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IMPACT OF AGROTECHNICAL METHODS ON THE ENERGETIC PRODUCTIVITY OF SWEET SORGHUM

Summary

Since the contemporary energy policy in most European countries is based, to a significant degree, on the import of the energetic raw materials and the resources of the fossil sources of energy will be exhausted in the nearest perspective, investigation of new, alternative kinds of fuel is at present a highly urgent task. Sweet sorghum belongs to the crops with a high biomass potential due to its high drought. The conducted investigations envisaged to study the impact of various doses of mineral nutrients and the measures of protection of sowings against weeds on the energetic productivity of the sweet sorghum Silosnoje 42 variety and the Medovij hybrid. The experiments were conducted using a method of systematic repetitions and applying common methodologies of agronomy. It was established that application of mineral fertilisers with the dose $N_{80}P_{80}K_{80}$ on the background of the herbicide Dialen Super favoured increased release of energy by 195.1 GJ ha^{-1} for the Silosnoje 42 variety and by 224.8 GJ ha^{-1} for the Medovij hybrid. When a dose of mineral fertilisers $N_{160}P_{160}K_{160}$ was applied, the increase was respectively 254.8 and 340.2 GJ ha^{-1} in comparison with variants without fertiliser and herbicide application.

***Key words**: sweet sorghum, variety, hybrid, yield, energy, biofuel, productivity*

WPŁYW METOD AGROTECHNICZNYCH NA WYDAJNOŚĆ ENERGETYCZNĄ SŁODKIEGO SORGO

Streszczenie

Odkąd współczesna polityka energetyczna w większości krajów europejskich jest oparta, w znacznym stopniu, na imporcie surowców energetycznych a zasoby paliw kopalnianych w najbliższej perspektywie zostaną wyczerpane, badanie nowych, alternatywnych rodzajów paliw stało się bardzo pilnym zadaniem. Słodkie sorgo należy do upraw o silnym potencjale biomasy, wynikającym z wysokiej zawartości suchej masy. Przeprowadzono badania wpływu różnych dawek nawozów mineralnych i herbicydów na energetyczną wydajność słodkiego sorgo odmiany Silosnoje 42 i hybrydy Medovij. Eksperymenty przeprowadzono z użyciem metody systematycznych powtórzeń i stosowania ogólnie przyjętych metodyk agronomii. Ustalono, że aplikowanie dawki nawozów mineralnych $N_{80}P_{80}K_{80}$ wraz z herbicydem Dialen Super powodowało wzrost wartości energetycznej do 195.1 GJ ha^{-1} dla odmiany Silosnoje 42 i do 224.8 GJ ha^{-1} dla hybrydy Medovij. Gdy zastosowano dawkę nawozów mineralnych $N_{160}P_{160}K_{160}$, nastąpił wzrost odpowiednio do 254.8 i 340.2 GJ ha^{-1} w porównaniu z wariantami bez podania nawozu i herbicydu.

***Słowa kluczowe**: słodkie sorgo, odmiana, hybryda, plon, energia, biopaliwo, wydajność*

1. Introduction

Most European countries only partly supply themselves with the conventional kinds of energy resources and are forced to import approximately 65% of energy carriers [1, 6]. On the whole, the contemporary energy policy is based, to a significant degree, on the import of the energetic raw materials whose price is continuously rising. This tendency will increase from year to year because the extraction of fossil sources of energy is shrinking, and in the nearest perspective the resources of these energy carriers will be finally exhausted [12, 14].

An important role in ensuring energetic independence, including energetic independence of an agroindustrial complex (AIC), should be played by the renewable sources of Energy (RSE) whose ratio in the total energy balance of each country in the year 2010, according to the EU requirements, should be not less than 20%. The development strategy in this field prognosticates significant increase of investments into advancement of bioenergetics [4].

Intense opposite movement of two processes is going on in the world's energetics. On the one hand, the consumption of energy is growing. Let us say, in comparison with the present, the need for motor fuels in Europe in the year 2030 will increase 8 times. On the other hand, the resources of energetic fossil sources are rapidly decreasing. The decisive factor is that, depending on the kind (petroleum, gas, coal, uranium ore, etc.), the fossil resources will last only 40-250 years [2, 7].

According to literary sources [3, 12, 14] the energetic potential for such countries as Ukraine constitutes approximately 24 million tons of conditional biofuel, 2% of which is consumed at the present time. Not a less important factor is that the price of the energy produced from phytomass is lower than from the energy carriers obtained from the conventional sources.

It turns out to be particularly topical an introduction of the latest products from the alternative kinds of fuel and a wider application of the already existing, specially grown biomass, which will make it possible to reduce the dependence of most countries in Europe on the imported energy carriers [13].

At present the investigation of a sugar-containing plant raw material as biofuel for multiple uses is extremely urgent. Sweet sorghum belongs to the crops with a high biomass potential. The average output of sap from the stalks of the crop having 14% of sugar content is 50% of the weight of the stalks. Correspondingly, if the yield is 20 tons of stalks from 1 ha, it is possible to obtain 10 tons of sap or 1.6 tons of treacle, as well as 8 tons of the dry residue [16].

The results of investigations indicate that there is no other plant in nature now that could synthesise sucrose so rapidly, which constitutes 60 - 80% among the cell sap carbohydrates [8]. Considering the low requirements for the soil fertility and salinity, the low drought resistance, the domestic sorts and hybrids of sweet sorghum are able to ensure production of a significant amount of cheap biomass [9, 13, 15].

The aim of the investigations was to study the energetic productivity of sweet sorghum depending on the sort variations of the crop, the fertilisation systems and the protection methods of the sowings against the weeds.

2. The object and methodology of research

Field experiments have been carried out during the last 5 years. The characteristics of the investigated plots of soil are the following. The soil – typical black earth (chernozem) of low humus content. The content of humus in the topsoil is 3.7%, the easily hydrolysable nitrogen – 10.3, and the labile forms of phosphorus and potassium – 23.3 and 13.5 mg per 100 g of soil, respectively; pH of the soil solution – 5.6, the hydrolytic acidity – 15 mg-equivalent / 100 g of soil.

The experiment was conducted using a method of systematic repetitions: in each repetition the variants of the experiment were distributed on the plots in consecutive order. The repetition rate was 3 times. Sowing was carried out at the depth of 4...6 cm with 30 cm inter-row spacings, and the density of 300 thousand items/ha. The experiment provided for a study of the following factors: factor A – the sort (Silosnoje 42) and the hybrid (Medovij), factor B – fertilisers ($N_0P_0K_0$, $N_{80}P_{80}K_{80}$, $N_{160}P_{160}K_{160}$), factor C – chemical methods of weed control (Dialen Super 1.0-1.25 l/ha at the stage of 3-5 leaves of the crop).

3. Results and discussion

Mineral fertilisers are the most efficient and quick-acting means to raise soil fertility and productivity of agricultural crops. Mineral fertilisers have a great impact on all the living functions of the plant organism, namely, its growth and development; they raise the resistance of the plants against unfavourable conditions and affect positively the indicators of the area of the leaf surface, the height of the plants, the diameter of the stalk, and other parameters of the sweet sorghum plant productivity [5].

The weed control of the sweet sorghum sowings is also of great importance, particularly at the beginning of vegetation. Characteristic biological peculiarity of sorghum consists in its slow growth after sprouting (in the first 25-35 days the daily increase in the height is within the range 1-2 cm), and it is due to the rapid growth and development of the root system. During this time the sorghum plants are very sensitive to the impact of the weeds whose growth rate is twice as fast [10, 11, 17].

Interrelation between the factors to be studied and the sweet sorghum plant productivity manifested itself in a different manner and depended on the sort peculiarities of sorghum. The use of high-yielding sorts and hybrids with rational doses of the applied fertilisers and efficient protection of the sowings against weeds favours high yields both of the green and the dry mass at a high output of common sugars. All the investigated factors affected the biometric indicators of the sweet sorghum plants, the parameters of the productivity, and the output of biofuel and energy. Table 1 presents the biometric indicators of the investigated sort and hybrid depending on the agrotechnical conditions of growing.

Maximum values of the height of the sweet sorghum plant sort and the hybrid were reached at the stage of full ripeness. The height of the investigated sort and hybrid varied depending on the variant of the experiment; by the way, application of chemical protection means of sowing in the variants without fertilisers favoured increase in the height of the plants for the sort Silosnoje 42 by 14.8%, the hybrid Medovij – by 13.3%; when using an average dose of fertilisers – by 17.8% and 18.8%; in variants using a full dose of fertilisers – by 19.3 and 16.9%, respectively, in comparison with the control of the weedy plots. All this suggests that increase in the height and intensity of growth of the sweet sorghum plants depends not only on the hydrothermal conditions and biological peculiarities of each genotype but also on the agrotechnical conditions of growing the crop.

It was established that the potential yield of the green mass depends not only on the height but also on the thickness of the stalks. The diameter of the stalks is an indicator playing a significant role in the resistance of the plants against lodging, which reduces considerably the losses of the leafy and the stalky mass during its harvest. A maximum value of the diameter of the stalk in each of the variants of the experiment was observed at the stage of full ripeness because at this stage there takes place a transition to the generative period of development, i.e. simultaneous processes of atrophy of the leaves on the stalks of the plant and accumulation of the dry matter. The diameter of the stalks of the sweet sorghum plant at the stage of full ripeness on the unfertilised plots was 1.62 cm for the sort Silosnoje 42, and 1.79 cm for the hybrid Medovij; on the plots fertilised with $N_{80}P_{80}K_{80}$ – 1.71 and 1.90 cm; on the plots fertilised with $N_{160}P_{160}K_{160}$ – 1.89 and 2.10 cm in the best variant with herbicide application. At the stage of full ripeness the growth of the leafy mass of the investigated sort and the hybrid practically stops and the reproductive period starts. Under such conditions the surface area of the leaves of all the investigated plants sharply decreases irrespective of the fact that the sowings are supplied with mineral fertilisers. Thus, on the average, the surface area of the leaves on the unfertilised plots diminished by 4.9%, on the plots fertilised with $N_{80}P_{80}K_{80}$ – by 3.2%, on the plots fertilised with $N_{160}P_{160}K_{160}$ – by 3.6% at the expense of an extended atrophy process of the lower leaves and their diminished surface area.

Maximum indicators of the yields of both the green and the dry mass can be obtained in case when the plant is provided with a necessary amount of nutritive elements and an efficient protection system, considering the sort peculiarities. As the investigated sort and the hybrid have different genotypes, they react differently in their development to the biomass formation.

It has been established on the basis of the obtained data (Table 2) that the productivity of the sweet sorghum varies depending on the dose of the applied fertilisers and the methods of weed control. On the average, three years of observations allow to trace a common regularity – an increase in the yield of biomass, when the norm of mineral fertilisers is increased, in the variants with chemical protection of the sowings against weeds.

Application of herbicides for the weed control promotes increase in the yields of the green mass of the sort Silosnoje 42 by 31.1% and of hybrid Medovij by 17.8% when $N_{80}P_{80}K_{80}$ is applied, but, using $N_{160}P_{160}K_{160}$, the increase for the sort Silosnoje 42 is by 33.1%, for the hybrid Medovij – 32.6% because the conditions for mineral nutrition and the photosynthesis processes of the sweet sorghum plants are improved.

The energy account envisaged that all the sap obtained from the sorghum stalks will be used to produce bioethanol but the dry stalks after sap extraction – to produce solid biofuel (the calorific efficiency of 1 kg bioethanol is 25 MJ, solid fuel – 16 MJ). The total output of energy consists of the sum of energy obtained from solid biofuel and bioethanol (Table 3).

According to the results of the conducted investigations, a high output of bioethanol was observed in all the variants of testing while applying maximum doses of fertilisers to the sweet sorghum sowings.

Application of mineral fertilisers with a dose $N_{80}P_{80}K_{80}$ in the variants of chemical treatment favoured increase in the calculated output of bioethanol for the sort Silosnoje 42 by 14.2%, the hybrid Medovij – by 21.6% in contrast to the variants without fertiliser application. When a full dose of mineral fertilisers was applied, the increase was 33.6% for the sort Silosnoje 42 and 57.7% for the hybrid Medovij.

Solid biofuel (fuel pellets and granules) are produced from the dry mass which remains after extraction of the sap from the stalks of the plants. Application of a medium norm of fertilisers was beneficial for higher output of solid fuel of the sort Silosnoje 42 by 27.2%, the hybrid Medovij – by 31.5% in contrast to the variants without fertiliser application on the plots treated with herbicides.

A full dose of mineral fertilisers raised this indicator for the sort Silosnoje 42 by 48.5%, the hybrid Medovij – by 67.8% in contrast to the variants without fertiliser application. A minimum output both of bioethanol and solid fuel was observed in the control variants (untreated plots).

Table 1. Biometric indicators of the sweet sorghum sort Silosnoje 42 and hybrid Medovij at the stage of full ripeness depending on the agrotechnical conditions of growing (average for the years 2011-2013)

Variety, hybrid	Variant of protection of the sowings against weeds	Dose of fertilisers	Height of the plants, cm	Area of the leaf surface, cm^2	Diameter of the stalk, cm
Silosnoje 42	Control without application	no fertilisers	200.4	900.6	1.23
		$N_{80}P_{80}K_{80}$	213.7	1000.7	1.32
		$N_{160}P_{160}K_{160}$	219.9	1089.7	1.43
	Herbicide Dialen Super	no fertilisers	230.2	1279.32	1.62
		$N_{80}P_{80}K_{80}$	251.7	1397.4	1.71
		$N_{160}P_{160}K_{160}$	262.4	1538.2	1.89
Medovij	Control without application	no fertilisers	210.3	963.7	1.29
		$N_{80}P_{80}K_{80}$	221.6	1112.4	1.41
		$N_{160}P_{160}K_{160}$	234.3	1196.5	1.49
	Herbicide Dialen Super	no fertilisers	238.4	1412.25	1.79
		$N_{80}P_{80}K_{80}$	263.2	1529.6	1.90
		$N_{160}P_{160}K_{160}$	274.1	1936.4	2.10
HCP_{05}			6.4	354.7	0.3

Table 2. Yields of the green and the dry mass of sweet sorghum depending on the agrotechnical conditions of growing, t ha^{-1} (average for the years 2011-2013)

Variety, hybrid	Dose of fertilisers	Background	
		Control without application	Herbicide Dialen Super
Yield, t ha^{-1}			
Silosnoje 42	No fertilisers	40.0	62.4
	$N_{80}P_{80}K_{80}$	54.3	71.2
	$N_{160}P_{160}K_{160}$	59.6	79.3
Medovij	No fertilisers	41.2	64.2
	$N_{80}P_{80}K_{80}$	63.0	74.2
	$N_{160}P_{160}K_{160}$	69.0	91.5
$LCD_{05\ total}$		2.8	
Dry mass, t ha^{-1}			
Silosnoje 42	No fertilisers	7.0	12.4
	$N_{80}P_{80}K_{80}$	10.4	15.8
	$N_{160}P_{160}K_{160}$	12.4	18.4
Medovij	No fertilisers	8.1	13.6
	$N_{80}P_{80}K_{80}$	13.3	17.8
	$N_{160}P_{160}K_{160}$	15.9	22.8
$LCD_{05\ total}$		0.8	

Table 3. The calculated output of biofuel and energy from sweet sorghum, applying different doses of mineral fertilisers and using chemical protection of the sowings from weeds (average for the years 2011-2013)

Variety, hybrid	Methods of protection of sowings	Dose of fertilisers	Calculated output of		
			bioethanol, t ha^{-1}	Solid biofuel, t ha^{-1}	energy, GJ ha^{-1}
Silosnoje 42	Control without application	no fertilisers	1.41	7.7	158.7
		$N_{80}P_{80}K_{80}$	1.98	11.5	233.2
		$N_{160}P_{160}K_{160}$	2.21	13.7	274.2
	Herbicide Dialen Super	no fertilisers	2.68	13.6	285.3
		$N_{80}P_{80}K_{80}$	3.06	17.3	353.8
		$N_{160}P_{160}K_{160}$	3.58	20.2	413.5
Medovij	Control without application	no fertilisers	1.53	8.9	180.8
		$N_{80}P_{80}K_{80}$	2.42	14.7	295.0
		$N_{160}P_{160}K_{160}$	2.79	17.5	349.0
	Herbicide Dialen Super	no fertilisers	3.05	14.9	315.5
		$N_{80}P_{80}K_{80}$	3.71	19.6	405.6
		$N_{160}P_{160}K_{160}$	4.81	25.0	521.0

The chemical protection means of the sowings using a medium norm of fertilisers promoted increased average output of bioethanol by 54%, solid fuel – by 40.8% in comparison with the variants of weedy plots. When a full dose of mineral fertilisers was applied, the increase was 67.6 and 44.9%. As it is evident from the obtained results of investigations, the total output of energy was dependent also on the sort peculiarities and the agrotechnical methods of growing. The output of total energy exhibited a tendency to increase in the variants with fertiliser application and herbicide treatment. Thus, the total output of energy for the sort Silosnoje 42, when a medium norm of fertilisers was applied to the sowings treated with a herbicide, increased by 51.7%. When a full dose of fertilisers was applied, the increase was 50.8%. For the hybrid Medovij the rate of increase constituted 37.5%, when a medium norm of fertilisers was applied, and 60.0% in case of a full norm of applied fertilisers in comparison with the variants of weedy plots. The same tendency was obtained also for the output of energy from solid fuel and bioethanol. The high norms of fertilisers made a positive impact on the output of energy in all the variants of the test, yet the increase of energy in the variants with a full dose of fertilisers was less than in the variants with the dose $N_{80}P_{80}K_{80}$ if variants with a medium dose of fertilisers and without any fertilisers are compared. The output of energy from a unit of the area was determined by the productivity of the sweet sorghum sowings. The variants of a test in which the highest yield of the green mass was obtained showed correspondingly also the highest output energy. The variants with the best protection of sowings against weeds had better results by the bioenergetic indicators. The highest output of energy was reached in variants in which chemical protection of sowings against weeds was implemented.

4. Conclusions

1. The total output of energy, when sorghum is cultivated for the production of biofuel, depends both on the sort and the agrotechnical methods of growing. Favourable conditions for raising energetic productivity of the sweet sorghum plants were stated if mineral fertilisers are applied and the sowings are treated with herbicides.
2. Application of chemical protection means of the sowings against weeds using a dose of fertilisers $N_{80}P_{80}K_{80}$ ensures a yield of the green mass for the sort Silosnoje 42 – 71.2 t ha^{-1}, the hybrid Medovij – 74.2 t ha^{-1}; but using a dose of fertilisers $N_{160}P_{160}K_{160}$ – 79.3 and 91.5 t ha^{-1}, respectively.
3. The yields of sorghum 42-74 t☉ha^{-1} ensure the output of energy for the sort Silosnoje 42 using a medium norm fertilisers – 353.8 GJ☉ha^{-1}, the hybrid Medovij – 406.6 GJ☉ha^{-1}.
4. The yields 79.3 and 91.5 t ha^{-1}, when a full dose of mineral fertilisers ($N_{160}P_{160}K_{160}$) is applied, ensure the output of energy 413.5 and 521.0 GJ ha^{-1}, the increase in the energy output being lower.

5. References

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