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The effect of nitrogen fertilizers on the productivity of grain sorghum

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Due to the warming and increasing aridity of the climate in the steppe regions, the selection and introduction into production of high-yielding, drought-resistant crops, one of which is grain sorghum, becomes relevant. The use of mineral fertilizers is of a great importance in increasing its productivity. The purpose of the research is to determine the most effective dose of nitrogen fertilizer for grain sorghum with pre-sowing application of phosphorus fertilizers on the optimal background. It has been established that the most appropriate doses of pre-sowing nitrogen fertilizer range from N_{45} to N_{60} kg / ha of active ingredient. At this dose, an average of 4 years of research yielded the highest yield of sorghum grain (5.81 t / ha). In comparison with control, the increase was maximum and amounted to 0.91 t / ha. The introduction of N_{30} and N_{90} kg / ha allowed to obtain an additional 0.69 and 0.89 t / ha of grain. The use of the recommended dose of nitrogen contributed to the high collection of feed units (7.06 t / ha) and crude protein (6.10 t / ha). The energy content in the sorghum grain harvest during the years of research was the most significant (73715 MJ / ha) was also established with the addition of N_{60} kg / ha. Averaging the morphological and structural indicators of the grain sorghum crop depending on the doses of nitrogen fertilizers used indicate that the height of the plants increased and its maximum (94.8-95.5 cm) was established when N_{60}-N_{120} kg / ha was applied. The panicle length (22.6 cm), the weight of 1 panicle (34.2 g), the grain mass in a panicle (29.1 g) were the highest when using N_{45}-N_{60} kg / ha of active substance..

Keywords: nitrogen fertilizers, grain sorghum, moisture and nutrient regime of the soil, weather conditions of the growing season, crop structure, yield, grain quality.

INTRODUCTION

The territory of the Lugansk region is characterized by a sharply continental climate with an uneven distribution of precipitation throughout the year and arid-dry wind phenomena. Prolonged droughts are the most serious agricultural problem of the Steppe zone. The selection of crops with high drought tolerance, productivity and versatility of use is an important task to overcome these problems (Cherenkov et al., 2011, Volodin et al., 2018). In modern conditions, sorghum is becoming an alternative for the main traditional spring grain crops - barley and corn, the area of which over the past 10-12 years has begun expanding and now, in connection with the introduction of the latest precocious and high-yielding hybrids, modern cultivation technologies, they reach in the Lugansk region 10-20 thousand ha (Kumar et al., 2016, Tazoe et al., 2016).

In 2011, in the farms of the region, grain sorghum occupied an area of 10 thousand hectares and ensured an average yield of 3.69 tons / ha of grain, while spring barley was sown on an area of 79.2 thousand hectares and collected only 1.96 tons / ha (Baranovsky et al., 2014).

The State Register of Breeding Achievements of the Russian Federation for 2019 includes 120 varieties of grain sorghum, of which 42 are foreign varieties.

With a good phytosanitary condition of crops, the main criterion for a further increase in the yield of grain sorghum is optimization of the conditions of mineral and, above all, nitrogen nutrition of plants (Mishra et al., 2015, Mut et al., 2017, Kapustin et al., 2019). According to Shepel N.A. (1994), nitrogen is the most scarce nutrient for sorghum, due to natural fertility it provides this culture only by 38.7%, phosphorus - by 53.2%, potassium - by 93.7%.

The highest nitrogen consumption by sorghum plants is in the phases of an intensive growth and the formation of generative organs, especially 10-15 days before scavenging and 10-15 days after panicle bloom. The introduction of excessive doses of nitrogen can lead to undesirable consequences — weakening of drought tolerance, increasing in the duration of the growing season, excessive tillering and branching, which is especially undesirable for grain sorghum (Malinovsky, 1992, Kapustin et al., 2018, Singh et al., 2014).

Modern technology for obtaining high and sustainable crops is impossible without the use of fertilizers, which account for up to 30-40% of the increase in yield. Sorghum uses 23-25 kg of nitrogen, 9-10 kg of phosphorus and 28-30 kg of potassium from the soil to form 1 ton of grain and the corresponding amount of leaf-stem mass. With a yield of 5-6 t / ha, sorghum consumes about 140-160 kg of nitrogen, 50-60 kg of phosphorus and 150-180 kg of potassium per 1 ha (Samoilenko et al., 2011, Baranovsky et al., 2019).

The purpose of the study is to determine the most appropriate and effective dose of nitrogen fertilizer for grain sorghum with pre-sowing application of phosphorus fertilizers on the optimal background.

MATERIALS AND METHODS

Field experiments to study the effect of nitrogen fertilizers on the yield of the recommended for the hybrid grain sorghum hybrid (Richardson Seed company, USA) were conducted on the experimental field of the Lugansk national agrarian university in the crop rotation of the Department of Agriculture and Environmental Ecology in 2008-2011. according to generally accepted methods (Dospekhov, 1985). The soil of the experimental plot is ordinary low-humus chernozem on loesslike loam with a content of 3.3-3.4% humus in the arable layer, an average content of mobile nitrogen and phosphorus, and a high content of exchange potassium.

Against the background of phosphorus nutrition of plants (P_{40}), we studied increasing doses of nitrogen (without nitrogen, N_{30}, N_{60}, N_{90}, N_{120}) in spring with pre-sowing. The predecessor is winter wheat. Repeatability is fourfold. The area of the accounting plot is 50 sq.m. The sowing period is the end of April – first decade of May. The seeding rate is 600-700 thousand / ha of seeds, followed by the manual formation of plant density - 140 thousand / ha. Agrotechnology in the experiments was generally accepted for the conditions of the region. Crops were kept clean from weeds. To combat cereal aphids, field experiments at the beginning of the growing season (June) were treated with insecticides. Harvested at full ripeness of the grain from the entire plot, in terms of standard indicators.

In 2008, weather conditions were favorable in spring and very hot and arid in June, August and September. Reserves of productive moisture at time of sorghum seedlings were good. 2009 was a dry year. In the summer, there was not enough rainfall, the temperature in June was 3.3°C, and in July it was 2.0°C higher than normal.

In 2010, summer stocks were very dry, especially in August. The air temperature in May was 2.1°C, in June - 3.7°C, in July - 3.5°C, in August - 5.0°C exceeded the norm. In May, timely seedlings were received in May; the rains of June and July improved the condition of sorghum crops. The air temperature in 2011 was more moderate (22.9°C) than in hot 2010 (26.4°C).

RESULTS AND DISCUSSION

The vegetative period of development of sorghum in 2011 was 57-61 days, in dry 2010 - 52-57 days with a long-term value of 50-55 days. The reproductive period in 2011 was 44-51 days, in 2010 - 33-38 days, with a norm of 50-55 days. During the most critical period of the development of sorghum, the maximum reserve of mineral nitrogen was in dry 2010 in all 3 soil layers (Table 1).

Table 1. The content of mineral nitrogen in the soil, depending on the pre-sowing application of nitrogen fertilizers in the phase of 7-8 sorghum leaves, 2009-2011

Experience options	Soil layer, cm	The average content of mineral nitrogen in the soil, mg / kg					
		2009		2010		2011	
		$N\text{-}NO_3$	$N\text{-}NH_4$	$N\text{-}NO_3$	$N\text{-}NH_4$	$N\text{-}NO_3$	$N\text{-}NH_4$
Control with no fertilizer	0-20	6.73	1.88	14.37	7.72	14.18	10.43
	20-40	7.21	2.11	16.97	5.31	7.96	6.10
	40-60	6.26	1.18	10.83	7.32	7.43	4.63
N_{30} in spring before sowing	0-20	16.15	2.06	21.72	7.01	20.40	7.88
	20-40	8.68	3.31	18.94	6.48	10.74	5.66
	40-60	6.73	1.90	13.96	6.07	8.75	4.93
N_{60} in spring before sowing	0-20	12.42	3.73	23.93	6.84	23.12	6.71
	20-40	8.15	2.61	16.12	5.06	10.64	5.24
	40-60	8.94	4.37	13.56	6.85	7.27	4.45
N_{90} in spring before sowing	0-20	12.03	7.86	27.41	6.28	24.89	6.93
	20-40	5.66	8.11	22.99	7.42	9.48	5.69
	40-60	6.94	6.82	13.25	5.32	7.09	4.68
N_{120} in spring before sowing	0-20	14.60	6.68	32.71	8.61	34.38	7.05
	20-40	9.68	6.74	24.58	6.22	9.96	5.75
	40-60	5.05	7.79	15.52	5.53	6.74	4.29

In 2008, the longest panicle length (24.3 cm) and its weight (39.5 g), the number of grains in it (1085 pcs.), The mass of grain from a test sheaf (682 g) and the height of plants (99.5 cm) obtained on the variant with the introduction of an average dose of nitrogen (N_{60}) in pre-sowing spring fertilizer (table. 2). The maximum mass of 1000 grains and panicle length were on the plots with a high dose of nitrogen (N_{90}).

In a more arid year of 2009, the main indicators of the crop structure of sorghum plants were significantly worse than in 2008. The mass of grain from a panicle was 21.0-27.8 g, the weight of 1000 grains had a value of 29.9-34.7 g and gradually increased from increasing doses of nitrogen fertilizer.

In 2010, the weight of 1000 grains was 27.6-30.5 g and gradually increased from an increase in doses of nitrogen fertilizers. The maximum number of grains in a panicle (1092 pcs.), the mass of grain from a panicle (30.7 g), the mass of grain from a test sheaf (574 g / m^2) was obtained from the use of a minimum dose of nitrogen (N_{30}).

Due to severe drought throughout the summer, single-stem plants with a panicle length of 21.3-25.7 cm were obtained on all variants in all variants. The panicle weight was in the range of 27.1-30.7 g, the weight of 1000 grains was 27, depending on the options. 6-29.8 g. After drying to an air-dry mass, the ratio of grain to leaf-stem mass in all cases was almost the same and averaged 1:1. The highest yields (5.63 t / ha) were obtained with a minimum dose of nitrogen (N_{30}). The growth amounted to 0.73 t / ha. The highest plant height and panicle length were obtained when a dose of nitrogen N_{90} was added to the pre-sowing spring fertilizer.

Under the conditions of 2011, the plants of the sorghum Prime hybrid developed a much longer period (vegetation 101-108 days or 16-18 days longer than in dry 2010). This contributed to the formation of a much larger grain crop yield. Due to the increase in the number of panicles from a unit area, grain harvest significantly increased (the coefficient of productive tillering and branching was 1.24-2.12). The resulting pattern is associated with increased productive bushiness and branching of sorghum, which occurred in almost 50-55% of plants. The panicle length and the mass of 1000 grains were practically not corrected with the doses of fertilizers and the number of grains in it and varied between 19.9-21.8 cm and 31.8-32.9 g, respectively. A clear dependence of a decrease in panicle weight from 34.1 up to 25.8 g, grains in a panicle - from 27.8 to 21.2 g and the number of grains in it - from 916 pcs. up to 654 pcs. with an increase in doses of nitrogen fertilizers.

Conducting a continuous record of the crop in the phase of full ripeness from the entire accounting area of the plot during the years of research showed (Table 3) that the highest yield of a pure and standard grain moisture hybrid Prime was obtained by spring application of an average dose of nitrogen (N_{60}).

Table 2. The main indicators of the structure of the biological crop of grain sorghum depending on the use of nitrogen fertilizers (2008-2011)

Experience options	Panicle structure				1000 grain mass, g	Height of plants, sm
	Length of panicle, sm	Mass of panicle , gr	Number of grains, things	Grain mass , g		
2008						
Control	18.7	33.1	926	29.8	32.0	94.1
N_{30}	23.7	36.7	1125	34.7	30.9	98.6
N_{60}	24.3	39.5	1085	35.8	33.0	99.5
N_{90}	24.5	38.7	1018	33.9	34.3	99.0
N_{120}	23.6	36.3	997	32.1	33.2	98.9
2009						
Control	17.1	25.2	705	21.0	29.9	80.8
N_{30}	19.3	28.9	768	24.1	32.1	84.5
N_{60}	20.2	32.4	823	26.5	32.6	87.6
N_{90}	19.7	31.6	857	27.8	33.0	86.3
N_{120}	19.5	29.9	781	26.2	34.7	85.2
2010						
Control	23.8	34.2	981	27.1	27.6	95.8
N_{30}	24.7	34.3	1092	30.7	29.8	99.0
N_{60}	25.0	35.8	1079	30.4	29.6	98.9
N_{90}	25.7	33.1	1015	28.9	30.5	101.0
N_{120}	23.4	34.0	1018	28.8	28.5	101.8
2011						
Control	20.6	34.1	916	27.8	32.6	88.8
N_{30}	19.9	32.3	873	25.9	31.8	91.4
N_{60}	20.9	29.2	790	23.7	32.9	93.2
N_{90}	21.8	27.2	674	21.8	32.8	95.7
N_{120}	20.9	25.8	654	21.2	32.4	96.1
Average for four years						
Control	20.1	31.7	882	26.4	30.5	89.9
N_{30}	21.9	33.1	965	28.9	31.2	93.4
N_{60}	22.6	34.2	944	29.1	32.0	94.8
N_{90}	22.9	32.7	891	28.1	32.7	95.5
N_{120}	21.9	31.5	863	27.1	32.2	95.5

Due to the obtained grain growth (0.91 t / ha or 18.6%), each kilogram of fertilizer nitrogen provides an additional production of 15.2 kg of grain. A further increase in nitrogen doses did not contribute to the growth of crop productivity.

In the conditions of the wet vegetation period of 2011 (hydrothermal coefficient HTC_{V-VIII} = 1.08), an increase in nitrogen doses for cereal sorghum above 60 kg / ha of the active substance was ineffective. The same dependence was obtained in 2008 (HTC_{V-VIII} = 0.75). In the most arid conditions of 2009 and 2010 (HTC_{V-VIII} equal to 0.57 and 0.65, respectively), to ensure optimum yield, it was sufficient to introduce a minimum dose of nitrogen - N_{30}.

The introduction of a minimum dose of nitrogen (N_{30}) ensured a grain growth of 0.78 over the years, respectively; 0.57; 0.73; 0.69 t / ha, that is, the payback of 1 kg of introduced nitrogen fertilizer reached a maximum value of 26.0; 19.0; 24.3; 23.0 kg of sorghum grain.

Based on the results of 4-year research data, it was found that the zone of maximum productivity of the sorghum hybrid Prime is in the range of nitrogen doses - N_{30}-N_{60} and provides an average of 5.59-5.81 t / ha of grain. Taking into account the weather conditions during the growing season of the crop, it is advisable to annually during the pre-sowing season apply nitrogen fertilizers under cultivation at the level of 45-60 kg / ha of the active nitrogen substance.

The highest energy content (73,715 MJ / ha) in the grain sorghum crop was obtained using the variant with the introduction of an average dose of nitrogen fertilizers (N_{60}) in the spring pre-sowing season (Table 4).

Table 3. The yield of grain sorghum hybrid Prime, depending on the doses of pre-sowing application of nitrogen fertilizers (2008-2011)

Experience options	Grain yield sorghum, t / ha						Average for four years		
	years				average for four years	grain increase, t / ha	crude protein content in grain,%	crude protein harvest, t / ha	collection of feed units, t / ha
	2008	2009	2010	2011					
Nitrogen free	5.62	4.02	4.90	5.05	4.90	-	10.10	0.50	5.90
N_{30} before sowing	6.40	4.59	5.63	5.74	5.59	0.69	10.50	0.59	6.74
N_{60} before sowing	6.67	4.88	5.53	6.16	5.81	0.91	10.50	0.61	7.06
N_{90} before sowing	6.64	4.92	5.41	6.19	5.79	0.89	10.88	0.63	7.05
N_{120} before sowing	6.43	4.85	5.39	6.03	5.68	0.78	10.83	0.62	6.94
SSD_{05}, t / ha	0.09	0.18	0.26	0.30	0.02				
$S\bar{x}$, %	0.45	5.06	1.53	1.66	1.25				

Table 4. The energy content in the grain crop of sorghum during the years of research, MJ / ha

Experience options	2008	2009	2010	2011	Average
Nitrogen free (control)	71677	50781	60896	62983	61584
N_{30} before sowing	80610	57952	70121	71096	69945
N_{60} before sowing	85745	62123	68657	78336	73715
N_{90} before sowing	84435	61950	67877	80263	73631
N_{120} before sowing	83468	61174	67137	77900	68719

Compared to unfertilized control, energy reserves in sorghum grain increased by an average of 12131 MJ / ha (19.7%). The highest energy content was in 2008 with the addition of N_{60} (85745 MJ / ha), and the lowest - 50781 MJ / ha under control without the use of nitrogen fertilizers in the dry year of 2009.

CONCLUSION

With careful implementation of all agrotechnical requirements for the cultivation of grain sorghum recommended early ripe hybrid, depending on weather conditions during the growing season, the most appropriate and scientifically sound doses of pre-sowing nitrogen fertilizer range from N_{45} to N_{60}.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

BAV and KTM designed and performleed the experiments. BAV and KSI wrote the manuscript. KSI and KAS performed data analysis. All authors read and approved the final version

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