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FORMATION OF SPRING WHEAT PLANT PRODUCTIVITY ON GRAY POZOLIZED SOILS UNDER THE INFLUENCE OF APPLIED FERTILIZATION OPTIONS IN CONDITIONS OF CLIMATE CHANGE IN THE RIGHT-BANK FOREST-STEP OF UKRAINE

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This scientific paper presents the results of two years of research aimed at analysing the impact of mineral fertilisers and growth regulators on the development and formation of productive characteristics of spring wheat varieties grown on grey podzolic soils of Vinnytsia region.

The highest wheat yields were observed in the plots where $N_{42}P_{42}K_{42}$ fertilisers were applied as the main fertiliser and nitrogen (N_{30}) fertilisation during tillering. Additionally, the plants were treated with the growth regulator Fresh Florid at a dose of 1 l/ha and foliar fertilisation with urea (N_{10}) at the stage of early earing. The lowest height of spring wheat plants was recorded in areas where the same mineral fertilisers were used ($N_{42}P_{42}K_{42}$ and N_{30} at the tillering stage), as well as plants were treated with Fresh Florid growth regulator and foliar feeding with urea.

The highest weight of 1000 grains, which ranged from 41.1-42.0 g, was achieved in the plots where $N_{42}P_{42}K_{42}$ fertiliser and N_{30} fertiliser were used at the tillering stage, and the plants were treated with Fresh Florid and Fresh Energy growth regulators. In addition, the plants were fertilised with urea at the tube stage using the foliar method.

The weight of grain per ear of spring wheat varied depending on the dosage of mineral fertilisers, the timing of their application and the use of growth regulators. In the areas with the highest fertiliser doses, this figure ranged between 1.19 and 1.21 g.

On average, over two years, the maximum yield of spring wheat grain was observed in plots where $N_{42}P_{42}K_{42}$ mineral fertilisers and N_{30} fertiliser were applied during tillering. Plants were treated with Fresh Florid growth regulator, and at the stage of early tube emergence, foliar feeding with urea was carried out. This ensured an average yield of 5.2 t/ha.

Keywords: *spring wheat, fertilisers, morphological characteristics of plants and grain yield.*
Table 8. Lit. 25.

Introduction. The grain industry is the basis for the sustainable development of the agricultural sector. Despite favourable soil and climatic conditions in Ukraine, which contribute to high yields, the industry is unable to fully meet domestic needs or export high quality grain. Spring wheat is becoming an important strategic crop to solve the problem of high quality grain production.

Given the limited resources and insufficient lending to agriculture, spring wheat crops are frugal with respect to resources and soil.

From a technological point of view, spring wheat demonstrates increased resistance to diseases and grain shattering, and its extended ripening period facilitates the harvesting process. Modern achievements in breeding spring wheat varieties ensure their productivity at the level of 60-70 c/ha. However, in Ukraine, spring wheat is grown on relatively small areas, mainly as a reserve crop in case of partial or complete loss of winter wheat crops.

Statement of the problem. The natural and climatic zones of Ukraine create favourable conditions for growing both durum and soft varieties of spring wheat. However, despite these advantages, the area under this crop remains relatively small, particularly in Vinnytsia region.

Modern spring wheat varieties have a high yield potential, which in research reaches 5.0-5.5 t/ha, while in production conditions it is about 3.0-3.5 t/ha. One of the reasons for this is the insufficient study of the conditions for effective fertiliser application, taking into account the level of moisture and availability of nutrients in the soil [13, 22].

To achieve success in growing spring wheat, it is important to take into account its biological characteristics, which significantly affect agronomic practices. This crop has specific requirements for environmental conditions, which must be taken into account when planning crops [5, 9].

Spring wheat is demanding on the content of readily available nutrients in the soil, which is explained by its short growing season and reduced capacity of the root system to absorb these elements. The absorption of mineral salts per 1 kg of root weight is 12-14.5 mg, while for barley this figure is 7-9 mg, for oats - 2-4 mg, for millet - 2-3 mg, and for winter rye - 4-6 mg [16-18].

To produce 1 tonne of grain, spring wheat consumes an average of 4.5-6.0 kg of nitrogen, 1.0-1.6 kg of P_2O_5 and 2.5-3.0 kg of K_2O [3, 13].

The introduction of new modern durum spring wheat varieties requires adaptation and improvement of existing cultivation technologies to maximise its yield. The key aspects of the technology are crop rotation, proper selection of predecessors, as well as thorough basic and pre-sowing soil preparation and adherence to optimal sowing dates [7, 14, 15, 25].

The choice of predecessors for durum spring wheat is of great importance, as this crop is quite demanding on nutritional conditions and weed-free fields due to its limited root system and low tillering ability. In the Eastern Forest-Steppe, the most suitable predecessors in long-term crop rotations are grain corn, soybeans and sugar beet [2].

To achieve the maximum potential yield of modern durum spring wheat varieties, ploughing is the most effective method of primary tillage, which can increase yields by 0.25-1.20 t/ha depending on the variety [25].

Fertilisers play a key role in improving the efficiency of grain growing technologies. The need for their use is confirmed by the ability of soils to gradually deplete plant nutrients, as well as the direct correlation between mineral fertiliser application and increased crop yields [8].

Studies conducted within the framework of the All-Union Geographical Network of Field Experiments have revealed patterns of influence of individual nutrients on spring wheat yields. Nitrogen is the most important, followed by phosphorus and potassium [19-21].

For the healthy functioning of plants, the basic elements of nitrogen, phosphorus and potassium are not enough. Trace elements are also important because they are involved in the synthesis of proteins, carbohydrates and vitamins. They help to improve photosynthesis, increase drought resistance and strengthen the plant's immunity against diseases. As a result, yields can increase by 5-12% and grain quality improves [6].

One of the most promising methods of increasing crop productivity is the use of growth regulators. They help to realise the potential of plants, regulate the ripening period, improve product quality and increase crop yields [1].

With the introduction of intensive plant growing technologies, the role of growth regulators is becoming increasingly important. They can increase not only yields but also product quality and plant resistance to adverse conditions, phytotoxic effects of pesticides and diseases [10, 16].

Studies have shown that biological products activate plant life processes, including membrane functions, cell division, photosynthesis and respiration. By activating the rhizosphere, regulators can significantly reduce the negative effects of adverse conditions. It is important to use environmentally friendly products that come from natural sources [18].

The purpose of the study. The aim of the study is to scientifically substantiate and determine the effect of mineral fertilisers and growth regulators on the growth, development and productivity of spring wheat plants in the experimental field of Vinnytsia National Agrarian University.

Presentation of the main material. In the conditions of the experimental field of the VNAU village of Agronomichne, Vinnytsia district, during 2023-2024, we conducted an evaluation of the spring wheat variety Barvysta under the influence of mineral fertilizers and plant growth regulators on gray podzolized soils [23, 24].

The climate of the experimental field is temperate continental. The air temperature during the growing season in 2023 averaged 16.2 °C, which is 1.7 °C higher than the long-term average. Accordingly, in 2024, the air temperature rose to 17.0 °C, which is 2.5 °C higher than the long-term average.

In terms of precipitation, 387 mm was recorded in 2023, which is 8.0 mm more than the long-term average (379 mm), while in 2024, 314.5 mm of precipitation fell, which is 54.5 mm less than the long-term average.

Analysing the data, it can be noted that the highest amount of precipitation was recorded in May and June, while in July and August there was a certain drought.

Research methods. Field research aimed at studying the effect of fertilisation options on spring wheat productivity was conducted on grey podzolic soil in accordance with generally accepted methods [4, 11].

The experimental methodology was based on the use of split plots, where the main factors were the spring wheat variety Barvysta, as well as various mineral fertilisers and growth stimulants (Fresh Energy, Fresh Florid). The experimental plot had an area of 50 m², and the experiment was conducted in triplicate, which ensured the statistical reliability of the results [11].

Accounting and statistical processing of the research results was carried out according to the Methodology of state variety testing [11].

Spring wheat cultivation techniques were developed taking into account the predecessor, soybean, and were generally accepted for the growing area [13].

Harvesting and accounting of the crop was carried out according to the method of a trial sheaf of 1 m^2 in 3 replications with subsequent manual threshing of seeds [11, 12].

Results of experimental studies. One of the key technological techniques that determines the growth and development of crops is optimising plant nutrition. This issue has become particularly relevant in recent years due to the deterioration of soil fertility. Many lands are being depleted, and organic and mineral fertilisers are being applied in insufficient quantities, which hinders the restoration of fertility.

Among the factors affecting plant height, the key one is the level of mineral nutrition. Mineral fertilisers, in particular nitrogen fertilisers, have a positive impact on plant growth. Research shows that the use of complete mineral fertiliser provides the best results in plant height.

The effectiveness of mineral fertilisers and growth regulators as components of spring wheat cultivation technology depends on both growing conditions and weather factors, as shown in Table 1.

Table 1

Number of productive shoots of spring wheat depending on mineral fertilisers and growth regulators

№	Application option	Number of productive shoots, pcs./m^2		
		2023	2024	Average
1.	Control (no fertiliser)	296	280	288
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	433	421	427
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	444	427	436
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	447	433	440
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	450	438	444

The source was obtained as a result of own research results

Our studies have shown (Table 1) that in areas without mineral fertilizers, as well as in those where mineral fertilizers were used at the rate of $N_{42}P_{42}K_{42}$ together with N_{30} fertilization in the tillering phase of spring wheat and growth regulators in the earling phase, significant changes in the formation of crop productivity elements were observed.

Thus, when applying mineral fertilisers at the specified rate and applying the growth regulator Fresh Energy in the tube stage, the average number of productive shoots was 427 pcs/m² for two years. In contrast, in areas where fertilisers were used at the same rate together with the growth regulator Fresh Florid in the tube stage, the number of productive stems increased to 436 pcs/m².

Compared to the control plots, where the number of productive stems averaged 288 pcs/m², the results in the treated plots were significantly better. With additional foliar treatment with urea in the phase of entering the tube at a rate of N_{10}, the number of productive shoots increased to 440-444 pcs/m².

The highest productivity of spring wheat was recorded in areas where the main fertiliser $N_{30}P_{30}K_{30}$ was applied together with N_{30} fertilisation in the tillering phase and Fresh Florid growth regulator at a rate of 1 l/ha. In 2023, the number of productive shoots reached 450 pcs/m², and in 2024, under less favourable climatic conditions, this figure was 438 pcs/m². On average, over the two years of research, the number of productive stems was 444 pcs/m². Studies of the impact of mineral fertilisers, as well as the treatment of spring wheat plants with growth regulators and urea fertilisation at the N_{10} earing stage on biometric parameters, have shown that plant height and ear length largely depend on the use of these products, in particular nitrogen fertilisers. In particular, when applying mineral fertilisers and fertilising during the tillering phase of spring wheat at N_{10}, the plant height varied from 66 to 79 cm, and the spike length ranged from 9.7 to 9.9 cm. It is important to note that the height of spring wheat plants varied depending on the year, with the best performance in the more favourable year 2023 in all experimental plots. These indicators depend not only on weather conditions, but also on the use of growth regulators and mineral fertiliser application rates (Table 2).

Table 2

Height of spring wheat plants depending on mineral fertilisers and growth regulators

№	Application option	Plant height, cm		
		2023	2024	Average
1.	Control (no fertiliser)	86	80	83
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	79	75	74
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	66	61	63
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	80	78	79
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	70	63	66

The source was obtained as a result of own research results

The lowest plant height was observed in the plots where mineral fertilisers were applied at the rate of $N_{42}P_{42}K_{42}$ together with N_{30} fertilisation in the tillering phase and Fresh Florid growth regulator with N_{10} urea foliar application, with an average height of 66 cm over two years. The highest height of spring wheat plants was recorded in the control plots, where no growth regulators or mineral fertilisers were used, and reached 83 cm on average over two years.

The length of the spike in the control plots, where no fertilisers or growth regulators were used, averaged 8.5 cm over the two years of research. The introduction of mineral fertilisers, growth regulators and foliar treatments of spring wheat crops contributed to an increase in this indicator.

The highest values of spike length were recorded in the plots with the application of mineral fertilisers at the rate of $N_{42}P_{42}K_{42}$ together with N_{30} fertilisation in the tillering phase, as well as spraying with Fresh Florid growth regulator and foliar application of urea, where this indicator was 11.1 cm. For comparison, in the control plots, the length of the ear was much shorter - only 8.5 cm (Table 3).

Table 3

Spike length of spring wheat depending on mineral fertilisers and growth regulators

№	Application option	Spike length, cm		
		2023	2024	Average
1.	Control (no fertiliser)	8,7	8,3	8,5
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	10,4	9,0	9,7
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	10,7	9,1	9,9
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	11,6	10,2	10,9
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	11,8	10,4	11,1

The source was obtained as a result of own research results

Thus, the biometric parameters of spring wheat plants show a dependence on the application of mineral fertilisers and growth regulators. The formation of productivity elements, in particular the number of grains per ear, also correlates with weather conditions and the background of cultivation (Table 4).

During the two years of research in the plots where mineral fertilisers and growth regulators were applied, the number of grains per ear was significantly higher than in the control plots where no fertiliser was applied. Thus, in the control plots, the number of spring wheat grains per ear ranged from 22-25, while in the plots with fertilisers and growth regulators, this figure increased to 28-36. It is important to note that with the increase in fertiliser application rates, the number of grains also increased (Table 4).

Table 4

Number of grains per ear of spring wheat plants depending on mineral fertilisers and growth regulators

№	Application option	Number of grains per ear, pcs.		
		2023	2024	Average
1.	Control (no fertiliser)	25	22	24
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	30	28	29
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	32	30	31
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	34	31	33
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	36	33	35

The source was obtained as a result of own research results

During the two years of research, a significant increase in the number of grains per ear was observed in the plots where mineral fertilisers and growth regulators were applied compared to the control plots where no fertiliser was applied. In the control plots, the number of spring wheat grains per ear ranged from 22 to 25, while in the treated plots this figure increased to 28-36 grains per ear. This result confirms the importance of agronomic practices in increasing crop productivity, as the number of grains also increased with increasing fertiliser rates.

Another important indicator that is often used to characterise grain is its grain size, which is defined as the weight of 1000 grains. This indicator, in turn, depends on many factors, including the amount of nutrients in the soil, climatic conditions, and agronomic practices. The maximum weight of 1000 grains was 41.1-42.0 g in areas where mineral fertilisers were applied at the rate of $N_{42}P_{42}K_{42}$ + N_{30} in the tillering phase, and crops were sprayed with Fresh Florid and Fresh Energy growth regulators. Additional foliar spraying with urea N_{10} in the tube phase also contributed to the improvement of this indicator (Table 5).

Table 5

Formation of elements of spring wheat plant productivity depending on the application of mineral fertilisers and growth regulators

№	Application option	Weight of 1000 grains, g		
		2023	2024	Average
1.	Control (no fertiliser)	30,7	29,5	30,1
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	38,5	37,1	37,8
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	40,1	39,1	39,6
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	41,4	40,8	41,1
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	42,4	41,6	42,0

The source was obtained as a result of own research results

In addition, an important aspect is that the use of fertilisers and growth regulators not only increases the number of grains, but also affects the overall development of plants, their resistance to diseases and pests, as well as the quality of the products obtained. Thus, optimising plant nutrition is a critical element in achieving high yields and ensuring sustainable spring wheat production.

Thus, the formation of elements of spring wheat plant productivity, as well as their biometric characteristics, largely depended on climatic conditions, the use of growth regulators and the application of mineral fertilisers, in particular nitrogen fertilisers. The interaction between agronomic measures and natural conditions is key to optimising growing processes and ensuring stable productivity.

The impact of growth regulators and fertiliser application on plant productivity, in particular on the number of productive shoots and structural yield parameters such as number of grains per ear and weight of 1000 grains, significantly affected the overall yield of spring wheat (Table 6).

Table 6

Grain weight per ear of spring wheat depending on on fertilisation system and growth regulators

№	Application option	Grain weight per ear, g		
		2023	2024	Average
1.	Control (no fertiliser)	0,84	0,80	0,82
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	1,06	1,02	1,04
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	1,18	1,10	1,14
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	1,20	1,17	1,19
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	1,22	1,20	1,21

The source was obtained as a result of own research results

According to Table 6, the weight of grain per ear in the control variant averaged 0.82 g, while in the areas where mineral fertilisers and growth regulators were applied, this figure increased to 1.04-1.21 g. This shows that optimisation of agronomic practices can significantly improve not only the quantitative but also the qualitative characteristics of the crop.

The weight of grain per ear of spring wheat largely depended on the use of mineral fertilisers and the timing of their application, as well as on the use of growth regulators. In particular, in the areas where the maximum dose of mineral fertilisers was applied, the grain weight ranged from 1.19 to 1.21 g.

The analysis of the results confirms that both growth regulators and fertiliser background have a significant impact on the yield of spring wheat (Table 7).

Table 7

Seed yield of spring wheat depending on on fertiliser system and growth regulators

№	Application option	Yield, t/ha		
		2023	2024	Average
1.	Control (no fertiliser)	3,6	3,2	3,4
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	4,5	4,1	4,3
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	4,6	4,2	4,4
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	5,2	4,8	5,0
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	5,4	5,0	5,2
	HIP_{05}	1,1	1,2	

The source was obtained as a result of own research results

The highest productivity and grain quality are achieved when these factors are optimally combined during all stages of plant growth and development. Taking into account the elements that affect yields, it is possible to significantly reduce the negative impact of weather and use controlled cultivation technologies more efficiently (Table 8).

Studies have shown that in the control variants, the protein content in the grain was 13.6% and gluten 28.3%. After the application of $N_{42}P_{42}K_{42}$ mineral fertiliser and foliar feeding with urea, as well as treatment with Fresh Florid growth regulator, the protein content in spring wheat grain increased to 14.2% and gluten content to 29.2% (Table 8).

Table 8

Impact of mineral fertilisers and growth regulators on grain quality of spring wheat (average 2023-2024)

№	Варіант внесення	Protein, %	+/- to control	Crude gluten content, %	+/- to control
1.	Control (no fertiliser)	13,6	-	28,3	-
2.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Energy	13,8	0,2	28,7	0,4
3.	$N_{30}P_{30}K_{30}$ +N_{30} + Fresh Florid	13,8	0,2	28,9	0,6
4.	$N_{42}P_{42}K_{42}$ +N_{30} + N_{10}+ Fresh Energy	14,0	0,4	29,1	0,8
5.	$N_{42}P_{42}K_{42}$+ N_{30} + N_{10}+ Fresh Florid	14,2	0,6	29,2	0,9

The source was obtained as a result of own research results

In general, the results confirm that the use of growth regulators in combination with mineral fertilisers during the main fertilisation and fertilisation in the tillering phase, as well as foliar feeding with urea, contribute to a significant increase in the quality and yield of spring wheat grain.

Conclusions. The highest productivity of spring wheat plants was recorded in areas where $N_{42}P_{42}K_{42}$ was used as the main fertiliser, as well as N_{30} fertilisation in the tillering phase. Additionally, the plants were treated with the growth regulator Fresh Florid at a rate of 1 l/ha and foliar fertilisation with urea N_{10} at the beginning of the earing phase.

On average, over two years, the maximum yield of spring wheat grain was observed when applying mineral fertilisers $N_{42}P_{42}K_{42}$ and fertilising with N_{30} in the tillering phase. Plants were also sprayed with Fresh Florid growth regulator, and foliar feeding with urea at N_{10} was carried out at the beginning of the earing phase. As a result, the grain yield averaged 5.2 t/ha.

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АНОТАЦІЯ

ФОРМУВАННЯ ПРОДУКТИВНОСТІ РОСЛИН ПШЕНИЦІ ЯРОЇ НА СІРИХ ОПІДЗОЛЕНИХ ҐРУНТАХ ПІД ВПЛИВОМ ЗАСТОСОВАНИХ ВАРІАНТІВ УДОБРЕННЯ В УМОВАХ ЗМІНИ КЛІМАТУ ПРАВОБЕРЕЖНОГО ЛІСОСТЕПУ УКРАЇНИ

У представленій науковій роботі наведено результати двохрічних досліджень, спрямованих на аналіз впливу мінеральних добрив та регуляторів росту на розвиток та формування продуктивних характеристик сортів ярої пшениці, вирощених на сірих опідзолених ґрунтах Вінниччини.

Максимальні показники урожайності пшениці спостерігались на ділянках, де було застосовано добрива $N_{42}P_{42}K_{42}$ для основного внесення, а також підживлення азотом (N_{30}) під час кущіння. Додатково проводилась обробка рослин регулятором росту Фреш Флорід в дозі 1 л/га і позакореневе підживлення карбамідом (N_{10}) на стадії початку виходу в трубку.

Найменшу висоту рослин ярої пшениці зафіксовано на ділянках, де використовували ті ж мінеральні добрива ($N_{42}P_{42}K_{42}$ та N_{30} на фазі кущіння), а також обробляли рослини регулятором росту Фреш Флорід і здійснювали позакореневе підживлення карбамідом.

Найбільша маса 1000 зерен, яка варіювала в межах 41,1–42,0 г, була досягнута на ділянках, де використали добрива $N_{42}P_{42}K_{42}$ і підживлення N_{30} на стадії кущіння, а також провели обробку рослин регуляторами росту Фреш Флорід і Фреш Енергія. Крім того, на стадії виходу в трубку рослини підживлювали карбамідом позакореневим методом.

Вага зерна з одного колоса ярої пшениці варіювала залежно від дозування мінеральних добрив, термінів їх внесення та застосування регуляторів росту. На ділянках з найбільшими дозами добрив цей показник коливався між 1,19 і 1,21 г.

У середньому за два роки максимальна врожайність зерна ярої пшениці спостерігалась на ділянках, де застосовували мінеральні добрива $N_{42}P_{42}K_{42}$ та підживлення N_{30} під час кущіння. Рослини обробляли регулятором росту Фреш Флорід, а на етапі початку виходу в *трубку проводили позакореневе підживлення карбамідом. Це забезпечило середній врожай на рівні 5,2 т/га.*

Ключові слова: *пшениця яра, удобрення, морфологічні особливості рослин та врожайність зерна.*

Табл. 8. Літ. 25.

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