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Effect of mineral fertilizers on the formation of the structure indicators of grain sorghum yield capacity

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Abstract. In the process of gradual warming, producers carry out the search of the crops, which develop high productivity of excellent quality grain in the difficult soil-climatic conditions. Grain sorghum is one of these crops. Similar to any other agricultural crop, its productivity depends on the effect of numerous factors including the elements of the cultivation technology. One of these elements is the application of mineral fertilizers. The purpose of the research was to study the effect of the plant mineral nutrition on the formation of the structure indicators of grain sorghum yield capacity in the conditions of the Right bank Forest steppe zone of Ukraine. The experiment was carried out in the zone of unstable humidity in 2016–2020. The trial scheme consisted in studying grain sorghum cultivars and various fertilizer rates; the trial was initiated with the method of regular replications, a fourfold replication was applied. Having analyzed the research results, it was found out that as the fertilizer rates increased, the element indicators of the yield structure also increased; in turn grain yield capacity of the studied cultivars was higher. However, the optimal fertilizer rate for the expected yield is the estimated one which will reduce the production cost of the output.

Keywords: *rates; cultivars; productivity; correlation.*

Introduction

Sorghum is a unique cereal plant both in terms of its biological peculiarities and economically valuable features. Sorghum is the fifth largest grain crop in the world after wheat, rice, corn and barley. The homeland of sorghum is Equatorial or Northeast Africa. Derivative centers of its origin are considered to be India and China, from where it was imported to other countries [1, 2]. In some regions, this crop replaces corn due to its high yield capacity, drought and heat resistance [3, 4]. Sorghum is adapted to a wide range of environments, it is grown in the tropics as well as in arid regions of the world. As a C_4 plant, sorghum effectively fixes carbon in high and low temperature environments. Conversely, it is the resistance of sorghum to waterlogging that helps it thrive in tropical environments. This is a universal short-day crop, as it uses moisture and precipitation effectively, restores its growth after a long dry period and forms a fairly high yield, which means it can be grown in arid areas [5, 6].

In the context of climate change and variability, increasing small grain yield is critical for food and nutrition security [7]. Droughts and low soil fertility are common in semi-arid regions, trapping smallholder farmers in a cycle of poverty [8]. Drought is a primary sorghum production constraint and is the leading cause of yield decrease [9].

Grain sorghum is a key food crop for food production and for the use in fodder production [10, 11]. In the arid and semi-arid regions of the developing world, millions of people consume sorghum as their main source of food, while it is mainly used for livestock feed and for industrial use, namely for bioethanol production in the industrialized countries, including the United States of America [12–14].

Recently sorghum grain production has increased. Modern varieties and hybrids have a high potential for productivity, and are suitable for the use of intensive technologies for the production of feed grain. Increased requirements to organic production necessitate the nutritional parameter optimization in the conditions of the unstable agriculture with the unbalanced accumulation of nutrients in the soil. The

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mineral fertilizer application is one of the most effective factors influencing the dynamics of grain sorghum growth and development, its ability to form high yield capacity and grain quality in different climatic conditions [15–17].

Grain sorghum responds positively to the application of mineral fertilizers, it consumes only 38.7% of nutrients of the total uptake from soil reserves [18]. According to some scientists [19, 20], it has been investigated that half of the increase in crop yield capacity can be obtained due to fertilizers.

It has been proved that biometric and yield structure indicators are influenced by different tillage practices, varieties and the level of mineral fertilizers [21].

In South-Eastern Romania, it is recommended to grow grain sorghum using a rate of mineral fertilizers $N_{120}P_{60}K_{60}$, having obtained the highest grain yield capacity [22].

In India the recommended rate of fertilizers is $N_{80}P_{40}K_{40}$, which provides a higher net profit and a low cost of cultivation [23].

In Ukraine, according to the authors, the optimal rate of fertilizers for growing grain sorghum was the application of $N_{60}P_{60}K_{60}$. According to this technology, crop productivity was 8.0–8.49 t ha^{-1} [1, 18].

According to many scientists, the effective use of fertilizers can increase the resistance of grain sorghum to unfavorable external factors, increase germination energy, ensure the intensive growth at the early stages of organogenesis and a high productivity of generative organs [24–26].

Inadequate and imbalanced application of fertilization to crops not only leads to low crop yields but also decreases soil quality [27].

In Ukraine, the issue of studying the effect of different rates of grain sorghum fertilizers on the elements of crop yield structure has been studied insufficiently, so it requires some detailed research.

By optimizing the technology elements of the cultivation of agricultural crops, including grain sorghum, it is possible to influence the formation of the elements of the yield capacity structure and, accordingly, to obtain high and sustainable productivity. The structure elements of the grain sorghum yields include such indicators as the number of panicles per hectare, the number of grains in the panicle, the mass of grain in the panicle, the mass of 1000 seeds, etc. [28].

The aim of the work was to study the effect of plant mineral nutrition on the formation of the structure indicators of grain sorghum yield capacity in the conditions of the Right-Bank Forest-Steppe zone of Ukraine.

Materials and methods

The research was carried out in Bila Tserkva research-breeding station of the Institute of bio-energy crops and sugar beet of Ukraine's National Academy of Agrarian Sciences in 2016–2020.

The following factors were studied in the trial – cultivars (factor A): 'Dniprovskyi 39', 'Vinets' and fertilizer rates (factor B): $N_0P_0K_0$ – without fertilizers (control); $N_{30}P_{30}K_{30}$; $N_{60}P_{60}K_{60}$; $N_{90}P_{90}K_{90}$; $N_{120}P_{120}K_{120}$ and an estimated fertilizer rate which was $N_{50}P_{40}K_{70}$ on the average in the years under study.

The estimated fertilizer rate was calculated with help of a balance-calculating method. The trial was initiated with the method of regular replications; in each replication the treatments were placed in the plots successively. A fourfold replication was applied. The observation and accounting were done according to the recommendations of Bila Tserkva IBCSB [29].

The soils of the experimental plot are chornozems of typically deep low-humus coarse dust average loamy granule-metric composition. Magnesium and calcium carbonates lie at the depth of 55–65 cm. About 17 % of silt particles and 46–54 % of coarse dust are in a plowing layer (0–30 cm). The relief is flat; the depth of ground water is 8 m. A saturation degree of bases is 90 %.

According to the data of Bila Tserkva meteorological station, the weather conditions (temperature and precipitation) of the vegetative period in the years of 2016, 2017, 2018, 2019 and 2020 were characterized with slight fluctuations, exceeding average long-term data.

In 2016 on the average the air temperature was 17.9 °C, which is higher than average long-term data by 2.48 °C, the amount of precipitation was lower by 102.6 mm (Figures 1, 2).

In 2017 on the average the air temperature was 17.2 °C, which exceeded the long-term indicators by 1.85 °C. The amount of precipitation was 186.8 mm, which was smaller by 159.2 mm as compared with the average long-term data.

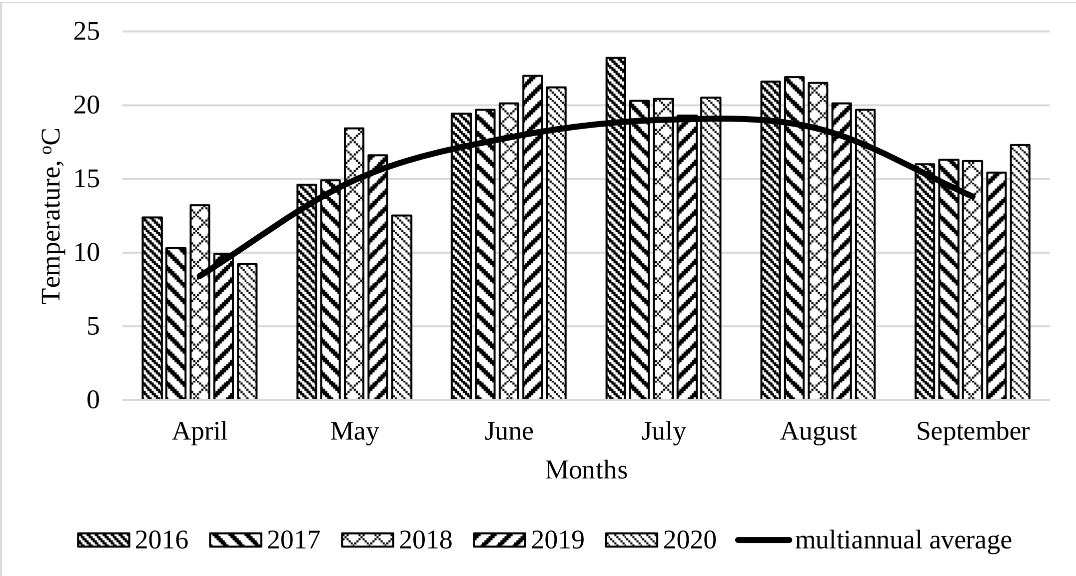

Fig. 1. Air temperature in the vegetative period from 2016 to 2020

In 2018 and 2019 the air temperature exceeded the average long-term indicators by 2.91 and 1.83 °C; the precipitation amount was smaller by 84.8 and 72.7 mm. A similar tendency was recorded in 2020: the air temperature exceeded by 1.35 °C and the precipitation amount was smaller by 102.5 mm as compared with the average long-term indicators.

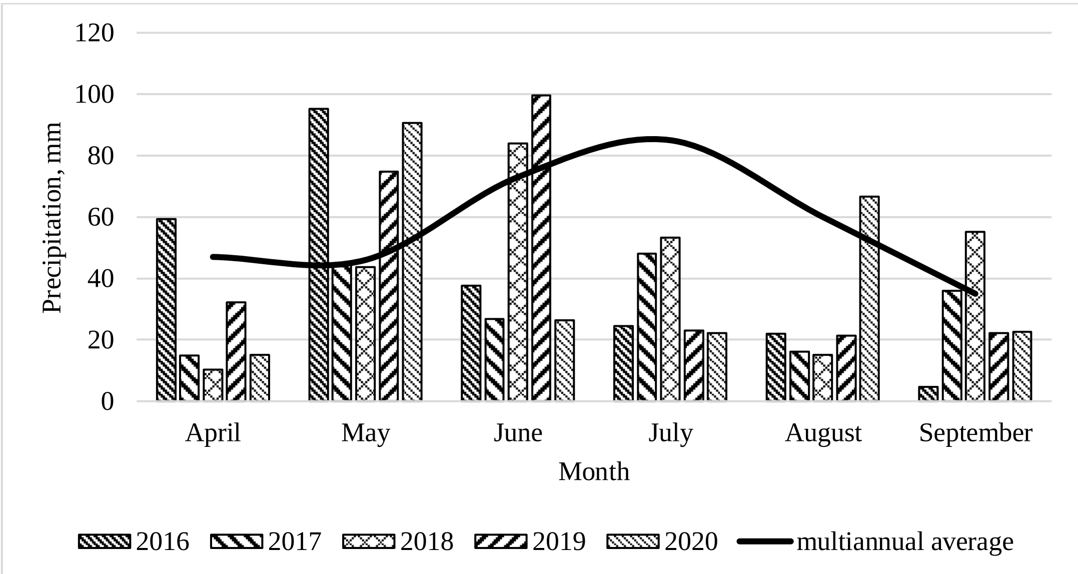

Fig. 2. Precipitation amount in the vegetative period from 2016 to 2020

In the years under study, the weather conditions were favorable for the cultivation of grain sorghum.

Early-ripening cultivars with a good response to fertilization and irrigation were studied [30].

Cultivar 'Dniprovskyi 39' is an originator: Synelnykivska research-breeding station of the state-run institution – the Institute of grain crops of the National academy of agrarian sciences of Ukraine. The cultivar is recommended to be cultivated for grain. The potential yield capacity is 6–7 t ha^{-1}.

Cultivar 'Vinets' is an originator: Henichesk research station of the state-run institution – the Institute of grain crops of the National academy of agrarian sciences of Ukraine. The purpose of the cultivation is to get grain, fodder grain. The grain yield capacity is 4–6 t ha^{-1} (on non-irrigated soils).

The following techniques were used in the research: field, laboratory, comparative methods, analyses, generalized, mathematic-statistical methods

Statistical analysis. To determine statistical significance for the treatment effects (P = 0.05 or less), after first undergoing an analysis of variance (ANOVA), all data were analyzed with the software SAS (SAS Institute Inc., USA). Significant differences between individual means were determined using the least significant difference (LSD) test.

Results and discussion

Due to its biological features, grain sorghum has a positive response to the application of mineral fertilizers. When sorghum plants are well supplied with a sufficient amount of nutrition, they can develop a high grain yield capacity.

Based on the research results, a significant effect of the mineral fertilizers on the formation of structure elements of grain sorghum yield capacity was recorded (Table 1). In the treatment without the fertilizer application the indicators of the yield structure elements were the lowest, namely, the length and mass of panicle were 26.9 cm and 48.2 g for cultivar 'Dniprovskyi 39', and the indicators for cultivar 'Vinets' were 26.1 cm and 47.5 g; the number of grains in panicle and their mass were equal to 1482 pcs and 39.7 g and 1451 pcs and 41.4 g, respectively; also the mass of 1000 grains changed and it was 23.1 g for 'Dniprovskyi 39' and 23.9 g for 'Vinets'.

Table 1

Structure elements of grain sorghum yield depending on fertilizer rates in the period from 2016 to 2020

Cultivars	Fertilizer rates	Panicle length, cm	Panicle mass, g	Grain number in panicle, pcs	Grain mass from panicle, g	Mass of 1000 grains, r
'Dniprovskyi 39'	Without fertilizers (control)	26.9	48.2	1482	39.7	23.1
	$N_{30}P_{30}K_{30}$	27.4	49.9	1590	43.2	25.2
	$N_{60}P_{60}K_{60}$	28.2	51.9	1618	46.4	26.9
	$N_{90}P_{90}K_{90}$	28.6	52.6	1629	47.3	27.5
	$N_{120}P_{120}K_{120}$	29.1	53.8	1634	48.1	27.9
	Estimated rate	28.9	52.7	1627	47.8	27.8
'Vinets'	Without fertilizers (control)	26.1	47.5	1451	41.4	23.9
	$N_{30}P_{30}K_{30}$	26.7	48.1	1468	42.9	24.7
	$N_{60}P_{60}K_{60}$	27.8	49.2	1524	44.3	25.6
	$N_{90}P_{90}K_{90}$	28.3	50.3	1567	45.7	26.3
	$N_{120}P_{120}K_{120}$	28.6	51.6	1604	45.9	26.5
	Estimated rate	28.1	51.2	1596	45.8	26.4
$LSD_{0.05}$		0.63	0.91	8.12	0.87	1.02

As to cultivar 'Dniprovskyi 39', with the lowest fertilizer rate $N_{30}P_{30}K_{30,}$ the length and mass of panicle increased by 0.5 cm and 1.7 g; at the highest fertilizer rate $N_{120}P_{120}K_{120}$ these indicators increased by 2.2 cm and 5.6 g, or by 8.2 and 3.5 %, respectively. The estimated fertilizer rate ensured the increase of the length and mass of panicle by 7.4 and 9.3 %.

One of the important indicators of the yield structure element is the grain number and mass in panicle which depends on the fertilization level. At the lowest fertilizer rate $N_{30}P_{30}K_{30,}$ as compared with the treatment without fertilization, the number of grains and their mass in panicle were higher for cultivar 'Dniprovskyi 39' by 7.3 % and 8.8 % or by 108 pcs and 3.5 g. These indicators for cultivar 'Vinets' were higher by 1.2 and 3.6 % or by 17 pcs and 1.5 g. At the maximal fertilizer rate, the number of grains in panicle of cultivar 'Dniprovskyi 39' increased by 1634 pcs and that of cultivar 'Vinets' – by 1604 pcs; the grain mass from panicle was 48.1 and 45.9 g, respectively. At the estimated fertilizer rate, the increase of the grain number in panicle and grain mass from panicle was recorded: by 9.8 and 20.4 % for cultivar 'Dniprovskyi 39' and by 9.9 and 10.6 % for cultivar 'Vinets'.

Depending on the application of different fertilizer rates, the mass of 1000 grains increased and it ranged within 23.1 and 27.9 g for cultivar 'Dniprovskyi 39' and within 23.9 and 26.5 g for cultivar 'Vinets'.

The analysis of the average indicator meanings of the yield structure elements of grain sorghum confirms that cultivar 'Dniprovskyi 39' has higher indicators than cultivar 'Vinets' which is well explained by the biological features of the cultivars (Table 2). As far as fertilization is concerned, the higher the level of the fertilizer rates, the higher the indicators of the yield structure elements are; however, the estimated rate for the planned yield capacity is the most optimal one, as it will reduce the production cost of the output.

When fertilizers are applied the grain yield capacity increases as compared with the control and in relation to the fertilizer rate (Figure 3). At the high fertilizer rates ($N_{90}P_{90}K_{90}$ and $N_{120}P_{120}K_{120}$) and the estimated rate ($N_{50}P_{40}K_{70}$), the grain yield capacity of cultivar 'Dniprovskyi 39' was higher than that of the control, namely, by 1.9, 2.7 and 2.1 t ha^{-1}, respectively; the indicators were higher by 2.9, 3.5 and 2.7 t ha^{-1} for cultivar 'Vinets'.

Table 2

Average indicator meanings of the structure elements of grain sorghum yield depending on the studied factors in the period from 2016 to 2020

Indicator		Panicle length, cm	Panicle mass, g	Grain number in panicle, pcs	Grain mass from panicle, g	Mass of 1000 grains, g
Average by factor A	‘Dniprovskyi 39’	28.2	51.5	1596.7	45.4	26.4
	‘Vinets’	27.6	49.7	1535.0	44.3	25.6
Average by factor B	Without fertilizers (control)	26.5	47.9	1466.5	40.6	23.5
	$N_{30}P_{30}K_{30}$	27.1	49.0	1529.0	43.1	24.9
	$N_{60}P_{60}K_{60}$	28.0	50.6	1571.0	45.4	26.3
	$N_{90}P_{90}K_{90}$	28.4	51.5	1598.0	46.5	26.9
	$N_{120}P_{120}K_{120}$	28.8	52.7	1619.0	47.0	27.2
	Estimated rate	28.5	51.9	1611.5	46.8	27.1

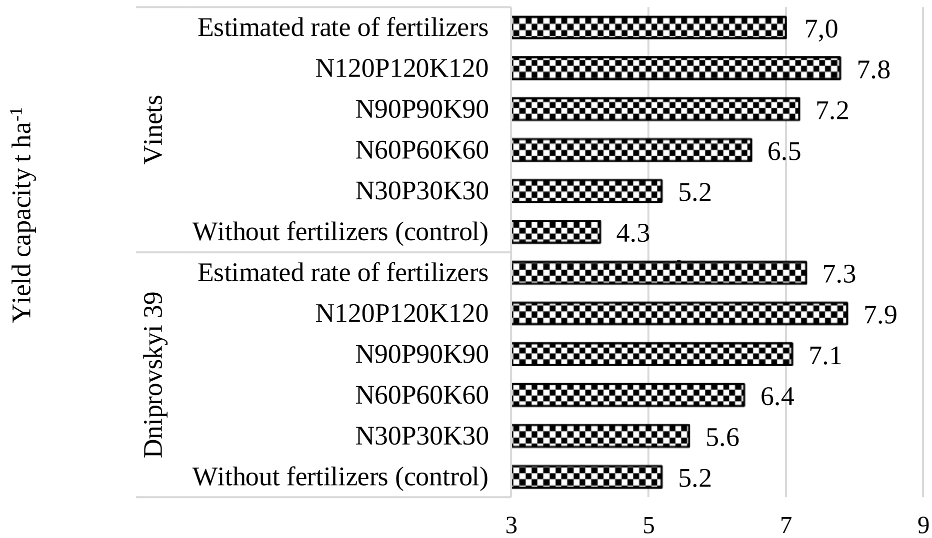

Fig. 3. Yield capacity of grain sorghum depending on the varietal features and the application of different fertilizer rates in the period from 2016 to 2020

The correlation-regression analysis showed a strong polynomial correlation between the grain yield capacity and the grain number in panicle with a determination coefficient $R^2 = 0.9553$ for cultivar ‘Dniprovskyi 39’ and $R^2 = 0.9604$ for cultivar ‘Vinets’. A correlation coefficient was $R = 0.8190$ and $R = 0.9606$, respectively (Figure 4).

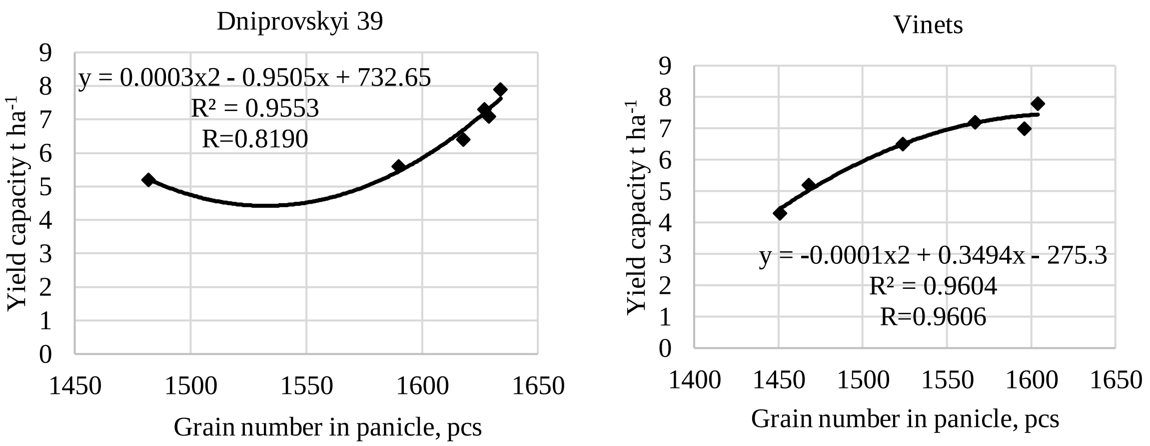

Fig. 4. Correlation-regression connection between grain yield and grain number in panicle, in the period from 2016 to 2020

The results of our research proved a significant increase of the grain yield capacity in relation to the increase of the grain mass from panicle. The data was confirmed by the correlation-regression analysis which showed a significant correlation between the grain yield and the grain mass from panicle: a determination coefficient and a correlation coefficient were $R^2 = 0.9696$ and $R = 0.999$ in cultivar 'Dniprovskyi 39' and $R^2 = 0.9627$ and $R = 0.9811$ in cultivar 'Vinets' (Figure 5).

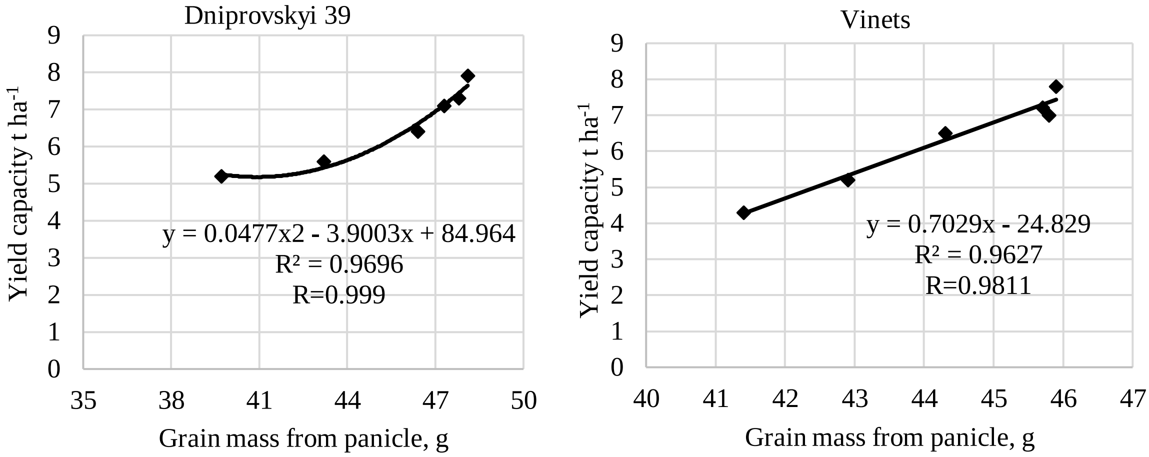

Fig. 5. Correlation-regression connection between grain yield and grain mass in panicle in the period from 2016 to 2020

Conclusions

The obtained research results are statistically reliable and relevant. It was found out that the structure elements of the grain sorghum yield capacity depended on the application of different rates of fertilizers. With their increase from $N_{30}P_{30}K_{30}$ to $N_{120}P_{120}K_{120}$, the indicators of the structure elements of the yield capacity also increased, and accordingly the grain yield capacity of the studied cultivars increased. However, we recommend applying the estimated rate of fertilizers for the planned yield capacity to reduce production costs.

It has been investigated that there is a close connection between the elements of the yield capacity structure and the grain yield capacity, namely between the grain yield and the number of grains in panicle the coefficient of determination was $R^2 = 0.9553$ in Dniprovsky 39 and $R^2 = 0.9604$ in 'Vinets'. The correlation coefficient was $R = 0.8190$ and $R = 0.8606$. Between the grain yield capacity and the grain mass from panicle, the coefficient of determination and correlation was $R^2 = 0.9696$ and $R = 0.999$ in cultivar Dniprovsky 39, and $R^2 = 0.9627$ and $R = 0.9811$ in cultivar 'Vinets'.

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Правдива Л. А.*, Присяжнюк О. І., Доронін В. А. Вплив мінеральних добрив на формування структурних показників урожайності сорго зернового. *Новітні агротехнології*. 2023. Т. 11, № 3. https://doi.org/10.47414/na.11.3.2023.288680

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Анотація. В умовах поступового потепління, виробничники здійснюють пошук культур, які в складних ґрунтово-кліматичних умовах формують високу продуктивність зерна відмінної якості. Однією з таких культур є сорго зернове. Продуктивність його, як і будь якої іншої сільськогосподарської культури, залежить від впливу багатьох факторів, зокрема й елементів технології вирощування. Одним із таких елементів є внесення мінеральних добрив. Метою цього дослідження було вивчити вплив мінерального живлення рослин на формування показників структури врожайності сорго зернового в умовах Правобережного Лісостепу України. Дослід проводився у 2016–2020 роках в зоні нестійкого зволоження. Схема дослідів включала вивчення сортів сорго зернового та різних доз добрив, дослід закладали методом систематичних повторювань, повторність дослідів чотириразова. Аналізуючи результати досліджень встановлено, що із збільшенням доз добрив, показники елементів структури урожайності також підвищувались, і відповідно збільшувалась урожайність зерна досліджуваних сортів. Проте оптимальною є розрахункова доза добрив під заплановану врожайність, що зменшить собівартість продукції.

Ключові слова: *дози; маса зерна; продуктивність; кореляційний зв'язок.*

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