INFLUENCE OF MAIZE HYBRID AND HARVEST TIME ON YIELD AND SUBSTRATE COMPOSITION FOR BIOGAS PRODUCTION

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Abstract

Maize is increasingly used for energy production in agricultural biogas plants. The first biogas production project in agriculture is realized in the Research and Study Farm (RSF) "Vecauce" of the Latvia University of Agriculture in 2008 and animal manure together with plant biomass are planned to be used as substrate. The paper aimed to evaluate ten maize hybrids possibly suitable for biomass production at three different harvesting times.

Field trial was carried out in Research and Study farm "Vecauce" of the Latvia University of Agriculture in 2008. Ten maize hybrids with different maturity rating according FAO numbers (FAO 180 – 270) were harvested at three different times beginning on 5 September at fourteen days intervals. Results showed that harvest time effect on maize yield was substantial ($p<0.05$), but hybrid influence on the average yield per all harvest dates was not substantial ($p>0.05$). The highest organic dry matter yield was obtained harvesting maize on October 3. The Total N, crude ash, protein, fiber, cellulose, lignin, neutral detergent fibre (NDF) and acid detergent fibre (ADF) concentration decreased, but crude fat concentration increased during plant development. Relevance was not noticed between harvest dates and total carbon and hemi – cellulose content. The C : N ration rose from 34.76 at first, early harvest on 5 September to 37.97 at the last harvest on 3 October.

Key words: maize hybrid, harvesting time, biogas, chemical composition.

Introduction

From an ecological and economical perspective, biogas is an important source of energy. The fossil resources are limited. With the technological progress made in recent years, high energy efficiency and low-maintenance operation have made investment into biogas facilities more attractive. In the last ten to twenty years, biogas plants have become a major point in the effort to use renewable sources of energy to generate electricity in Western Europe. It is essential to develop sustainable energy supply systems that aim to cover the energy demand from renewable sources. Mitigation of greenhouse gas emissions through renewable energy production is of rising importance. Biogas production is of major importance for the sustainable use of biomass from agriculture as renewable energy source (Amon et al., 2007a). Production of methane rich biogas through anaerobic digestion of organic materials provides a clean and versatile form of energy. Biogas can be used for heat and power generation.

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).

Three biogas plants that use organic waste are operated now in Latvia. The biogas produced is used for electricity co-generation. Nowadays, only 1% of electricity produced from renewable energy resources is produced using biogas. But the Ministry of Environment of Latvia has developed a programme for biogas production and utilization in the period 2007-2011. The greatest potential of biogas production is related to agricultural sector: from 13 million m^3 of the biogas produced in 2011, ~64% should be produced using substrates from agriculture. In Latvia according to drastically increasing prices for energy during the recent years, the interest about energy from alternative energy resources and especially for biogas increases (Adamovics et al., 2008). The first biogas production project in agriculture is realized in the Research and Study Farm (RSF) "Vecauce" of the Latvia University of Agriculture in 2008 and animal manure together with plant biomass are used as substrate.

Maize has recently been established as an energy-rich and technically advantageous substrate for the production of electricity from renewable sources of energy in biogas plants. Maize is yet the most dominating crop for biogas production in Europe. Maize is considered to have the highest biomass yield potential of all field crops grown in Central Europe (Amon et al., 2007a). In Germany the acreage of maize for co-digestion with slurry or mono-digestion has been expanded which is mainly due to its high methane yields per hectare and the storability of maize silage (Herrmann et al., 2006). The increasing use of maize as a biogas substrate raises questions concerning the morphology and chemical composition of the ideal maize (Schittenhelm, 2008).

Key factors for a maximum biogas yield from maize are hybrid, time of harvesting, mode of conservation and pretreatment of the biomass prior to the digestion process, but also the nutrient composition of the energy crop. Guidelines on optimum maize production, optimum harvesting time, optimum nutrient composition, optimum conservation and pre-treatment technology must be developed. Requirements on the biomass quality are different when crops are anaerobically digested in biogas plants compared to being fed to cattle. The digester at the biogas plant offers more time to degrade the organic substance than the rumen does. In addition it is likely to assume that the micro-organism population in the digester is different from that in the rumen. Biogas plants can degrade cellulose to an extent of about 80% (Ress et al., 1998) whereas in the rumen and total digestive tract of ruminants cellulose will be broken down to a degree of approximately 40% and 59%, respectively. T. Amon (2002) found that maize silage gave a 21% higher specific methane yield than fresh maize. Lactic acid formation during silage delivers precursors that are important for methane formation during anaerobic digestion. Ninety five percent of maximum possible methane yield was achieved after 40 – 45 days of anaerobic digestion with all experiments.

With biogas production, the key factor to be optimized the methane yield per hectare. This may result in different harvesting strategies when growing energy crops for anaerobic digestion compared to growing them as a forage source for ruminants. Specific harvest and processing technologies and specific genotypes are required when crops are used as a renewable energy source (Amon et al., 2007b). Many problems that are still unresolved are pointed out in the fields of harvest time optimization, assessment of energy maize production with respect to C and N flows at system level (Herrmann et al., 2006).

The paper aimed to evaluate ten maize hybrids possibly suitable for biomass production at three different harvesting times.

Materials and Methods

Two-factor field trial was carried out in 2008 in Research and Study farm "Vecauce" (latitude: N 56° 28´, longtitude: E 22° 53´) of the Latvia University of Agriculture. Trials were arranged in four replication randomized blocks with plot size 16.8 m^2. Row width was 0.7 m. Planted population density 82000 plants per ha. Original seed of ten maize hybrids (Factor A) with different maturity rating defined by FAO number (Tango (standard, FAO 210), Target (FAO 180), Estelle (FAO 200), Salgado (FAO 200), Silas (FAO 210), Turini (FAO 220), Ceklad (FAO 235), Celio (FAO 250), Cemet (FAO 260), Celido (FAO 270)) were used. 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}, humus content – 19 g kg^{-1}. Maize was sown on May 6. Traditional soil tillage was used: mould-board ploughing in previous fall, cultivation and rototilling before sowing in spring. The following fertilizers were given : 34 kg ha^{-1} P, 75 kg ha^{-1} K, 148 kg ha^{-1} N (18+70+60). Planting was carried out by hand handled planter at 3-4 cm depth. Weeds were controlled by spraying herbicides (arrat d.g. 200 g ha^{-1} (triosulfuron 250 g kg^{-1}; dicamba 500 g kg^{-1}) and titus 25 d.g. 50 g ha^{-1} (rimsulfuron 250 g kg^{-1}) together with surfactant) on June 6, and mechanically on July 7. Harvesting was done at three different times (factor B), beginning with September 5 (120 days after sowing). The second harvest time was done on September 19 (134 days after sowing) and the third on October 3 (148 days after sowing). Yield was accounted from 0.7 m^2 on 5 and September 19 and from 8.4 m^2 on October 3. The following observations were carried out during the season: field germination, flowering, plant density before harvest, plants per ha (data are not presented), green, dry matter (DM) and organic dry matter (ODM) yield, t ha^{-1}. The following parameters were determined 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 ach content) content of fresh yield, crude protein, g kg^{-1} of DM (ISO 5983), crude fiber, g kg^{-1} of DM (ISO 5498:1981), cellulose, g kg^{-1} of DM (calculated from NDF and ADF), hemicellulose, g kg^{-1} of DM (calculated from NDF and ADF), lignin, g kg^{-1} of DM (calculated from ADF), crude fat, g kg^{-1} of DM (ISO 6492:1999) total N, (by Kjeldahl method), neutral detergent fibre (NDF), g kg^{-1} of DM (LVS EN ISO 16472:2006), acid detergent fibre (ADF), g kg^{-1} of DM (Forage analyses, USA, method 4.1:1993) and ash (XA), g kg^{-1} of DM (ISO 5984), total carbon (C), g kg^{-1} of DM (CS – 500 method)). Results were statistically analyzed using analysis of variance. Average day and night temperature from April 25 to October 3 was 14.3 °C. Sum of precipitation during the same period was 230 mm. Average soil temperature during maize germination from May 6 till May 21 was 10.8 °C. Season was cool and dry if compared with long term average data.

Results and Discussion

Plant management and the stage of vegetation when maize is harvested must be optimally chosen to maximize the methane yield (Amon et al., 2007a). Maize was harvested at three different times in course of the vegetation period. ODM yield substantially ($p<0.05$) depended on harvest time. Average ODM yield increased from September 5 till October 3 by 2.35 t ha^{-1} (Table 1). Maize hybrid influence on average ODM yield was not substantial ($p=0.148$). Range of average DM content of maize hybrids per all three harvest dates was wide (from 216.7 g kg^{-1} (Celio) to 266.4 g kg^{-1} (Target)) (Table 2), but average per all three harvest dates ODM yield for maize hybrids ranged from 11.28 t ha^{-1} (Silas) to 12.78 t ha^{-1} (Turini). Maize hybrid influence on ODM 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 ($p=0.02$). Average ODM yield was 95.2% from the total DM yield. T. Amon et al., (2007a) found the similar average ODM yield (95.8%) from the total DM yield.

T. Amon et al., (2004) reported that methane yield per hectare is markedly influenced by hybrid and time of harvesting. Late ripening maize hybrids (FAO 600) make better use of their potential to produce biomass than medium (FAO 300 – 600) or early ripening (FAO 240 – 300) hybrids in Austria. With early to medium ripening hybrids, the optimum harvesting time is at the „end of wax ripeness". Late ripening hybrids may be harvested later, towards „full ripeness". Z. Gaile (2008b) found that in conditions of Latvia wax ripeness could be reached only by using hybrids characterised by FAO numbers up to 220 and even so not always. It means that according to previous results hybrids, mentioned as "early ripening" in Austria are too late for Latvia (Gaile, 2008a).

Table 1

Organic Dry Matter Yield of Maize Depending on Hybrid and Harvesting Time, t ha^{-1}

Hybrid – factor A	FAO	Maize harvesting time – factor B			Average for A
		5.09.2008.	19.09.2008.	3.10.2009.	$p=0.148$
Tango - st.	210	11.63	12.42	11.77	11.94
Ceklad	235	10.23	11.75	12.15	11.38
Celio	250	11.17	12.49	13.19	12.28
Cemet	260	10.47	12.34	14.52	12.44
Celido	270	10.85	11.55	13.80	12.07
Estelle	200	10.79	11.37	14.01	12.06
Target	180	11.32	12.76	12.68	12.25
Turini	220	11.56	13.38	13.40	12.78
Salgado	200	10.96	12.38	13.21	12.18
Silas	210	9.70	10.71	13.44	11.28
Average for B $LSD_{0.05}=0.56$	x	10.87	12.12	13.22	x
$LSD_{0.05}$ or p – value for hybrid at specific harvest time	x	$p=0.41$	$p=0.39$	$p=0.02$ $LSD_{0.05}=1.87$	x

T. Amon et al., (2007a) found that the latest harvest at full ripeness resulted in a loss in net total biomass yield. The reduction in biomass yield from late harvesting of early ripening maize hybrids may be due to respiration and/or breakage losses. The optimum harvesting time for maize is reached at a dry matter content of 30 – 35%. Maize can then easily be ensilaged and gives maximum biomass yields. A. Lemmer et al., (2003) found that the maize hybrids showed a clear dependence of dry matter yield per area unit on the time of harvest and maturity group. Scientists recommend using maize for biogas production that matures only slightly later (maximal 50 FAO units) than the forage maize typically grown at a given location (Schittenhelm, 2008).

DM content depended on harvest time. Average per all three harvest dates DM content for maize hybrids ranged from 216.7 g kg^{-1} (Celio) to 266.4 g kg^{-1} (Target) (Table 2). Another hybrid which showed high average DM content per all three harvest dates was Turini (259.7 g kg^{-1}). The highest average DM content was reached when maize was harvested on October 3. Highest DM content was reached by two hybrids (Target 307.40 g kg^{-1}, Silas

305.80 g kg^{-1}) on 3 October (Table 2). From September 5 to October 3 DM content increased by 67.6 g kg^{-1}.

Average dry matter content 294.9 g kg^{-1} was reached by early ripening (FAO 180-220) maize hybrids at last (October 3) harvest time, but for medium ripening maize hybrids (FAO 235 – 270) average DM content at the same harvest date was 247.8 g kg^{-1}. T. Amon et al., (2004) found that with late ripening maize hybrids, the optimum methane yield per hectare is achieved if maize is harvested at >430 g kg^{-1} (43%) dry matter. Methane yield from late ripening hybrids reached a maximum at full ripeness. Possibility in our conditions to reach so late development stage and so high DM content of yield is doubtful even using early maturity hybrids.

Table 2

Dry Matter Content of Maize Depending on Hybrid and Harvesting Time, g kg^{-1}

Hybrid – factor A	FAO	Maize harvesting time – factor B			Average for A
		5.09.2008.	19.09.2008.	3.10.2009.	
Tango - st.	210	221.20	250.90	280.40	250.80
Ceklad	235	191.60	234.70	246.90	224.40
Celio	250	188.80	217.60	243.70	216.70
Cemet	260	195.00	213.80	258.40	222.40
Celido	270	184.70	206.20	242.00	211.00
Estelle	200	219.00	254.80	289.90	254.50
Target	180	234.10	257.70	307.40	266.70
Turini	220	223.40	262.20	293.60	259.70
Salgado	200	218.90	247.20	292.10	252.70
Silas	210	207.90	259.40	305.80	257.70
Average for B	x	208.46	240.44	276.02	x

The total N, crude ash, protein and fiber, cellulose, lignin, NDF and ADF concentration decreased during plant development (Table 3). The highest ash content 41.2 g kg^{-1} was noted on 5 September. The highest average crude protein was also noted on 5 September (77.9 g kg^{-1}) and lowest on 3 October (69.1 g kg^{-1} %). Average Crude protein content between hybrids ranged from 67.8 g kg^{-1} (Tango) to 76.6 g kg^{-1} (Celido).

Methane production from organic substrates mainly depends on their content of substances that can be degraded to CH_4 and CO_2. Composition and biodegradability are key factors for methane yield from energy crops. Crude protein, crude fat, crude fiber, cellulose, hemi – cellulose, starch and sugar markedly influence methane formation (Amon et al., 2007a).

Table 3 gives average chemical content of maize hybrids at different harvesting times. The C : N ration rose from 34.76 at first, early harvest on 5 September to 37.97 at the last harvest on 3 October.

The raw fiber content has a decisive influence on the degradability of the organic dry substance and thus negatively affects the methane yield. C : N ration of the substrates also exerts a significant influence on the methane yield (Lemmer et al., 2003). When the C : N ration is too wide, carbon can not optimally be converted to CH_4 and the CH_4 production potential is not fully used. A. Lemmer et al., (2003) found that if C : N ration is only approximately (15 : 1) the organic mass cannot be completely converted even at low fiber contents. Substrates having a C : N ratio of (37 to 45 : 1), like silo maize, allow a significantly higher percentage of the organically bound energy to be converted. The crude fiber content decreased from first to the last harvesting date.

According to findings of T. Amon et al., (2004) crude protein, crude fiber and cellulose content declined in the course of the vegetation period. Hemi – cellulose and starch content increased.

Table 3

Average Content of Chemical Components of Ten Maize Hybrids, g kg^{-1}

Chemical components	g kg^{-1} in dry matter		
	5.09.2008.	19.09.2008.	3.10.2009.
Crude ash	41.2	38.5	34.8
Total N	12.5	11.8	11.1
Crude protein	77.9	73.8	69.1
Total carbon	433.5	410.7	419.3
Crude fiber	232.3	208.8	202.7
Crude fat	15.9	19.7	22.3
Cellulose	240.4	234.6	225.3
Hemi – cellulose	224.5	191.9	197.3
Lignin	10.3	8.9	8.9
Neutral detergent fibre	461.2	435.4	431.5
Acid detergent fibre	250.7	243.5	233.2
C : N ration	34.76	34.76	37.94

Strong harvest date effect was noticed of NDF and ADF content. Table 3 shows that from September 5 to September 19 average NDF content decreased by 25.8 g kg^{-1} and from September 19 to October 3 by another 3.9 g kg^{-1}.

Crude fat concentration increased during plant development. Average crude fat content for maize hybrids ranged from 15 g kg^{-1} (Celio) to 23 g kg^{-1} (Target). Marked relevance was not noticed between harvest dates and total carbon and hemi-cellulose content.

Hybrids with a high protein, fat cellulose, hemi – cellulose, and starch content and with a high potential for biomass production were especially suitable for anaerobic digestion. Crude fiber did not give much methane (Amon et al., 2004). T. Amon (2002) reported that specific methane yield did not depend on the maturity group, but on the nutrient composition that varied between hybrids.

Conclusions

Maize is optimally harvested when organic dry matter yield per hectare reaches a maximum. Our results showed strong harvest time effect on maize ODM yield. Highest ODM yield was obtained harvesting maize on October 3. The maize hybrid influence was not substantial on average ODM yield per three harvest dates. The data presented in this paper demonstrated that ODM yield increase from the first to the last harvesting date.

Delayed harvest of maize in Latvia resulted mainly in crude ash, total N, crude protein, crude fiber, cellulose, lignin, neutral detergent fibre (NDF) and acid detergent fibre (ADF) concentration decrease but crude fat concentration increase. Marked relevance was not noticed between harvest dates and total carbon and hemi – cellulose content.

This paper demonstrated that the C : N ration rose from 34.76 at first, early harvest on 5 September to 37.97 at the last harvest on 3 October.

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