Agronomy Research **18**(S2), 1147–1153, 2020
https://doi.org/10.15159/AR.20.072

Sorghum dry biomass yield for solid bio-fuel production affected by different N-fertilization rates

D. Bartzialis*, K.D. Giannoulis*, E. Skoufogianni, A. Lavdis, G. Zalaoras, G. Charvalas and N.G. Danalatos

University of Thessaly, Dept. of Agriculture, Crop Production & Rural Environment, Fytokoy street, GR38443 Volos, Greece
*Correspondence: dbartz@uth.gr; kyriakos.giannoulis@gmail.com

Abstract. The objective of this study was to examine the effect on the dry biomass yield of two dfferent sorghum hybrids (H1 and H2) under five different N-fertilization levels (0, 70, 140, 210 and 280 kg ha^{-1}) in a soil which was formed by lacustrine deposits of Karla Lake and is characterized from the downward movement of calcium carbonate from the surface horizons due to leaching (*Fluventic Xerochrept*) during 2017. The results demonstrated a significant effect ($P < 0.05$) of fertilization only for one hybrid. Biomass yield ranged from 22.2 to 37.5 t ha^{-1}. For both hybrids, sorghum accumulated a high amount of biomass in stems. Dry stem/total biomass ratio was rather constant throughout the different fertilization treatments achieving 81.6 and 77.5% for the first (H1) and the second hybrid (H2), respectively. The second hybrid (H2) had a higher percentage of leaf biomass (20.1 vs. 13.8%) than the first (H1), but lagged behind in seed production (2.4 vs. 4.6%). Biomass dry matter partitioning and total dry weight are important selection criteria for energy crops, due to different gross calorific value and ash content but also because of the different economic importance they may have e.g. the seed is also used as animal feed. The above high biomass yields of sorghum, confirming the high potential of this crop, should be taken into serious consideration regarding land use planning, but further investigation for the gross calorific value and the ash content is needed as well as biomass characteristics that are quite important in case to improve the combustion process.

Key words: biomass, sorghum, dry weight, stems, leaves.

INTRODUCTION

Nowadays countries all over the world are facing a problem due to the depletion of the conventional fossil fuel sources and the prediction of doubling the energy demand within a decade, and thus have raised concerns about unsure energy supply in the coming future (Rehman et al., 2013; Nurmet et al., 2019). Therefore, the interest of new environmental friendly energy sources, has increased as well as the development of new technologies, which are the main reasons for using biofuels (Vitazek et al., 2018).

Bioenergy production from biomass has an increased interest during the last decades. Today the most known and cultivated energy crop due to its high specific biomass yield, the growing knowhow of almost all farmers worldwide and the investigation on its breeding, is maize (*Zea mays* L.; Graß et al., 2015). Bioenergy production results to green environmental friendly energy. Therefore, sustainable biomass and bioenergy production systems should adapt to climate and care for the environment (Lobell et al., 2013; Semenov et al., 2014). Biomass is one of the most important sources of producing energy and synthetic fuels. Therefore, carbon-trading laws are good motivation for greater usage of biomass (Urbancl et al., 2019).

One of the crops that attracted worldwide attention during the last fifteen years is sorghum, which produces non-food feedstock, enhancing energy production while helping to reduce greenhouse gas emissions (Liu et al., 2015). There are many reports where sorghum is reported for its short growth cycle, the high water and nitrogen use efficiency, the low-input requirements (Stone et al., 2001; Farré & Faci, 2006¸ Ananda et al., 2011), the high soil-climatic adaptability (Teetor et al., 2011) and finally due to its C4 photosynthesis efficient the high biomass yield (Wortmann et al., 2010; Zegada-Lizarazu et al., 2012; Xu et al., 2018). According to its use sorghum can be classified in groups and one of them is the energy sorghum (Shakoor et al., 2014), which can further be divided in two categories i) the sweet and ii) the biomass sorghum (Rooney et al., 2007).

Energy crops must produce high biomass quantities (Sanderson & Wolf, 1995). Sorghum biomass may be a reasonable alternative energy crop because it could easily fit into existing production systems and it has high biomass production (Rocateli et al., 2012).

In order to increase biomass yield, farmers are applying higher amounts of nitrogen (Sheriff, 2005; Le Noë et al., 2017), which is one of the most important nutrients and it could increase sorghum biomass yield (Zhao et al., 2005; Almodares et al., 2008; Good & Beatty, 2011; Han et al., 2011; Sowiński & Głąb, 2018).

Nitrogen plays a crucial role in plant growth (Stals & Inze, 2001; Zhao et al., 2005; Saraswathy et al., 2007) and a deficiency of N results in lower sorghum biomass production due to reductions in LAI (leaf area index) and photosynthetic rate (Zhao et al., 2005). The need to maximize biomass yield for biofuel production makes nitrogen management research a priority.

There are a few studies where minimal or statistically insignificant effectsof increased N-dressings on sorghum biomass yield have been reported (Barbanti et al., 2006; Wortmann et al., 2010; Tamang et al., 2011; Erickson et al., 2012; Adam et al., 2015). Furthermore, it is reported (Erickson et al., 2012) that the optimum requirement based on yield and nutrient recovery responses is about 90–110 kg N ha^{-1}, while rates lower than the 80 kg N ha^{-1} are not affecting sorghum biomass (Wortmann et al., 2010).

Although in previous studies it is reported that N-fertilizers had significant effects on sorghum growth (Ayoubet al., 2003; Almodares et al., 2008), only few are known for different nitrogen application rates on sorghum biomass yield, especially for higher rates over the 150 kg of nitrogen per hectare.

The aim of this study was to identify the efficient nitrogen fertilizer application rates for sustainable energy sorghum cultivation in a soil characterized from the downward movement of calcium carbonate from the surface horizons due to leaching with focuses on improvement of dry biomass production yield.

MATERIALS AND METHODS

Two field experiments were established for the study in the main agricultural plain of Greece (Thessaly; Velestino area) to evaluate the effect of different nitrogen fertilization levels on two new hybrids (H1: EJ7281 and H2: ES5200) of energy sorghum yield in 2017. The experimental site is located at 39°02´ N and 22°45´ E (Velestino area;

Magnesia). Velestino soil was classified as *Calcixerollic Xerochrept*, according to USDA (1975). Soil analysis of a depth 0–40 cm showed average organic matter of 2.4%, pH 8.1, total N 0.2 mg kg^{-1}, available P and K, 5 and 197 mg kg^{-1} respectively.

Sowing took place on the 20^{th} of June (due to the fact that there was pea cultivation in the field which was incorporated as green manure) with sowing distances, 75 cm between rows and 8 cm on the row (according to the instructions of the production company for the hybrids).

Five different nitrogen fertilization levels were applied under 4 replications (blocks) for each tested hybrid. Plot size was 20 m^2 (5 m width × 4 m length), while the total plots per crop were 20 (5 N-fertilization levels × 4 blocks). The type of fertilizer that was used wasurea 46-0-0, while all plots were irrigated using a drip irrigation system.

Final biomass yield measured on final samplings (end of October for both hybrids), where the whole aerial biomass were cut 8–10 cm above ground. From the center lines of each plot was selected for cutting 1 meter (0.75 m^2) so as to avoid any border effect. The samples were weighed in the field and then a sub-sample was taken for further laboratory measurements and air drying. Thereafter, the dry samples sub-samples were weighed.

Complete weather data were recorded on a daily basis by an automated meteorological station, which was installed in the experimental farm of the University of Thessaly.

Finally, the statistical package GenStat (7^{th} Edition) was used for the analysis of variance (ANOVA) within sample timings for all measured and derived data. The $LSD_{0.05}$ was used as the test criterion for assessing differences between means (Steel & Torrie, 1982) of the main and/or interaction effects.

RESULTS AND DISCUSSION

Weather conditions

The study area is characterized by a typical Mediterranean climate with cold humid winters and hot-dry summers.

In particular, the average air temperature ranged from 21 °C to 27.4 °C during the summer 2017. Precipitation in the same period was 146.4 mm, while the 108 mm were observed during the second ten days of July (Fig. 1).

The best temperature for sorghum growth is 20–30 °C, while its base temperature is 13 °C (*Ferraris* and *Charles-Edwards*, 1986). Therefore during this field

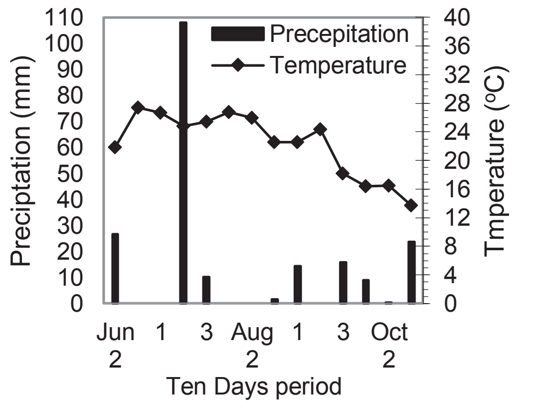

Figure 1. Temperature and precipitation (10-days mean values) occurring in studied site during the growing periods of sorghum in 2017.

study, mean temperature between 20 °C to 30 °C was consistently reached by June and maintained until almost end of September.

Biomass and seed yield

No statistical significant effects of nitrogen fertilization on total dry biomass yield for both tested sorghum hybrids were found (Tables 1, 2). Total dry yield was fluctuated between 22.2 to 37.5 t ha^{-1}, with the higher dry yield corresponding to the hybrid 2 under the higher N-fertilization level (280 kg N ha^{-1}), while the lower corresponded to the hybrid 1 without fertilization. Hybrid 1 had a negative effect of N-supply above the 210 kg N ha^{-1}, while hybrid 2 followed the principle the higher the nitrogen supply, the higher yield can be obtained indicating that hybrid 2 did not reach the potential biomass yield.

Table 1. Effects of different N-fertilization levels (0, 70, 140, 210, 280 kg N ha^{-1}) biomass and seed yield of sorghum hybrid 1 (H1: EJ7281)

Fertilization	Total Dry Weight (t ha^{-1})	Dry Stem Weight (t ha^{-1})	Dry Leaves Weight (t ha^{-1})	Seed Weight (kg ha^{-1})
0	22.24	17.71	3.60	931
70	35.31	29.66	4.24	1,414
140	31.55	25.42	4.31	1,822
210	34.77	28.77	4.46	1,534
280	29.10	23.54	4.22	1,341
$LSD_{0.05}$	ns	9.072	ns	491.5
CV (%)	22.3	23.5	21.1	22.7

In both hybrids, sorghum accumulated a high amount of biomass in stems, while the stem/total biomass ratio was rather constant in each hybrid. Hybrid 1 produced higher stem yield than hybrid 2, which was affected from nitrogen fertilization (Table 1). This ratio achieved the 81.6 and 77.5%for the first (H1) and the second hybrid (H2), respectively. In the case of leaves the second hybrid (H2) had a higher percentage of leaf biomass (20.1 vs. 13.8%) than the first (H1). Petrova Chimonyo et al (2018) reported that the leaves yield at the harvest was the 30% of the total biomass, percentage higherthan found in the current study. Furthermore, it has been reported that in case of energy crops the gross calorific value of leaves is always lower comparing to the caloric value of the rest biomass (Gravalos et al., 2016) and thus the reduced biomass of leaves will lead to increased total calorific value for the studied hybrids. Hybrid 1 produced double the seed yield of hybrid 1 (1,400 vs. 720 kg ha^{-1}; Tables 1, 2), which can be used as animal feed.

Table 2. Effects of different N-fertilization levels (0, 70, 140, 210, 280 kg N ha^{-1}) biomass and seed yield of sorghum hybrid 2 (H2: ES5200)

Fertilization (kg N ha^{-1})	Total Dry Weight (t ha^{-1})	Dry Stem Weight (t ha^{-1})	Dry Leaves Weight (t ha^{-1})	Seed Weight (kg ha^{-1})
0	25.98	19.88	5.27	830
70	24.17	18.51	5.08	580
140	25.28	19.41	5.25	620
210	29.26	23.01	5.67	580
280	37.44	29.28	7.17	990
$LSD_{0.05}$	ns	ns	ns	ns
CV (%)	22.3	23.5	21.1	22.7

The produced biomass yield is higher than the reported yield (Buxton et al., 1999; Regassa & Wortmann., 2014; Wannasek et al., 2017) and in agreement with previous reports for sweet sorghum (Zhao et al., 2009), biomass sorghum (Rooney et al., 2007) and forage sorghum hybrids (Venuto & Kindiger, 2008). The produced sorghum dry biomass of the unfertilized treatments in the current study agrees with the reported yield of 23 t ha^{-1} (Pannacci & Bartolini, 2018). In the case of hybrid 1, stems dry yield had been significant affected by nitrogen fertilization which has been reported in previous studies (Ayoub et al., 2003; Pholsen & Sornsungnoen, 2004; Pholsen & Suksri, 2007). Nitrogen fertilization (up to 140 kg ha^{-1}) had the same effect on sorghum dry biomass yield as with the reported effect to sunflower biomass (Skoufogianni et al., 2019).

CONCLUSIONS

The tested sorghum hybrids showed that high dry biomass yield can be produced even under low nitrogen fertilization or even without fertilization when pea cultivation is the previous one and has been used as green manure. Furthermore, a sufficient amount of seed yield could be produced and could boost animal feed production. A general conclusion could be that sorghum, should be taken seriously into consideration in land use planning, producing high dry biomass yields for solid biofuels, but further investigation of the gross calorific value and the ash content is needed.

REFERENCES

Adam, C.B., Erickson, J.E. & Singh, M.P. 2015. Investigation and synthesis of sweet sorghum crop responses to nitrogen and potassium fertilization. *Field Crops Res*. **178**, 1–7.

Almodares, A., Taheri, R., Chung, I.M. & Fathi, M. 2008. The effect of nitrogen and potassium fertilizers on growth parameters and carbohydrate contents of sweet sorghum cultivars. *J. Environ. Biol* .**29**, 849–852.

Ananda, N., Vadlani, P.V. & Prasad, P.V.V. 2011. Evaluation of drought and heatstressed grain sorghum (Sorghum bicolor) for ethanol production. *Ind. Crops Prod.* **33**, 779–782.

Ayoub, M., Nadeem, M.A., Tanveer, A. & Husnain, A. 2003. Effect of different levels of nitrogen and harvesting times on the growth: yield and quality of sorghum fodder. *Asian J. Plant Sci.* **1**, 304–307.

Barbanti, L., Grandi, S., Vecchi, A. & Venturi, G. 2006. Sweet and fiber sorghum (*Sorghum bicolor* (L.) Moench), energy crops in the frame of environmental protection from excessive nitrogen loads. *Eur. J. Agron.* **25**, 30–39.

Buxton, D.R., Anderson, I.C. & Hallam, A. 1999. Performance of sweet and forage sorghum grown continuously, double-cropped with winter rye, or in rotation with soybean and maize, *Agron. J.* **91**, 93–101.

Erickson, J., Woodard, K. & Sollenberger, L. 2012. Optimizing sweet sorghum production for biofuel in the Southeastern USA through nitrogen fertilization and top removal. *Bioenergy Res*. **5**, 86–94.

Farré, I. & Faci J.M., 2006. Comparative response of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) to deficit irrigation in a Mediterranean environment. *Agric. Water Manage.* **83**, 135–143.

Ferraris, R. & Charles-Edwards, D.A. 1986. A comparative analysis of the growth of sweet and forage sorghum crops. I. Dry matter production, phenology and morphology. *Aust. J. Agric. Res.* **37**, 495–512.

Good, A.G. & Beatty, P.H. 2011. Fertilizing nature: a tragedy of excess in the commons. *PLoS Biol.* **9**, e1001124.

Graß, R., Thies, B., Kersebaum, K.C. & Wachendorf, M. 2015. Simulating dry matter yield of two cropping systems with the simulation model HERMES to evaluate impact of future climate change. *Eur. J. Agron.* **70**, 1–10.

Gravalos, I., Xyradakis, P., Kateris, D., Gialamas, T., Bartzialis, D. & Giannoulis, K. 2016. An Experimental Determination of Gross Calorific Value of Different Agroforestry Species and Bio-Based Industry Residues. *Natural Resources* **7**, 57–68.

Han, L.P., Steinberger, Y., Zhao, Y.L. & Xie, G.H. 2011. Accumulation and partitioning of nitrogen: phosphorus and potassium in different varieties of sweet sorghum. *Field Crops Res.* **120**, 230–240.

Le Noë, J., Billen, G. & Garnier, J. 2017. How the structure of agro-food systems shapes nitrogen, phosphorus, and carbon fluxes: the generalized representation of agro-food system applied at the regional scale in France. *Sci. Total Environ.* **586**, 42–55.

Liu, H., Ren, L., Spiertz, H., Zhu, Y. & Xie, G.H. 2015. An economic analysis of sweet sorghum cultivation for ethanol production in North China. *GCB Bioenergy* **7**, 1176–1184.

Lobell, D.B., Hammer, G.L., McLean, G., Messina, C., Roberts, M.J. & Schlenker, W. 2013. The critical role of extreme heat for maize production in the United States. *Nat. Clim. Chang.* **3**, 497.

Nurmet, M., Mõtte, M., Lemsalu, K. & Lehtsaar, J., 2019. Bioenergy in agricultural companies: financial performance assessment. *Agronomy Research* **17** (3), 771–782

Pannacci, E. & Bartolini, S. 2018. Effect of nitrogen fertilization on sorghum for biomass production. *Agronomy Research* **16**(5), 2146–2155.

Petrova Chimonyo, V.G., Modi, A.T. & Mabhaudhi, T. 2018. Sorghum radiation use efficiency and biomass partitioning in intercrop systems. *South African Journal of Botany* **118**, 76–84.

Pholsen, S. & Sornsungnoen, N. 2004. Effects of nitrogen and potassium rates and planting distances on growth, yield and fodder quality of a forage sorghum (*Sorghum bicolor* L. Moench). *Pak. J. Biol. Sci.* **7**, 1793–1800.

Pholsen, S. & Suksri, A. 2007. Effects of phosphorus and potassium on growth, yield, and fodder quality of IS 23585 forage sorghum cultivar (*Sorghum bicolor* L. Moench). *Pak. J. Biol. Sci.* **10**, 1604–1610.

Regassa, T.H. & Wortmann, C.S. 2014. Sweet sorghum as a bioenergy crop: literature review, *Biomass Bioenergy* **64**, 348–355.

Rehman, S.U.M., Rashid, N., Saif, A., Mahmood, T. & Han, J. 2013. Potential of bioenergy production from industrial hemp (*Cannabis sativa*): pakistan perspective. *Renew. Sust. Ener. Rev.* **18**, 154–164.

Rocateli, A.C., Raper, R.L., Balkcom, K.S., Arriaga, F.J. & Bransby, D.I. 2012. Biomass sorghum production and components under different irrigation/tillage systems for the southeastern U.S. *Ind. Crop. Prod.* **36**, 589–598.

Rooney, W.L., Blumenthal, J., Bean, B. & Mullet, J.E. 2007. Designing sorghum as a dedicated bioenergy feedstock. *Biofuel Bioprod. Biorefin.* **1**, 147–157.

Sanderson, M.A. & Wolf, D.D. 1995. Morphological development of switchgrass in diverse environments. *Agron. J.* **87**, 908–915.

Saraswathy, R., Suganya, S. & Singaram, P. 2007. Environmental impact of nitrogen fertilization in tea ecosystem. *J. Environ. Biol.* **28**, 779–788.

Semenov, M.A., Stratonovitch, P., Alghabari, F. & Gooding, M.J. 2014. Adapting wheat in Europe for climate change. *J. Cereal Sci.* **59**, 245–256.

Shakoor, N., Nair, R., Crasta, O., Morris, G., Feltus, A. & Kresovich, S. 2014. A Sorghum bicolor expression atlas reveals dynamic genotype-specific expression profiles for vegetative tissues of grain, sweet and bioenergy sorghums. *BMC Plant Biol.* **14**, 1–35.

Sheriff, G. 2005. Efficient waste? Why farmers over-apply nutrients and the implications for policy design. *Appl. Econ. Perspect. Policy* **27**, 542–557.

Skoufogianni, E., Giannoulis, K.D., Bartzialis, D. & Danalatos, N.G. 2019. Cost efficiency of different cropping systems encompassing the energy crop *Helianthus annuus*L. *Agronomy Research* **17**(6), 2417–2427.

Sowiński, J. & Głąb, L. 2018. The effect of nitrogen fertilization management on yield and nitrate contents in sorghum biomass and bagasse. *Field Crops Research* **227**, 132–143.
Stals, H. & Inze, D. 2001. When plant cells decide to divide. *Trends Plant Sci.* **8**, 359–364.
Stone, L.R., Goodrum, D.E., Jaafar, M.N. & Khan, A.H. 2001. Rooting front and water depletion depths in grain sorghum and sunflower. *Agron. J.* **93**, 1105–1110.
Tamang, P.L., Bronson, K.F., Malapati, A., Schwartz, R., Johnson, J. & Moore-Kucera, J. 2011. Nitrogen requirements for ethanol production from sweet and photoperiod sensitive sorghums in the Southern High Plains. *Agron. J.* **103**, 431–440.
Teetor, V.H., Duclos, D.V., Wittenberg, E.T., Young, K.M., Chawhuaymak, J., Riley, M.R. & Ray, D.T. 2011. Effects of planting date on sugar and ethanol yield of sweet sorghum grown in Arizona. *Ind. Crop. Prod.* **34**, 1293–1300.
Urbancl, D., Krope, J. & Goričanec, D. 2019. Torrefaction – the process for biofuels production by using different biomasses. *Agronomy Research* **17**(4), 1800–1807.
Venuto, B. & Kindiger, B. 2008. Forage and biomass feedstock production from hybrid forage sorghum and sorghum-sudan grass. *Grassl. Sci.* **54**, 189–196.
Vitazek, I., Tulik, J. & Klucik, J., 2018. Combustible in selected biofuels. *Agronomy Research* **16** (2), 593–603.
Wannasek, L., Ortner, M., Amon, B. & Amon, T. 2017. Sorghum, a sustainable feedstock for biogas production? Impact of climate, variety and harvesting time on maturity and biomass yield. *Biomass Bioenergy* **106**, 137–145.
Wortmann, C.S., Liska, A.A., Ferguson, R.B., Lyon, D.J., Klein, R.N. & Dweikat, I.M. 2010. Dryland performance of sweet sorghum and grain crops for biofuel in Nebraska. *Agron. J.* **102**, 319–326.
Wortmann, C.S., Liska, A.J., Ferguson, R.B., Lyon, D.J., Klein, R.N. & Dweikat, I. 2010. Dryland performance of sweet sorghum and grain crops for biofuel in Nebraska. *Agron J.* **102**, 319–326.
Xu, Y.J., Li, J., Moore, C., Xin, Z.G. & Wang, D.H. 2018. Physico-chemical characterization of pedigreed sorghum mutant stalks for biofuel production. *Ind. Crops Prod.* **124**, 806–811.
Zegada-Lizarazu, W., Zatta, A. & Monti, A. 2012. Water uptake efficiency and above-and belowground biomass development of sweet sorghum and maize underdifferent water regimes. *Plant Soil.* **351**, 56–60.
Zhao, D., Reddy, K.R., Kakani, V.G. & Reddy, V.R. 2005. Nitrogen deficiency effects on plant growth, leaf photosynthesis and hyperspectral reflectance properties of sorghum. *Eur. J. Agron.* **22**, 391–403.
Zhao, Y.L., Dolat, A., Steinberger, Y., Wang, X., Osman, A. & Xie, G.H. 2009. Biomass yield and changes in chemical composition of sweet sorghum cultivars grown for biofuel. *Field Crops Res.* **111**, 55–64.