MAIZE PRODUCTION FOR BIOGAS IN LATVIA

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Abstract
Anaerobic digestion is becoming more popular in producing biogas. Nowadays biogas production is traditionally based on biomasses such as manure, sewage sludge and industrial waste, but during recent years, in many countries, the use of energy crops as agricultural substrate has increased. One of the most used substrate for biogas production in European countries is maize. Researchers have mentioned that key factors for a maximum biogas yield from maize are selected hybrid, time of harvesting, type of conservation and pretreatment of the biomass. Also the nutrient composition of the energy crop is important. The paper aimed to evaluate impact of hybrid, harvest time and agro-meteorological condition on maize biomass production for biogas. A field trial was carried out in the Research and Study farm "Vecauce" of the Latvia University of Agriculture (LLU) from 2008 till 2011. Ten (in 2008), eleven (in 2009) and fifteen (in 2010 and 2011) maize hybrids with different maturity ratings according to FAO numbers (FAO 180–340) were harvested at three different times beginning on 5 September at fourteen-day intervals. Composition of fresh maize was analyzed for all hybrids using standard methods. Results were statistically analyzed using analysis of variance, correlation and descriptive statistics. Results showed that harvest time effect on maize organic dry matter (ODM) content and yield was substantial ($p<0.05$) in all years. The highest average ODM yield in all years was reached when maize was harvested at the last harvest time. The influence of maize hybrid, vegetation period and hybrid on average ODM yield was substantial ($p<0.05$).
Key words: maize hybrid, yield and organic dry matter.

Introduction

The main reason for the development of renewable energy is the environment, especially in relation to global climate change and the need to improve security and diversity of energy supply. The biogas production has positive impact on the environment since less CO_2 is formed during combustion than it is used for photosynthesis by plants from which it is produced (Vindis et al., 2009). Renewable technologies create job-places using local resources in a new "green" industry in many countries of the world. Rapid growth of the number of biogas plants accelerates the search for a suitable substrate for biogas production. Biogas production is a key technology for the sustainable use of agricultural biomass as a renewable energy source. Production of methane – rich biogas through anaerobic digestion of organic materials provides a clean and versatile form of energy. In a biogas plant, each group of substrates has a specific potential for biogas production. The best properties are raw-harvested plant material with low lignin content (Klimuik et al., 2010).

Biogas production from energy crops is of growing importance. Biogas production has higher demands for arable land, assets and work than other forms of renewable energy production. Therefore, economic efficiency must be given particular attention. Economic biogas production requires high biogas yields (Ress et al., 1998). Fifteen biogas plants are operating now in Latvia. The produced biogas is used for electricity co-generation. Most of the existing agricultural biogas plants are operating with maize substrate.

Energy crops used for biogas production should provide high organic dry matter yield and high methane output per hectare. Most suitable crops are those rich in easily degradable carbohydrates (Heiermann et al., 2009). The literature indicates that maize may be suitable for biogas production because it has the highest biomass yield potential of all field crops grown in Central Europe. Maize is yet the most dominating crop for biogas production in Europe (Cus et al., 2009). Also for agroecological condition of Latvia, maize can be suitable having high annual organic dry matter yield per hectare, and optimal for ensiling dry matter content. Several factors can affect biogas yield from maize substrate. Key parameters affecting biogas yield investigated so far, are the maize variety, time of harvesting, mode of conservation, and pre-treatment of the biomass prior to the digestion process (Amon et al., 2007). As crop growing season and plant developmental stage at harvest are other important factors that influence the forage quality of maize (Darby and Lauer, 2002), then we can predict that the same factors can affect also quality of maize as biogas substrate. The increasing use of maize as a biogas substrate raises questions concerning the morphology and chemical composition of the ideal maize (Schittenhelm, 2008). Maize is a crop with a rapid growth rate that yields best under moderate to warm temperatures. Cool temperatures slow down the progress to maturity, and high temperatures hasten maturity (Brown, 1997). The organic dry matter (ODM) content is an important factor influencing the microbial population and activity during ensilaging.

Many problems that are still unresolved are pointed out in the fields of harvest time optimization, and assessment of energy maize production with respect to C and N flows at system level (Herrmann et al., 2006). In Latvia some investigations about harvest time influence on maize yield and quality were made before, but with typical forage maize hybrids (Gaile, 2010). Also results of our investigations on harvest time influence on maize OMD yield using other hybrids are previously partly published and reported during a scientific seminar (Bartuševics, Gaile, 2010), but in this paper new results of two additional years are included and outcome of all four research years' period is analyzed.

The paper aims to evaluate the impact of hybrid, harvest time and agro-meteorological conditions on maize biomass production for biogas

Materials and Methods

A three-factor field trial was carried out during 2008-2011 in the Research and Study farm "Vecauce" (latitude: N 56° 28´, longitude: E 22° 53´) of the Latvia University of Agriculture. Trials were arranged in four-replication randomized blocks with plot size of 16.8 m^2. Row width was 0.7 m. Planted population density was 83300 plants per ha. Original seed of ten maize hybrids (Factor B) in 2008, of eleven maize hybrids in 2009, and of fifteen maize hybrids in 2010 and 2011 (Factor A) with different maturity ratings defined by FAO number were used: Tango* (standard, FAO 210), Target[a] (FAO 180), Estelle[a] (FAO 200), Salgado* (FAO 200), Silas* (FAO 210), Turini[a] (FAO 220), Marco[b] (FAO 220), Progress[b] (FAO 220), Ceklad* (FAO 235), Ronaldinio** (FAO 240), Bombastic[b] (FAO 240), Celio* (FAO 250), KX A8151** (FAO 250), Cemet* (FAO 260), Fernandez** (FAO 260), Paroli[b] (FAO 260), Celido* (FAO 270), and Cefran** (FAO 340). The seven hybrids marked with asterisk were used in all trial years, four hybrids marked with two asterisks – in three (2009-2011) years, but others – only in one year – 2008 ([a]) or in last two years: 2010 and 2011 ([b]). Soil at the site was strongly altered by cultivation: sand loam with pH KCl – 6.7, available for plants content of P – 112 mg kg^{-1}, K – 99 mg kg^{-1}, and humus content – 19 g kg^{-1} in 2008, sand loam with pH KCl – 6.4, available for plants content of P – 129 mg kg^{-1}, K – 143 mg kg^{-1}, and humus content – 21 g kg^{-1} in 2009; and sod-gleyic sand loam with pH KCl – 7.2, available for plants content of P – 232 mg kg^{-1}; K – 190 mg kg^{-1}, and humus content – 26 g kg^{-1} in 2010 and 2011. Traditional soil tillage was used: mould-board ploughing in previous fall, cultivation and rototilling before sowing in spring. The following fertilizers were given: 148 kg ha^{-1} N (18+70+60), 34 kg ha^{-1} P, 75 kg ha^{-1} K. Maize was sown on May 6. Planting was carried out by a hand-handled planter at a 3-4 cm depth. Weeds were controlled by spraying herbicides: Arrat d.g. (tritosulfuron, 250 g kg^{-1}; dicamba, 500 g kg^{-1}) 200 g ha^{-1} and Titus 25 d.g. (rimsulfuron, 250 g kg^{-1}) 30-50 g ha^{-1} together with surfactant in 2008 and 2009, and Maisters OD 61 s.c. (foramsulfuron, 30 g L-^{1}, + jodosulfuron-methyl-sodium, 1 g L^{-1}) 1.5 L ha^{-1} + Estet 600 e.c. (2.4 – D, 600 g L^{-1}) 0.5 L ha^{-1} in 2010 and 2011 were applied when maize reached 3-6 leaves stage. In addition, Lontrel s.c. (clopiralid, 300 g L^{-1}) 0.4 L ha^{-1} together with Estete e.c. 0.5 L ha^{-1}were applied in 2009 for control of *Tussilago farfara* and *Artemisia vulgaris*. Mechanical weeding was used for the remained weeds in later maize development stages (in July of all years). Harvesting was done at three different times beginning on 5 September in 2008 and 2011, on 4 September in 2009, and on 3 September in 2010 at fourteen-day intervals. The yield was accounted from 0.7 m^2 at first and second harvest times, and from 8.4 m^2 at last harvest time. Samples were taken for every hybrid from every replication.

Composition of fresh maize yield was analyzed for all hybrids using standard methods: dry matter (DM) (samples were dried up to constant weight at 105°C) and organic dry matter (ODM) (calculated from DM and ash content) content. Results were statistically processed using methods of correlation and regression analysis.

Daily maximum and minimum temperatures were recorded by an automatic weather station located near the field experiment.

Sum of precipitation during the same period (May-September) was 230 mm in 2008, 327 mm in 2009, 454 mm in 2010, and 420 mm in 2011.

June and September of 2008 were cool, and the season in general was dry if compared with long-term average data; sum of active temperature was 1943 °C. Start of the season (May, June) in 2009 was too cold (Table 1) and unsuitable for the development of maize, but average day and night temperature in September was warmer if compared with long-term average data, active temperature sum per season was 2037 °C. The vegetation period in 2010 and 2011 was very suitable for development of maize. The trial years (2010-2011) were warmer than the long-term average. For characterizing conditions for maize growing in specific year, growing degree days (GDD) were calculated. To calculate daily GDD accumulation, the average temperatures for that day were taken (lowest plus highest, divided by 2) and subtracted the base temperature, which for maize is 10 °C. If the lowest temperature for a day is above 10 °C and the highest is 32 °C or lower, then this calculation can be done using actual temperature. If the lowest temperature is less than 10 °C, then 10 °C was used as the low temperature in the equation. If the highest temperature is above 32 °C, then 32 °C was used as the high temperature in the equation (Hoeft et al., 2000).

In 2010, accumulated GDD between planting and last harvest date were greater (931) if compared to 2011 (893), 2009 (761), and 2008 (735) respectively.

Table 1

The average day and night temperature and precipitation during maize growing season in 2008-2011 and in comparison with long-term average

Month	Long-term average temperature	Temperature, ºC				Long-term average precipitation	Precipitation, mm			
		2008	2009	2010	2011		2008	2009	2010	2011
May	11.2	11.3	11.0	11.9	11.3	43	24.2	18.0	72.6	47.6
June	15.1	14.6	13.7	14.6	16.8	51	44.2	95.0	37.8	40.0
July	16.6	17.1	17.1	20.8	18.8	75	56.8	136.0	131.8	149.8
August	16.0	16.4	15.8	18.2	16.1	75	90.2	38.8	133.4	150.6
September	11.5	10.6	12.9	10.8	12.5	59	14.8	39.8	78	32.2

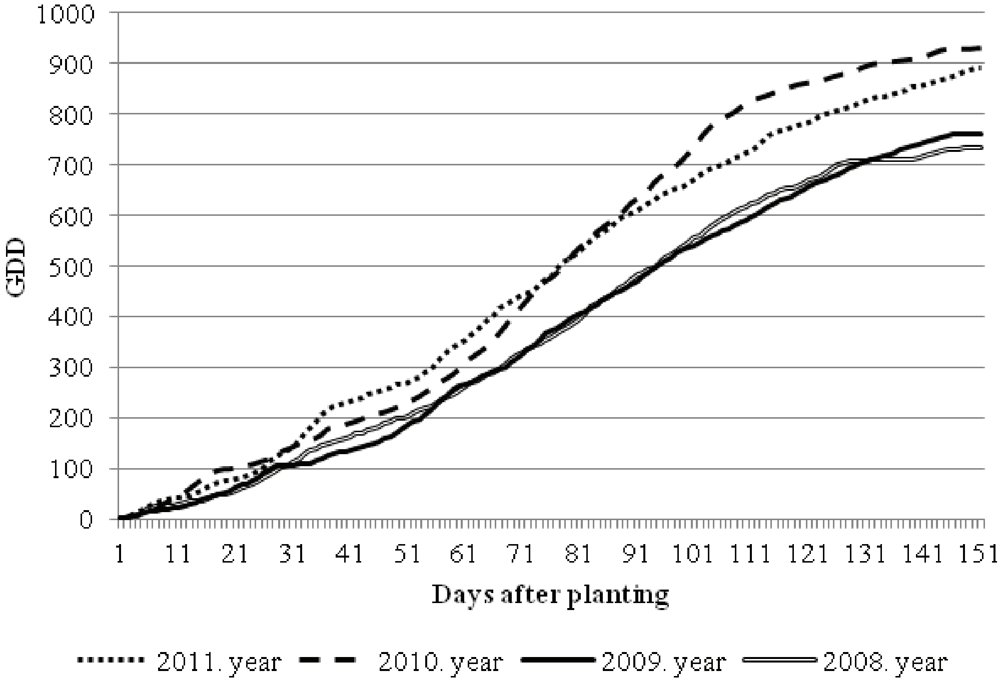

Figure 1. **GDD accumulation in the period between planting and last harvest date in all years**

Figure 1 shows that all the season of 2011 and 2010 was characterized by better warmth conditions if compared with 2009 and 2008.

Results and Discussion

In 2008, original seed of ten forage maize hybrids was used, because we were not informed about hybrids' best performance for biogas production. In that study year we tried to find out which maize hybrid produces the highest rate of organic dry matter (ODM) for biogas production. Consequently, starting with the second trial year, we included some new hybrids that are specially bread for biogas production. ODM yield substantially ($p<0.05$) depended on harvest timing in 2008. Average ODM yield increased by 2.35 t ha^{-1} from September 5 till October 3. Maize hybrid influence on ODM yield at first two harvest times (September 5 and September 19) was not substantial ($p=0.41$ and $p=39$, respectively), but maize hybrid influence at last harvest time (3 October) was substantial ($p=0.02$). Maize hybrid influence on average ODM yield also was not substantial ($p=0.148$) in 2008.

Performance of seven maize hybrids included in the trial during four years (2008-2011). Comparing results of all four trial years and of seven maize hybrids', ODM yield substantially ($p<0.05$) depended on harvest time. Average ODM yield increased from first till last harvest date. The influence of maize hybrid and vegetation period on average ODM yield was substantial ($p<0.05$). Highest average ODM yield from those seven hybrids per all years and harvest times gave hybrid Celio (13.99 t ha^{-1}). The highest average ODM yield per all harvest dates was reached in 2011 (15.48 t ha^{-1}). Range of average ODM yield of maize hybrids per all four trial years was wide – from 11.81 t ha^{-1} in 2008 to 15.48 t ha^{-1} in 2011 (Table 2). The lowest average yield of ODM yield was noted for hybrid Ceklad (12.15 t ha^{-1}). Our results showed that ODM yield in

Table 2

Organic dry matter yield of maize depending on year, hybrid and harvesting time, t ha^{-1}

Year - factor A	Harvest date	Hybrid - factor B							Average for A p<0.05
		Tango	Ceklad	Celio	Cemet	Celido	Salgado	Silas	
2008	05.sept	11.63	10.23	11.17	10.47	10.85	10.96	9.70	11.81
	09.sept	12.23	11.58	12.29	12.14	11.38	12.18	10.54	
	03.okt	11.59	11.96	12.99	14.29	13.59	13.00	13.23	
2009	04.sept	8.63	7.80	12.39	11.11	9.00	9.01	10.37	12.27
	21.sept	9.90	12.53	14.46	11.75	12.09	15.32	11.76	
	05.okt	13.51	13.37	14.87	15.18	13.03	15.72	15.85	
2010	03.sept	13.95	12.53	15.69	16.64	13.35	12.93	17.40	15.05
	17.sept	12.30	15.56	16.71	15.37	13.59	16.71	16.55	
	04.okt	12.24	13.74	15.30	16.67	16.33	15.47	16.91	
2011	05.sept	12.91	15.23	15.22	15.86	15.06	15.08	17.56	15.48
	19.sept	13.54	14.56	17.29	15.32	15.64	13.41	15.90	
	03.okt	15.22	16.50	15.87	16.69	15.21	15.74	17.40	
Average for B; p<0.05		12.30	12.15	13.99	13.73	12.58	13.48	13.59	x

Table 3

Organic dry matter yield of medium ripening maize depending on year, hybrid and harvesting time, t ha^{-1}

Year - factor A	Harvest date	Hybrid - factor B							Average for A p<0.05
		Ronaldinio	Celio	KX A8151	Cemet	Fernandez	Celido	Cefran	
2009.	04.sept	12.25	12.39	11.80	11.11	12.02	9.00	9.43	13.51
	21.sept	15.55	14.46	13.56	11.75	15.79	12.09	12.66	
	05.okt	16.09	14.87	17.93	15.18	17.44	13.03	15.22	
2010.	03.sept	15.88	15.69	18.34	16.64	20.57	13.35	16.75	17.21
	17.sept	18.16	16.71	19.24	15.37	18.59	13.59	16.48	
	04.okt	20.05	15.30	19.00	16.67	21.79	16.33	16.83	
2011.	05.sept	16.87	15.22	15,50	15.86	18.76	15.06	12.58	16.26
	19.sept	17.32	17.29	16.41	15.32	20.68	15.64	14.72	
	03.okt	16.67	15.87	15.73	16.69	16.46	15.21	17.66	
Average for B p<0.05		16.54	15.31	16.39	14.95	18.01	13.70	14.70	×

2008 and 2009 at all harvest dates was lower than that at all harvest dates in 2010 and 2011.

Performance of maize hybrids included in the trial during three years (2009-2011). Also comparing three – trial – year results of the group of four early ripening (200 – 239) maize hybrids and of the group of seven medium ripening maize hybrids (240 – 340), ODM yield substantially ($p<0.05$) depended on harvest date. In both maturity groups, ODM yield substantially ($p<0.05$) depended on conditions of vegetation period, and hybrid influence also was substantial ($p<0.05$). Average ODM yield per all harvest times and three (2009-2011) years of early ripening (FAO 200-239) maize hybrids was 13.98 t ha^{-1}, but of medium ripening maize hybrids (FAO 240 – 340) at the same harvest dates per three years – 15.66 t ha^{-1}. Among the maize hybrids of maturity class FAO 200-239, the hybrid Silas gave the highest ODM yield per hectare (15.52 t ha^{-1}). Among the hybrids of maturity class FAO 240-340, the highest ODM yield was achieved by the hybrid Fernandez (18.01 t ha^{-1}). The highest average yield in all harvest dates among early ripening hybrids was in 2011 (15.25 t ha^{-1}), and among medium ripening hybrids in 2010 (17.21 t ha^{-1}) (Table 3). A. Lemmer et al. (2003) found that the maize hybrids showed a clear dependence of dry matter yield per unit area on the time of harvest and maturity group.

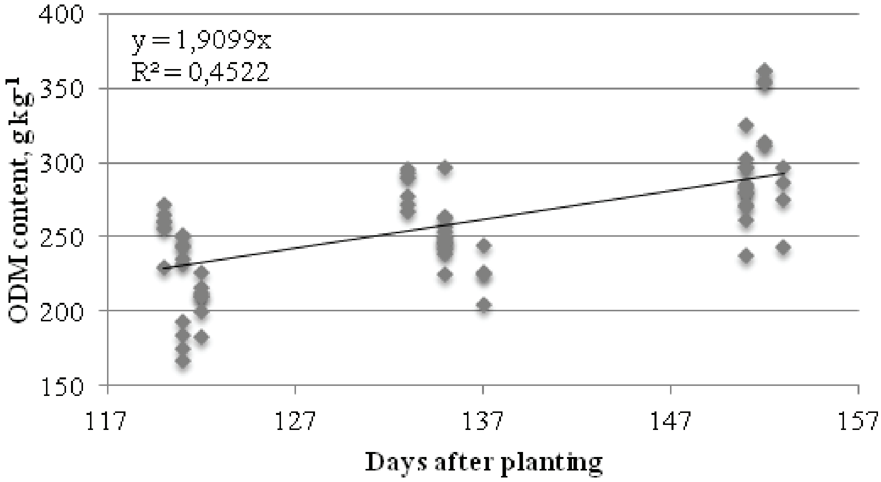

Figure 2. **ODM content of early ripening maize per all years depending on harvest time after sowing, $p<0.05$.**

Performance of maize hybrids included in the trial during two years (2010-2011). Suitable air temperature during the late three months of the growing season (July–September) caused good climatic conditions for biomass production in both last trial years (2010 and 2011). The greatest gain of ODM yield per hectare when harvesting later was found for hybrids included into the medium ripening group (FAO 240-340) in two trial years (2010-2011). Among the maize hybrids from maturity class FAO 200-239, the hybrid Silas gave the greatest ODM yield per hectare (16.95 t ha^{-1}). Among the hybrids of maturity class FAO 240-340, the highest ODM yield was achieved by the hybrid Fernandez (19.47 t ha^{-1}). There was an insignificant ($p>0.05$) year influence on ODM yield of early ripening maize hybrids, but hybrid and harvest date substantially ($p<0.05$) influenced ODM yield. A strong effect of meteorological conditions and hybrid on ODM yield was noted ($p<0.05$) for medium ripening maize hybrids, but influence of harvesting time was insignificant ($p>0.05$).

T. Amon et al. (2004) found that for late ripening maize hybrids the optimum methane yield per hectare is achieved if maize is harvested at the stage of dry matter content higher than 430 g kg^{-1} (43%). Methane yield from late ripening hybrids reached a maximum at full ripeness. Possibility in our conditions to reach so late developmental stage and so high DM content in yield is doubtful even using early maturity hybrids. In addition, hybrids which are considered medium ripening, in conditions of middle Europe are only early ripening.

There was a significant correlation between harvest time and ODM content of early ripening (FAO 180-239) maize hybrids ($r = 0.79 > r_{0.05} = 0.25$) (Figure 2) and also of medium ripening (FAO 240-340) hybrids ($r = 0.68 > r_{0.05} = 0.21$). Range of ODM content of all maize hybrids per all three harvest dates and all years was wide (from 158.73 g kg^{-1} (Celido at first harvest date in 2009) to 362.1 g kg^{-1} (Salgado at last harvest time in 2010)).

When maize was harvested with a high content of dry matter, the C:N ratio was outside the optimum range with regard to producing a maximum specific methane yield. Co-digestion of substrates with a narrower C:N ratio could help to overcome this disadvantage (Oslaj et al., 2010).

Conclusions

Four year period allowed to evaluate maize performance in different meteorological conditions – two years (2010-2011) were suitable even for growing medium ripening (FAO 240-340) hybrids, but in two years only earlier maturing (FAO 180-239) hybrids provided yield with more acceptable ODM content at later harvest dates. Our results showed that ODM yield in 2008 and 2009 at all harvest dates was lower than that at all harvest dates in 2010 and 2011. Warmth conditions of season were of great importance. But even in complicated growing conditions of 2009, some medium ripening hybrids (like Ronaldinio (FAO 240), Fernandez (FAO 260), and KXA 8151 (FAO 250)) showed good results.

Maize hybrid, vegetation period and hybrid influence on average ODM yield was substantial ($p<0.05$). An exception was noted if only results of last trial years (2010 and 2011) were compared: then harvest time influence was insignificant ($p>0.05$) for medium ripening maize hybrids and vegetation period influence was insignificant ($p>0.05$) on ODM yield of early ripening maize hybrids. The highest average ODM yield in all years was reached when maize was harvested at the last harvest time. But, according to the results of current investigation, it was not possible to conclude unambiguously that the last harvest date was always the best one: it depended on season and used hybrid. There was a significant correlation between the length of the growing season (days from sowing till harvesting) and the ODM content at harvest.

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Acknowledgments

This publication has been prepared within the framework of the ESF Project „Attraction of human resources to the research of the renewable energy sources", Contract No. 2009/0225/1DP/1.1.1.2.0/09/APIA/VIAA/129.