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Research paper

Sorghum, a sustainable feedstock for biogas production? Impact of climate, variety and harvesting time on maturity and biomass yield

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ABSTRACT

The experiments comprised three vegetation periods of five sorghum varieties. Novel data on the development of biomass yield, maturity level and biogas production were gained. Dry matter (DM) biomass yield ranged between 15.7 and 20.67 t ha^{-1} when sorghum was grown as main crop. The variety SOR 4 achieved a methane yield of 6500 m^3 ha^{-1}. The suitability of different sorghum varieties as summer catch crops was measured and assessed by combining growing degree days (GDD; temperatures > 10 °C) and maturity stage. This paper introduces a correlation of yields in course of the vegetation period with GDD values which enables to transfer yield and economic efficiency predictions from present results to other sites.

Sorghum is able to provide high-yields when used as catch crop, whereby an adapted varietal selection is indispensable. The sorghum variety SOR 2 (year2) of 1100 growing degree days (GDD) proofed to be fast ripening and is especially suitable as a summer catch crop. This variety achieved mean DM yields of 12.4 t ha^{-1} when used as summer catch crop.

Within this study crop maturities between 20 and 45% DM were investigated. Within this range, no decrease in specific methane yield with the increase in maturity and DM yield was observed.

The three year experimental data also included one year with low precipitation. The statistical analysis did not reveal a significant influence of the precipitation on the biomass yield which confirms the drought resistance of sorghum. This result is especially important in view of adaptation to climate change.

1. Introduction

Anaerobic digestion (AD) of energy crops has seen a startling series of developments since the late 90s. Due to various developments in the recent past (energy and commodity prices, food/fuel discussions, climate change, etc.) the use of a wider spectrum of energy crops and organic biomass has gained a growing importance. Up to date about 17 000 AD-plants with a total installed electric capacity of about 8.3 GW are operated within the EU. Germany, a leading country in this field, generates 5 GW from 10 000 AD plants [1].

Maize is currently the most predominant cultivated energy crop for biogas production in Central Europe. In Germany, maize represents about 73% of the total biomass used for AD [2]. According to a number of estimates 25% of total bioenergy production in Europe will be covered by biogas production in the near future [3]. Considering these estimates the demand for the cultivation of energy crops will consequently increase [4]. Outside Europe especially China and India are intensifying the establishment of renewable energies and technologies such as biogas production will play an

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important role in the future [5,6].

Since the cultivation of energy crops is usually carried out in parallel with agricultural food and feed production on the same arable land solutions are required for the competition between agricultural crops.

The sustainable production of food and feed must be a priority. The cultivation of energy crops on former forest and pastures as proposed by some authors, would lead to a significant increase in greenhouse gas emissions in the long run and is therefore not a sustainable alternative to overcome the aforementioned issues [7]. The growing demand for biomass cannot be covered by an increase in cultivation areas.

The development towards increased prices of agricultural commodities in the recent past has led to a rethink of regulatory framework conditions in various European countries. As a result AD plants solely accepting main crops will be restricted in the future, so called 2nd generation AD plants are underway favouring alternative feedstocks such as agricultural residues and catch crops [8–10]. Catch crops have short growth periods and can be cultivated between the vegetation periods of the main crops. Typical time periods for catch crops in Europe range from June to October (summer catch crops) and from October to April (winter catch crops). Furthermore, they are usually not used for food production and thus they positively contribute to solving the food vs. fuel debate. The selection of a suitable cultivar adapted to given climate conditions as well as the efficient cultivation in an integrated crop rotation systems is crucial in order to achieve high biomass yields [11]. The increase in efficiency in cultivation with regard to limited resources such as agricultural areas and plant-available water in the context of climate change, is therefore an indispensable necessity [12].

In the search for alternative biogas raw materials, sorghum is currently of a growing interest. It is a fast growing crop and is characterised by a wide adaptability to different environments and soil conditions and by an improved drought resistance compared to typical energy crops used in agriculture [13–15].

In several cultivation studies it could be shown that sorghum is able to provide biomass yields similar to the one of maize. It was demonstrated that sorghum can be cultivated in various climatic regions such as in Southeast China, central USA, Brazil and Europe. Typical biomass dry matter yields ranged between 10 and 23 t ha^{-1} [16–24]. Typical varieties investigated in long time field tests were *sorghum bicolor* and *sorghum sudanese.*

Although not many data on early and late maturing sorghum cultivars are available, varieties such as *Bovital* showed average yields between 11.6 t ha^{-1} and 15.2 t ha^{-1}. In a one year cultivation study of various sorghum varieties *Maja* and *Cerberus* achieved at two different locations biomass yields of 15.4–20.7 and 18.6–22.7 t ha^{-1}, respectively [18,19,23]. In the frame of a field study in Shanghai applying sorghum in constructed wetlands to treat pig manure, biomass yields between 10.0 and 17.6 t ha^{-1} DM could be achieved [20]. Similar yields could be observed in a cultivation study at two sites in Brazil with different rainfall impact (774 mm vs. 1352 mm annual rainfall) [24].

A few studies also examined the potential of sorghum as a feedstock for biogas production. Methane yields from sorghum biomass ranged from 207 to 387 m^3 t^{-1}.

Pazderu et al. tested the influence of row spacing on biomass yield and methane yield, respectively. For the sorghum cultivars *Bovital, Sucrosorgo* and *Goliath* methane yields between 207 and 246 m^3 t^{-1} were achieved [19]. A similar study by Mahmood et al. who compared five different sorghum varieties (*Goliath, Bovital, Aron, Rona 1* and *Akklimat*) showed methane yields between 232 and 282, except Aron und *Rona 1*, where yields of 316 and 387 m^3 t^{-1} were observed [25]. A methane yield of 279 m^3 t^{-1} of sorghum variety *Rona 1* was determined by Wünsch et al. [26].

The aforementioned studies investigated the influence of different parameters such as row spacing, type of cultivar as well as irrigation on the biomass and biogas yield, respectively. However, in order to achieve optimal productivity with regard to land efficiency and biomass yield in existing crop rotations, there is a need to determine also plant and site specific parameters such as growth and maturity dynamics of individual cultivars considering also climate and soil conditions.

The cultivation of sorghum in existing crop rotations offers the possibilities of efficient energy crop cultivation, both either as main crop or as two-crop even in dry climatic regions of Central Europe. In a comprehensive field study over 4 years the authors could show that applying crop combination in double cultivation can even achieve higher biomass yield compared to single cultivation. The combination e.g. winter barley/sorghum reached in average 5% higher yields as maize in single cultivation [27]. But also other crop rotations including early harvested crops such as bread cereals and rapeseed fast-growing with sorghum and hybrids of sorghum/Sudan grass as second crop are promising combinations to increase field utilisation efficiency.

Very often so called plant growth calendars (calendar days) are used in agriculture to predict plant development for management decisions. However, calendar days can be misleading, especially for early crop growth stages. For example, a cool May can significantly delay a plant reaching the four-leaf stage, which directly affects optimal plant control strategies [28]. By means of GDD, growth experiences of certain varieties can be better compared over several years at one location. In addition, appropriate cultivation strategies can also be transferred to colder or warmer regions. Up to date about 30 different sorghum varieties are available on the market. Detailed information on growth characteristics and biomass yield are usually unavailable and/or not sufficiently provided. In general, crops are characterised mainly by the following three categories: Biomass yield (high/low); Maturity (early/late); Resistance against droughts, disease (high/low).

The focus within this study was set to select cultivars which cover the commercially available spectrum of sorghum species. The present study examines (i) the biomass yield and maturity development in course of the vegetation period and the total biomass yield of five different types of sorghum in a three year field experiment. Based on the measured growth dynamics, (ii) the optimum harvesting time at optimum silage quality was determined. (iii) A varietal assessment for single and double cultivation was performed including biomass yield, maturity and growth dynamics. Finally (iv) the specific methane-producing capacity as a function of the vegetation stage and crop type was analysed.

2. Material and methods

2.1. Crop selection

The sorghum species used in the experiments are listed in Table 1. All crops are pure sorghum bicolor types except SOR 2, which is a hybrid between *sorghum bicolor* and *sorghum Sudanese*.

2.2. Crop cultivation

2.2.1. Field site

The cultivation experiments were carried out at an experimental field site of the University of Natural Resources and Life Sciences (BOKU) Vienna in Gross-Enzersdorf (East Austria, 151 m above sea level, 48°20′N, 16° 56′E).

The climate is characterised by an average annual rainfall of 550 mm and an annual average temperature of 9.9 °C (Central