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THE INFLUENCE OF MINERAL FEEDING ELEMENTS TO THE OUTPUT OF BIOETHANOL FROM SUGAR SORGHUM

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Abstract. The article provides the results of studies about the effect of basic fertilizer and foliar nutrition of sugar sorghum plants on energy and bioethanol yield in the conditions of the Forest-Steppe southwestern part of Ukraine. The assimilation surface area of sorghum leaves in the variant with the application of $N_{60}P_{60}K_{60}$ and foliar nutrition in the phase of tillering by the Yarylo preparation at the rate of 3 l/ha increased from 39.6 to 49.1 thousand m^2/ha compared to the control and the net productivity of photosynthesis increased by 3.29 g/m^2 per day. The sugar content of sorghum stem juice in the stage of panicle formation and wax ripeness of grain in this variant increased by 1.7% – from 15.2 to 16.9%, and the sugar collection – from 5.16 to 8.68 t/ha compared to the control without fertilizer. A high yield of bioethanol was achieved when harvesting sugar sorghum in the wax ripeness phase – ranging from 2.26 to 2.28 t/ha. In the variant using mineral fertilizers ($N_{60}P_{60}K_{60}$) in autumn and foliar feeding in spring in the tillering phase with the complex microfertilizers Yarylo (3 l/ha) the bioethanol yield was 1.51 t/ha (panicle earing stage) and 2.58 t/ha (wax maturity stage).

Key words: Sugar sorghum; Mineral fertilizers; Foliar nutrition; Productivity; Bioethanol yield.

Реферат. В статье приведены результаты исследований о влиянии основного удобрения и некорневой подкормки растений сорго сахарного на выход энергии и биоэтанола в условиях юго-западной части Лесостепи Украины. Площадь ассимиляционной поверхности листьев сорго на варианте внесения $N_{60}P_{60}K_{60}$ и некорневой подкормки в фазе кущения препаратом Ярыло нормой 3 л/га по сравнению с контролем увеличивалась с 39,6 до 49,1 тыс. м^2 /га; чистая продуктивность фотосинтеза увеличилась на 3,29 г/м^2 в сутки. Содержание сахара в соке стеблей сорго в фазы формирования метёлки и восковой спелости зерна в этом варианте увеличилось на 1,7% – с 15,2 до 16,9%, а количество сахара – с 5,16 до 8,68 т/га по сравнению с контролем (без удобрений). Высокий выход биоэтанола был при сборе сорго сахарного в фазу восковой спелости – в пределах от 2,26 до 2,28 т/га. В варианте внесения с осени минеральных удобрений нормой $N_{60}P_{60}K_{60,}$ а весной – проведение внекорневой подкормки в фазу кущения комплексным микроудобрением Ярыло 3 л/га он составил в фазе выбрасывания метелки и восковой спелости соответственно 1,51 и 2,58 т / га.

Ключевые слова: Сорго сахарное; Фон питания; Некорневая подкормка; Продуктивность растений; Выход биоэтанола.

INTRODUCTION

The growing scarcity of petroleum products, their high cost and the deterioration in their use of the state of the environment are pushing for alternative sources of energy. Promising in this regard is the use of energy photosynthetic activity of plants in the form of bioethanol, the production of which has increased more than three times in the last decade. It is mainly used as fuel mixtures to increase octane: the addition of 10% bioethanol to gasoline can reduce aerosol particulate emissions by 50%, and carbon monoxide emissions by 30%.

The search for promising raw materials for its manufacture is an urgent task today. Sugar sorghum, which yields 90-100 t/ha of biomass with a sugar content of 18-20% (Гелетуха, Г.Г. et al. 2001; Курило, В.Л. et al. 2012; Роїк, М.В., Курило, В.Л. et al. 2012), is an effective sugar crop for the production of bioethanol.

Along with the lack of basic macronutrients, there is often a lack of micronutrients that can be established by the appearance of plants that lack nutrition and limit crop yield. Macros and micronutrients for plant nutrition cannot be replaced by any other. The amount of trace elements required for a plant compared to macro elements (nitrogen, phosphorus and potassium) is small, but even a slight deficiency of them can cause chlorosis, significantly impair the absorption of basic nutrients and even lead to the death of the plant. In such cases, the necessary nutrients are introduced by foliar nutrition, which is more quickly absorbed by the plants compared to the root nutrition. It should be borne in mind that highly concentrated solutions of salts that can burn the leaves cannot be used for foliar feeding, so they must be diluted to the required concentration before spraying. Separate solutions are generally used after the application of the main fertilizer as a foliar additive (Горбаченко, Н. І. 2013).

Macro- (nitrogen, phosphorus, potassium, magnesium) and micronutrients (boron, manganese, zinc, copper, molybdenum) are introduced in the non-root method.

Foliar feeding is carried out by spraying the plants with nutrient solution early in the morning or in the evening. During the day you can only spray in cloudy (but not rainy) weather.

The lack of trace elements is most felt on acid soils, moistened, sandy and other types of soils due to lack of moisture. The peat soils lack copper, the acidic sod-podzolic and gray forest - molybdenum, the red earths - boron and molybdenum, the carbonate and sandy soils - manganese, iron and zinc - lime. If high doses of nitrogen fertilizers are introduced into the soil, the plants should be nourished with molybdenum, copper, boron and cobalt.

If manure and ash are introduced into the soil, it is not necessary to feed the plants with trace elements. It is not necessary to make micro fertilizers also for the use of complex fertilizers - superphosphate of boron, molybdenum and manganese.

Combining basic fertilizer and foliar fertilization as opposed to root fertilization is the best method of introducing nutrients for plants. It timely and qualitatively regulates nutrition during the vegetation of plants in accordance with the weather conditions of the year. An important role is played by a balanced ratio of macro and micronutrients, since all the nutrients are closely interconnected in a single biochemical process and the role of each is very important, so it is advisable to use the trace elements in combination with the basic elements, taking into account the biological characteristics of the culture. The absorption of elements is carried out by all aboveground organs, including leaves, stems, fruits, etc. In doing so, they fall directly into the part of the plant in which, as a rule, the most intense are the physiological processes, and this is where their lack is most often encountered. Of the trace elements sorghum is most sensitive to manganese, zinc, iron, molybdenum; less sensitive - copper, weakly responsive to boron and sulfur. All these elements contain the Yarylo microfertilizer; it is non-toxic to humans and bees, non-allergenic, environmentally friendly.

The microfertilizer *Yarylo intensive growth* has the following composition, g/l: N - 60, P_2O_5 - 85, K_2O - 110, SO_3 - 5,3, Fe - 0,5, Mn - 2, B - 1, Zn - 0,6, Cu - 0.6, Mo - 0.05 (7).

The use of the microfertilizer Yarylo allows to satisfy plant needs in nutrients, increases plant resistance to diseases, pests, adverse soil and climatic and anthropogenic factors, has a positive effect on improving the processes of photosynthesis and exchange reactions in the plant.

The Yarylo microfertilizer promotes: increase of seed viability; stimulation of plant growth and development; strengthening of plant resistance to disease; the growth of productive shrubs; increase of heat resistance and drought resistance of plants; increase of crop yields by 10-15%; improving grain quality.

The microfertilizer *Yarylo intensive growth* provides an increase in leaf surface area and in the net productivity of photosynthesis by 10-40%. It strengths the root system and increases plant productivity.

MATERIALS AND METHODS

The research was conducted during 2015-2017 at the Department of Fruit and Vegetable Production of Podilsky State Agrarian and Technical University. The field experiment for the study of the elements of the technology of cultivation of sugar sorghum was carried out according to the scheme:

Control - without fertilizers.

$N_{60}P_{60}K_{60}$ - introduced since autumn under plowing.

Yarylo intensive growth - used in the tillering phase 3 l/ha dissolved in 300 l/ha of water.

$N_{60}P_{60}K_{60}$ autumn + *Yarylo intensive growth* - tillering phase 3 l/ha dissolved in 300 l/ ha of water.

The area of the basic planting area is 39.2 m^2 (2.8 x 14 m), the accounting area is 28 m^2 (2.8 x 10 m), the repetition rate is four times.

The area of the assimilation surface of the plants was determined by A.A. Nychyporovych (1961), the experimental data were analyzed by the method of variance (Ермантраут, E.P. et al. 2007).

Sugar sorghum cultivation technology, with the exception of the investigated elements, was generally accepted in the region. The sowing rate of the Sylosne 42 variety for sowing with spacings of 45 cm was 200 thousand seeds/ha. The yield of green mass of sugar sorghum was harvested in the phases of the panicle earing and waxy ripeness of the grain.

The soil of the experimental field is black soil leached, slightly humus, medium loam on forest loam.

The humus content (according to Tyurin) in the soil layer 0-30 cm was 3.86-4.11%; the easily hydrolyzable nitrogen (according to Kornfild) compounds were 111-121 mg/kg (high), mobile phosphorus (according to Chirikov) 90 mg/kg (medium) and exchangeable potassium (according to Chirikov) 179 mg/kg of soil (high). Hydrolytic acidity is 0.76-0.87 mg-eq/100 g of soil, the degree of saturation with bases is 94.7 and 99.0%.

RESULTS AND DISCUSSIONS

The physiological role of manganese (Mn) is to participate in redox reactions in plant cells and is associated with the activity of oxidizing enzymes, oxidases. Its lack in plants reduces the intensity of redox processes and the synthesis of organic substances.

Manganese is involved in the transport of substances through the organs of plants, in the processes of absorption of ammonium and nitrate nitrogen. At ammonium nutrition of plants it acts as a strong oxidant, and at nitrate - as a strong reducing agent. Due to the lack of manganese, the restoration of nitrate nitrogen is impaired, which leads to the accumulation of nitrates in plant tissues. Manganese is involved in the process of photosynthesis and synthesis of vitamin C. In the absence of manganese in plants, the synthesis of organic substances is reduced, the content of chlorophyll in plants - chlorosis is reduced. Low humidity, low soil temperature, and cloudy weather prevent manganese from being absorbed. Manganese deficiency is observed on soils with a neutral or alkaline reaction.

Zinc (Zn) increases the total content of carbohydrates, starch and protein substances, participates in redox breathing reactions, regulation of ATP synthesis, auxin metabolism and RNA. It has a positive effect on the heat resistance of plants and the formation of grains in dry conditions, increases the cold resistance of plants. Zinc deficiency disrupts protein synthesis, decreases its content in plants; soluble nitrogen compounds - amides and amino acids - accumulate in plants. High levels of phosphorus and lime, low soil temperature, interfere with the absorption of zinc.

Iron (Fe) in plants is actively involved in metabolism, is part of enzymes, activates respiration, affects the formation of chlorophyll. It is part of enzymes that are involved in redox reactions, metabolism associated with the transport of electrons from the respiratory substrate to molecular oxygen. With the help of ferredoxin phosphorylation is carried out, in which the energy of light is converted into chemical energy accumulated in ATP and NADP. It gives the plants fungicidal properties. Lack of iron leads to a decrease in the intensity of photosynthesis and chlorosis occurs on young plants. High soil moisture is prevented by iron absorption.

Molybdenum (Mo) is an integral part of nitrate reductase enzymes that are involved in the reduction of nitrates to ammonia in root and leaf cells. If this element is lacking, many nitrates are accumulated in the tissues of the plants, their recovery is delayed, which disrupts normal nitrogen metabolism; after application of nitrate fertilizers, the need for plants in molybdenum is much higher than ammonia fertilizers after nitrate fertilizer application. Ammonia is more intensively used by the plant under the influence of molybdenum for the formation of amino acids and proteins.

Molybdenum is involved in redox reactions and plays an important role in the transfer of electrons from the oxidized substrate to the recovered substance. It is involved in carbohydrate metabolism and in the exchange of phosphorus compounds, synthesis of vitamins and chlorophyll, improves plant nutrition with calcium, improves iron absorption.

The introduction of basic mineral fertilizers ($N_{60}P_{60}K_{60}$) and the complex fertilizer Yarilo 3 l/ha during the tillering phase of sugar sorghum contributed to the extension of the growing season by 2-3 days (Table 1).

Table 1. *Influence of the researched technologies of cultivation of sugar sorghum on photosynthesis performance (average for 2015-2017)*

Fertilizing variant	The duration of the growing season period, days	The area of leaf surface, thousand m² / ha	Photosynthetic potential, million m² · days / ha	Net productivity of photo synthesis, g/m² per day
Control - no fertilizers	138	39,6	5,46	2,23
$N_{60}P_{60}K_{60}$ - since autumn	141	47,3	6,67	4,31
Yarylo in the tillering phase 3 l / ha	140	41,1	5,75	4,62
$N_{60}P_{60}K_{60}$ - in autumn + Yarylo tillering phase 3 l / ha	141	49,1	6,92	5,52
HIP_{05}	2	1,5	1,2	1,2

The area of the assimilation surface of the culture under the influence of the introduced complete mineral fertilizers and foliar fertilization by the complex microfertilizers, compared to the control, increased significantly from 39.6 to 49.1 thousand m²/ha.

The net productivity of photosynthesis compared with the control increased by 2.08 g/m² per day for the full fertilizer application in autumn ($N_{60}P_{60}K_{60}$); for the foliar feeding in the tillering phase with the microfertilizer Yarylo (3 l/ ha) – by 2.39 g/m² per day and for the combined application of $N_{60}P_{60}K_{60}$ in autumn + Yarylo foliar application in the tillering phase at the rate of 3 l/ha – by 3.29 g/m² per day.

The increase in green mass continued until the wax ripeness phase of the sugar sorghum grain. If during the panicle earing phase the yield of green mass was in the range of 51.2-55.8 t/ha, then in the phase of wax maturity it increased to 79.2-84.5 t/ha (Table 2). Compared to the control without fertilizers, in the variant with the application of the basic mineral fertilizers ($N_{60}P_{60}K_{60}$) an additional yield of green mass was obtained: 3.4 t/ha in the phase of panicle earing and 3.8 t/ha in the wax ripeness phase. In the variant with the foliar feeding of sorghum by the microfertilizer (3 l/ha) in the tillering phase the additional yield was of 1.4 and 2.2 t/ha respectively, and with autumn application of $N_{60}P_{60}K_{60}$ + Yarylo in the tillering phase (3 l/ha) – 4,6 and 5,3 t/ha respectively .

The dry solids harvest was similar to that of the green mass: it also increased to the wax ripeness phase of the sugar sorghum grain. If, during panicle earing phase, the harvest was in the range of 11.8-13.4 t/ha, then in the wax maturity phase it increased to 17.2-19.4 t/ha. The application of basic mineral fertilizers ($N_{60}P_{60}K_{60}$) contributed to the increase of dry matter collection by 1.3 t/ha in the panicle earing phase and by 1.9 t/ha in the wax ripeness phase. In the variant with foliar feeding of sorghum by the micronutrient fertilizer Yarilo (3 l/ha) in the tillering phase the increase was by 1.6 and 2.2 t/ha respectively.

Table 2. *Yield and dry matter collection by stages of growth and development of sugar sorghum (average for 2015-2017)*

Fertilizing variant	Harvesting date			
	panicle earing		wax ripeness	
	t / ha	± to Control	t / ha	± to control
Green mass				
Control - no fertilizers	51,2	–	79,2	–
$N_{60}P_{60}K_{60}$ - since autumn	54,6	3,4	83,0	3,8
Yarylo in the tillering phase 3 l/ha	52,6	1,4	81,4	2,2
$N_{60}P_{60}K_{60}$ - in autumn + Yarylo tillering phase 3 l/ha	55,8	4,6	84,5	5,3
HIP_{05}	–	1,3	–	1,4
Dry mass				
Control - no fertilizers	11,8	–	17,2	–
$N_{60}P_{60}K_{60}$ - since autumn	13,1	1,3	19,1	1,9
Yarylo in the tillering phase 3 l/ha	12,6	0,8	18,7	1,5
$N_{60}P_{60}K_{60}$ - in autumn + Yarylo tillering phase 3 l/ha	13,4	1,6	19,4	2,2
HIP_{05}	–	0,6	–	1,1

Sugar yield and sugar content in the aboveground mass increased as the sorghum matured (table. 3).

Table 3. Sugar content and sugar yield *by growth and development phases of sugar sorghum (average for 2015-2017)*

Fertilizing variant	Harvesting date			
	panicle earing		wax ripeness	
	sugar content,%	sugar yield, t/ha	sugar content,%	sugar yield, t/ha
Control - no fertilizers	14,6	4,54	16,2	7,80
$N_{60}P_{60}K_{60}$ - since autumn	14,9	4,95	16,8	8,48
Yarylo in the tillering phase 3 l/ha	14,8	4,73	16,5	8,17
$N_{60}P_{60}K_{60}$ - in autumn + Yarylo tillering phase 3 l/ha	15,2	5,16	16,9	8,68
HIP_{05}	0,3	0,23	0,3	0,4

Sugar collection according to the variants of the experiment varied as follows. In the variant with the basic application of mineral fertilizers ($N_{60}P_{60}K_{60}$) it increased from 4.95 (panicle earing phase) to 8.48 t/ha (wax maturity phase). In the variant witn the foliar feeding of sorghum by the microfertilizer – from 4.73 to 8.17 and when the basic fertilizer was applied ($N_{60}P_{60}K_{60}$) in autumn + Yarylo (3 l/ha) in the tillering phase – from 5.16 to 8.68 t/ha.

The yield of bioethanol depends on the sugar content of the juice; the average proportion of stems in the green mass of sugar sorghum was 77%. The yield of purified bioethanol from sorghum sugar was 0.29 t / t. Its total output is given in table. 4.

Table 4. *Output of bioethanol by phases of growth and development of sugar sorghum, t/ha (average for 2015-2017)*

Fertilizing variant	Harvesting date	
	panicle earing	wax ripeness
Control - no fertilizers	1,32	2,26
$N_{60}P_{60}K_{60}$ - since autumn	1,45	2,46
Yarylo in the tillering phase 3 l/ha	1,37	2,37
$N_{60}P_{60}K_{60}$ - in autumn + Yarylo tillering phase 3 l/ha	1,51	2,58
HIP_{05}	0,05	0,09

Higher yield of bioethanol was obtained by harvesting sugar sorghum in the wax ripeness phase, ranging from 2.26 to 2.28 t/ha. The best nutritional background for sugar sorghum for the production of bioethanol is the introduction of full mineral fertilizers ($N_{60}P_{60}K_{60}$) since autumn, and in the spring, it will be advisable to apply foliar feeding with the complex microfertilizer Yarylo 3 l/ha.

The chemical composition of the sorghum sugar was: dry matter content – 16,5-18,7%, content of fermented sugars: only 14,3-16,2%, including: sucrose 8,8-9,9% , fructose 0.9-1.4%, glucose 2.3-2.7%, other monosaccharides 1.5-2.3%.

CONCLUSIONS

Compared to the control without fertilizers, the introduction of complete mineral fertilizers and foliar fertilization by the complex microfertilizers contributed to the increase of the area of assimilation surface of sugar sorghum plants from 39.6 to 49.1 thousand m^2/ha. The net productivity of photosynthesis increased by 2.08 g/m^2 per day on application of mineral fertilizers ($N_{60}P_{60}K_{60}$); by 2.39 g/m^2 on foliar feeding in the tillering phase with the fertilizer Yarylo (3 l/ha) and by 3.29 g/m^2 per day on combined application of $N_{60}P_{60}K_{60}$ since autumn + Yarylo foliar application in the tillering phase at the rate of 3 l/ha.

The yield of green mass increased by 3.4 t/ha (panicle earing phase) and 3.8 t/ha (wax ripeness phase) in the variant using $N_{60}P_{60}K_{60}$, compared to the control without fertilizers, while in the variant with foliar feeding by the micronutrient fertilizer Yarylo (3 l/ha) in the tillering phase green mass yield increased by 1.4 and 2.2 t/ha respectively, and with the autumn application of $N_{60}P_{60}K_{60}$ + Yarylo (3 l/ha) in the tillering phase – by 4.6 and 5.3 t/ha respectively. Dry solids collection was similar to green mass yields.

Sugar harvest increased from 4.95 in the panicle earing phase to 8.48 t/ha in the wax maturity phase in the variant with ($N_{60}P_{60}K_{60}$). With Yarylo (3 l/ha) applied in the tillering phase it increased from 4.73 to 8.17 t/ha and when using $N_{60}P_{60}K_{60}$ in autumn + Yarylo 3 l/ha in the tillering phase – from 5.16 to 8.68 t / ha.

The yield of bioethanol ranged from 2.26 to 2.28 t/ha when sugar sorghum was harvested in the wax ripeness phase. It was the largest in the variant using the complete mineral fertilizers at the rate of $N_{60}P_{60}K_{60}$ in autumn and foliar feeding in the tillering phase with the complex microfertilizer Yarylo 3 l/ha.

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