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*Full Length Research Paper*

# The impact of different tillage systems and nutrient levels on the biomass and Brix values of sweet sorghum (*Sorghum bicolor* L. Moench)

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**The biomass and Brix content of sweet sorghum was investigated in 2009 and 2010 to determine the most suitable tillage and fertilization treatments. The experiment was carried out at the Biomass Utilization and Crop Production Demonstration Centre of Szent István University. Both humus content and nitrogen (N) supply of the topsoil was insufficient. In 2009, which was a typical drought year, the yields ranged from 12.14 t/ha (direct drilling) to 56.11 t/ha (ploughing). There were significant differences between the tilled and non-tilled plots. In 2010 as in 2009, the highest yield of 63.52 t/ha was measured in case of ploughing, however cultivating and disk harrowing treatments showed similar biomass results. This study indicates that fertilizers had a significant effect on yields, as in both years highest biomass was obtained at 100 kg ha$^{-1}$ nitrogen rate. The highest Brix values were measured in 2009 (18.21%) and in 2010 (9.01%) in case of cultivation treatments. In the examination years, direct drilling showed the lowest results for biomass and also regarding Brix values. The results demonstrate that the fertilisation and suitable tillage is very important in the cultivation of sweet sorghum.**

**Key words:** Sweet sorghum (*Sorghum bicolor*), tillage, biomass, Brix.

## INTRODUCTION

The production and utilization of bioethanol have attracted worldwide attention as a strategy for reducing global warming and improving global energy security. However, the feedstocks for bioethanol production should be derived from inedible parts of food crops in order to avoid direct competition between bioethanol and food production (Sakai et al., 2007). Recently, the use of liquid biofuels (bioethanol and biodiesel), especially in transportation systems has shown a rapid global growth (Tabatabaei et al., 2011). First-generation fuels are generally made from sugar, grains or seeds, using only a specific (often edible) portion of the above-ground biomass produced by a plant, and relatively simple processing of the biomass is required to produce a finished fuel (Larson, 2008). Sugar cane, sweet sorghum and sugar beet are examples of bioethanol feedstocks that contain sugar (Ruane et al., 2010).

Sweet sorghum is closely related to grain sorghum. It is a member of the family Poaceae. The plant grows to a height of between 120 to 400 cm depending on the variety and growing conditions, and can be an annual or short perennial crop (Yu et al., 2008). It is highly tolerant to drought and it is a prospective plant for arable production due to its adaptability to poor soils (Sakellariou-Makrantonaki et al., 2007). Drought tolerance of sorghum is related to its extensive root system, the high number of fine roots and the structure of stems and leaves. In drought periods, sorghum is able to stop its metabolism processes. From the agronomic point of view, sweet sorghum is more environmentally friendly than maize because of its relatively low nitrogen (Barbanti et al., 2006) and water requirements (Mastorilli et al., 1999).

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**Table 1.** Depth of cultivation methods applied.

| Cultivation methods | Plough | Cultivation | Disc harrow | Direct drilling |
|---|---|---|---|---|
| Depth of tillage (cm) | 22 - 25 | 10 - 14 | 16 - 20 | 0 |

Compared to corn, sorghum has greater ability to recover from drought and has a higher yield potential under dry conditions (Bolsen et al., 2003). While it is grown for forage in temperate belt countries, it is often cultivated to obtain sugary juice in tropical and subtropical regions. Its sugar content is higher than that of sugar beet, and can be as high as 18 - 20%; however, it does not yield crystalline sugar.

Sweet sorghum can give a high alcohol output and it is suitable for bioethanol production. The best genotypes are able to produce 6,000 L/ha of bioethanol. This is also supported by the studies of Zhao et al*.* (2009) where bioethanol output derived from sugars found in the stem of sweet sorghum was as high as 5,414 L/ha. Gnansounou et al. (2005) concluded that sweet sorghum is one of the most favourable plants for bioethanol production amongst those currently being investigated and researched for suitability for use at an industrial level. Sweet sorghum is not only suitable for bioethanol production, but can also be a feedstock for hydrogen. During the fermentation of 1 ton of sweet sorghum stem with n-butyl acetate, 30 $m^3$ hydrogen, 114 kg butanol and 40 kg acetone are produced (Pantskhava and Pozharnov, 2006). Similar to maize, sweet sorghum is an excellent material to produce biogas. There is a significant potential to use it in biogas plants (Karellas et al., 2010). One ton of sweet sorghum has a biogas output of 600 – 1,000 $m^3$ (Weiland, 2000).

Sweet sorghum can be a suitable crop for bioethanol and biogas production and it offers an alternative in regions where maize production is uneconomic. However, further studies are needed on the subjects of harvesting, storage, cultivation methods and biology to utilize all the potential of this plant. The objective of this research was to study the effect of different tillage systems and nitrogen and potassium fertilisers on sweet sorghum under Hungarian climate conditions.

## MATERIALS AND METHODS

The experiment was set up at the Biomass Utilization and Crop Production Demonstration Centre of Szent István University (47° 46'N and 19° 21'E, 227 m elevation). The soil type of the trial area was classified as a rust-brown forest soil (Chromic Luvisol). The soil parameters (0 - 40 cm) were as follows: pH ($H_2O$) 6.76; organic matter content 1.32%; phosphorus content 371.1 mg $kg^{-1}$ and potassium content 184.0 mg $kg^{-1}$. Both the humus content and the nitrogen (N) supply of the topsoil were poor. The potassium and phosphorus supply of the soil were sufficient. The upper 40 cm layer of the soil contains 53% sand, 26% loam and 20% clay fractions, respectively. The climate is continental and weather extremes are typical. The mean annual temperature is 9.7℃. The average annual precipitation is 550 mm, two-thirds of which falls in the summer term (April-September). In the year 2009, the seasonal rainfall (133 mm) was distributed as follows: April, 2 mm; May, 28 mm; June, 54 mm; July, 18 mm; Aug., 27 mm; Sep., 4 mm. In the second cropping year (2010) the total rainfall (561 mm) was distributed as follows across the year: April, 40 mm; May, 161 mm; June, 172 mm; July, 43 mm; Aug., 38 mm; Sep., 107 mm. Hours of sunshine (from April 1 to October 31) was 1368 h in 2009 and in 2010 it was 1056 h. The trial included four cultivation treatments (ploughing-PL, disc harrowing-DH, cultivating-CU and direct seeding-DS) and seven different fertilisation treatments. The Table 1 shows the average depth of tillage in different cultivation treatments.

Nitrogen, as ammonium nitrate at ($N_0$, $N_1$, $N_2$) 0, 50, 100 kg $ha^{-1}$ and potassium as potassium chloride at ($K_0$, $K_1$, $K_2$) 0, 40, 80 kg $ha^{-1}$, were applied. The fertilization treatment combinations were as follows: $N_0K_0$, $N_1K_0$, $N_2K_0$, $N_0K_1$, $N_0K_2$, $N_1K_1$ and $N_2K_2$. Nitrogen was applied in two steps just before sowing and during the germination period because to minimize nitrogen leaching in extremely rainy season. The potassium fertilization was carried out before primary tillage. The sweet sorghum variety used in the trial was *Sucrosorgo*. The previous crop was winter wheat both in 2009 and 2010. Flail mowing and shallow soil mixing were followed by basic soil cultivation. After weeds appeared on the stubble, mechanical stubble cultivation was carried out. Mechanical weed control was carried out once with a cultivator. Chemical pest control was not necessary. The seeds were sown at a row distance of 70 cm and at a plant distance of 10 cm. The plot size used was 10 × 8 m with a walkway of 2 m between the plots. The number of plots was 84 with an individual plot area of 80 $m^2$. The experiment followed a strip-plot design with three replications.

Sweet sorghum plants from two 5 m inside rows were cut by hand from each treatment plot to determine biomass. Then the plants were measured on industrial tare scales type Kern De with a scaling of 10 g. Two plant samples were taken from each replication of each treatment. Brix content measurements were carried out between each node. Each node of the plant was cut and the internodes were pressed one by one. The juice samples obtained after pressing were tested. Samples were measured using a digital hand refractometer type ATAGO PR-201 (0 - 60% Brix). The refractometer was calibrated by distilled water before each series of measurements to ensure accurate results. The influence of the fertiliser levels and the cultivation methods on the biomass and Brix was analysed by one-way ANOVA (LSD 5%) test using SPSS (Sváb, 1981).

## RESULTS

### Effects of cultivation and fertilization on the green mass of sweet sorghum

In the first months of the trial year in 2009, the amount of rainfall was very low, only 15 mm between January and April. The upper 25 - 30 cm layer of soil dried out by the time of sowing. The dry soil conditions affected the germination and the initial growth of the plants. The cropping period was dry; there was only 133 mm of

**Table 2.** Biomass at harvest time (t/ha).

| Treatments | Cultivation methods | | | | F | Sig. | Mean |
|---|---|---|---|---|---|---|---|
| | PL | CU | DH | DS | | | |
| **2009** | | | | | | | |
| $N_0K_0$ | 26.51 | 21.43 | 22.86 | 14.52 | 3.9 | 0.05 | 21.33* |
| $N_1K_0$ | 40.63 | 25.56 | 28.33 | 13.73 | - | - | 27.06$^{ns}$ |
| $N_2K_0$ | 56.11 | 35.24 | 34.13 | 15.16 | 8.3 | 0.00 | 35.16* |
| $N_0K_1$ | 39.76 | 18.97 | 19.76 | 13.97 | 6.5 | 0.01 | 23.12* |
| $N_0K_2$ | 37.94 | 22.70 | 26.03 | 14.21 | - | - | 25.22$^{ns}$ |
| $N_1K_1$ | 42.78 | 24.60 | 26.98 | 12.14 | 10.2 | 0.00 | 26.63* |
| $N_2K_2$ | 46.35 | 48.97 | 30.24 | 21.19 | 4.2 | 0.04 | 36.69* |
| F | 8.7 | 5.6 | 5.4 | - | | | |
| Sig. | 0.00 | 0.00 | 0.00 | - | | | |
| Mean | 41.44* | 28.21* | 26.90* | 14.99$^{ns}$ | | | |
| **2010** | | | | | | | |
| $N_0K_0$ | 45.19 | 44.10 | 42.76 | 27.29 | 11.4 | 0.00 | 39.83* |
| $N_1K_0$ | 60.10 | 51.05 | 52.71 | 36.81 | - | - | 50.17$^{ns}$ |
| $N_2K_0$ | 63.43 | 55.90 | 55.24 | 37.67 | 12.0 | 0.00 | 53.06* |
| $N_0K_1$ | 46.48 | 43.76 | 47.57 | 27.38 | 24.9 | 0.00 | 41.30* |
| $N_0K_2$ | 47.52 | 44.57 | 42.76 | 28.24 | - | - | 40.77$^{ns}$ |
| $N_1K_1$ | 61.38 | 50.48 | 52.48 | 35.86 | 61.1 | 0.00 | 50.05* |
| $N_2K_2$ | 63.52 | 50.81 | 53.86 | 36.52 | 7.4 | 0.01 | 51.18* |
| F | - | 6,7 | 2.9 | 9.9 | | | |
| Sig. | - | 0.00 | 0.04 | 0.00 | | | |
| Mean | 55.37$^{ns}$ | 48.67* | 49.63* | 32.82* | | | |

*Significant and ns = not significant at LSD 5%.

precipitation until September, which is almost 100 mm less than the summer average. By contrast with 2009, the year 2010 was extremely wet, with high levels of precipitation measured in May and June and the mean temperature in cropping period was lower than usual. The amount of biomass harvested during the trial must be evaluated taking these facts into consideration (Table 2).

The green mass at harvest time was measured when the sweet sorghum was judged to be fully mature. In 2009, the highest stem yield (56.11 t/ha) was achieved with PL and the lowest was achieved with DS (12.14 t/ha). Significant differences were observed between tilled and non-tilled (direct seeding) plots. In 2009, DS was unfavourable for the growing of sweet sorghum. In the case of DS, winter precipitation could not be absorbed and stored by the soil properly. Dry periods during the cropping season may have resulted in lower fertiliser use efficiency, which further increased drought stress and had negative effects on biomass production. In 2010 as in 2009, we measured the highest amount of stem yield (63.52 t/ha) for PL treatment. The high level of rainfall in 2010 had the effect of levelling out the differences between the tilled plots; however, the CU and DH treatments could not reach as high biomass levels as were measured in the PL plots. The non-till treatment (DS) was inefficient in 2010; however, the high levels of precipitation helped the crop growth. The soil had enough moisture during the growing season in 2010 to ensure sufficient water uptake for crop growth. Also, adequate nitrogen mobilisation was achieved due to adequate water availability. The various nutrient levels were significantly different compared to the control in both years. The largest amount of green mass (56.11 t/ha) in 2009 was achieved with $N_2K_0$ treatment, while in 2010 the highest green mass (63.51 t/ha) resulted in case of $N_2K_2$ treatment.

## Refractometric sugar (Brix) levels in the stem of sweet sorghum

Sugar accumulation mechanisms in the stem must be examined to determine the optimum harvest time because sweet sorghum stalk is the feedstock for fermentation. Brix degree was used to determine the sugar content in the stem of sweet sorghum because it has high correlation with total sugar content. Measurements were carried out four times. Table 3 shows the refractometric sugar (Brix) values at biomass harvest time. The Brix degree at harvest time in 2009 ranged

**Table 3.** Refractometric sugar (Brix) levels at harvest time.

| Treatments | Cultivation methods | | | | F | Sig. | Mean |
|---|---|---|---|---|---|---|---|
| | PL | CU | DH | DS | | | |
| 2009 | | | | | | | |
| $N_0K_0$ | 15.92 | 13.81 | 15.76 | 13.72 | 9.7 | 0.00 | 14.80* |
| $N_1K_0$ | 18.03 | 16.21 | 16.57 | 15.26 | 7.1 | 0.00 | 16.52* |
| $N_2K_0$ | 17.15 | 18.21 | 17.96 | 17.65 | 3.5 | 0.01 | 17.74* |
| $N_0K_1$ | 14.95 | 13.44 | 16.87 | 13.89 | - | - | 14.79$^{ns}$ |
| $N_0K_2$ | 16.96 | 16.67 | 16.81 | 17.43 | - | - | 16.97$^{ns}$ |
| $N_1K_1$ | 17.94 | 17.23 | 17.44 | 14.75 | 7.9 | 0.00 | 16.84* |
| $N_2K_2$ | 16.39 | 17.93 | 15.63 | 15.07 | 7.2 | 0.00 | 16.26* |
| F | 10.5 | 8.6 | 5.9 | 8.4 | | | |
| Sig. | 0.00 | 0.00 | 0.00 | 0.00 | | | |
| Mean | 16.76* | 16.21* | 16.72* | 15.40* | | | |
| 2010 | | | | | | | |
| $N_0K_0$ | 7.77 | 8.29 | 8.53 | 6.70 | 10.4 | 0.00 | 7.83* |
| $N_1K_0$ | 7.45 | 9.01 | 7.93 | 7.03 | - | - | 7.86$^{ns}$ |
| $N_2K_0$ | 6.15 | 7.25 | 8.20 | 6.48 | - | - | 7.02$^{ns}$ |
| $N_0K_1$ | 7.93 | 7.99 | 7.71 | 6.99 | - | - | 7.65$^{ns}$ |
| $N_0K_2$ | 6.68 | 7.54 | 7.30 | 5.87 | - | - | 6.85$^{ns}$ |
| $N_1K_1$ | 6.83 | 7.94 | 6.18 | 7.38 | - | - | 7.08$^{ns}$ |
| $N_2K_2$ | 7.93 | 7.87 | 7.87 | 5.03 | 4,8 | 0,03 | 7.18* |
| F | 6.8 | 3.7 | 6.5 | 3.5 | | | |
| Sig. | 0.00 | 0.01 | 0.00 | 0.03 | | | |
| Mean | 7.24* | 7.99* | 7.67* | 6.45* | | | |

*Significant and ns = not significant at LSD 5%.

from 13.44 to 18.21%. Both the highest and the lowest Brix values were obtained for the CU treatment. In 2010, the average decreases in Brix values were about 10% for all the cultivation and fertilization treatments. The highest Brix value was obtained in the CU treatment (9.01 %). In 2010, the hours of sunshine were less than usual in this region and this had the effect that the sugar could not properly accumulate in the stalk.

Another major factor was that the average monthly temperatures were also low throughout the whole growing season. After evaluating the data, the highest Brix values compared to the control ($N_0K_0$) nutrient level were found with the $N_2K_0$ treatment in 2009. In 2010, the most suitable nutrient level was $N_1K_0$. In the $N_0K_0$ treatment, the Brix values were between 13.72 and 15.92%. Moreover, in both years, the DS treatment showed the lowest values among all the treatments. The mean results showed that no significant differences occurred between the tilled plots (PL, CU, and DH treatment). However, we found significant differences between the fertilization treatments in both 2009 and 2010. In the case of the cultivation treatments, significant differences between them were found only in year 2009. This could be because in 2010, the high levels of precipitation ”washed away’’ the differences between the cultivation treatments as there was sufficient water for the sweet sorghum during the cropping period. Apparently, both cultivation and fertilisation had an effect on the sugar content.

## DISCUSSION

Laddha and Totawat (1997) found that there is strong interdependence between yield and cultivation methods in sweet sorghum crop. Deep ploughing treatments increased the soil volumetric water content in the surface, sub-surface and deeper soil layers at sowing as well as at harvest time. This trial has confirmed this. The highest biomass values were obtained in the case of ploughing, cultivating and disking. The differences between the tilled plots and the non-tilled plots (direct sowing) are significant. Under tilled treatments, the growth of roots was not obstructed by compacted soil conditions and this helped the roots’ water uptake efficiency. Nitrogen affected the sorghum biomass in tilled plots of treatments PL, CU and DH compared to the non-tilled treatment DS. For the no-till treatment (DS), the limited water holding capacity of the soil reduced the effective nutrient uptake by plants. Similar results as this on influence of deep tillage on nitrogen uptake leading to biomass yield differences have been reported by Ouédraogo et al. (2007). Dry periods during the growing season may result in lower fertiliser use efficiency, which further increases drought stress and subsequently has a negative effect on yield.

Beside biomass, another key agronomic parameter for bioethanol production is Brix. Our experiment showed that in a dry season, Brix values ranged from 13 to 18% in the tilled and 13 to 17% in the non-tilled plots in 2009. These results are in the same range as reported by Almodares and Hadi (2009) and other authors who reported approximately 16 - 18% Brix as an average (Gnansounou et al., 2005; Zhang et al., 2010). Looking at Brix values across the growing season, the Brix value increased by 1 - 1.5% every week following the first measurement time. These results agree with the work reported by Davila-Gomez et al. (2011); they found that the selected sweet sorghum cultivars accumulated approximately 2% Brix per week. The aim of the Brix measurements carried out at different times was to establish the maximum sugar output per hectare and to define the optimal harvesting time. According to Prasad et al. (2007), the optimal harvesting stage is when the juice contains 15.5 to 16.5% Brix and this parameter is one of the most important to maximize ethanol yield. Nitrogen and potassium levels both had effects on the Brix value and fertilisation increased the Brix value in the stalk of sorghum. In contrast to the trial of Pholsen et al. (2001), the Brix degree was not increased by levels of nitrogen and potassium compared to the control treatment. The sugar content of sorghum stem decreased by 20% as a result of application of nitrogen and potassium at higher doses (187.5 and 150 kg/ha, respectively). According to their results, sugar content was not increased by potassium to any significant extent. In addition, Buxton et al. (1999) established that heavy nitrogen application inhibits the potassium absorption by roots. Based on the results of this study, to obtain the highest biomass and Brix values, ploughing is recommended as the most appropriate soil cultivation method. Nitrogen level should not exceed 100 kg/ha and potassium should not exceed 80 kg/ha.

## Conclusions

The results of this study indicated that sweet sorghum provides acceptable yields even when produced under conditions of limited precipitation. Therefore, sweet sorghum may be viable as an alternative feedstock for the bioethanol industry in the near future. However, in Hungary, there is no sweet sorghum based bioethanol factory. Our trial confirmed that the water storage capacity of soil in less-favoured production areas can be preserved with the help of appropriate soil preparation. Based on our results, PL proved to be the best agricultural cultivation method. Winter precipitation penetrates the soil and is stored more easily if the soil is sufficiently, rotated and compressed. Sweet sorghum was able to rely on this water supply in the case of the ploughing treatment. The stem is the most economically important product from sweet sorghum cultivation. According to our studies, the most optimal nutrient levels were $N_2K_0$, $N_1K_1$ and $N_2K_2$. The development of the vegetative parts was promoted by nitrogen and potassium. Fertiliser applications containing exclusively potassium ($N_0K_1$; $N_0K_2$) were ineffective. The ecological conditions of the trial area were particularly unfavourable; the field was also affected by drought (2009) followed by extremely high precipitation (2010) in the investigated years.

Sweet sorghum production as an energy source can perform well even in less-favoured conditions, thus the above results can serve as guidelines for more favourable harvest years also. The results of crop production studies may only be cautiously extrapolated to other weather conditions, even where similar conditions occur. However, our results from the year 2009 may indicate a sound basis for sweet sorghum production as an energy source, due to the fact that dry years are increasingly likely to occur in Hungary.

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