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ESTIMATION OF THE PRODUCTIVE POTENTIAL DEPENDANCE OF SWEET SORGHUM HYBRIDS ON SOIL NUTRITION MANAGEMENT

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Abstract: The results of studying the growth and yield characteristics of hybrids of domestic and American selection during cultivation under the conditions of the northern Ukrainian Steppe are presented. Fertilizing with nitrogen fertilizer and vermicomposting extract by fertigation helped to strengthen vertical growth, and increase the yield of green biomass and sweet sorghum grains. The greatest effect was obtained for American hybrids. For Ukrainian hybrids, the application of nitrogen fertilizers had a positive effect on black soil and loess–like loam, while the effect of vermicomposting extract was noticed only on loess–like loam.

Keywords: sweet sorghum, black soil, loess–like loam, irrigation, fertigation, theoretical ethanol yield

1. INTRODUCTION

Among the annual cereals, sweet sorghum (*Sorghum saccharatum (L.) Moench*) is the main alternative source for the production of fuel ethanol and butanol (*Sipos et al., 2009*). Bioethanol is almost the only substitute for gasoline, and so its global production is growing at a rapid pace. The cheapest bioethanol in the world is made from tropical sugarcane. Soluble sugars in the form of glucose, fructose, and sucrose in sweet sorghum are readily fermentable. Agronomic traits such as a short life cycle of approximately 4 months, unpretentiousness, low cost of cultivation, and C4 photosynthesis are especially helpful for its adoption as a biofuel feedstock (*Regassa and Wortmann, 2014; Mathur et al., 2017*).

The yield and technological properties of sweet sorghum, which can be grown in a temperate climate, are similar to those of the wild. Sorghum does not require the use of large doses of fertilizers and pesticides (*Ren et al., 2012; Fu et al., 2016*). Numerous data show good adaptation abilities of sweet sorghum to conditions of moisture and nutrient deficiency (*Shoemaker and Bransby, 2010*). However, water deficit stress significantly decreased bioethanol yield (*Koksal et al., 2021*). Therefore, under growing conditions affected by water shortage and nutrient deficiency, the optimal combination of irrigation and nitrogen (N) fertilization rate is a central issue for sustainable farming systems (*Scordia et al., 2021*).

Among fertilizer treatments, inorganic fertilizer was found to be the most effective, since it gave higher agronomic, sugar, and yield (*Beltran et al., 2019*). In the meantime, vermicompost can be an alternative input of nutrients because it can enhance growth and productivity. Using prime land to grow crops for the production of ethanol, biodiesel, or bioenergy feedstock is not a logical choice (*Perrin et al., 2018*). The potential of marginal land for the cultivation of second generation crops as biofuels has received increased attention in recent years (*Blanco–Canqui 2016*).

The unpretentiousness of sorghum with respect to environmental conditions determines the prospect of growing this plant on unproductive lands, thus avoiding a conflict between food production and biofuels (*Ameen et al., 2017; Mehmood et al., 2017*). Therefore, reclaimed mining rocks may be used to grow this energy plant. Such soils are considered marginal because they often contain few organic substances and have physical and chemical characteristics that are unfavorable for plant growth. However, the cultivation of sweet sorghum on such lands may be quite appropriate. Increasing profitability can be achieved through the use of additives and fertilizers that improve fertilization of the soil.

The main objective was to study the dependence of the sweet sorghum hybrids on the management of soil nutrition.

2. MATERIALS & METHODS

This research was carried out under the conditions of the Ukrainian steppe zone at the Pokrov land reclamation station of the Dnipro State Agrarian and Economic University (DSAEU). In Ukraine, sorghum is grown mainly in the southern and central regions of the steppe. A significant part of the steppes is

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concentrated in the zone where 400–450 mm of annual precipitation falls and the sum of effective temperatures is optimal for the cultivation of sorghum.

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.

In the field, two Ukrainian selection sweet sorghum hybrids (Medove and Zubr) and two American hybrids (SS506 and Mohawk) were investigated. A three–factor field experiment was established. Including factor A – domestic and American origin; factor B – black soil (BS) and long–term meliorated loess–like loam (LLL); factor C – plant fertigation with mineral nitrogen fertilizer and vermicomposting extract. The humus content in the loess–like loam is about 1.1%, and in the black soil is 3.3. The ratio of humic and fulvic acids is 0.65 (LLL) and 1.36 (BS).

The sorghum seeds were seeded in early May and biometric indices, productivity, conservative sugar yield, and theoretical ethanol yield were researched. The height of the plant was measured using a measuring line. To determine the yield of above–ground biomass, each cultivar was harvested after the grain reached the hard dough stage by cutting to a height of 10 cm from the ground level and weighing. After that, the biomass was dried to a constant weight and then weighed again.

The sugar concentration in the sweet sorghum stalks is measured in Brix units, which represents the percent of soluble sugars. One degree Brix is equal to 1 g of sugar per 100 g of juice. 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% Brix expressed in g kg –1 of sugar juice (*Wortmann et al., 2010; Rutto et al., 2013; Ekefre et al., 2017*). The equation was used:

$$\mathrm{CSY} = (\mathrm{FSY} - \mathrm{DSY}) \cdot \mathrm{Brix} \cdot 0.75 \qquad (1)$$

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}). The theoretical ethanol yield was calculated as the sugar yield multiplied by a conversion factor (0.58 L of ethanol per kg of sugar):

$$\mathrm{TEY} = \mathrm{CSY} \cdot 0.58 \qquad (2)$$

where, TEY is theoretical ethanol yield (L ha^{-1}).

Data received in field experiments performed were processed using statistical methods using the StatGraphics Plus5 software package with all significance tests carried out at a type 1 error rate of 5%.

3. RESULTS

The height of the hybrid 'Zubr' plants was found to be slightly higher than in previous years (300–310 cm), and the hybrid 'SS506', in contrast, was lower than 221 cm (*Kharytonov et al., 2019*). Differences in growth rates and yields of the sugar sorghum hybrids studied were observed depending on the type of substrate and different fertigation options.

The plants of the hybrid 'Medove' in loess were observed to be higher than in chernozem in all variants of the experiment. The height of the plants of other hybrids in the variants without irrigation and fertilization (control) was almost the same on both substrates.

The use of irrigation in black soil led to an increase in plant height of 7–8% (hybrids 'Zubr' and 'Mohawk') to 30% ('Medove'). At the same time, additional irrigation on loess like loam did not give a noticeable result (Figure 1 and 2). Additional agricultural measures have helped increase the yield of the biomass of green sorghum above ground. The greatest effect was obtained for American hybrids, especially for 'Mohawk'.

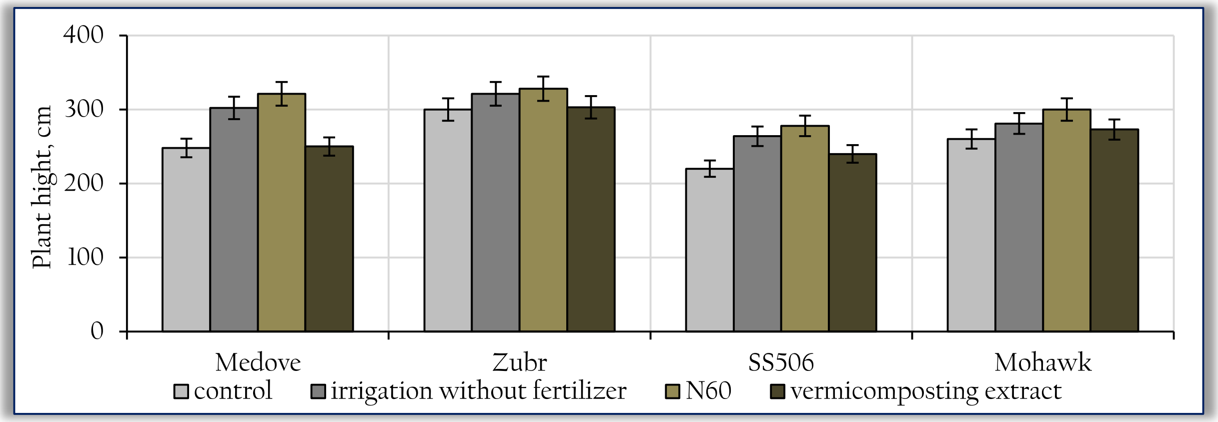

Figure 1 – Height of sweet sorghum cultivated in black soil, cm

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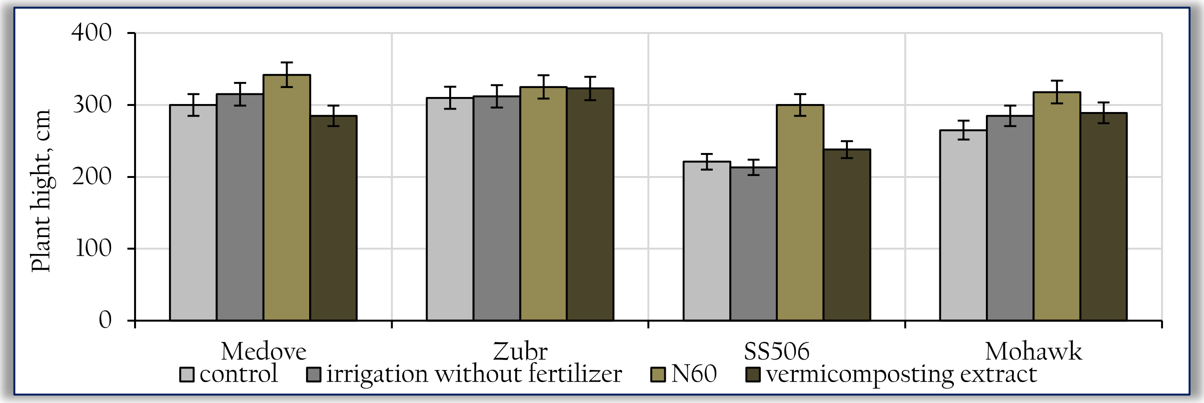

Figure 2 – Height of sweet sorghum grown in loess like loam, cm

The yield of the 'Mohawk' cultivar in black soil increased by 26, 55 and 29%, respectively, under the impact of irrigation, nitrogen fertilizer and vermicomposting extract. This effect was even more noticeable on loamy like loess: 52, 93 and 45%, respectively. The reaction of the hybrid 'SS506' was more significant on black soil than on loamy soil such as loess. Nitrogen fertilization led to an increase in vertical growth of sorghum in black soil, except for the hybrid 'Zubr', of 15–20%.

The addition of nitrogen fertilizer to loamy–like loess did not significantly affect Ukrainian hybrids, but had a noticeable positive effect (21–36%) on the growth of American hybrids. Fertigation with vermicomposting extract did not affect the growth of Ukrainian cultivars and had a weak effect (7.5–11%) on American cultivars. The yield of the green biomass above ground of sweet sorghum in the control trials on different substrates did not differ significantly.

Medove, Zubr and SS506 yield was slightly higher in loess like loam (by 2.5–7%), and hybrid Mohawk, in contrast, was lower by 6.6% than in black soil (Table 1). For Ukrainian hybrids, the application of nitrogen fertilizers had a positive effect on both substrates, while the effect of vermicomposting extract was manifested only on loess like loam. The grain yield among the hybrids studied was the highest in the 'Medove' hybrid on both substrates (Table 2).

Table 1. The yield of aboveground biomass of sweet sorghum American hybrids

Hybryds	Black soil				Loess like loam			
	C	I	N_{60}	VE	C	I	N_{60}	VE
	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]
Medove	76.0	84.2	98.6	79.6	77.8	86.0	98.2	87.9
Zubr	85.6	96.0	105.8	86.2	91.6	95.6	104.0	103.8
SS506	59.0	70.0	82.2	72.0	62.0	70.4	78.0	66.2
Mohawk	62.1	78.4	96.4	80.0	58.0	88.2	111.8	84.0
C – control, I – irrigation, N_{60} – nitrogen, VE – vermicomposting extract								
$LSD_{0.95}$	A–2.63	B–2.56	C–2.59	AB–2.71	AC–2.81	BC–2.96	ABC–3.49	

Table 2. The yield of aboveground biomass of sweet sorghum Ukrainian hybrids

Hybryds	Black soil				Loess like loam			
	C	I	N_{60}	VE	C	I	N_{60}	VE
	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]	[t/ha]
Medove	4.4	7.0	7.6	4.8	6.2	6.8	7.8	6.5
Zubr	1.2	3.2	4.2	2.5	3.2	3.4	6.1	6.0
SS506	2.5	3.6	3.62	3.0	1.0	1.5	3.0	1.2
Mohawk	1.7	2.2	3.0	1.8	1.8	2.0	2.8	2.4
C – control, I – irrigation, N_{60} – nitrogen, VE – vermicomposting extract								
LSD_{095}	A–1.23	B–0.87	C–1.23	AB–1.74	AC–2.46	BC–1.74	ABC–3.48	

The grain productivity of the hybrid 'Zubr' on loess like loam was 2.5 times higher than on black soil, while for the hybrid 'SS506' the opposite dynamics was observed. At the same time, the yield of the 'Mohawk' hybrid was almost the same on both substrates.

The greatest effect of additional irrigation, fertilizer application, and vermicomposting extract on black soil was observed for the hybrid 'Zubr' (167, 250 and 108%, respectively). A significant increase in grain yield was observed only in trials with fertilizer and vermicomposting extract in loess like loam. Irrigation and application of mineral fertilizers in black soil increased grain yield by 30–76% for the hybrids 'Medove', 'SS506' and 'Mohawk', while the effect of vermicomposting extract was rather insignificant (6–20%).

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A significant increase in grain yield of 200% was observed under the influence of nitrogen fertilizer on loamy–like loess for the hybrid 'SS506'. Irrigation and fertigation of vermicomposting extracts led to an increase in productivity of 20 and 50%, respectively.

The addition of mineral fertilizer and vermicomposting extract (56 and 33%, respectively) had a positive effect on the 'Mohawk' hybrid. A small increase in yield (26%) was observed for the 'Medove' hybrid in the trial with mineral fertilizer. The amount of juice in the sweet sorghum stalks and their sugar content are important indicators in the production of bioethanol.

The values of these parameters can vary depending on the growing conditions and the influence of environmental factors (*Zou et al., 2011*). The highest sugar content in the sweet sorghum stems was found in the milk–wax ripeness stage. During the years of research, it varied from 18% to 21% in black soil and from 17% to 21% in loamy–like loess.

Among the hybrids studied, the highest sugar content of stem juice is characteristic of the hybrid 'Mohawk' and the lowest is characteristic of the hybrid 'Zubr'. The influence of agronomic measures on the value of sugar content in sorghum stalks was also observed in the ripeness phase of milk wax (Table 3).

Table 3. Sugar content in the sweet stems of sweet sorghum

Hybryds	Black soil				Loess like loam			
	C	I	N_{60}	VE	C	I	N_{60}	VE
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
Medove	18.0	18.7	20.7	18.3	17.7	18.3	20.0	18.0
Zubr	18.0	16.7	15.7	17.0	17.7	16.3	14.7	16.0
SS506	20.2	19.5	20.3	19.5	19.3	18.7	19.7	19.0
Mohawk	20.8	20.0	20.0	19.8	20.7	19.2	19.0	19.3
C – control, I – irrigation, N_{60} – nitrogen, VE – vermicomposting extract								
LSD_{095}	A – 2.03	B–2.49	C– 2.46	AB–3.43	AC–3.36	BC–3.2	ABC–4.0	

An increase in sugar content was observed in all trials of the field experiment for the hybrid 'Medove'. The highest effect was obtained in the nitrogen fertilizer trial. The sugar content in the stem biomass increased by 13% (loess like loam) and 15% (black soil).

The dynamics of reducing the sugar content of stem juice took place for other varieties. The highest deviations were observed for the hybrid 'Zubr': from 7.2 to 7.9% under additional irrigation conditions, from 5.5 to 9.6% with the addition of vermicomposting extract and from 12.8 to 16.9% in the nitrogen fertilizer trial.

The decrease in sugar content was not significant for the 'Mohawk' hybrid due to lack of soil. However, it ranged from 6.8% (vermicomposting extract) to 8.2% (nitrogen fertilizer) in the loess like loam. The most stable sugar content was found in the stems of the hybrid 'SS506'. Meanwhile, in loamy–like loess it was less than in black soil by 4.5%. However, the fluctuations of this parameter in different experiments did not exceed 3.5%.

The theoretical ethanol yield was calculated taking into account biomass productivity, the amount of juice, and its sugar content as a sugar content in the sorghum stalks. It was found that on marginal lands of Ukrainian cultivars 'Medove' and 'Zubr' it is possible to produce between 2536 and 4250 l / ha of ethanol.

The potential of American hybrids 'SS506' and 'Mohawk' is slightly lower – 2248–3400 l / ha. Despite the fact that in the previous two years the yield of the above–ground green biomass and the sugar content of the stem juice in almost all hybrids was higher than in the experimental year, the amount of juice was lower. This led to a lower theoretical ethanol yield in black soil by 29–30% for Ukrainian hybrids and 15–18% for American hybrids. On loess like loam, this decrease was 5–15% for Ukrainian hybrids and 22–29% for American hybrids. The reaction of American hybrids to additional agronomic measures was more pronounced compared to Ukrainian (Figure 3 and 4).

For example, the theoretical ethanol yield of the hybrid 'Medove' in black soil under conditions of additional irrigation, nitrogen fertilization and vermicomposting extract increased by 11.0, 46.7 and 6.5%, respectively. This increase in the American hybrid 'Mohawk' was 19.4, 49.3 and 20.6%. The effect was even greater in the loess like loam: 14.3, 42.6 and 14.9% for the 'Medove' hybrid, and 36.5, 68.3, and 29.9% for the 'Mohawk' hybrid.

Increasing the yield of the above–ground green mass of the hybrid 'SS506' had a compensatory effect in the tests with additional irrigation and nitrogen fertilization, despite the decrease in the sugar content in the stems. As a result, the theoretical ethanol yield increased from 7.0 to 14.5% (irrigation) to 26.3 to 40.0% (nitrogen fertilizer).

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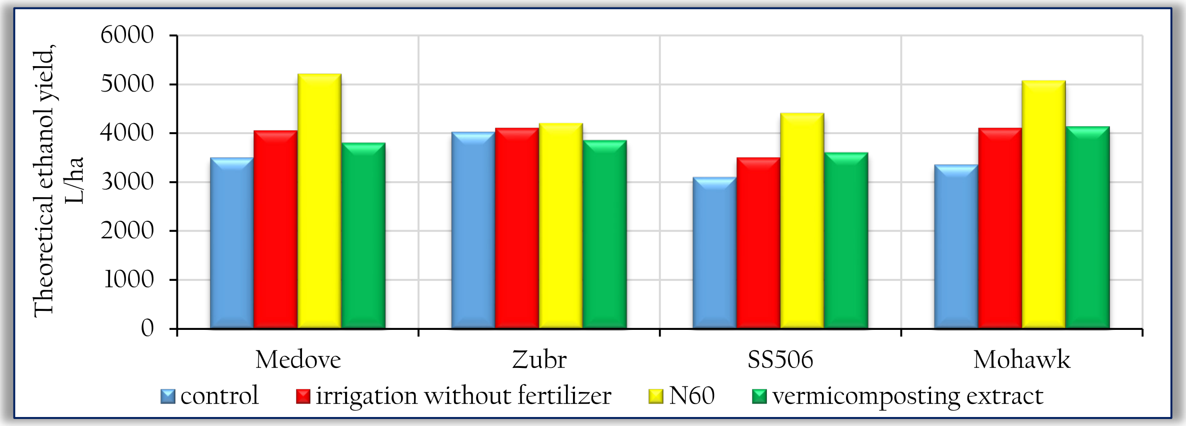

Figure 3 – Production of theoretical ethanol from sweet sorghum in black soil, l/ha

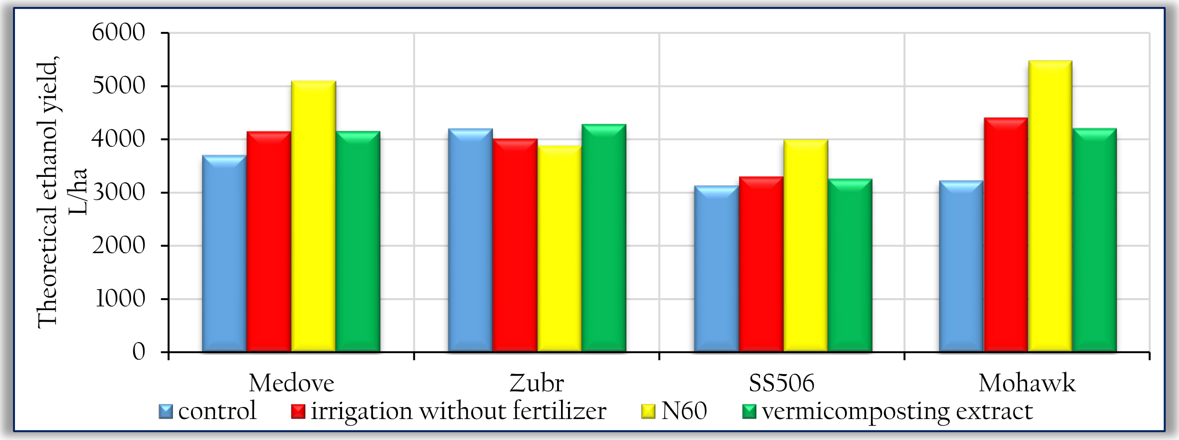

Figure 4 – Production of theoretical ethanol from sweet sorghum in loess like loam, l/ha

4. CONCLUSIONS

The biomass production of Medove, Zubr and SS506 above ground was slightly higher in loess like loam (by 2.5–7%), and hybrid Mohawk, on the contrary, was lower by 6.6% than in black soil. For Ukrainian hybrids, the application of nitrogen fertilizers had a positive effect on both substrates, while the effect of vermicomposting extract was manifested only on loess like loam. The grain productivity of the hybrid 'Zubr' on loamy–like loess was 2.5 times higher than on black soil, while for the hybrid 'SS506' the opposite dynamics was observed. Among the hybrids studied, the highest sugar content of stem juice is characteristic of the hybrid 'Mohawk' and the lowest is characteristic of the hybrid 'Zubr'. The theoretical ethanol yield of the 'Medove' in black soil under conditions of additional irrigation, fertilization with nitrogen fertilizer and vermicomposting extract increased by 11.0, 46.7 and 6.5%, respectively. Meantime, the effect was even greater in the loess–like loam: 14.3, 42.6 and 14.9% for the 'Medove' hybrid, and 36.5, 68.3, and 29.9% for the 'Mohawk' hybrid.

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References

[1] Ameen, A., Yang, X., Chen, F., Tang, C., Du, F., Fahad, S., & Xie, G.H. (2017). Biomass Yield and Nutrient Uptake of Energy Sorghum in Response to Nitrogen Fertilizer Rate on Marginal Land in a Semi–Arid Region. BioEnergy Research.Volume 10, Issue 2, 363–37
[2] Beltran, A.K.M., Samson, E.G., Angeles, D.E., Cabahug, R.A.M., & Rivera H.F.R.(2019). Agronomic and Yield Performance of Sweet Sorghum under Different Fertilizer Schemes. Philippine Journal of Crop Science (PJCS) 44 (3), 87–92.
[3] Blanco–Canqui, H. (2016). Growing Dedicated Energy Crops on Marginal Lands and Ecosystem Services. Soil Sci Sci. Am. 80, 845–868.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

[4] Dursun, B., Nazmi, D., Cengiz, E., Edip, B., & Bayir, Y.A. (2021). "Yield and bioethanol productivity of sorghum under surface and subsurface drip irrigation," Agricultural Water Management, Elsevier, vol. 243(C)
[5] Fu, H.M., Meng, F.Y., Molatudi, R.L. et al. (2016). Sorghum and Switchgrass as Biofuel Feedstocks on Marginal Lands in Northern China. Bioenerg. Res.. Vol. 9(2). 633–642
[6] Kharytonov, M., Martynova, N., Babenko, M., Rula, I., Gumentyk, M., Bagorka, M., & Pashova, V. (2019). The production of biofuel feedstock on reclaimed land based on sweet sorghum biomass. Agriculture and forestry journal. Vol. 65. № 4, 233–240
[7] Koksal, A., Dursun, B., Nazmi, D., Cengiz, E., Edip B., & Bayir Y.A. (2021). Yield and bioethanol productivity of sorghum under surface and subsurface drip irrigation, Agricultural Water Management, Elsevier, vol. 243(C)
[8] Mathur, S., Umakanth, A.V., Tonapi, V.A., Sharma, R., & Sharma M.K. (2017). Sweet sorghum as biofuel feedstock: recent advances and available resources. Biotechnol Biofuels. Vol.10(146), 1–19
[9] Regassa, TH, & Wortmann, CS. (2014). Sweet sorghum as a bioenergy crop: literature review. Biomass Bioenergy. Vol.64, 348–355. https://doi.org/10.1016/j.biombioe.2014.03.052.
[10] Ren, LT, Liu, ZX, Wei, TY, & Xie, GH. (2012). Evaluation of energy input and output of sweet sorghum grown as a bioenergy crop on coastal saline–alkali land. Energy Vol.47. P.166–173
[11] Scordia, D., Cosentino, S.L. Mantineo, M., Testa, G., & Patanè C.(2021). Nitrogen Balance in a Sweet Sorghum Crop in a Mediterranean Environment. Agronomy. 2021, 11(7),
[12] Shoemaker, C., & Bransby, D.I. (2010). The role of sorghum as a bioenergy feedstock.In Sustainable alternative fuel feedstock opportunities, challenges androadmaps for six US regions. Ankeny, IA: Soil and Water ConservationSociety.,149–159.
[13] Sipos, B.,Réczey, J., Somorai, Z., Kádár, Z., Dienes, D., Réczey, K. (2009). Sweet Sorghum as Feedstock for Ethanol Production: Enzymatic Hydrolysis of Steam–Pretreated Bagasse. Appl Biochem Biotechnol. 153(1–3), 151–62
[14] Perrin, R., Fulginiti, L., Bairagi, S., & Dweikat, I. (2018). Sweet Sorghum as Feedstock in Great Plains Corn Ethanol Plants: The Role of Biofuel Policy. Journal of Agricultural and Resource Economics 43(1), 34–45.
[15] Wortmann, C.S., Liska, A. J., Ferguson, R. B., Lyon, D. J., Klein, R. N., & Dweikat, I. (2010). Dry land Performance of Sweet Sorghum and Grain Crops for Biofuel in Nebraska. Agronomy Journal, vol.102(1), 319–326
[16] Zou, G.,Yan, S., Zhai, G., Zhang, Z., Zou, J., & Tao, Y. (2011). Genetic variability and correlation of stalk yield–related traits and sugar concentration of stalk juice in a sweet sorghum (Sorghum bicolor L. Moench) population. AJCS. 5(10), 1232–1238.

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