РОСЛИННИЦТВО ТА КОРМОВИРОБНИЦТВО

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FORMATION OF PRODUCTIVE ELEMENTS IN WINTER WHEAT BY SEED DRESSING APPLICATION WITH SLOW-RELEASE COMPLEX FERTILIZERS

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Abstract. *Optimization of plant nutrition in the initial stages of the development is important for the formation of productive elements of the main and additional spikes and grain yield. The article presents the results of the studying of the effect of slow-release chlorine-free fertilizers in seed dressing application at the rate of 100 kg/ha on the formation of productive elements in winter wheat compared with the zone control (nitroammophoska) and a variant without fertilizers. Field research was conducted in 2019–2021 on winter bread wheat cultivars Bohdana and Samurai. The fertilizers produced by FertinAgro were studied: DuraSOP with the content of NPK(S) – 9:20:12:(15), 10:10:17:(20), and 4:26:12:(10). It is established that the influence of weather conditions on the variability of grain weight per spike, grain number per spike, thousand kernel weight significantly exceeded the studied factors in both cultivars. The formation of productivity elements under the impact of the studied fertilizers depended on the cultivars and manifested themselves in different ways in different weather conditions. DuraSOP fertilizers did not have a significant difference in the effect on grain number and weight per spike in cv. Bohdana compared to the control in arid conditions, but grain weight from spike increased to 1.74–1.78 g compared to the application of nitroammophoska,*

and grain number per spike varied insignificantly under favorable conditions. Application of DuraSOP fertilizers in cv. Samurai allowed to form 1.17–1.21 g of grain in spike under the arid conditions and 1.47–1.49 g – in the favorable conditions, which did not differ significantly from the control. The DuraSOP ActiBION increased the number of productive shoots by 8.4% and DuraSOP Phos – by 7.7% in cv. Bohdana, while only DuraSOP Phos significantly affected the productive shoots in cv. Samurai (an increase of 3.8%). Application of slow-release fertilizers allows obtaining grain yield of 6.58 to 7.03 t/ha in cv. Bohdana and 6.61–6.80 t/ha in cv. Samurai. Fertilizers have higher efficiency in cv. Bohdana, while there was a significant increase in cv. Samurai only when DuraSOP Phos was applied (0.31 t/ha or 4.8%). The application of slow-release fertilizers also increases the protein content in the grain by 0.3-0.5%. Sensitivity of cultivars to different ratios of macronutrients in pre-sowing fertilizers is one of the elements of technology that have a high impact on wheat cultivation, so the use of effective forms can increase yields up to 11.4% compared with typical fertilizers.

Keywords: *yield, protein content, standing density, cultivar, thousand kernel weight*

Introduction.

Growing high and sustainable yields, obtaining quality grain is the basis of profitable grain production in Ukraine. The productivity of cereals has already reached a plateau and its growth rate has slowed significantly compared to the second half of the 20th century. Improving the elements of technology adapted to the variety is the key to increasing wheat productivity in the last decade in Ukraine (Popov et al., 2014). Optimization of the fertilizer system and some most sensitive elements are the basis for increasing the productivity of cereals at low additional costs (Barabolia et al., 2018).

World experimental data show that the productivity potential of winter wheat can be extremely high (Hatfield & Beres, 2020). The biological potential of productivity of modern winter wheat cultivars reaches 24.6 t/ha, but Ukraine's record for moderate investments in cultivation technology was 13.2 t/ha. Grain yields in the countries with the highest average yields (the United Kingdom, Germany, and France) are only half of the officially registered world records, so the optimization of cultivation technologies remains the main tool for productivity management (Asseng et al., 2020).

To obtain a high wheat yield, it is necessary to optimize the interaction of the two main components: a high genetic productive potential and growing conditions that can ensure its full disclosure (Ghane et al., 2009). Main problems of traditional nitrogen fertilizers include unproductive losses (ammonia weathering for amide fertilizers, leaching for nitrate, denitrification and immobilization of nitrogen), the mismatch between the rate of nitrogen consumption by plants and its release from fertilizers, and impossibility (or limited possibility) to do the differential application of nitrogen (Vozhehova & Serhieiev, 2018; Shiwakoti et al., 2020).

Analysis of recent researches and publications.

The cost of mineral fertilizers is already approaching half the cost of cultivation technology for high-yielding wheat cultivars. Fertilizer rates should be deter-

mined according to soil conditions, the ability of crops to absorb the elements, and, most importantly, the presence of available moisture (Mazurenko et al., 2020). According to scientific research (Lemon, 2007), the dominant group of factors influencing the yield, quality, and protein harvest of winter wheat are soil and climatic conditions, nitrogen fertilizers, crop rotation, and varietal characteristics of plants, which in total causes more than 50% of the variation in this indicator (Behdi et al., 2015). The quality and shape of nutrients are less important for the plant than the total amount, but we can improve product quality by optimizing this element of technology, which will affect the selling price (Karabach, 2020). Common wheat (*Triticum aestivum* L.) forms enough protein in grain with high baking quality at high rates of nitrogen fertilizers with a sufficient number of other macro- and micronutrients in an accessible form (Morgun et al., 2010; Rybalka, 2011).

The grain yield of winter wheat and the formation of its productivity during the growing season largely depends on the gross supply of nitrogen, phosphorus, and potassium (Hartmann et al., 2015). Methods of applying various fertilizer forms and rates are aimed at optimal and most effective use during the growing season to obtain a high yield with appropriate quality by placing them in the adequate depth of soil (Kalenska et al., 2012). The main methods of fertilizer application are scattering before basic tillage with their subsequent earning, locally in strips, or completely under pre-sowing cultivation, in rows during sowing and root or foliar fertilization (Shyrynian et al., 2006).

Purpose of research. To establish the influence of sowing ultra-local application of slow-release complex fertilizers on the elements of crop structure and winter wheat productivity.

Materials and methods of research.

The field experiment was conducted during 2 growing seasons of winter crops at the Agronomic Research Station of NULES of Ukraine in 2019–2021.

The average air temperature was +8.5 °C in the first growing season (2019–2020), but it was +7.2 °C in the second (2020–2021), which significantly exceeded the long-term values (+5.8 °C). Years were contrasting in terms of moisture because precipitations during the winter wheat vegetation were 213.5 mm in the first year (46.7% of the long-term value) and 504.6 mm (110% of the long-term value) in the second year.

The soil of the experimental field is typical low-humus (humus content is 4.04%). The previous crop is peas. Each variant has four replications. The cultivation system is a classic fallow. Fertilizer system provided the application of 200 kg/ha of diammophos ($N_{20}P_{52}K_{52}$) in the main application, the pre-sowing application of fertilizers was the studied factor, and one spring fertilization. There was the application of 200 kg/ha of ammonium nitrate (N_{69}) in tillering stage (BBCH 31–38) in this fertilization. The sowing rate was 450 pcs/m^2, the inter-row space was 19 cm, the depth of seed wrapping was 4–6 cm, and the sowing period was the third decade of September. Seeds were treated with Kinto Duo (2.5 L/t). Crop protection included 2 sprayings by fungicide Abacus (1.5 L/ha) and a single application of insecticide Fastak (0.1 L/ha). The experimental design and the characteristics of fertilizers are shown in Table 1.

The impact of FertinAgro fertilizers (Spain) on wheat productivity was studied in comparison with the control of nitroammophoska. FertinAgro fertilizers are made by DuraSOP technology – slow-release chlorine-free fertilizers containing potassium sulfate.

1. Design of field experiment

Factor A Cultivar	Factor B Seed dressing, 100 kg/ha physical weight	Fertilize characteristics and nutrient content, %			
		N	P_2O_5	K_2O	Other
A1. Bohdana A2. Samurai	B1. Without fertilizers	–	–	–	–
	B2. Nitroammophoska (control)	16	16	16	SO_3 – 6
	B3. DuraSOP ActiBION	9	20	12	SO_3 – 15
	B4. DuraSOP Elite	10	10	17	SO_3 – 20
	B5. DuraSOP Phos	4	26	12	SO_3 –10

Elements of crop yields were determined by generally accepted methods. Thousand kernel weight, grain weight per spike, and grain yield are calculated based on moisture content of 14%. The difference between the variants was determined by ANOVA and post-hoc Fisher`s LSD_{05}.

Results.

It was found that the form of fertilizers affects certain elements of wheat productivity during research. The effect of fertilization on the grain number per spike, grain weight per spike, thousand kernel weight, and wheat yield were studied.

Grain number per spike (Fig. 1) is the most variable yield element in the experiment. It was influenced by weather conditions and varietal characteristics, and in some cases, the fertilizer forms. The cv. Bohdana formed 26.3 grains/spike in 2020, but this parameter increased significantly in 2021 (36 grains/spike). The cv. Samurai had a lesser variation of this parameter because it formed 28.3 and 32.7 grains per spike in 2020 and 2021, respectively. From this case, we can conclude that cv. Bohdana is better adapted to improving growing conditions than cv. Samurai in "grain number per spike" parameter.

On other hand, all fertilizers had a significant positive effect on grain number per spike compared to the variant without their application, but a case of small amounts was better than the control. DuraSOP Elite and DuraSOP Phos significant-

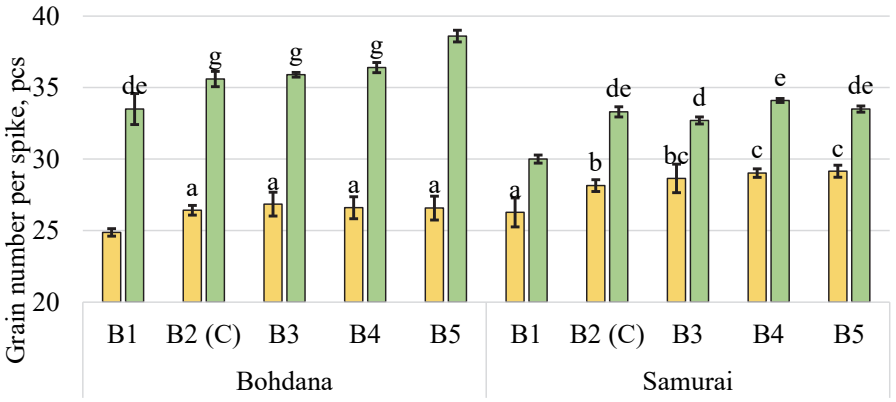

Fig. 1. Grain number per spike

ly increased this parameter in cv. Sumurai in 2020, but DuraSOP fertilizers had not a significant effect compared to nitroammophoska in cv Bohdana in this year.

The situation changed in 2021 with a sufficient level of precipitations. DuraSOP Phos was more effective in terms of grain number per spike than the control in cv. Bohdana, but there was no difference between the fertilizers in cv Samurai in 2021.

*Grain weight per spike (*Fig. 2) also varied greatly. According to our research, it was found that on average over two years the application of DuraSOP fertilizers led to an increase in grain weight per spike compared to the application of nitroammophoska for seed dressing, but their effectiveness was different in some years and certain cultivars.

Grain weight per spike significantly depended on the weather conditions of the year in both cultivars. It should be noted that there was a tendency for a significant increase in this parameter in cv. Bohdana with an improvement of the moisture regime in 2021, when this figure averaged 1.70 g against 1.12 g in 2020. The cv. Samurai had a lesser gap in grain weight per spike because it increased from 1.14 to 1.44 g as weather conditions improved.

Sowing without fertilizers led to a decrease in grain weight per spike compared to the control (nitroammophoska) by 0.15 g (10.6%) in the cv. Bohdana and by 0.20 g (15.2%) in cv. Samurai. Application of DuraSOP fertilizers gave an increase in the grain weight per spike from 2.8 to 5% in cv. Bohdana and from 0.08 to 3% in cv. Samurai on average for two years. It should be noted that this increase was significant when using all DuraSOP fertilizers compared to nitroammophoska in cv. Bohdana, but only DuraSOP Elite had a significant effect on this parameter in cv. Samurai. In both cases, DuraSOP Elite gave the highest increase in grain weight per spike.

Thousand kernel weight (Fig. 3) also differed in cultivars, years, and fertilizer forms. Thousand kernel weight (TKW) was 42.8 g in cv. Bohdana in 2020, and it was 47.3 g in 2021, while TKW was 40.4 and 43.9 g in cv. Samurai in these years.

Fertilizers had a positive effect on thousand kernel weight in both years of research. There was no significant difference between fertilizers in cv. Bohdana in 2020, including nitroammophoska, while DuraSOP ActiBION and DuraSOP Elite increased this figure to 48.6 and 49.6 g, respectively, in 2021, which is significant-

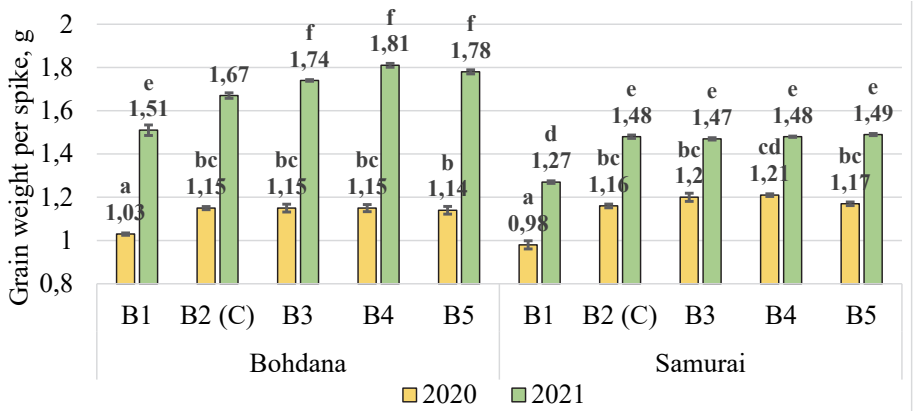

Fig. 2. Grain weight per spike (g) in 2020 and 2021

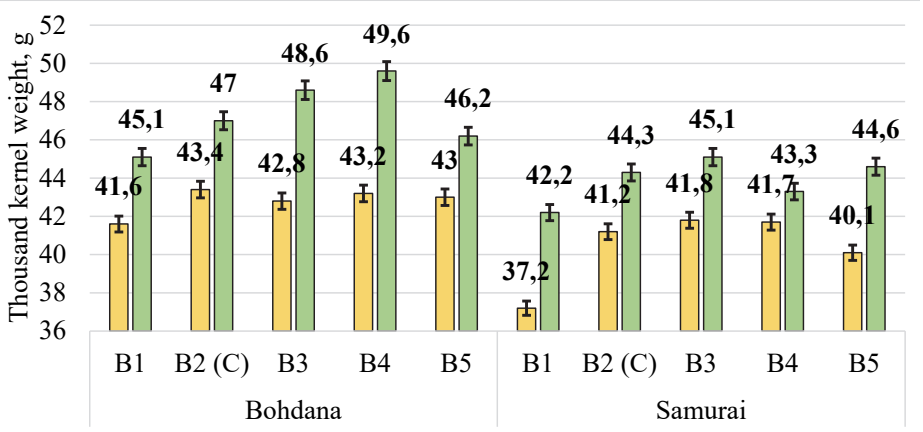

Fig. 3. Thousand kernel weight in 2020 and 2021 (g)

ly more than in the control variant. On another side, these two brands did not have a significant difference compared with the control in cv. Samurai in 2020, but the application of DuraSOP Phos decreased the thousand kernel weight to 40.1 g in this year. The difference between the fertilizers in terms of influence on this parameter in 2021 was insignificant.

Standing density is formed throughout the growing season. The largest number of shoots is observed at the beginning of the jointing phase (BBCH 31), after which the reduction of weak shoots begins. The number of shoots that formed the spike and those that formed the grains differ insignificantly, but the reduction may occur at the level of formation of the organs in the spike and fertilization in the anthesis.

There was no significant difference in the productivity of the main shoot and tillers, and the number of low-yielding shoots was insignificant, so we can analyze the standing density in one array (Table 2).

2. Standing density of winter wheat (spikes/m^2)

Cultivar	Seed dressing	Year		Average per 2020–2021	Increase compared with control	
		2020	2021		t/ha	%
Bohdana	B1. Without fertilizers	417	402	410	–42	–9,3
	B2. Nitroammophoska (c)	477^{ab}	427^{b}	452^{a}	0	0
	B3. DuraSOP ActiBION	512^{eh}	468^{c}	490^{bc}	38	8,4
	B4. DuraSOP Elite	473^{a}	428^{b}	451^{a}	–1	–0,2
	B5. DuraSOP Phos	513^{eh}	460^{c}	487^{bc}	35	7,7
Samurai	B1. Without fertilizers	490^{bcd}	465^{c}	478^{b}	–16	–3,2
	B2. Nitroammophoska (c)	500de	488^{d}	494^{c}	0	0
	B3. DuraSOP ActiBION	505de	488^{d}	496^{c}	2	0,5
	B4. DuraSOP Elite	498^{cde}	487^{d}	493^{c}	–1	–0,2
	B5. DuraSOP Phos	531^{h}	495^{d}	513	19	3,8
LSD_{05}		10	15	13	–	–

Sowing without fertilizers led to a decrease in the number of productive shoots by 9.3% in cv Bohdana and 3.2% in cv. Samurai on average for two years. At the same time, the application of DuraSOP fertilizers had almost no effect on the number of productive shoots compared to the variants where nitroammophoska was applied, except for DuraSOP ActiBION and DuraSOP Phos in cv. Bohdana. The increase in the number of shoots in these variants was 7.7–8.4%, while the number of shoots increased significantly in cv. Samurai only with the application DuraSOP Phos (3.8%). The impact of fertilizers on the standing density was similar in these cultivars in 2019 and 2020.

Grain yield of winter wheat was formed based on the elements of the crop structure, depending on all factors, including weather conditions. On average, according to the experiment, cv. Bohdana formed 5.39 t/ha of grain in 2020 and 7.46 t/ha in 2021, while cv. Samurai formed 5.77 and 6.97 t/ha, respectively (Table 3).

Grain yield in cv. Bohdana in the control variant (nitroammophoska) was 6.31 t/ha on average for two years, while it was only 5.2t/ha without pre-sowing fertilization that is 1.11 t/ha less, i.e. yield reduction was 18.6%. Application of DuraSOP fertilizers significantly increased grain yield – by 0.27 t/ha with DuraSOP Elite (an increase of 4.3%) and 0.72 t/ha (an increase of 11.4%) with DuraSOP ActiBION and DuraSOP Phos, respectively. It should be noted that the application of DuraSOP Elite did not have a significant difference compared with the control in 2020, it only slightly exceeded LSD_{05} in 2021.

Variability of grain yield in cv. Samurai differed from cv. Bohdana under influence of DuraSOP fertilizers. Sowing without fertilizers led to a decrease in yield by an average of 1.15 t/ha (17.7% decrease) compared to variant with nitroammophoska application, but the application of DuraSOP Elite and DuraSOP ActiBION slightly increased the average yield compared to the control. A significant increase in grain yield in cv. Samurai was only in a variant with the application of DuraSOP Phos, when the increase was 0.31 t/ha, i.e. 4.8%, compared with the control.

3. Grain yield of winter wheat

Cultivar	Seed dressing	Year		Average per 2020–2021	Increase compared with control	
		2020	2021		t/ha	%
Bohdana	B1. Without fertilizers	4.32	6.08	5.20	–1.11	–18.6
	B2. Nitroammophoska (c)	5.47	7.15	6.31	–	–
	B3. DuraSOP ActiBION	5.88	8.17	7.03	0.72	11.4
	B4. DuraSOP Elite	5.44	7.73	6.58	0.27	4.3
	B5. DuraSOP Phos	5.86	8.20	7.03	0.72	11.4
Samurai	B1. Without fertilizers	4.79	5.89	5.34	–1.15	–17.7
	B2. Nitroammophoska (c)	5.79	7.20	6.49	–	–
	B3. DuraSOP ActiBION	6.05	7.19	6.62	0.13	2.0
	B4. DuraSOP Elite	6.02	7.19	6.61	0.11	1.7
	B5. DuraSOP Phos	6.21	7.40	6.80	0.31	4.8
LSD_{05}		0.34	0.54	0.23	–	–

4. Protein content of winter wheat

Cultivar	Seed dressing	Year	
		2020	2021
Bohdana	B1. Without fertilizers	13.0	12.7
	B2. Nitroammophoska (c)	13.9	13.4
	B3. DuraSOP ActiBION	14.3	13.6
	B4. DuraSOP Elite	14.3	14.1
	B5. DuraSOP Phos	14.5	14.4
Samurai	B1. Without fertilizers	13.0	12.4
	B2. Nitroammophoska (c)	12.7	12.2
	B3. DuraSOP ActiBION	13.2	12.8
	B4. DuraSOP Elite	13.0	12.7
	B5. DuraSOP Phos	13.3	12.9
LSD_{05}		0.5	

The protein content of winter wheat in all experimental variants was determined and protein collection was calculated (Table 4). It is known that drier conditions contribute to the formation of higher protein content in grains, which is confirmed by our results. Application of DuraSOP fertilizers allowed to obtain a high protein content in the grain (14.3–14.5%) in cv. Bohdana in 2020, so according to this indicator it can be classified as the first class, while the cv. Samurai formed the grain of the second class in all variants (lesser than 14%), including without fertilizer, but the application of DuraSOP increased the protein content compared to the control variant.

Weather conditions in 2021 were more favorable, but the protein content was lower, which is known to be due to the negative correlation between yield and protein content. Therefore, the grain of the first class in cv. Bohdana this year was formed only in the variants of DuraSOP Elite and DuraSOP Phos fertilizers (14.1 and 14.4% protein, respectively), while the protein content in cv. Samurai corresponded to the second class in the variants with the application of DuraSOP fertilizers. Application of nitroammophoska or sowing without fertilizers contributed to the formation of grain of the third class (lesser than 12.5 % of protein).

Conclusions.

The application of slow-release DuraSOP fertilizers in seed dressing significantly increases grain weight per spike and the standing density of plants compared to the application of nitroammophoska in cultivar Bohdana. At the same time, only DuraSOP Phos has a significant effect on increasing yields in cv. Samurai, mainly due to the increase in standing density of plants. This difference is due to the different directions of application and the peculiarities of the productivity formation in studied cultivars because cultivar Samurai produces less protein, and its requirements for the fertilizer system and the ratio of nutrients will be different.

Each cultivar of common winter wheat has its requirements for the ratio of nutrients in the seed dressing application of fertilizers, so further research is relevant given the optimization of cultivation technologies adapted to the cultivar.

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Анотація. *Оптимізація живлення рослин на початкових етапах розвитку має важливе значення для формування елементів продуктивності головного та бічних пагонів і врожаю зерна. У статті представлено результати дослідження впливу повільнодіючих безхлорних добрив у припосівне внесення в нормі 100 кг/га на формування елементів продуктивності пшениці озимої порівняно з зональним контролем – нітроамофоскою 16:16:16. Для вирішення поставлених завдань закладався польовий дослід у 2019 – 2021 рр. на двох сортам пшениці м'якої озимої – Богдана та Самурай. Вивчалися комплексні повільнодіючі добрива NPK(S) виробництва FertinAgro (Іспанія) марки DuraSOP ActiBION 9:20:12:(15), DuraSOP Elite 10:10:17:(20), DuraSOP Phos 4:26:12:(10). Вплив погодних умов на формування таких елементів продуктивності пшениці озимої, як маса зерна з колоса, кількість зерен у колосі й маса 1000 зерен, суттєво перевищував досліджувані чинники в обох сортів. Формування елементів продуктивності за впливу досліджуваних добрив залежало від сортів і по-різному проявлялося в різних погодних умовах. Добрива DuraSOP не мали суттєвої різниці у впливі на кількість і масу насіння з колосу у сорту Богдана порівняно з контролем у посушливих умовах, але маса насіння з колоса суттєво зросла порівняно з контролем (від 1,67 до 1,74-1,78 г) за сприятливих умов, тоді як кількість зернівок суттєво не різнилася. Форма добрив у припосівне внесення в сорту Самурай немала істотного впливу, оскільки за посушливих умов формувалося 1,17-1,21 г зерна в колосі, а за сприятливих 1,47-1,49 г, що суттєво не відрізнялося від контролю (нітроамофоска). Застосування DuraSOP ActiBION дозволило збільшити кількість продуктивних стебел на момент збирання на 8,4 % порівняно з контролем і на 7,7 % у сорті Богдана у разі застосування DuraSOP Phos. Сорт Самурай слабше реагував на повільнодіючі добрива, тому суттєва різниця була лише у варіанту DuraSOP Phos коли кількість продуктивних стебел За різностороннього впливу на формування елементів продуктивності всі досліджувані повільнодіючі добрива суттєво впливали на формування врожаю зерна у сорту Богдана – у середньому урожайність на цих варіантах становила від 6,58 до 7,03 т/га (приріст 0,27–0,72 т/га), тоді як на контрольному варіанті формувалося 6,31 т/га зерна. Водночас у сорту Самурай приріст від заміни нітроамофоски на повільнодіючі форми добрив становив 0,11–0,31 т/га, тобто суттєве збільшення урожайності було лише за застосування DuraSOP Phos, що дало можливість отримати 6,80 т/га зерна, тобто приріст становив 4,8 % від контролю (6,49 т/га). Використання повільнодіючих добрив також дало змогу збільшити вміст білка в зерні на 0,3–0,5 %,що загалом є несуттєвим приростом, але в окремих випадках дає змогу підвищити клас зерна під час реалізації.*

Сортова реакція на різне співвідношення макроелементів у добривах для припосівного внесення є одним з елементів технології, які мають високий вплив на продуктивність пшениці та її розвиток на початкових етапах, тому використання ефективних форм дає можливість підвищити врожайність до 11,4 % порівняно з типовими комплекс ними добривами.

Ключові слова: *урожай, уміст білка, густота стояння, сорт, маса 1000 зерен*