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B.O. Mazurenko*
PhD, Assistant of the Department of Plant Science
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

S.M. Kalenska
Doctor of Agricultural Sciences, Professor Head of the Department
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

L.M. Honchar
Candidate of Agriculture Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

M.Ya. Hrygirevskiy
Master
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Formation of productive elements in winter wheat by seed dressing application with slow-release complex fertilisers

Abstract. Optimisation of plant nutrition in the initial stages of development is important for the formation of productive elements of the main and additional shoots and grain yield. The study presents the results of examining the effect of slow-release chlorine-free fertilisers 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 – azophoska 16:16:16 and a variant without fertilisers. Field studies were conducted in 2019-2021 on winter bread wheat varieties Bohdana and Samurai. The fertilisers produced by FertinAgro were examined: 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 shoot, grain number per shoot, thousand seed weight substantially exceeded the factors under study in both varieties. The formation of productivity elements under the impact of the examined fertilisers depended on the varieties and manifested themselves in different ways in different weather conditions. DuraSOP fertilisers did not have a substantial difference in the effect on grain number and weight per shoot in the Bohdana variety compared to the control in arid conditions, but grain weight from shoot increased to 1.74-1.78 g compared to the application

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*Corresponding author

of azophoska, and grain number per shoot varied insubstantially under favourable conditions. Application of DuraSOP fertilisers in the Samurai variety allowed to form 1.17-1.21 g of grain per shoot under the arid conditions and 1.47-1.49 g – in the favourable conditions, which did not differ substantially from the control. The DuraSOP ActiBION increased the number of productive shoots by 8.4% and DuraSOP Phos – by 7.7% in the Bohdana variety, while only DuraSOP Phos substantially affected the productive shoots in the Samurai variety (an increase of 3.8%). Application of slow-release fertilisers allows for obtaining grain yield of 6.58 to 7.03 t/ha in the Bohdana variety and 6.61-6.80 t/ha in the Samurai variety. Fertilisers have higher efficiency in the Bohdana variety, while there was a substantial increase in the Samurai variety only when DuraSOP Phos was applied (0.31 t/ha or 4.8%). The application of slow-release fertilisers also increases the protein content in the grain by 0.3-0.5%. The sensitivity of varieties to different ratios of macronutrients in pre-sowing fertilisers 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 fertilisers

Keywords: yield, protein content, standing density, variety, thousand seed weight

INTRODUCTION

Growing high and sustainable yields and obtaining quality grain are the basis of profitable grain production in Ukraine. The productivity of cereals has already reached a plateau and its growth rate has slowed substantially 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). Optimisation of the fertiliser 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 shows that the productivity potential of winter wheat can be extremely high (Hatfield & Beres, 2020). The biological potential of productivity of modern winter wheat varieties reaches 24.6 t/ha, but Ukraine's record for yield 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 optimisation of cultivation technologies remains the main tool for productivity management (Asseng *et al.*, 2020).

It is necessary to optimise the interaction of the two main components to obtain a high wheat yield: a high genetic productive potential and growing conditions that can ensure its full realisation (Ghane *et al.*, 2009). The main problems of conventional nitrogen fertilisers include unproductive losses (ammonia weathering for amide fertilisers, leaching for nitrate, denitrification and immobilisation of nitrogen), the discrepancy between the rate of nitrogen consumption by plants and its release from fertilisers, and impossibility (or limited possibility) to implement the differential application of nitrogen (Vozhehova & Serhieiev, 2018; Shiwakoti *et al.*, 2020).

ANALYSIS OF RECENT STUDIES AND PAPERS

The cost of mineral fertilisers is already approaching half the cost of cultivation technology for high-yielding wheat varieties. Fertiliser rates should be determined 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 a study by J. Lemon (2007), the dominant group of factors influencing the yield, quality, and protein harvest of winter wheat are soil and climatic conditions, nitrogen fertilisers, 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 form of nutrients are less important for the plant than the total amount, but the product quality can be improved by optimising 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 fertilisers 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 depend on the gross supply of nitrogen, phosphorus, and potassium (Hartmann *et al.*, 2015). Methods of applying various fertiliser 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 fertiliser application are scattering before basic tillage with their subsequent earning, locally in rows, or by scattering under pre-sowing cultivation, in rows during sowing and foliar fertilisation (Shyrynian *et al.*, 2006).

Purpose of the study. Establish the influence of sowing ultra-local application of slow-release complex fertilisers on the elements of crop structure and winter wheat productivity.

MATERIALS AND METHODS

The field experiment was conducted during 2 growing seasons of winter crops at a Separated subdivision of the National University of Life and Environmental Sciences of Ukraine "Agronomic Research Station",

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 substantially exceeded the perennial 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 perennial value) and 504.6 mm (110% of the perennial value) in the second year.

The soil of the experimental field is typical low-humus (humus content is 4.04%). The predecessor crop is peas. Each variant has four replications. The cultivation system is classic fallow. The fertilising system provided the pre-sowing application of 200 kg/ha of diammophos ($N_{20}P_{52}K_{52}$). The application of 200 kg/ha of ammonium nitrate (N_{69}) in tillering stage (BBCH 31-38) was conducted. 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 scheme and the characteristics of fertilisers are shown in Table 1.

Table 1. Scheme of the field experiment

Factor A Variety	Factor B Seed dressing, 100 kg/ha physical weight	Fertilise characteristics and nutrient content, %			
		N	P_2O_5	K_2O	Other
A1. Bohdana A2. Samurai	B1. Without fertilisers	–	–	–	–
	B2. Azophoska (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

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

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

RESULTS

It was identified that the form of fertilisers affects certain elements of wheat productivity during research. The effect of fertilisation on the grain number per shoot, grain weight per shoot, thousand seed weight, and wheat yield were studied.

The grain number per shoot (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 fertiliser forms. The Bohdana variety formed 26.3 grains/shoot in 2020, but this parameter increased substantially in 2021 (36 grains/shoot). The Samurai variety had a lesser variation of this parameter it formed 28.3 and 32.7 grains per shoot in 2020 and 2021, respectively. From this case, it can be concluded that the Bohdana variety is better adapted to improving growing conditions than the Samurai variety in the "grain number per shoot" parameter.

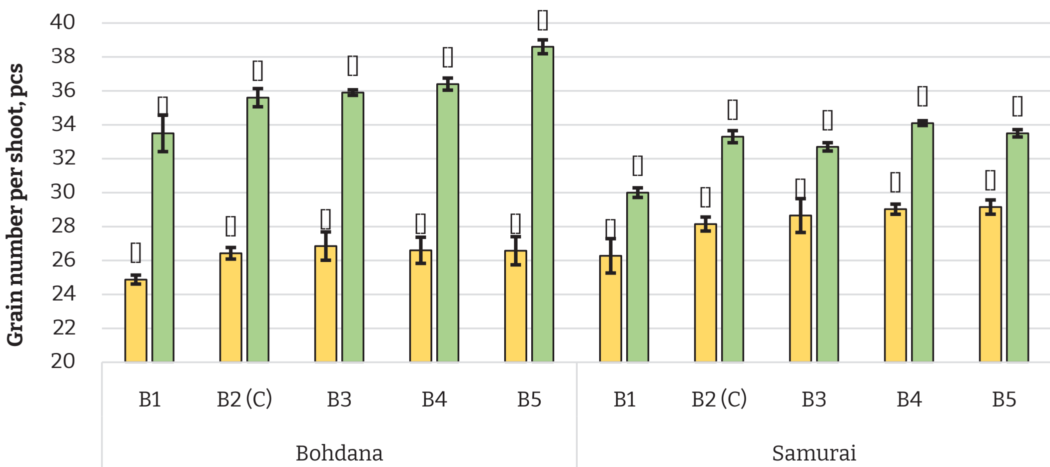

Figure 1. Grain number per shoot

On other hand, all fertilisers had a substantial positive effect on grain number per shoot compared to the variant without their application, but a case of small amounts was better than the control. DuraSOP Elite and DuraSOP Phos substantially increased this parameter in the Sumurai variety in 2020, but DuraSOP fertilisers had not a substantial effect compared to azophoska in the Bohdana variety this year.

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

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

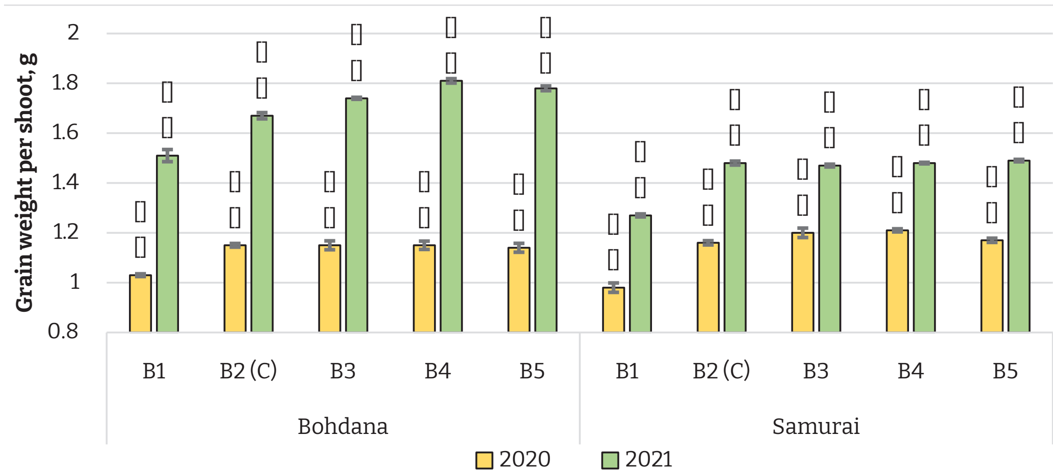

Figure 2. Grain weight per shoot (g) in 2020 and 2021

Grain weight per shoot substantially depended on the weather conditions of the year in both varieties. Notably, there was a tendency for a substantial increase in this parameter in the Bohdana variety with an improvement of the moisture regime in 2021, when this figure averaged 1.70 g against 1.12 g in 2020. The Samurai variety had a lesser gap in grain weight per shoot, it increased from 1.14 to 1.44 g as weather conditions improved.

Sowing without fertilisers led to a decrease in grain weight per shoot compared to the control (azophoska) by 0.15 g (10.6%) in the Bohdana variety and by 0.20 g (15.2%) in the Samurai variety. Application of DuraSOP fertilisers resulted in an increase in the grain weight per shoot from 2.8 to 5% in the Bohdana variety and from 0.08 to 3% in the Samurai variety on average for two years. Notably, this increase was substantial when using all DuraSOP fertilisers compared to azophoska in the Bohdana variety, but only DuraSOP Elite had a substantial effect on this parameter in the Samurai variety. In both cases, DuraSOP Elite gave the highest increase in grain weight per shoot.

Thousand seed weight (Fig. 3) also differed in varieties, years, and fertiliser forms. Thousand seed weight (TSW) was 42.8 g in the Bohdana variety in 2020, and it was 47.3 g in 2021, while TSW was 40.4 and 43.9 g in the Samurai variety in these years.

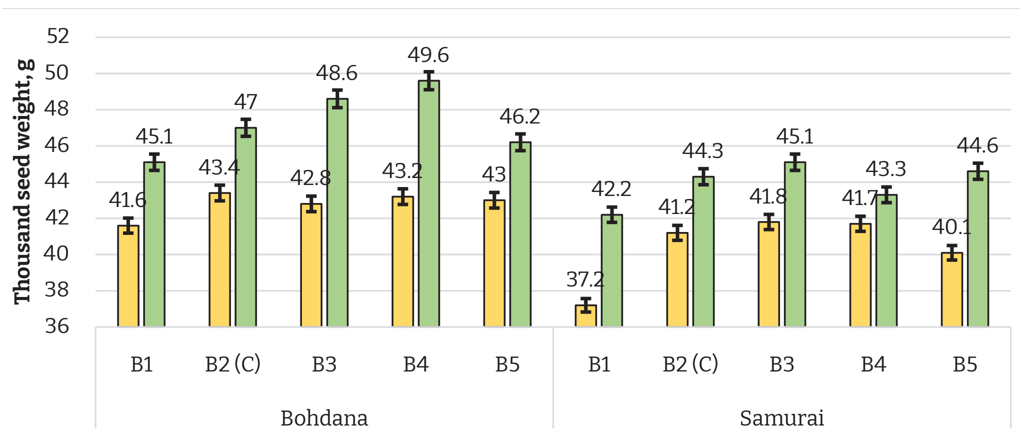

Figure 3. Thousand seed weight in 2020 and 2021 (g)

Fertilisers had a positive effect on thousand seed weight in both years of research. There was no substantial difference between fertilisers in the Bohdana variety in 2020, including azophoska, while DuraSOP ActiBION and DuraSOP Elite increased this figure to 48.6 and 49.6 g, respectively, in 2021, which is substantially more than in the control variant. On another side, these two brands did not have a substantial difference compared with the control in the Samurai variety in 2020, but the application of DuraSOP Phos decreased the thousand seed weight to 40.1 g this year. The difference between the fertilisers in terms of influence on this parameter in 2021 was insubstantial.

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 weak shoots begin to die off. The number of shoots that formed the grains and those that did not differ insubstantially, but the reduction may occur at the level of formation of the organs in the shoot and fertilisation in the anthesis.

There was no substantial difference in the productivity of the main and side shoots, and the number of low-yielding shoots was insubstantial, so the standing density can be analysed in one array (Table 2).

Table 2. Standing density of winter wheat (shoots/m²)

Variety	Seed dressing	Year		Average per 2020-2021	Increase compared with control	
		2020	2021		t/ha	%
Bohdana	B1. Without fertilisers	417	402	410	–42	–9,3
	B2. Azophoska (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 fertilisers	490^{bcd}	465^{c}	478^{b}	–16	–3,2
	B2. Azophoska (c)	500^{de}	488^{d}	494^{c}	0	0
	B3. DuraSOP ActiBION	505^{de}	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 fertilisers led to a decrease in the number of productive shoots by 9.3% in the Bohdana variety and 3.2% in the Samurai variety on average for two years. Therewith, the application of DuraSOP fertilisers had almost no effect on the number of productive shoots compared to the variants where azophoska was applied, except for DuraSOP ActiBION and DuraSOP Phos in the Bohdana variety. The increase in the number of shoots in these variants was 7.7-8.4%, while the number of shoots increased substantially in the Samurai variety only with the application DuraSOP Phos (3.8%). The impact of fertilisers on the standing density was similar in these varieties in 2019 and 2020. The 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 results of the experiment, the Bohdana variety formed 5.39 t/ha of grain in 2020 and 7.46 t/ha in 2021, while the Samurai variety formed 5.77 and 6.97 t/ha, respectively (Table 3).

Table 3. Grain yield of winter wheat

Variety	Seed dressing	Year		Average per 2020-2021	Increase compared with control	
		2020	2021		t/ha	%
Bohdana	B1. Without fertilisers	4.32	6.08	5.20	–1.11	–18.6
	B2. Azophoska (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 fertilisers	4.79	5.89	5.34	–1.15	–17.7
	B2. Azophoska (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	–	–

Grain yield in the Bohdana variety in the control variant (azophoska) was 6.31 t/ha on average for two years, while it was only 5.2t/ha without pre-sowing fertilisation that is 1.11 t/ha less, i.e. yield reduction was 18.6%. Application of DuraSOP fertilisers substantially 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. Notably, the application of DuraSOP Elite did not result in a substantial difference compared with the control in 2020, it only slightly exceeded LSD_{05} in 2021.

The variability of grain yield in the Samurai variety differed from the Bohdana variety under influence of DuraSOP fertilisers. Sowing without fertilisers led to a decrease in yield by an average of 1.15 t/ha (17.7% decrease) compared to the variant with azophoska application, but the application of DuraSOP Elite and DuraSOP ActiBION slightly increased the average yield compared to the control. A substantial increase in grain yield in the Samurai variety 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.

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

Table 4. The protein content of winter wheat

Variety	Seed dressing	Year	
		2020	2021
Bohdana	B1. Without fertilisers	13.0	12.7
	B2. Azophoska (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 fertilisers	13.0	12.4
	B2. Azophoska (c)	12.7	12.2
	B3. DuraSOP ActiBION	13.2	12.8

Table 4. Continued

Variety	Seed dressing	Year	
		2020	2021
Samurai	B4. DuraSOP Elite	13.0	12.7
	B5. DuraSOP Phos	13.3	12.9
LSD_{05}		0.5	

Weather conditions in 2021 were more favourable, 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 the Bohdana variety this year was formed only in the variants of DuraSOP Elite and DuraSOP Phos fertilisers (14.1 and 14.4% of protein, respectively), while the protein content in the Samurai variety corresponded to the second class in the variants with the application of DuraSOP fertilisers. Application of azophoska or sowing without fertilisers contributed to the formation of the grain of the third class (lesser than 12.5% of protein).

CONCLUSIONS

The application of slow-release DuraSOP fertilisers in seed dressing substantially increases grain weight per shoot and the standing density of plants compared to the application of azophoska in the Bohdana variety. Therewith, only DuraSOP Phos has a substantial effect on increasing yields in the Samurai variety, mainly due to the increase in the density of shoots. This difference is due to the different areas of application and the specific features of the productivity formation in varieties under study as the Samurai variety produces less protein, and its requirements for the fertiliser system and the ratio of nutrients will be different.

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

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Б.О. Мазуренко
Кандидат біологічних наук, асистент кафедри рослинництва
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
С.М. Каленська
Доктор сільськогосподарських наук, професор, завідувач кафедри
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
Л.М. Гончар
Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
М.Я. Григоревський
Магістр
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Формування елементів продуктивності пшениці озимої за припосівного внесення повільнодіючих комплексних добрив

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 сорта 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 сорт 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 сорта 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