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Utilization of Sweet Sorghum as a Catch Crop for providing Raw Materials for the Production of Bioethanol and Biogas

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A combination of the production of bioethanol from sugar orstarch crops and biogas from the residues is reasonable for the optimization of small and decentralized plants.Sorghum could be an interesting alternativefeedstock with high biomass potential. Compared to e.g. maize sorghum provides similar yields at a shorter vegetation period by less water demand. Moreover, it is an alternative to maize and wheat concerning the production of bioethanol. Different processing lines for the combined production of bioethanol and biogas were developed.
In the present study three different sorghum varieties (Sugargraze 1, Sugargraze 2 and Chopper) were compared regarding sugar, starch and overall biomass yieldsto provide data for the calculation of bioethanol and biogas potential.

1. Introduction

Bioethanol production from wheat grain and maize corn compete directly with food and feed production. The utilization of alternative crops that can be grown within a shorter vegetation period can relieve this conflict since also food, feed or other energy crops can be grown on the same field in the same year. Sorghum is a promising option as it provides similar biomass yields as conventional crops (Geng et. al, 1989; Amaducci, 2004). To achieve a wide application of sorghum as a crop for bioenergy production it is necessary to prove its economic equality or even advantage to maize or wheat. In this work the integrated process of combined bioethanol (EtOH) and biogas production based on different types of Sorghum is described. To provide data for an evaluation of the process field tests with different Sorghum varieties were carried out. Ethanol yields per hectare were calculated using sugar and starch yields. Possible biogas yields were calculated using the quantity and the composition of the remaining biomass. The Sugargraze 1 (SG 1) main crop (MC) type was planted on May, 5th and the catch crop (CC) varieties of SG 1, Sugargraze 2 (SG 2) and Chopper (C) were planted on May, 25th.

1.1 Concepts

Depending on the Sorghum variety different process chains can be applied for the combined production of bioethanol and biogas (Figure 1). Focusing on the starch variety it is necessary to

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separate the straw from the grain while carrying out the harvest. Depending on the water content of the grain it can be necessary to perform a post drying in order to guarantee a stable storage of the starch. The straw is conserved as silage and can be used directly for biogas production. The grain can be processed continuously throughout the year, therefore only a small sized plant is needed. The starch has to be hydrolysed to sugars, which is done using e.g. α-Amylase at temperatures between 28 °C and 60 °C (Robertson et al., 2006).

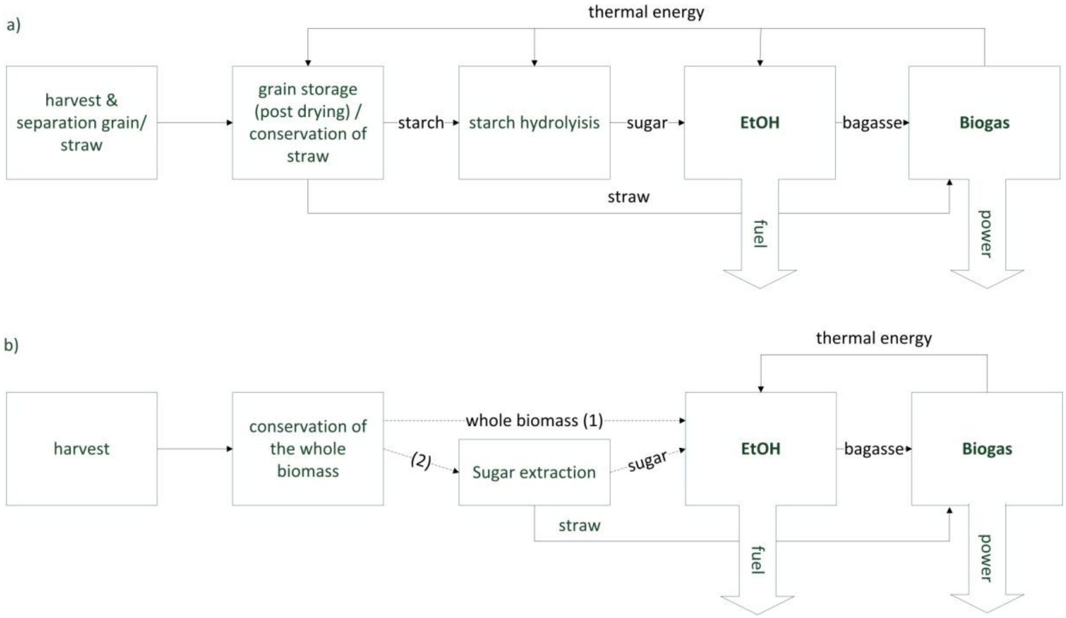

Figure 1: process chains for the combined production of bioethanol and biogas from Sorghum using a) a starch variety or b) a sugar variety

If the sugar variety is used the fermentation can be performed directly. Depending on the sugar content either only extracted sugar (e.g. pressing) or the whole biomass passes through ethanol fermentation. For distillation of the ethanol thermal energy is required. Residuesand bagasse generated in the process are used for biogas production.

Thermal heat required for drying, hydrolysis and distillation can be provided using the biogas for combined heat and power (CHP) production. This offers an opportunity for increasing the overall efficiency of small and decentralized plants.

2. Methods

To estimate the potential of Sorghum for bioethanol and biogas production the knowledge of the exact sugar and biomass yields is necessary. Determination of DM and sugars was done in field tests carried out between July and November (Table 1).

Table 1: harvesting dates

1st harvest	2nd harvest	3rd harvest	4th harvest	5th harvest
26. July	24. August	13. September	29. September	01.November

2.1 Sugar content

Sugar content was analyzed according to the procedure of Becker et al. (2012) after lyophilizing and derivatization of the samples using GCMS (GC 7890A / MSD 5975C instrument with a fused silica HP-5ms column and helium as the carrier gas).

2.2 Calculation of ethanol potential

Using the starch variety for ethanol production first a hydrolysis of the starch to fermentable sugars has to be done. Starch can be completely hydrolyzed to sugars (Barcelos et al., 2011).

$$C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6 \quad (1)$$

Calculation of the ethanol potential was done using equation(2),according to which0.51 kg of ethanol and 0.49 kg of CO_2 can be produced from 1 kg of sugar. In practice yields of 90% (Wang et al., 2008) could be obtained.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (2)$$

2.3 Calculation of biogas potential

The calculation of the theoretical biogas potential as well as the expected methane concentration was done using the model according to VDI 4630 (2006) which requires data regarding contents of carbohydrates, fats and proteins (Table 2). For determination of Carbohydrate, fat and protein content Weender analytic was used (Kirchgeßner and Roth, 2008).

Table 2: theoretical biogas production and methane concentration of carbohydrates, fats and proteins according to VDI 4630

substrate	biogas l_N kg VS^{-1}	methane %
carbohydrates	750	50
fats	1390	72
proteins	800	60

3. Results

The sugar yield of the SG1 varieties (both CC and MC)had beenincreasing until the second and third harvest respectively and decreased then slightly. The main crop reaches its maximum before the catch crop. The fifth harvest could not be carried out because the crops were damaged by stormy weather and were lying on the ground already decomposing. Maximum sugar yield of the SG2 CC variety was measured at the second harvest, but at about 2 t per hectare it was only the half in comparison to the SG1 varieties. From the third to the fifth harvest sugar yieldwas under 1 t per hectare (Table 3).

Table 3: sugar yield of three catch crop (CC) Sorghum varieties (SG1, SG2 and C) and one main crop (MC) variety (SG1) grown in Lower Austria 2011

	1st harvest t ha^{-1}	2nd harvest t ha^{-1}	3rd harvest t ha^{-1}	4th harvest t ha^{-1}	5th harvest t ha^{-1}
C	0.59	1.87	1.71	8.06*	1.80
SG1 CC	0.64	1.90	4.46	3.66	0.00
SG2 CC	1.08	1.99	0.37	0.67	0.45
SG1 MC	1.55	4.00	3.92	3.31	0.00

*0.86 free sugars from residual biomass and 7.20 sugars from grain (starch)

As C mainly builds starch, the content of free sugars in the green parts ofthe plant is only of minor interest for ethanol production. Nevertheless, it promises a high biogas production if the straw is conserved properly. As the sugar is transformed to organic acids, e.g. lactic acid, it is of great importance for the quality of the silage. The sugar yields from the straw vary between 0.59 and 1.87 t per hectare. At the fourth harvest also the sugar resulting from the starch was calculated as this is the most realistic harvesting period in practice. In total the sugar yield is 8.06 t per hectare where 7.2 t are resulting from starch. Fructose and glucose decrease from a starting point of 30% of the sugar content to a level of 20 % in fourth and fifth harvest. In the same period the sucrose content increases from 40 % to 60 %. Galactose has its maximum at the fourth harvest at 2%. Total sugar content in the plant has its minimum at the fourth harvest that could have its reason in the increased starch formation at the same time. Total sugar content increases again at the fifth harvest.

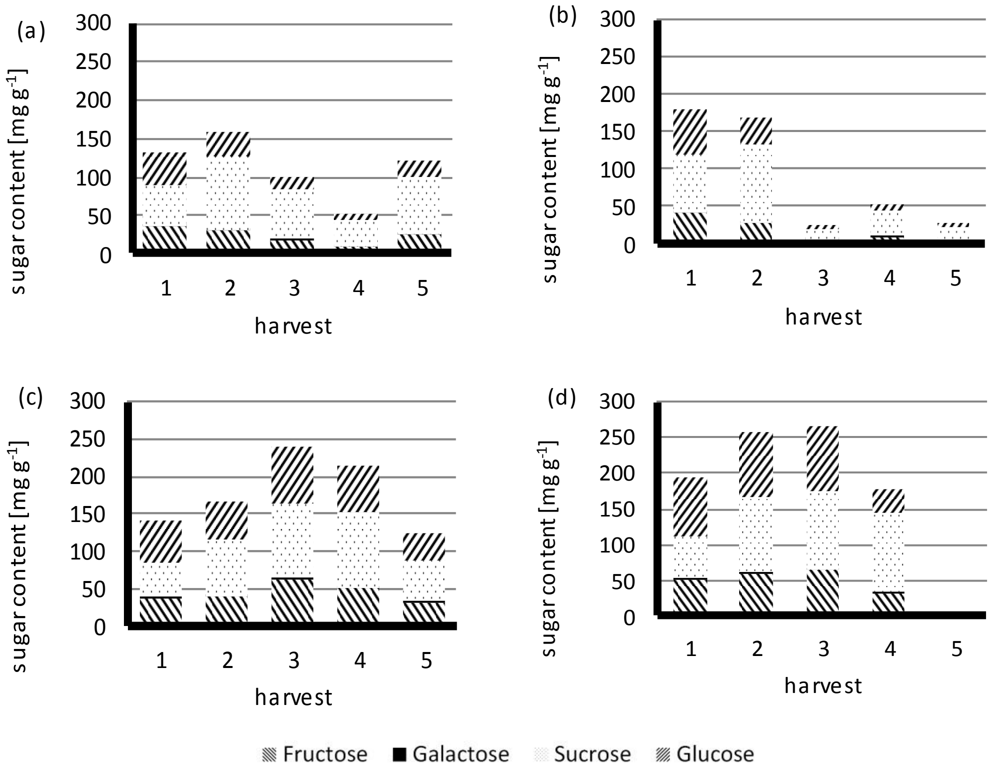

Figure 2:Composition of the sugar content of the Sorghum varieties a) C (CC), b) SG2 (CC), c) SG1 (CC) and d) SG1 (MC)grown in 2011

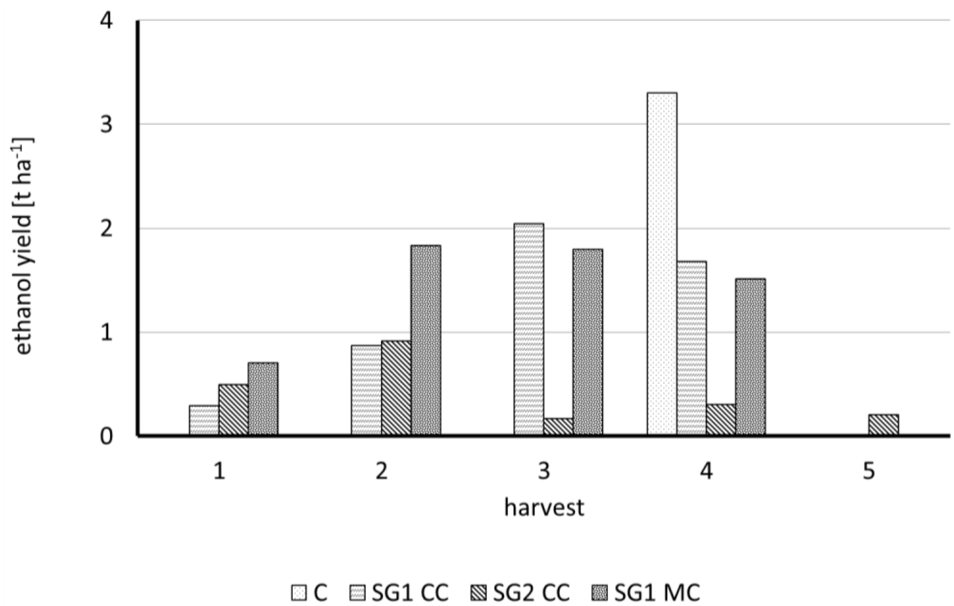

Figure 3: calculated ethanol yields of three different Sorghum varieties (SG1, SG2 and C) grown as catch crop (CC) and one variety (SG1) grown as main crop (MC) in 2011

Focusing on the SG1 CC sample it can be seen that fructose content is stable at 25 %. Galactose is throughout the whole vegetation period under 1 %. Sucrose increases from 30 % to 45 % while glucose decreases from 40 % to 30 %. The fructose content of the SG1 MC variety decreases continuously from 27 % to 18 %, Glucose content also decreases from 42 % to 19 %. Sucrose increases at the same time from 30 % to over 60 %. Galactose content is under 1 %.
The concentrations of the sugars in SG2 CC are fluctuating very much in the course of the vegetation period. The major constituent is sucrose, starting at 40 % and with a peak of 62 % at the second harvest. At the end 60 % of the sugar content is sucrose. Glucose and fructose decrease continuously from 34 % to 17 % and from 22 % to 14 % respectively. The highest galactose content was at 3 % at third and fifth harvest (Figure 2).
The relation between the ethanol potentials of the different Sorghum varieties is more or less the same as the relation between the sugar yields. Only the variety C gives other potentials as only the starch is used for ethanol production (Figure 3). Remaining free sugars in the straw are used for biogas production.

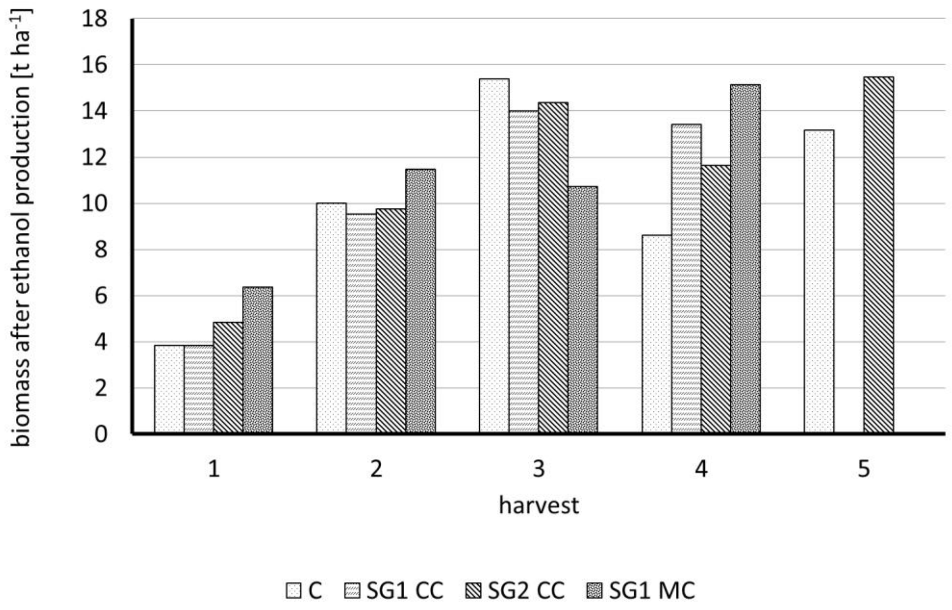

Figure 4: yield of residual biomass after bioethanol production of three different Sorghum varieties (SG1, SG2 and C) grown as catch crop (CC) and one variety (SG1) grown as main crop (MC) in 2011

Assuming a complete transformation of the sugars and also a complete distillation of the ethanol, the highest biomass yields are provided at the third and fourth harvest (Figure 4). For practical application the fourth harvest is the most important one.

Table 4: biogas potentials of three Sorghum varieties grown as catch crops

	biogas	methane	biomass	methane per hectare
	l_N kg VS^{-1}	l_N kg VS^{-1}	t ha^{-1}	m^3 ha^{-1}
SG1 CC	592,84	308,29	13,42	4.138,13
SG2 CC	405,20	210,15	11,66	2.449,89
C (straw)	664,11	340,59	8,61	2.933,84

The calculated methane potential of SG1 CC is at the highest level, followed by the remaining straw of C. SG2 CC provides the least methane per hectare (Table 4). Assuming a lower heating value of 8 kWh per kg of ethanol and 10 kWh per m³ of methane the highest energy output can be expected using the grain of C for ethanol and the crop residues for biogas production. This option allows production of 29,372 kWh per hectare. Utilization of SG1 CC could provide 17,581 kWh per hectare. SG2 CC could only provide 4,915 kWh per hectare as sugar content and therefore also ethanol yields are very low.

4. Conclusion

The tremendous potential of Sorghum for energy production has been proven. The provision of several different types of renewable energy (fuel, electrical and thermal energy) from distinct decentralized plants can meet various requirements. The choice of the Sorghum variety is of great importance and depend e.g. on climate- and soil conditions as well as on harvesting and processing technologies. Under the growing conditions of Lower Austria in 2011 the starch variety Chopper provided the highest energy output.

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