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SWEET SORGHUM CULTIVATION IN BLACK SOIL AND PHYTOMELIORATED ROCKS IN UKRAINE

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Abstract: A comparative analysis of the prospects for growing sweet sorghum Silosne-42 on the zonal soils and mining substrates brought to the surface during process of manganese ore mining in the steppe zone of Ukraine (loess-like loam, red-brown clay and gray-green clay) is performed. The best above-ground biomass productivity was shown on loess-like loam. The highest content of soluble sugars in the stem juice was found in samples grown on zonal black and loess-like loam (15.8–16%), and the smallest on green-grey clay (14.8%). Cultivar Silosne-42 has good potential for the production of bioethanol, the theoretical yield of which ranged from 1019.5 L ha^{-1} to 1454.5 L ha^{-1}.
Keywords: sweet sorghum, biomass yield, ethanol yield potential, black soil, rock phytomelioration

INTRODUCTION

Because of energy crisis increase all over the world, the acute problem of alternative energy source search appears before humanity. In Ukraine, there are favorable conditions for the production of biofuel from agricultural raw material. Many crops are used as feedstock for renewable energy. For instance, briquetted straw of wheat, rye, oats, sunflower is used to produce heat and electricity. Silage corn, rape, mustard, and flax are raw materials for diesel fuel. Plants containing a large amount of soluble sugars (corn, wheat, potatoes, topinambour, sugar beet, sorghum) are used to produce bioethanol (*Geletukha et al., 2014*). However, for the cultivation of energy crops, it seems more appropriate to use lands that are not suitable for classical farming: unproductive, clayey, saline, or even polluted by the economic activity of mining and processing facilities. In this regard, the urgent issue is the search of plants that can successfully grow and produce stable yields in such conditions. Sweet sorghum is a promising crop for obtaining cheap bioethanol on marginal lands. It has several advantages over other cultures.

First of all, sorghum is notable for high drought and salt tolerance. Leaves and stems of sorghum are covered with a wax bloom, which reduces evaporation. In addition, this plant is poorly damaged by pests. Sorghum removes salts from the soil; it transfers hard-to-reach forms of phosphorus to more accessible ones and draws readily available phosphates from a 1.5-2-meter layer of soil to 30-50 centimeter layer *(Reddy et al., 2007; Dalla Marta et al., 2014)*. The sweet sorghum includes a large number of cultivars that are remarkable by a high content of soluble sugars in stems (from 10 to 20%). The sugars in stems mainly comprise sucrose (about 80-85%) with some amount of fructose, glucose (about 12-15%) and starch (about 3%). In comparison to lignocellulosic biomass polysaccharides these sugars are readily fermentable (Almorades & Hadi, 2009; Wang et al., 2012; Regassa & Wortmann, 2014). Sweet sorghum serves as a raw material for the production of syrup, crystalline sugar, ethanol, methane, is used for ensiling and obtaining green mass. The yield of sugar from sweet sorghum can reach 5-7 t ha^{-1}, ethanol 3000-5000 L ha^{-1} (*Zhao et al., 2009; Kim & Day, 2011*).

Sorghum takes the fifth place in the world among cereals after corn, wheat, rice and barley. The main producers of sorghum are the USA (10 million tons yearly), Nigeria (10.5 million tons), India (7.8 million tons), and Mexico (5.5 million tons). In Ukraine sorghum is grown mainly in the steppe southern and central regions. A significant part of the steppes is concentrated in the zone where 400-450 mm of annual precipitation falls, and the sum of effective temperatures is optimal for sorghum cultivation. Sweet sorghum can be grown as monoculture for 3-5 years without loss of yield, provided proper protection against weeds and compensation for nutrient removal.

Unpretentiousness of sorghum to soil conditions makes it possible to use low-productive and unproductive lands for cultivation of this crop (*Ren et al., 2012; Fu et al., 2016*). Today in Ukraine, out of 32 million hectares of agricultural lands, 8 million hectares are unproductive. In addition, in industrial southeastern and central regions, as a result of mining and processing of minerals, huge areas are formed, which are wastelands with sites of destroyed soil and large volumes of mining wastes and empty rocks brought to the surface. Even after many years of reclamation, these technogenic lands differ significantly from zonal soils in the level of fertility, physical, chemical, agrochemical and other important ecological indicators, and therefore they are of little use for the cultivation of many crops. At the same time, the growing of energy crops, including sorghum, in such territories may prove promising and economically viable.

MATERIALS AND METHODS

The sweet sorghum cultivar Silosne-42 was studied. This variety was bred in 2003 at the Dnipro Institute of grain farming for obtaining green biomass, silage and sugar syrup. Its main characteristics are shown in Table 1.

Table 1. Morphological characteristics of sweet sorghum cultivar Silosne-42

Height, cm	Number stem per plant, pieces	Panicle form	Seed features	Growing season, days	Potential productivity of green biomass, t ha^{-1}
220-250	2-3	ellipsoid	large, brown	105-115-(wax ripeness) 120-125-(full ripeness)	55.0-76.0

The research was conducted at two sites: at Pokrov land reclamation station of Dnipro State Agrarian and Economic University and Sinelnikovo selection and experimental station of the National Academy of Agrarian Sciences of Ukraine. Geographically, both stations are located in the Dnipropetrovsk region in the steppe zone of Ukraine with moderately continental climate (hot summer and moderate winter). This zone is characterized by unstable water supply and frequent prolonged droughts during the growing season. The average hydrothermal coefficient is 0.9. In recent years, there has been a gradual increase in the average monthly air temperature with a simultaneous decrease in the amount of precipitation. The zonal soils (ZS) at the Sinelnikovo experimental station are quite homogeneous and consist mainly of ordinary low-humus full-profile black soils eroded to varying degrees. Specific gravity of these soils varied from 1.0 to 1.2 g/cm^3, total content of argillaceous fraction minerals is 28-35%, humus content is 3.4-3.5%, the level of the lowest moisture capacity is 27.2-31.0%.

Pokrov land reclamation station of Dnipro State Agrarian and Economic University is located in the Nikopol manganese ore deposit. The rocks of this ore basin were brought to the surface during process of manganese ore mining. The soil mass was taken off, piled up and heaped onto the land after the rock was replaced. Substrates formed in this way can be attributed to the category of Technosol which are soils strongly influenced by human activities, and as a result, their properties and pedogenesis are dominated by technical origin (De Kimpe & Morel, 2000). For experience were used three types of mining substrates taken from the board of the quarry and exposed to long-term soil stabilization: loess-like loam, (LLL), red-brown clay (RBC) and green-grey clay (GGC). The total content of argillaceous fraction minerals in these substrates varied from is 23.5 (LLL) to 63.5% (GGC), humus content is low (1.05-1.25%), maximal hygroscopicity level 7.6 (LLL)-20.5% (GGC).

Biometric indices, productivity, brix, conservative sugar yield, and theoretical ethanol yield were studied. The plant height was measured using a measuring line. To determine the yield of above-ground biomass, plants were harvested after the grain reached milky ripeness stage by cutting at the height of 10 cm from the ground level and weighed. After that, the biomass was dried to constant weight, and then weighed again. Brix was determined using a hand-held refractometer "RHBO–50ATC".

Conservative sugar yield (t ha^{-1}) was calculated based on an approach assuming that the sugar concentration is 75% of Brix expressed in g kg^{-1} sugar juice (Wortmann et al., 2010; Ekefre et al., 2017). It was used the equation: CSY= (FSY–DSY)*Brix*0.75. Where, CSY is conservative sugar yield (t ha^{-1}), FSY is fresh stem yield (t ha^{-1}), DSY is dry stem yield (t ha^{-1}). Theoretical ethanol yield was calculated as sugar yield multiplied by a conversion factor (0.58 L ethanol per kg of sugar): TEY=CSY*0.58 (Rutto et al., 2013; Ekefre et al., 2017). Where, TEY is theoretical ethanol yield (L ha^{-1}), CSY is conservative sugar yield (kg ha^{-1}).

RESULTS

A comparative analysis of the sweet sorghum cultivation on zonal soils and mining substrates showed some differences in biometric indicates depending on the type of soil. The tallest plants were noted on the loess like loam, the lowest on the green-grey clay (table 2). The disparity amounted 8-25%.

Table 2. Height of sweet sorghum Silosne-42 grown on different substrates, cm

Type of substrate			
ZS	LLL	RBC	GGC
222.0±2.31	240.3±4.50	212.9±2.43	203.0±2.87

In general, plants grew and developed better on loess-like loam and on zonal soil. As a result, the yield of biomass on these substrates was higher than on red-brown clay and green-grey clay (fig.1).

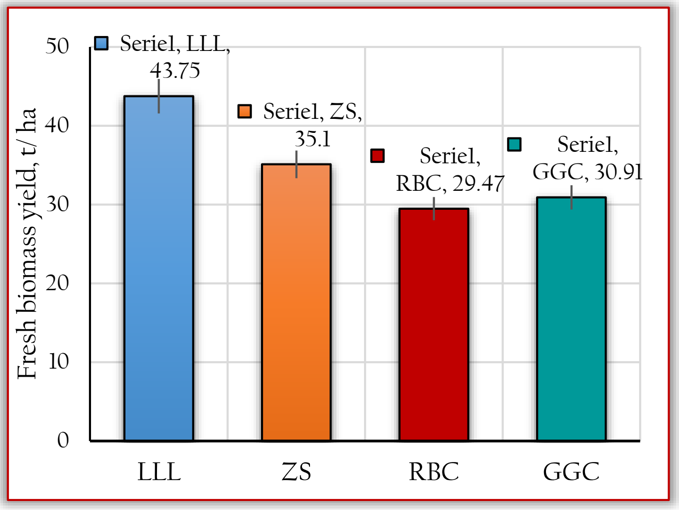

Figure 1 Biomass yield of sweet sorghum Silosne-42 as affected type of soil

The percentage of juice in the stems was the highest in plants grown on zonal soil (51.43%), and the lowest in plants grown on loess-like loam (47.36%). At the same time, the highest content of sugars in the juice was noted on this substrate. In other variants of the experiment, this index was lower by 1.3-7.5%. In consideration of productivity and sugar content, the conservative sugar yield on loess-like loam was higher than on other substrates by 14.0-30.1% (table 3).

Table 3. Brix and conservative sugar yield (CSY) of sweet sorghum Silosne-42

Parameters	Type of substrate			
	ZS	LLL	RBC	GGC
Brix, %	15.8±0.22	16.0±0.23	15.6±0.21	14.8±0.11
CSY, t ha^{-1}	2.14±0.04	2.49±0.04	1.75±0.02	1.74±0.02

The biomass yield and percent juice extracted are the best predictors of potential ethanol yield per area. This index was between 1454.5 L ha^{-1} on loess-like loam and 1019.5 L ha^{-1} on green-grey clay (fig.2).

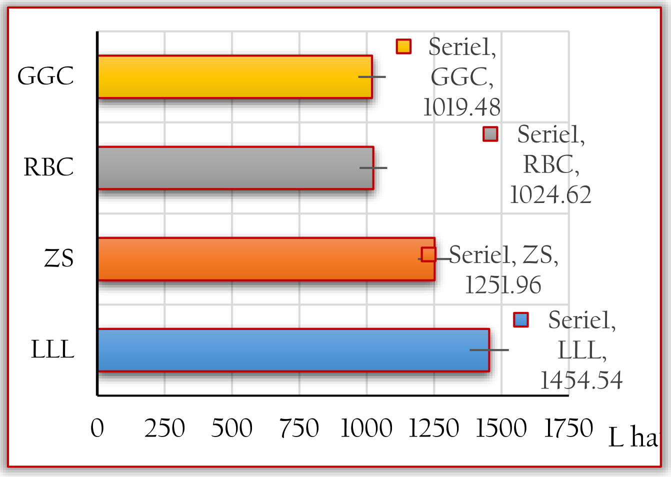

Figure 2. Potential ethanol yield per area in sweet sorghum Silosne - 42 (L ha^{-1})

According to different data (Macesic et al., 2008; Kim & Day., 2011; Ekefre et al., 2017), depending upon the various factors, the ethanol yields from the sweet sorghum fermentable sugars vary within a wide range, from 750 to 5800 L ha^{-1}. Our data are quite conform to those obtained by others and can be considered economically viable.

CONCLUSION

Sweet sorghum, with its low input requirements, is one of the leading candidates for growing on reclaimed mining lands as a biofuel feedstock. Domestic breeding cultivar Silosne-42 showed the highest productivity of biomass on loess-like loam. Thus, soil fertility is not a limiting factor for the accumulation of sorghum biomass. Despite the low humus content, loess-like loam has favorable agrophysical and agrochemical properties. The presence of calcium carbonate determines the water and air permeability. These properties were probably more important for growth processes. Sweet sorghum Silosne-42 has a good potential for bioethanol production at cultivation both on the zonal soils, and on meliorated mining substrates. Although the highest yield of ethanol was obtained on loess-like loam and zonal black soil, red-brown and green-grey clays are also quite suitable for growing this cultivar as a feedstock for the production of this biofuel type.

Note:
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References

[1] Almorades A., Hadi M.R. (2009). Production of bioethanol from sweet sorghum: A review. *African Journal of Agricultural Research*, vol.4(9), pp.772-780. http://www.academicjournals.org/journal/AJAR/article-full-text-pdf/6DDEDD738826;
[2] Dalla Marta A., Mancini M., Orlando F., Natali F., Capecchi L., Orlandini S. (2014). Sweet sorghum for bioethanol production: Crop responses to different water stress levels. *Biomass and Bioenergy*, vol. 64, pp. 211-219;
[3] De Kimpe C.R. & Morel J-L. (2000). Urban soil management: a growing concern. *Soil Science*, vol.165(1), pp.31-40;
[4] Ekefre D.E., Mahapatra A.K., Latimore Jr. M., Bellmer D.D., Jena U., Whitehead G.J., Williams A.L. (2017). Evaluation of three cultivars of sweet sorghum as feedstocks for ethanol production in the Southeast United States. *Heliyon*, vol. 3. e00490, pp. 1-18. doi:10.1016/j.heliyon.2017.e00490;
[5] Fu H.M., Meng F.Y., Molatudi,R.L, Zhang B.G. (2016).Sorghum and Switchgrass as biofuel feedstocks on marginal lands in Northern China. *Bioenergy Research*, vol. 9(2), pp 633-642;
[6] Geletukha G., Zheliezna T., Kucheruk P., Oliinyk Y. (2014). State of the art and prospects for bioenergy development in Ukraine UABio Position Paper N9, 32p. http://www.uabio.org/img/files/docs/position-paper-uabio-9-en.pdf;
[7] Kim M., Day D.F. (2011). Composition of sugar cane, energy cane, and sweet sorghum suitable for ethanol production at Louisiana sugar mills. *Journal of Industrial Microbiology & Biotechnology*, vol.38(7), pp.803-807;
[8] Macesic D., Uher D., Stafa Z. (2008). Biomass production and ethanol potential from sweet sorghum in Croatia. *Cereal Research Communications*, vol.36, pp.527-530. https://www.jstor.org/stable/90002757;
[9] Reddy, B V S and Kumar, A A and Ramesh, S (2007) *Sweet sorghum: A Water Saving Bio-Energy Crop*. In: International conference on Linkages between Energy and Water Management for Agriculture in Developing Countries, 2007, ICRISAT, Patancheru, India, pp.1-12. http://oar.icrisat.org/id/eprint/4835;
[10] Regassa T.H, Wortmann C.S. (2014). Sweet sorghum as a bioenergy crop: literature review. *Biomass Bioenergy*, vol.64, pp.348-355;

[11] Ren L.T, Liu Z.X, Wei T.Y, Xie G.H (2012) Evaluation of energy input and output of sweet sorghum grown as a bioenergy crop on coastal saline-alkali land. *Energy*, vol. 47, pp. 166-173;
[12] Rutto L.K, Xu Y., Brandt M., Ren Sh., Kering M.K. (2013). Juice, Ethanol, and Grain Yield Potential of Five Sweet Sorghum (*Sorghum bicolor* (L.) Moench) Cultivars. *Journal of Sustainable Bioenergy Systems*, vol.3, pp.113-118;
[13] Wang M., Xin Z., Tonnis B., Farrell G., Pinnow D., Chen Z., Davis J., Yu J., Hung Y., Pederson G.A. (2012). Evaluation of sweet sorghum as a feedstock by multiple harvests for sustainable bioenergy production. *Journal of Sustainable Bioenergy Systems*, vol. 2, pp. 122-137;
[14] 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. *Agronomy Journal*, vol. 102(1), pp. 319-326. doi:10.2134/agronj2009.0271;
[15] 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 Research*, vol.111 (1-2), pp. 55-64.

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