2009. Benefit of delayed cut on the increase of ABY can be non-significant under high reduction of SBY in the second cut where the DMY increase is lower in contrast to the first cut. These results about increasing ABY in spite of an SBY decrease support idea that requirements on the biomass quality are different when crops are anaerobically digested in biogas plants compared to being fed to cattle. The reason could be that the digester at the biogas plant offers more time to degrade the organic substance than the rumen does. Another important point could be a different micro-organism population in the digester (Amon et al. 2007) or fact that higher proportion of NDF in the forage does not result in lower dry matter intake in the case of biogas plant.

Using presented results of the yield, SBY, and above-mentioned calculation between biogas and methane content, the methane yield as sum of the first and second cut reached on average 4100 and 5000 m^3/ha under the cut in late bud and late bloom stage, respectively. When standard three cut management is considered, the third cut with yield about 4 t DM/ha and SBY similar in the second cut could increase methane yield approximately on the level of 5400–6500 m^3/ha. It must be remembered that the ABY is a function of DM yield and SBY so their reached level influenced this value. According to Amon et al. (2007), the highest methane yields of 7500–10 200 m^3/ha were achieved from maize whilst yields of cereals ranged from 3200 to 4500 m^3/ha and of sunflowers from 2600 to 4550 m^3/ha. In our experiment, lucerne reached lower methane yield per hectare in comparison with maize and probably would not play a dominant role in biogas production from crops growing on arable land. Nevertheless, the methane yield of lucerne seems to be higher or comparable with other crops as cereal or sunflower and lucerne growing could be a suitable supplement for biogas production due to lucerne non-productive function with positive impact on soil fertility and reduction of soil erosion. In this case, the traditional harvest management could be modified towards to delayed cuts due to maximizing a biogas yield per hectare which should also supported higher persistency of stand (Frame et al. 1997).

It must be remembered that absolute values of DMY and SBY in this experiment do not correspond with real field and biogas plant production. According to Ericsson and Nielson (2006), yields obtained from field experiments generally should not be extrapolated so as to apply on regional and national scales. As regard to SBY, this parameter is not related solely to forage composition but also to modification of substrate and to conditions in the biogas plants (Fuksa et al. 2012). For these reasons, we can evaluate only the described relations among parameters in our study.

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