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YIELD OF GRAIN SORGHUM DEPENDS ON FERTILIZER AND VARIETAL CHARACTERISTICS

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Grain sorghum (L.) is a valuable crop with high yields. The crop future perspective depends on the ability of producers to apply optimal growing technologies. The general prerequisite for high yields of sorghum crops is the most efficient satisfaction of plant needs during the growing season, that is, the use of necessary chemical nutrients. Sorghum yields can be significantly increased by providing adequate nutrients. Fertilizer management affects not only yield but also the quality of the final product. Providing sorghum crops with adequate doses of fertilizers assist in maximising of yields. That is, research is needed on the selection of sorghum varieties optimal for the growing zone and the application of appropriate elements of technology, in particular, determining the optimal rates of mineral fertilizers that can ensure high yields in the northeastern forest-steppe zone of Ukraine, which was the goal of our research. The research was conducted during 2021-2023 at the educational and scientific field of Sumy National Agrarian University. The experiment repetition was trice, the plot placement was systematic. Factor A – hybrid and varieties of grain sorghum: Yankee, Dniprovsky 39, Samaran 6. Factor B – fertilizer rate: variant without fertilizer application (control), Nitroammophos ($N_{16}P_{16}K_{16}$), ($N_{35}P_{35}K_{35}$.) and ($N_{70}P_{70}K_{70}$) active ingredient kg/ha were applied for pre-sowing cultivation.

The results showed that the use of fertilizer rates of $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$ increased sorghum yield from 2.30 to 6.32 t/ha depending on genotypes. With increasing fertilizer rates, the value of the yield coefficient and crop weight increased.

The highest yield coefficient was determined for the Yanki hybrid and the Samaran 6 variety with an average coefficient value of 35 – 37%. (fertilizer rates of $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$)

For Dniprovsky 39 and the Samaran 6 variety, the maximum level of yield increase was noted with application of $N_{35}P_{35}K_{35}$ – 11, 8 kg and 5,52 kg of grain per 1 kg of active substance, respectively.

For Yankee hybrid, the highest indicator values was 11.90 kg of grain per 1 kg of active substance with a maximum rate of $N_{70}P_{70}K_{70}$.

In general, for high level of yield, the optimal rates of fertilizer application were $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$. The yield of Yankee hybrid and the Dniprovsky 39 variety was the highest in the experiment so they could be recommended for the growing under region conditions.

Key words: *sorghum, variety, hybrid, yield, yield coefficient, seed weight, fertilizer rates.*

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Introduction. Sorghum is grown worldwide on different continents, including North America, Africa, Asia and Australia (Akram et al., 2007; Qi et al., 2016). Sorghum (L.) is a valuable annual crop with an excellent yield. Though world production of sorghum is currently stagnant in some regions, the future of the crop depends on the ability of producers to apply optimal cultivation technologies. The general prerequisite for a high yield of sorghum is the most effective satisfaction of plant needs during the growing season. The basis for obtaining high-yielding crops is good assimilation of nutrients, as well as the application and use of the necessary nutrients in an optimal ratio (Ikanović et al., 2010; Bollam et al., 2021; Dembele et al., 2021).

Sorghum is characterized by adaptation to marginal soils with low nutrient content (Qi et al., 2016) and resistance to abiotic stresses, including heat and drought (Legesse & Gobeze, 2015; Ganyo et al., 2019; Sanders, et al., 2018; Adotey et al., 2021). Crop can achieve a high level of productivity even in unfavorable environments (Ajeigbe et al., 2018; Bayu, et al., 2006; van Oosterom et al., 2010).

However, the yield of sorghum can increase significantly if adequate supply of nutrients is provided. Despite the relatively low need of sorghum plants in fertilizers (Hasan et al., 2017; Zhang et al., 2016), a satisfactory economic effect can be obtained with an optimal level of nitrogen nutrition and cultivation of crop genotypes

adapted for the certain zone. Fertilizer application management has a significant impact on yield as well as on the quality of the final products. It has been shown that there is an increase in the protein content of sorghum grain with an growth in available nitrogen (Rashid et al., 2008; Diallo, 2012; Kaufman et al., 2013; Holman et al., 2019; Ostmeyer et al., 2022). In general, research on grain quality as a function of fertilizers is quite limited (Kaufman et al., 2013; Mahama et al., 2014; Melaku et al., 2017).

Proper application of mineral fertilizers can play a crucial role in improving agro-ecological and soil conditions for sorghum cultivation, leading to higher yield potential and increased feed productivity per unit area. However, the optimal fertilizer application rate depends on a number of factors, including soil type, climate and growing practices. Excessive use of fertilizers can lead to negative effects on the environment, such as soil degradation and water pollution. Therefore, it is important to consider carefully the specific crop needs and the local environment when determining appropriate fertilizer application rates (Masebo & Menamo, 2016; McHenry, 2016; Hailu & Kedir, 2022; Ivanina & Pashynska, 2022; Getinet & Atinafu, 2022).

It is possible to maximize yield by providing sorghum crops with adequate doses of fertilizers. Significant increases in yield with increasing application of nitrogen and phosphorus fertilizers have been observed in many experiments. It was established that the application of fertilizers up to 138/69 kg N/P_2O_5/ha is the rate of application that ensures the maximum yield (Desta et al., 2022).

Doses of fertilizers significantly affect the duration of individual phases of vegetation, plant height, panicle length and weight, grain yield (Temeche et al., 2021). In intensive farming systems, higher yields of sorghum grain were achieved under the condition of sufficient supply of plants with nitrogen fertilizers: the yield (due to the increase in the number of seeds) of sorghum increased with a growth rate application (0, 45 and 90 kg/ha), (Mahama et al., 2014; Bollam et al., 2021).

Worland et al. (2017) reported that sorghum seed size can be controlled by changing the timing of nutrients application. In the experiments of Dembele et al. (2021), the nitrogen rate of 178 kg/ha and plant density of 53,300 units/ha provided the highest level of grain yield and high profit. In the experiments of Shibeshi et al. (2022) rates of nitrogen fertilizers significantly affected all parameters of growth and yield of sorghum varieties. The maximum level of productivity and related indicators was recorded when applying nitrogen fertilizer rate of 92 kg/ha. Although sorghum yield is largely determined by genetic factors, nitrogen fertilization can have a significant effect on this characteristic.

Most of the soils in the grain sorghum growing regions are only able to provide half of the nutrients required by plants, so the use of fertilizers is one of the most important factors that determine the yield and quality of grain of this crop (Boiko, 2016; Maliarchuk et al., 2019).

In general, detail research is needed on the selection of sorghum varieties and the application of appropriate elements of technology, in particular, the determination of optimal doses of mineral fertilizers that can ensure a high yield in the northeastern forest-steppe zone of Ukraine, which was the goal of our research. The aim was to study the effect of fertilizer application on sorghum grain yield and determine individual fertilization strategies according to sorghum varietal characteristics.

Materials and methods. The study was carried out for 2021–2023 at the educational and scientific field of the Sumy National Agrarian University. Repetition of the experiment was triple, placement of plots – systematic.

Factor A – hybrid and varieties of grain sorghum: Yanki, Dniprovsky 39, Samaran 6.

Factor B – rate of fertilizer application: variant without fertilizer application, Nitroamofos ($N_{16}P_{16}K_{16}$), ($N_{35}P_{35}K_{35}$) and ($N_{70}P_{70}K_{70}$) active substance, kg/ha was applied according to the scheme of the experiment for pre-sowing cultivation. Sowing rate was 330 thousand units/ha. The size of the accounting plot – 1.5 x 10 = 15.0 m^2. The predecessor was winter wheat.

The organization and implementation of experiments, the selection of plant samples, and their analysis were carried out in accordance with methodological instructions and State Standards of Ukraine (Methodology of state variety testing of agricultural crops. Issue 2: Cereal, cereal and leguminous crops, 2001; Yeshchenko et al., 2005).

Results. Productivity is an effective economic indicator that reflects the study of the influence of natural and economic conditions and the level of organizational activity. As a result of our research, it was found that this indicator increased in all varieties and hybrids with an increase in fertilizer rates (Table 1).

The maximum yield of the Yankee hybrid was noted for the application rate of fertilizers $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$ and equaled to 6.32 and 4.29 t/ha. On the control (without fertilizer), the yield was the lowest – 3.82 t/ha.

The Samaran 6 variety formed the maximum grain yield in the experiment with the $N_{70}P_{70}K_{70}$ fertilizer application – 2.30 t/ha, as well as on the variant with $N_{35}P_{35}K_{35}$ fertilizer rate – 2.02 t/ha. The lowest yield was fixed on the variant without fertilizing – 1.44 t/ha.

Thus, the optimal rates of fertilizer application are $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$. for obtaining a high level of yield. The best varieties for the zone were the Yankee hybrid, which provided the maximum yield, and the Dniprovsky 39 variety.

The data analysis shows that the factor of varietal characteristics of grain sorghum plants (factor A) had the greatest impact on yield formation: 64%. (Fig. 1).

Fertilizer (factor B) accounted for a significant share of the impact – 28%. The interaction of the two factors was at the level of 5%, 3% of the influence was provided by other factors.

Therefore, in order to obtain high yields, a reasonable approach to the selection of a variety or hybrid is required, because almost 60% of the yield depends on this factor.

Application of mineral fertilizers is obligatory component of achieving a high level of productivity. On the base of the research, it was found for all varieties and hybrid, with an increase in the fertilizer rates, the yield coefficient and the crop weight on the variants increased as well (Table 2).

Table 1

The yield of grain sorghum depends on varietal characteristics and fertilizer (2021–2023)

A – variety/ hybryd	B – fertilizer rate, kg/ha	Yield, t/ha						Average			
		2021		2022		2023		for variant, t/ha		for factor, t/ha	
		X	± к	X	± к	X	± к	X	± к	A	B
Dniprovsky 39	No fertilizer	2.08		2.32		2.56		2.32		3.2	2.53
	$N_{16}P_{16}K_{16}$	2.07	-0.01	2.34	0.02	2.73	0,17	2.38	0.06		2.59
	$N_{35}P_{35}K_{35}$	3.12	1.04	3.3	0.98	4.26	1.7	3.56	1.24		3.29
	$N_{70}P_{70}K_{70}$	3.98	1.9	4.62	2.3	4.96	2.4	4.52	2.2		4.38
Yankee	No fertilizer	3.41		3.36		4.69		3.82		4.59	
	$N_{16}P_{16}K_{16}$	3.52	0.11	3.59	0.23	4.71	0.02	3.94	0.12		
	$N_{35}P_{35}K_{35}$	3.56	0.15	4.19	0.83	5.12	0.43	4.29	0.47		
	$N_{70}P_{70}K_{70}$	5.71	2.3	6.47	3.11	6.78	2.09	6.32	2.5		
Samaran 6	No fertilizer	1.4		1.06		1.86		1.44		1.81	
	$N_{16}P_{16}K_{16}$	1.39	-0.01	1.07	0.01	1.92	0.06	1.46	0.02		
	$N_{35}P_{35}K_{35}$	2.32	0.92	1.2	0.14	2.54	0.68	2,02	0.58		
	$N_{70}P_{70}K_{70}$	2.39	0.99	1.53	0.47	2.98	1.12	2.3	0.86		
Average		2.91		2.92		3.76		3.2			
LSD 0.05 : A-0.2; B-0.23; AB-0.4											

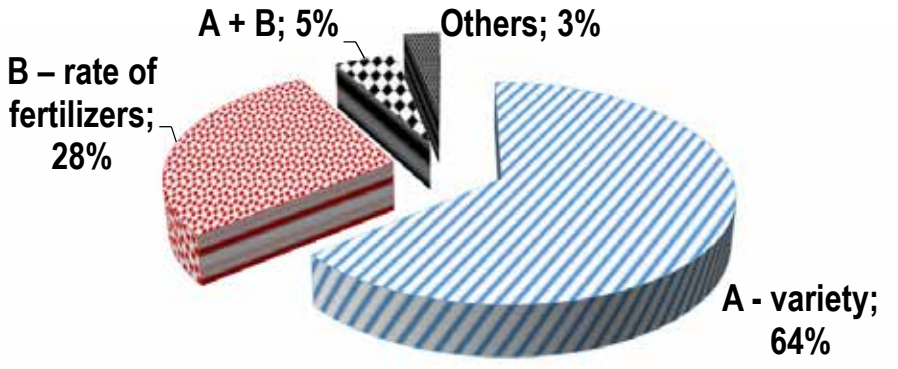

Fig. 1. Share of factor influence on sorghum yield (2021-2023)

Table 2

Phytomass accumulation and yield coefficient of grain sorghum depending on fertilizer rate (2021–2023)

Factor		Crop weight, g/м²	Yield coefficient,%			
A – variety/hybryd	B – fertilizer rate, kg/ha		average for variant		average for factor	
			X	± k	A	B
Dniprovsky 39	No fertilizer	873.19	27.3		30.38	29.87
	$N_{16}P_{16}K_{16}$	947.85	25.8	-1.50		28.97
	$N_{35}P_{35}K_{35}$	1091.91	33.5	6.20		34.97
	$N_{70}P_{70}K_{70}$	1330.74	34.9	7.60		36.87
Yankee	No fertilizer	1291.13	30.4		33.93	
	$N_{16}P_{16}K_{16}$	1305.92	31.0	0.60		
	$N_{35}P_{35}K_{35}$	1255.83	35.1	4.70		
	$N_{70}P_{70}K_{70}$	1656.58	39.2	8.80		
Samaran 6	No fertilizer	463.82	31.9		33.70	
	$N_{16}P_{16}K_{16}$	498.39	30.1	-1.80		
	$N_{35}P_{35}K_{35}$	571.78	36.3	4.40		
	$N_{70}P_{70}K_{70}$	647.47	36.5	4.60		
Average		994.55	32.7			

Thus, based on the analysis of average data by factors, it can be concluded that for the crop weight, by factor A, the Yankee hybrid and the Samaran 6 variety should be considered as an alternative variant, with the maximum yield coefficient. By factor B, the optimal fertilizer application rate is $N_{35}P_{35}K_{35}$ and $N_{70}P_{70}K_{70}$ with an average value of 35–37%.

An additional parameter characterizing the response of varieties to fertilizer rates is the yield increase per kg of active ingredient (Table 3).

In Dniprovsky 39 variety, the maximum level of yield increase, i.e. –11.8 kg of grain per one kg of active substance, was noted on plots with the application of $N_{35}P_{35}K_{35}$ ferilizer. The smallest increase was observed on the variant with the rate of $N_{16}P_{16}K_{16}$ – 1.25 kg/kg of active substance.

The Yankee hybrid has the same indicator – 11,90 kg of grain per one kg of active ingredient was noted on plots with the maximum fertilizer rate of $N_{70}P_{70}K_{70.}$ On the variant with the rate of $N_{35}P_{35}K_{35}$. an increase of 4.48 kg/kg of active substance was obtained. The smallest yield increase was on the variant with the rate of $N_{16}P_{16}K_{16}$ – and amounted to 2.50 kg of grain per one kg of active substance.

In the Samaran 6 variety, the maximum level, i.e. 5.52 kg of grain per one kg of active substance, was observed in variant with the application of $N_{35}P_{35}K_{35}$. The smallest increase was observed in the variant with the fertilizer rate of $N_{16}P_{16}K_{16\,-}$ 0.42 kg/kg of active substance.

With some differences between individual varieties, the index characterizes a gradual increase in the effectiveness of fertilizer rate of $N_{35}P_{35}K_{35}$ and higher.

The maximum yield in the experiment was obtained in the Dniprovsky 39 variety, at the rate of fertilizer application $N_{35}P_{35}K_{35}$ and $N_{70}P_{70}K_{70}$, (3.56 t/ha – 4.52 t/ha, respectively). The maximum yield of the Yankee hybrid was noted at the rates of $N_{70}P_{70}K_{70}$ fertilizer application.

Discussion. Recent studies have shown that the use of mineral fertilizers has increased lately (Ajeigbe et al.,2018), but low sorghum yield per fertilizer application, caused by low soil fertility, remains a problem in many crop growing regions (Sanders et al., 2018). Management practices for both crop production, which concerns soil fertility, and water resources, are further complicated by the variability of environmental factors and climate change. Analysis of the response of sorghum to soil fertility, for example, in Africa, demonstrated a 47–98% increase in yield when mineral fertilizers were applied. The combination of organic and mineral fertilizers as input factors was the most optimal option for both increasing yield and increasing soil fertility. This is crucial for sustainable productivity of agroecosystems, increasing nutrient use efficiency, reducing environmental stress, and adapting application rates to soil fertility gradients.

According to the research of Gupta et al. (2012), Mahama et al. (2014), the leading role in obtaining high yields of grain sorghum belongs to nitrogen (among other nutrients), but smaller one – to phosphorus and potassium. It was found that increased nitrogen supply contributes to maximum sorghum yield. However, the ideal rate of nitrogen fertilizers may vary depending on the crop rotation and technology used. By managing the application of nitrogen fertilizers and choosing the right crop rotation technique, it is possible to maximize sorghum productivity and obtain more profitable yields.

Many studies have shown that the application of phosphorus fertilizers also has a positive impact on grain yield, 1000-seed weight, and harvest index (Buah et al., 2012; Ajeigbe et al., 2018; Sebnie & Mengesha, 2018; Getinet & Atinafu, 2022).

A number of researchers believe that grain sorghum growing needs to avoid excessively high doses of nitrogen

Table 3

Additional yield of grain sorghum varieties and hybrid, provided with mineral fertilizers (2021–2023)

A – variety/hybryd	B – fertilizer rate, kg/ha	Additional yield , provided with mineral fertilizer kg/kg, active substance		
		average for variant	average for factor	
		X	A	B
Dniprovsky 39	No fertilizer		7.85	0.00
	$N_{16}P_{16}K_{16}$	1.25		1.39
	$N_{35}P_{35}K_{35}$	11.81		7.27
	$N_{70}P_{70}K_{70}$	10.48		8.83
Yankee	No fertilizer		6.29	
	$N_{16}P_{16}K_{16}$	2.50		
	$N_{35}P_{35}K_{35}$	4.48		
	$N_{70}P_{70}K_{70}$	11.90		
Samaran 6	No fertilizer		3.35	
	$N_{16}P_{16}K_{16}$	0.42		
	$N_{35}P_{35}K_{35}$	5.52		
	$N_{70}P_{70}K_{70}$	4.09		

fertilizers (Mahama et al., 2014; Masebo & Menamo, 2016; Melaku et al., 2018). However, low nitrogen rates may not affect crop productivity. Thus, the lowest fertilizer rate in our experiments – $N_{16}P_{16}K_{16}$ – did not provide a positive effect on the increase in yield and its components. In our opinion, increasing the yield level requires the use of higher fertilizer rates.

Hospodarenko & Klymovych (2006) note that high yield and quality of grain sorghum can be achieved only with balanced application of basic elements. According to researchers, the optimal rate of mineral fertilizers is determined by the dose of $N_{90}P_{90}K_{90}$ in the conditions of the Forest-Steppe on black soil, which provides a grain yield of 8.6 t/ha, and a protein content of 11.5%. Grain sorghum responds positively to the use of sufficiently high doses of mineral fertilizers ($N_{120}P_{120}K_{120}$), increasing grain yield by 1,82–2,45 t/ha.

High efficiency of mineral fertilizer application in grain sorghum crops was also observed in studies by Abunyewa et al. (2017); Mahama et al. (2014); Masebo et al. (2016); Melaku et al. (2018).

In our experiments, the optimal fertilizer rates were $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$ which ensured an increase in yield regardless of crop genotypes.

The high efficiency of an alternative organic-mineral fertilizer system for grain sorghum has been established. With the combined application of mineral fertilizers and winter wheat straw, the soil is additionally replenished with nutrients, enriched with organic matter, and the yield of grain sorghum significantly increases (Ivanina & Pashynska, 2022).

The combination of different types of fertilizers (organic and mineral) on sorghum crops will possibly provide a positive effect in the northeastern forest-steppe zone, but this needs additional research.

Conclusions. The use of fertilizer rates of $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$ increased the yield of sorghum from 2.30 to 6.32 t/ha depending on the genotypes. With increasing fertilizer rates, the value of the yield coefficient and the crop weight increased as well.

The highest yield coefficient was determined for Yankee hybrid and Samaran 6 variety, with an average value of 35–37% (with fertilizer rate of $N_{35}P_{35}K_{35}$ and $N_{70}P_{70}K_{70}$)

For Dniprovsky 39 and Samaran 6 variety, the maximum level of yield growth was noted with application of $N_{35}P_{35}K_{35}$ – 11.8 kg and 5.52 kg of grain per one kg of active substance, respectively.

For Yankee hybrid, the highest indicator values was 11.90 kg of grain per one kg of active substance with a maximum rate of $N_{70}P_{70}K_{70}$.

In general, to obtain a high level of yield, the optimal rates of fertilizer application were $N_{70}P_{70}K_{70}$ and $N_{35}P_{35}K_{35}$. The yield of Yankee hybrid and the Dniprovsky 39 variety was the highest in the experiment so they could be recommended for the growing under region conditions.

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Врожайність сорго зернового залежно від удобрення та сортових особливостей

Сорго зернове (L.) – цінна однорічна культура з відмінною врожайністю. Майбутнє культури залежить від здатності виробників застосовувати оптимальні технології вирощування. Загальною передумовою високої врожайності посіві сорго є максимально ефективне задоволення потреб рослин протягом вегетаційного періоду, тобто використання необхідних хімічних елементів живлення. Врожайність сорго може суттєво зростати за умови адекватного забезпечення поживними речовинами. Управління внесенням добрив впливає не лише на рівень врожайність, але й на якісний склад кінцевої продукції. Забезпечуючи посіви сорго адекватними дозами добрив, можна максимізувати врожайність. Тобто потрібні дослідження щодо вибору оптимальних для зони вирощування сортів сорго та застосування відповідних елементів технологій, зокрема визначення оптимальних доз мінеральних добрив, які можуть забезпечити високий врожай в зоні північно-східного лісостепу що й було метою наших досліджень. Дослідження проводили впродовж 2021–2023 рр. на навчально-науковому полігоні Сумського національного аграрного університету. Повторення досліду – триразове, розміщення ділянок – систематичне.

Фактор А – гібрид та сорти сорго зернового: Янкі, Дніпровський 39, Самаран 6. Фактор В – норма внесення добрив: варіант без внесення добрив (фон), Нітроамофос ($N_{16}P_{16}K_{16}$), ($N_{35}P_{35}K_{35}$) та ($N_{70}P_{70}K_{70}$) діючої речовини кг/га вносили відповідно до схеми досліду під передпосівну культивацію

Для отримання високого рівня врожайності, оптимальними нормами внесення добрив є $N_{70}P_{70}K_{70}$ та $N_{35}P_{35}K_{35}$. Найкращими сортами для зони були гібрид Янкі, який забезпечив максимальну врожайність та сорт Дніпровський 39. Застосування норм добрив $N_{70}P_{70}K_{70}$ та $N_{35}P_{35}K_{35}$ підвищило врожай сорго від 2,30 до 6,32 т/га залежно від генотипів. Зі збільшенням норм добрив зростало значення коефіцієнта урожайності та маса посіву.

Аналіз наведених вище даних показує, що на формування врожайності найбільший влив мав фактор сортових особливостей рослин сорго зернового (фактор А) : 64%. Суттєву частку часткою впливу склали добрива (фактор В) – 28%. Взаємодія двох факторів була на рівні 5%, 3% впливу забезпечили інші фактори.

Найвищий коефіцієнт врожайності визначено для гібриду Янкі та сорту Самаран 6. з середнім значенням коефіцієнта 35–37%. (нормою добрив $N_{35}P_{35}K_{35}$ та $N_{70}P_{70}K_{70}$)

Для сорту Дніпровський 39 та сорту Самаран 6 максимальний рівень прибавки врожаю відзначено за внесення $N_{35}P_{35}K_{35}$ – 11,8 кг та 5,52 кг зерна на 1 кг діючої речовини відповідно.

Для гібрида Янкі найвищі значення показника становили 11,90 кг зерна на 1 кг діючої речовини з максимальною нормою $N_{70}P_{70}K_{70}$.

Загалом для отримання високого рівня врожайності оптимальними нормами внесення добрив були $N_{70}P_{70}K_{70}$. та $N_{35}P_{35}K_{35}$. Урожайність гібрида Янкі та сорту Дніпровський 39 була найвищою в досліді, тому їх можна рекомендувати для вирощування в умовах регіону.

Ключові слова: *сорго, сорт, гібрид, урожай, коєфіцієнт урожайності, маса посіву, дози добрив.*