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INFLUENCE OF NITROGEN NUTRITION AND NITRIFICATION INHIBITOR ON THE YIELD OF CEREAL CROPS

S.V. Muntyan[1], Ph.D. in Agricultural Sciences, A.P. Shatkovskyi[2], Dr. of Agricultural Sciences, M.S. Retman[3], Ph.D. in Agricultural Sciences

[1] Institute of Water Problems and Land Reclamation of the NAAS of Ukraine, Kyiv, 03022, Ukraine;
https://orcid.org/0000-0002-8933-9283 ; e-mail: ais_888@ukr.net;
[2] Institute of Water Problems and Land Reclamation of the NAAS of Ukraine, Kyiv, 03022, Ukraine;
https://orcid.org/0000-0002-4366-0397; e-mail: andriy-1804@ukr.net;
[3] Institute of Water Problems and Land Reclamation of the NAAS of Ukraine, Kyiv, 03022, Ukraine;
https://orcid.org/0000-0002-6972-2410 ; e-mail: retman_m.s@ukr.net

Abstract. *The article presents the results of experimental studies to determine the effect of using different rates of nitrogen fertilizers in the form of KAS-32 and the nitrification inhibitor 3,4-dimethylpyrazol phosphate on the yield of winter wheat, winter rape and corn. Field studies were conducted during 2018–2021 in the research department of Druzhba Nova LLC in Varvynskyi district of Chernihiv region (a branch of the Kernel agricultural holding). Analytical and mathematical-statistical methods were used to process the experimental data. The scheme of the one-factor field experiment included the use of variants with different norms of nitrogen fertilizers (N_{100}, N_{120} and N_{130}), as well as the use of the nitrification inhibitor 3,4-dimethylpyrazol phosphate when added to KAS-32. The control variant was conditionally without nitrogen fertilizers $N_{10}P_{30}K_{40}$. The results of experimental studies have been proven. Thus, in winter wheat, on average, over the four years of research in 2019–2021, the yield increased from 3,74 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 6,27 t/ha and to 6,30 t/ha in the variants background + N_{100} + NI and background + N_{120} + NI and then slightly decreased in the experimental variant with the maximum rate of nitrogen fertilizers but without the use of NI (background + N_{120}) to 5,85 t/ha. For winter rape, on average over the three years of research in 2018–2021, the yield also increased from 2.48 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 3,06 t/ha and 3,16 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and further slightly decreased to 2,79 t/ha in the variant with the maximum rate of nitrogen fertilizers but without the use of NI (Background + N_{130}).*

For maize, on average, over 4 years of research in 2019–2021, is fixed an increase in yield from 8,14 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 9,75 t/ha and to 9,52 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and a slight decrease in yield in the experimental variant with the maximum rate of nitrogen fertilizers, but without the use of NI (Background + N_{130}) to 8,7 t/ha.

Keywords: *nitrification inhibitor, 3,4 dimethylpyrazol phosphate, urea-ammonia mixture, normalized differential vegetation index, yield, winter wheat, winter rape, corn*

Relevance of the study. A number of factors, such as climatic conditions, soil type, growing zone, crop rotation and fertilizer use, influence the formation of sustainable crop yields, but nitrogen fertilizers, first of all, play one of the main factors [1–5]. In turn, nitrogen fertilizers are in constant processes of transformation in the soil from amide form to ammonium form and finally to nitrate form, these processes have a negative effect on the environment, ecosystem and soil as nitrogen losses occur during such transformations [6, 7]. Therefore, it is natural that the effectiveness of nitrogen fertilizers is reduced due to its losses, such as nitrate leaching due to nitrification and evaporation in gaseous forms during denitrification, such losses can be up to 2530 % of the applied amount of nitrogen [8, 9]. Some researchers believe that the so-called inhibitors can reduce nitrogen losses in nutrition systems by up to 50 %, depending on the specific inhibitor and the rate of its use, as well as other conditions such as meteorological conditions and soil type [10, 11].

Taking all of the above into account, we can conclude that the study of the impact of different rates of nitrogen fertilizers in the form of KAS-32 in combination with the nitrification inhibitor (NI) 3,4-dimethylpyrazol phosphate (DMPP) on the yield of winter wheat, winter rape and corn is a relevant area of work.

Analysis of recent research and publications. A nitrification inhibitor is a chemical substance of selective action that can inhibit the processes of nitrification in the soil by inhibiting the development of *Nitrosomonas* bacteria without destroying it, namely by suppressing its activity for a certain period of time. The mechanism of action of the nitrification inhibitor is to prolong the conversion of some forms of nitrogen into others compared to the application of soluble mineral fertilizers: urea, ammonium sulfate, ammonium nitrate [12, 13]. In order to reduce nitrogen losses, namely during the nitrification process, nitrogen application rates are regulated and so-called nitrification inhibitors are used, and today 3,4-dimethylpyrazol phosphate is one of the most effective nitrification inhibitors [14, 15, 16]. In the European Union, nitrification inhibitors are regulated by law, including the inhibitor 3,4-dimethylpyrazol phosphate, and the decision of the European Union Regulatory Commission No. 1257/2014 amending Regulation (EC) No. 2003/2003 of the European Parliament and of the Council as regards fertilizers and amending Annexes I and IV of 24.11.2014 was introduced [17].

Thus, the **aim of the study** was to determine the effect of using different rates of nitrogen fertilizers in the form of KAS-32 in combination with the nitrification inhibitor 3,4-dimethylpyrazol phosphate on the yield of winter wheat, winter rape and corn.

Materials and methods of the study. The study was conducted at the research site of Druzhba Nova LLC in Varvynskyi district of Chernihiv region (a branch of the Kernel agricultural holding) within the Uday drainage system without groundwater level regulation. The soil of the experimental site is a typical low-humus chernozem, the topsoil of which is characterized by the following main indicators humus content – 3,4 %, pH neutral and close to neutral – 5,7–7,0, mobile phosphorus content – from high to very high – 15,4–26,3 mg/100 g of soil, exchangeable potassium – from medium to high – 7,1–16,2 mg/100 g of soil, easily hydrolyzed nitrogen – from high to high – 5,7–7,9 mg/100 g of soil. The research was conducted according to the scheme of a one-factor experiment. The sown area of the experimental plot was 0,6 hectares, the alternation of variants was sequential. The field experiments were laid out and performed according to the methodology of field experiments (Dospekhov B.A., 1985). Harvest accounting was carried out by continuous harvesting and weighing of the bunker mass from each plot with subsequent conversion to standard moisture and weediness according to DSTU 2240-93 in 3 replications. Mathematical and statistical data were proceeded using the Agrostat software and information complex.

In accordance with the regulation of the European Union Regulatory Commission, a minimum rate of 0,8 % of NI DMPP was used on amide NH_2^- and ammonium NH_4^+ forms of nitrogen. According to this minimum calculated rate of 0,8 %, the rate of use of NI DMPP on KAS- 32 -is 7,02 liters per 1000 kg of KAS-32.

Research results and discussion.

The analysis of data on the yield of winter wheat, winter rape and corn shows that this indicator varied significantly over the years of research depending on the fertilizer background. Thus, the yield of winter wheat in all experimental variants was higher in two years of research in 2018 in the range of 3,72–8,14 t/ha and in 2020 in the range of 3.77–7.25 t/ha. Yields in the other two years of research, namely in 2019 and 2021, fluctuated at a relatively lower level in the range of 3,63–5,10 t/ha in 2020 and 3,83–4,81 t/ha in 2021, respectively. The average yield of winter wheat in all experimental variants in 2018–2021 ranged from 3,74–6,30 t/ha (Table 1).

In turn, the yield of winter rape in all experimental variants was higher in 2018, ranging from 3,12–3,85 t/ha. Yields in 2020 and 2021 were lower and ranged from 2,21–2,98 t/ha in 2020 and 2,11–2,70 t/ha in 2021. No winter rapeseed trials were conducted in 2019 due to unfavorable weather conditions. The average yield of winter rape in all experimental variants in 2018–2021 ranged from 2.48–3,16 t/ha.

Corn yields also varied depending on the years of research in 2018–2021. Thus, corn yield in all experimental variants was higher in 2018 in the range of 8,60–11,02 t/ha and in 2021 in the range of 8,57–11,19 t/ha. Yields in 2019 and 2020 fluctuated at a lower level in the range of 7,20–8,89 t/ha in 2019 and 8,17–8,66 t/ha in 2020, respectively. The average yield of corn in all experimental variants in 2018–2021 ranged from 8,14–9,75 t/ha.

There is a clear pattern for all studied crops of winter wheat, winter rape and corn and for the four years of research in 2018, 2019, 2022 and 2021 as an increase in yields in the experimental variants depending on the increase in nitrogen rates and the use of NI, followed by a slight decrease in yields in the experimental variant with the maximum nitrogen fertilizer rate but without the use of NI.

Investigating the data of winter wheat yield by years of research and by experimental variants in 2018, the control variant $N_{10}P_{30}K_{40}$ yielded 3,72 t/ha, it increased in the experimental variants with increased rates of nitrogen fertilizers and

1. Yield of winter wheat, winter rape and corn depending on the use of different rates of nitrogen fertilizers with the addition of a nitrification inhibitor (2018–2021), t/ha

Option	**Yield, t/ha**				**Average yield 2018–2021, t/ha**
	2018	**2019**	**2020**	**2021**	
Winter wheat					
N_{10} $P_{30}K_{40}$ (background)	3,72	3,63	3,77	3,83	3,74
Background+N_{100}+NI	8,00	5,05	7,20	4,81	6,27
Background+N_{120}+NI	8,14	5,10	7,25	4,72	6,30
Background+N_{120}	7,40	4,64	6,85	4,50	5,85
NIR_{05}	0,133	0,186	0,203	0,249	-
Winter rape					
N_{10} $P_{30}K_{40}$ (background)	3,12	-	2,21	2,11	2,48
Background+N_{120} +NI	3,70	-	2,79	2,70	3,06
Background+N_{130} +NI	3,85	-	2,98	2,66	3,16
Background+N_{130}	3,45	-	2,31	2,60	2,79
NIR_{05}	0,312	-	0,266	0,363	-
Corn					
N_{10} $P_{30}K_{40}$ (background)	8,57	7,20	8,17	8,60	8,14
Background+N_{120} +NI	11,19	8,27	8,51	11,02	9,75
Background+N_{130} +NI	9,95	8,89	8,66	10,59	9,52
Background+N_{130}	9,77	7,75	8,38	9,97	8,97
NIR_{05}	0,275	0,335	0,291	0,887	-

the use of NI, namely, Background + N_{100} + NI and Background + N_{120} + NI to 8,00 t/ha and 8,14 t/ha, respectively, and slightly decreased in the experimental variant with the maximum rate of nitrogen fertilizers but without the addition of NI Background + N_{120} to the level of 7,40 t/ha. The same trend was observed in the other 3 years of research in 2019, 202 and 2021. Thus, in 2019, there was an increase in yield from 3,63 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 5,05 t/ha and to 5,10 t/ha in the variants Background + N_{100} + NI and Background + N_{120} + NI with a slight decrease to 4,64 t/ha in the variant Background + N_{120}. In 2020, fixed an increase in yield from 3,77 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 7,20 t/ha and to 7,25 t/ha in the variants Background + N_{100} + NI and Background + N_{120} + NI and a slight decrease to 6,85 t/ha in the variant Background + N_{120}, and in 2021, an increase in yield from 3,83 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 4,81 t/ha and to 4,72 t/ha in the variants Background + N_{100} + NI and Background + N_{120} + NI and a slight decrease to 4,50 t/ha in the variant Background + N_{120}. The NIR_{05} was 0,133 t/ha in 2018, 0,186 t/ha in 2019, 0,203 t/ha in 2020 and 0,249 t/ha in 2021.

On average, over the 4 years of research in 2019–2021, the yield of winter wheat also increased from 3,74 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 6,27 t/ha and to 6,30 t/ha in the variants Background + N_{100} + NI and Background + N_{120} + NI and then slightly decreased in the experimental variant with the maximum rate of nitrogen fertilizers but without the use of NI (Background + N_{120}) to 5,85 t/ha.

For winter rape, as well as for winter wheat, in all years of research 2018–2021, an increase in yields was observed in the experimental variants with an increase in the rate of nitrogen and the use of NI on the experimental variants Background + N_{120} + NI and Background + N_{130} + NI and a subsequent slight decrease in yields on the experimental variant with the maximum rate of nitrogen fertilizers but without the use of NI (Background + N_{130}). Thus, in 2018, the control variant $N_{10}P_{30}K_{40}$ yielded 3,12 t/ha, it increased in the experimental variants Background + N_{120} + NI and Background + N_{130} + NI to 3,70 t/ha and 3,85 t/ha, respectively, and slightly decreased to 3,45 t/ha in the experimental variant Background + N_{130}. The same trend was observed in the other 2 years of research in 2020 and 2021. Thus, in 2020, an increase in yield was observed in the control variant $N_{10}P_{30}K_{40}$ from 2,21 t/ha to 2,79 t/ha and 2,98 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI respectively, and a slight decrease in yield to 2,31 t/ha in the variant Background + N_{130}. And in 2021, the yield increased from 2,11 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 2,70 t/ha and 2,66 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI, and a slightly decreased to 2,60 t/ha in the variant Background + N_{130}. The NIR_{05} for winter rape was 0,312 t/ha in 2018, 0,266 t/ha in 2020 and 0,363 t/ha in 2021.

On average, over the years of research, the yield of winter rape also increased from the control variant $N_{10}P_{30}K_{40}$ from 2,48 t/ha to 3,06 t/ha and to 3,16 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and then slightly decreased in the experimental variant with the maximum rate of nitrogen fertilizers but without the use of NI (Background + N_{130}) to 2,79 t/ha.

A similar trend was observed in corn yield data. Thus, in 2018, the control variant $N_{10}P_{30}K_{40}$ yielded 8,60 t/ha, it increased in the experimental variants Background + N_{120} + NI and Background + N_{130} + NI to 11,02 t/ha and 10,59 t/ha, respectively, and slightly decreased in the experimental variant Background + N_{130} to 9,97 t/ha. In 2019, the yield of the control variant $N_{10}P_{30}K_{40}$ increased from 7,20 t/ha to 8,27 t/ha and to 8,89 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI, respectively, and a slight decrease in yield to 7,75 t/ha in the variant Background + N_{130}. Similarly, in 2020, corn yields increased from the control variant $N_{10}P_{30}K_{40}$ from 8,17 t/ha to 8,51 t/ha and 8,66 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and decreased slightly to 8,38 t/ha in the variant Background + N_{130}. And in 2021, the yield of corn also increased from the control variant $N_{10}P_{30}K_{40}$ from 8,57 t/ha to 11,19 t/ha and to 9,95 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and decreased to 9,77 t/ha in the variant Background + N_{130}. The NIR_{05} was 0,887 t/ha in 2018, 0,335 t/ha in 2019, 0,291 t/ha in 2020 and 0,275 t/ha in 2021.

Summarizing the corn yield data for the average of 4 years of research in 2019–2021, there is also an increase in yield from the control variant $N_{10}P_{30}K_{40}$ from 8,14 t/ha to 9,75 t/ha and to 9,52 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and a slight decrease in yield in the experimental variant with the maximum rate of nitrogen fertilizers, but without the use of NI (Background + N_{130}) to 8,97 t/ha.

In addition to fertilization, the amount and mode of productive precipitation had a significant impact on the productivity of all crops. Thus, during 2018–2020, in the spring period (from March to May), there was insufficient precipitation – 68,2, 87,6 and 130,0 mm, respectively, which had an extremely negative impact on both the period of spring renewal of winter crops and the conditions for sowing early spring crops. At the end of the growing season, in September 2018, the total amount of precipitation was the lowest in the years of research and amounted to 309,0 mm (Table 2).

The analysis showed that from 2019 to 2020, the amount of precipitation and the amount of productive moisture in the root layer of the soil from March to May remained below optimal values for all crop groups (198,4–222,8–258,2 mm in 2019 and 133,0–168,0–252,0 mm in 2020). At the end of the growing season, in September 2019 and 2020, the total amount of precipitation was almost at the same level and amounted to 341,8 mm and 343,8 mm. In 2021, during the spring growing season, the amount of precipitation was slightly higher compared to previous years and ranged from 196,3–241,7–327,1. Also, the amount of precipitation at the end of the growing season in September 2021 was the highest in the years of research and amounted to 509,9 mm.

The calculations show that the highest correlation between the amount of productive precipitation and crop yields was for grain corn – 0,74. For example, the corn grain yield in the wettest year of 2021 exceeded the drier years of 2019 and 2020 by 1,6 and 2,0 t/ha, respectively. In turn, for the group of winter crops (wheat, rapeseed), the impact of precipitation was less significant (correlation coefficient 0,42 and 0,47, respectively).

2. Dynamics of productive precipitation (cumulative total) by years of research during the growing season (March-September) (2018–2021), mm

Months	**Cumulative rainfall, mm**			
	2018	**2019**	**2020**	**2021**
March	68,2	198,4	133,0	196,3
April	87,6	222,8	168,0	241,7
May	130,0	258,2	252,0	327,1
June	208,6	275,4	286,4	359,3
July	261,8	315,2	322,0	444,7
August	269,4	325,2	329,8	499,1
September	309,0	341,8	343,8	590,9

Conclusions. The results of experimental studies have shown that the use of different norms of nitrogen fertilizers in the form of KAS-32 in combination with the nitrification inhibitor (NI) 3,4-dimethylpyrazol phosphate (DMPP) significantly affects the yield of winter wheat, winter rape and corn.

In winter wheat, on average, over the four years of research in 2019–2021, the yield increased from 3,74 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 6,27 t/ha and 6,30 t/ha in the variants – Background + N_{100} + NI and Background + N_{120} + NI and then slightly decreased in the experimental variant with the maximum rate of nitrogen fertilizers but without the use of NI (Background + N_{120}) to 5,85 t/ha.

In winter rape, on average over the three years of research in 2018–2021, the yield also increased from 2,48 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 3,06 t/ha and 3,16 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and then slightly decreased in the variant with the maximum rate of nitrogen fertilizers but without the use of NI (Background + N_{130}) to 2,79 t/ha.

For corn, on average, over 4 years of research in 2019–2021, fixed an increase in yield from 8,14 t/ha in the control variant $N_{10}P_{30}K_{40}$ to 9,75 t/ha and 9,52 t/ha in the variants Background + N_{120} + NI and Background + N_{130} + NI and a slight decrease to 8,97 t/ha in yield in the experimental variant with the maximum rate of nitrogen fertilizers but without the use of NI (Background + N_{130}).

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ВПЛИВ АЗОТНОГО ЖИВЛЕННЯ ТА ІНГІБІТОРА НІТРИФІКАЦІЇ НА ВРОЖАЙНІСТЬ ЗЕРНОВИХ КУЛЬТУР

С.В. Мунтян [1], канд. с.-г. наук, А.П. Шатковський[2], д-р с.-г. наук, М.С. Ретьман[3], канд. с.-г. наук

[1] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, 03022, Ukraine;
https://orcid.org/0000-0002-8933-9283; e-mail: ais_888@ukr.net;
[2] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, 03022, Ukraine;
https://orcid.org/0000-0002-4366-0397; e-mail: andriy-1804@ukr.net;
[3] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, 03022, Ukraine;
https://orcid.org/0000-0002-6972-2410; e-mail: retman_m.s@ukr.net

Анотація. *У статті наведено результати експериментальних досліджень із визначення впливу використання різних норм азотних добрив у вигляді КАС-32 та інгібітора нітрифікації 3,4-диметилпіразолфосфат на урожайність пшениці озимої, ріпаку озимого та кукурудзи. Польові дослідження проведено протягом 2018–2021 рр. в науково-дослідному відділі СТОВ «Дружба Нова» Варвинського району Чернігівської області (відділення агрохолдингу «Кернел»). Для обробки експериментальних даних використано аналітичні та математично-статистичні методи. Схемою однофакторного польового досліду було використання варіантів з різними нормами азотних добрив (N_{100}, N_{120} та N_{130}), а також використання інгібітора нітрифікації 3,4-диметилпіразолфосфат при додаванні в КАС-32. Контрольним був варіант умовно без азотних добрив $N_{10}P_{30}K_{40}$. Результатами експериментальних досліджень доведено. Так, по пшениці озимій в середньому за чотири роки досліджень 2019–2021 урожайність збільшувалась від контрольного варіанту $N_{10}P_{30}K_{40}$ з 3,74 т/га до 6,27 т/га та до 6,30 т/га на варіантах фон + N_{100} + ІН та фон + N_{120} + ІН та в подальшому дещо знижувалась на варіанті досліду із максимальною нормою азотних добрив але без використання ІН (фон + N_{120}) до 5,85 т/га. По ріпаку озимому в середньому за три роки досліджень 2018–2021 урожайність також збільшувалась від контрольного варіанту $N_{10}P_{30}K_{40}$ з 2,48 т/га до 3,06 т/га та до 3,16 т/га на варіантах Фон + N_{120} + ІН та фон + N_{130} + ІН та в подальшому дещо знижувалась на варіанті досліду із максимальною нормою азотних добрив але без використання ІН (Фон + N_{130}) до 2,79 т/га.*

По кукурудзі в середньому за 4 роки досліджень 2019–2021 так само спостерігається збільшення урожайності від контрольного варіанту $N_{10}P_{30}K_{40}$ з 8,14 т/га до 9,75 т/га та до 9,52 т/га на варіантах Фон + N_{120} + ІН та Фон + N_{130} + ІН та несуттєве зниження врожайності на варіанті досліду із максимальною нормою азотних добрив, але без використання ІН (фон + N_{130}) до 8,97 т/га.

Ключові слова: *інгібітор нітрифікації, 3,4 диметилпіразолфосфат, карбамідно-аміачна суміш, нормалізований диференційний вегетаційний індекс, урожайність, пшениця озима, ріпак озимий, кукурудза*