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YIELD OF WINTER WHEAT DEPENDING ON THE LONG-TERM APPLICATION OF FERTILIZERS IN CROP ROTATION AND SOIL FERTILITY

Popov S. I., Hutianskyi R. A., Kuzmenko N. V., Avramenko S. V.
Plant Production Institute named after V. Ya. Yuriev of NAAS, 142 Heroiv Kharkova Ave., Kharkiv, Ukraine, 61060

Topicality. *For agricultural enterprises that implement intensive technologies, the issue of efficient utilisation of nutrients from organic and mineral fertilisers, depending on nutrient content in the soil, is relevant. At present, the high probability of a shortfall in the forecasted yields in most farms is caused by a significant difference between the required and actual dose of fertiliser application. In this regard, the issue of optimising the fertiliser application in winter wheat cultivation is becoming a priority. Given the current understanding of this issue, we should investigate the impact of manure, complete mineral fertilisation and nitrogen feeding on soil fertility and grain yields, depending on the crop placement in the crop rotation.* ***Purpose.*** *To determine the impact of long-term application of different fertilisation systems on soil fertility and yield formation patterns of modern winter wheat varieties.* ***Methods.*** *Field, measuring and weighting, and statistical methods were used.* ***Results.*** *Over 30 years of research in the variants with the basal application of $N_{30}P_{30}K_{30}$ and $N_{60}P_{60}K_{60}$ on the background of manure, it was found that the content of exchangeable potassium (16.4–17.9 mg/100 g of soil) and mobile phosphorus (18.9–20.2 mg) in the soil corresponded to a high and very high level, and easily hydrolysed nitrogen (16.3–17.6 mg) – to a low and average level. In 2004–2021, on average, on an organic background with additional application of $N_{30}P_{30}K_{30}$, the increase in grain yield after black fallow was 0.38 and 0.66 t/ha, and after peas – 0.52 and 1.07 t/ha, respectively. Nitrogen feeding in rates of N_{20}, N_{40} and N_{60} on the non-fertilised background after black fallow provided an increase in grain yield of 12.0–16.6 %, and on the background of manure with $N_{30}P_{30}K_{30}$ – 28.6–36.4 %. After peas for grain as a predecessor, the increase in grain yield was 9.1–19.9 % and 37.6–47.7 %, respectively. When fertilising crops on an non-fertilised background, the highest payback of nitrogen fertilisers on grain was from 15.3 to 34.5 kg of grain per 1 kg of nitrogen. On the background of manure with $N_{30}P_{30}K_{30}$, the payback of 1 kg of NPK on grain, depending on the predecessor, was 8.3–9.2 kg.* ***Conclusions.*** *In 1991–2001, soil fertility was preserved and improved by maintaining crop rotation against the background of systematic organic-mineral fertilisation. High winter wheat yield after black fallow is possible to obtain by following a scientific-based crop rotation, and after peas – by using an organic-mineral fertilisation system.*

Key words: *crop rotation, soil fertility, nutritional background, nitrogen feeding, yield, efficiency, payback*

Introduction. Numerous studies in different soil and climatic zones of Ukraine have shown that almost half of the increase in grain yields is achieved through rational and balanced mineral nutrition of plants. The content of nitrogen, phosphorus and potassium in the soil largely determines the growth rate of winter wheat (*Triticum aestivum* L.) and its absorption rate of other nutrients [1]. Generalised data show that crop yields depend on soil nutritional conditions by 15–20 % and fertilisers by 30–40 % [2], and their payback largely depends on rates and dates of application, soil type, predecessors, moisture availability of crops, etc. [3–5].

Today, farmers face the challenge of adapting to changes in climate and market dedemands. They have to adapt their fertilisation systems and crop rotations, as insufficient and

Author information:

Serhii I. Popov, *Doctor of Agricultural Sciences, Professor, Head of the Department of Plant Production and Variety Studies,* e-mail: sergivpopov@gmail.com, https://orcid.org/0000-0002-1101-4454

Roman A. Hutianskyi, *Candidate of Agricultural Sciences, Senior Researcher, Leading Researcher at the Department of Plant Production and Variety Studies,* e-mail: rammale@ukr.net, https://orcid.org/0000-0002-5953-9428

Natalia V. Kuzmenko, *Candidate of Biological Sciences, Senior Researcher, Leading Researcher at the Department of Plant Production and Variety Studies,* e-mail: kuz.n.v.1964@gmail.com, https://orcid.org/0000-0002-4373-0666

Serhii V. Avramenko, *Doctor of Agricultural Sciences, Senior Researcher, Chief Researcher at the Department of Plant Production and Variety Studies,* e-mail: avsergiy1@gmail.com, https://orcid.ord/0000-0003-4737-8441

unbalanced application of mineral and organic fertilisers has a negative impact on soil health [6–9]. Research by Chinese scientists shows that the application of a combination of organic fertilisers and synthetic nitrogen fertilisers with reduced levels is an effective approach to promote sustainable intensification of winter wheat production in northern China [10, 11].

Investigation of the effect of manure, complete mineral fertilisation (NPK) and nitrogen feeding on grain yield of winter wheat and soil properties depending on the predecessor is essential. The most objective information on these issues is provided by the results of long-term stationary experiments.

Materials and Methods. The experiments were carried out in a stationary 9-field grain-fallow-row crop rotation laid out in 1972 with the following crop rotation: black fallow – winter wheat – sugar beet – spring cereals – peas – winter wheat – maize for grain (0.5 field) + soybeans (0.5 field) – spring cereals – sunflower. Soil is typical medium-low humus slightly alkaline chernozem.

The experiments were designed according to multifactorial schemes using the split-plot method, considering all the requirements of the field experiment methodology [12], where the plots of the first order were the application of organic and mineral fertilisers; the plots of the second order were other agricultural practices (varieties, rates of nitrogen feeding). The basal fertilisation system included: 1) control (without fertilisers) was the nutrition background formed due to crop rotation; 2) organic background was the introduction of manure (30 t/ha) on two fields of crop rotation, which was 6.6 t per 1 ha of crop rotation area; 3) organic-mineral limited background was the aftereffect of manure + $N_{30}P_{30}K_{30}$; 4) organic-mineral enhanced background was the aftereffect of manure + $N_{60}P_{60}K_{60}$. Before sowing, soil samples were taken from the arable layer (0–30 cm) to determine the content of the main nutrients (humus, easily hydrolysed nitrogen, mobile phosphorus and exchangeable potassium). During the fifth cycle of crop rotation, the efficiency of foliar feeding with ammonium nitrate at doses of N_{20}, N_{40}, N_{60}, depending on the nutrition background, in the tillering stage was studied. The plots were systematically arranged, with a total plot area of 34.0 m^2 and a record plot area of 25.0 m^2. The experiment was replicated three times. Integrated crop protection was used. Other agrotechnical practices were generally accepted for the eastern part of the Forest-Steppe of Ukraine.

Results and Discussion. Table 1 shows the level of soil availability of the main nutrients in long-term experiments.

According to the analysis results, in 2021, on the studied fertilisation backgrounds, the humus content in the soil was very high and ranged from 5.28–5.67 %. It was found that under systematic fertilisation in crop rotation, the alkaline-hydrolysed nitrogen content in the soil decreased over the years on all fertilisation backgrounds. In the period 1991–2001, this indicator corresponded to the average level for all nutrition backgrounds and was 18.8 and 18.9 mg/100 g of soil, respectively, while the slight fluctuations in the variants ranged from 0.1–0.3 mg/kg to 0.3–0.5 mg/100 g (LSD_{05}= 1.2 mg). Subsequently, for the periods 2001–2011 and 2011–2021, the content of easily hydrolysed nitrogen was significantly reduced on all nutrition backgrounds, especially on unfertilised. In 2011 and 2021, its content was 11.6 and 12.4 mg/100 g of soil, respectively, which is 2.4–5.0 mg and 0.2–3.4 mg less than in the fertilised variants. Over 30 years, on average, the available nitrogen content in the soil decreased to 13.4 mg/100 g of soil, which is 5.4 mg less than in 1991. Over the years of research, the most significant decrease in nitrogen reserves (15.3 mg) was noted on the background without fertilisers, which was 0.7–2.3 mg/100 g of soil less than on fertilised variants.

It was found that since 2001, the content of easily hydrolysed nitrogen in the soil on fertilised variants was average, and later it was low. In 2021, its average content (15.8 mg) was observed only on the increased fertilisation background. Therefore, the changes in the differentiation of hydrolysed nitrogen in the soil under the influence of fertilisers were more influenced by the time factor. Consequently, the organic background in combination with the additional application of the basal fertiliser $N_{30}P_{30}K_{30}$ over the years did not provide the average level of nitrogen available to plants that indicates the importance of nitrogen fertilisers in winter wheat cultivation.

In contrast to nitrogen, the content of mo-

Table 1. Effect of long-term systematic fertilisation in crop rotation on the content of mobile forms of NPK in the soil under winter wheat, mg/100 g

Fertilisation system (factor B)	Year (time factor A)				Average (factor B)	Effect of fertilisers
	1991	2001	2011	2021		
Easily hydrolysable nitrogen according to Kornfield						
No fertilisers (control)	18.8–A*	18.4–L	11.6– L	12.4–L	15.3–L	–
Organic system (manure)	19.2–A	19.1–L	13.0– L	12.6–L	16.0–A	+ 0.7
Manure + $(NPK)_{30}$	18.7–A	19.1-L	14.6–L	12.8–L	16.3–A	+ 1.0
Manure + $(NPK)_{60}$	18.7–A	19.2–L	16.6–A	15.8–A	17.6–A	+ 2.3
average (A)	18.8–A	18.9–A	13.9–L	13.4–L		
Effect of factor A compared to 1991 (LSD_{05} = 1.2)	–	+ 0.1	- 4.9	- 5.4		
Mobile phosphorus according to Chirikov						
No fertilisers (control)	10.3–I	12.9–I	9.1– A	8.2– A	10.1–I	–
Organic system (manure)	11.4–I	14.6–I	13.5–I	14.3–I	13.4–I	+ 3.3
Manure + $(NPK)_{30}$	12.9–I	17.2–H	15.8–H	18.9–H	16.2–H	+ 6.1
Manure + $(NPK)_{60}$	12.0–I	21.0–VH	18.5–H	20.2–VH	17.9–H	+ 7.8
average (A)	11.7–I	16.4– I	14.2–I	15.4–H	–	–
Effect of factor A compared to 1991 (LSD_{05} = 1.4)	–	+ 4.7	+ 2.5	+ 3.7	–	–
Exchangeable potassium according to Chirikov						
No fertilisers (control)	11.6– I	11.9– I	12.0–H	11.1– I	11.7- I	–
Organic system (manure)	12.2–H	12.7–H	14.7–H	13.2–H	13.2–H	+ 1.5
Manure + $(NPK)_{30}$	14.1–H	16.2–H	17.4–H	16.4–H	16.0–H	+ 4.3
Manure + $(NPK)_{60}$	13.4–H	17.5–H	18.6–VH	17.9–H	16.9–H	+ 5.2
average (A)	12.8–H	14.6–H	15.7–B	14.7–H	–	–
Effect of factor A compared to 1991 (LSD_{05} = 1.2)	–	+ 1.8	+ 2.9	+ 1.9		

Note: Nutrient content in the soil: L – low, A – average, I – increased, H – high; VH – very high.*

bile phosphorus in the variants with organic-mineral fertilisation increased significantly over the years compared to the control. Against the background of the aftereffect of manure + $N_{60}P_{60}K_{60}$, this indicator increased by 9.0 mg/100 g in 2021 compared to 1991 (12.0 mg) (see Table 1). Over 30 years in this variant, soils with increased phosphorus content changed to the category of high level, and in 2001 and 2021 – to very high level (20.2 and 21.0 mg). Against the background of manure + $N_{30}P_{30}K_{30}$, the phosphorus content was also increased, but with indicators lower by 3.8 mg and 1.3 mg, respectively. Since 2001, on both organo-mineral nutrition backgrounds, the P_2O_5 content in the soil exceeded the level of 15.0 mg/100 g of soil, which according to the literature [13] is characterised as the beginning of overphosphating, and the level of more than 20.0 mg/kg of soil is characterised as strong overphosphating. Consequently, winter wheat cultivation on these variants was carried out in the condition of excessive phosphate availability in the soil.

According to the analysis, the exchangeable potassium content in the control variant did not change significantly and remained increased in 2021 (11.1 mg). On the organic background, the potassium content corresponded to a high level (13.2 mg) with an excess of 2.1 mg/100 g of soil over the control. Significant increase in potassium content was noted in the variants of the basal application of $N_{30}P_{30}K_{30}$ and $N_{60}P_{60}K_{60}$ on the background of manure compared to the organic background by 3.2 and 4.7 mg, respectively.

The maximum value was on the background of manure + $N_{60}P_{60}K_{60}$ and varied from high (17.5 mg) in 2001 to very high (18.6 mg) in 2011. In 2021, the content of exchangeable potassium on the increased background was 8.2 mg higher than in 1991. On average, over 1991–2021, the potassium content in the soil did not change significantly on control, while on organic-mineral backgrounds it increased by 2.3 and 4.5 mg, respectively.

The analysis of yield data for the period of the fourth (2004–2012) and fifth (2013–2021) rotations showed that the effectiveness of fertilisation systems on winter wheat crops significantly depended on the weather conditions of the growing season, the predecessor and soil fertility. So, in relation to rotations on the unfertilised background with an average phosphorus and high potassium content in the soil, the level of grain yield increased from 5.38 to 6.20 t/ha after black fallow (Table 2), and from 4.55 to 5.42 t/ha after peas (Table 3).

Table 2. Yield of winter wheat after black fallow depending on long-term fertilisation system in crop rotation, t/ha

Year	Nutrition background			Effect of fertilisers, +/-		% to control	
	C	O	OM_{30}	O	OM_{30}	O	OM_{30}
Fourth crop rotation							
2004	6.44	6.08	6.13	- 0.36	- 0.31	94.4	95.2
2005	5.52	6.58	6.90	1.06	1.38	119.2	125.0
2006	0.70	0.62	0.94	- 0.08	0.24	88.6	134.3
2007	6.88	6.88	6.92	0.00	0.04	100	100.6
2008	7.47	6.80	7.14	- 0.67	- 0.33	91.0	95.6
2009	6.95	6.90	7.05	- 0.05	0.10	99.3	101.4
2010	3.54	3.73	3.47	0.19	- 0.07	105.0	98.0
2011	6.76	7.23	7.31	0.47	0.55	107.0	108.1
2012	4.18	4.76	4.99	0.58	0.81	113.9	119.4
Average	5.38	5.51	5.65	0.13	0.27	102.4	105.0
Fifth crop rotation							
2013	5.56	6.82	6.78	1.26	1.22	122.7	121.9
2014	6.81	7.23	7.46	0.48	0.65	106.2	109.5
2015	6.89	7.18	7.27	0.29	0.38	104.2	105.5
2016	5.10	5.93	6.60	0.83	1.50	116.3	129.4
2017	5.30	6.29	7.18	0.99	1.88	118.7	135.5
2018	5.80	6.79	7.04	0.99	1.24	117.1	121.4
2019	6.42	6.63	7.03	0.21	0.61	103.3	109.5
2020	6.94	7.26	7.75	0.32	0.81	104.6	111.7
2021	6.98	7.34	8.17	0.36	1.19	105.2	117.0
Average	6.20	6.83	7.25	0.64	1.05	110.3	116.9
Average for 2004–2021	5.79	6.17	6.45	0.38	0.66	106.4	111.0
LSD_{05}, t/ha: nutrition background – 0,19; year – 0,24; interaction – 0,36							

** Note: C – control (no fertilisers); O – organic background; OM_{30} – organic-mineral background (aftereffect of manure + $N_{30}P_{30}K_{30}$).*

After black fallow on fertilised backgrounds with high mobile phosphorus and exchangeable potassium content, increase in grain yield during the fifth rotation was significantly higher (0.64–1.05 t/ha) compared to the fourth rotation (0.13–0.27 t/ha), which is explained by a higher ratio of years with favourable weather conditions and varietal response.

During 2004 and 2006–2008, as a result of heavy rainfall and plant lodging during the period of grain formation and filling, the yield in variants with fertilisers application was equal to or significantly lower than in the control variant. A similar dependence, but with a higher yield in the variants with fertiliser application, was obtained in crops after the peas for grain, in which no lodging was observed.

On the organic background and with the additional application of $N_{30}P_{30}K_{30}$, on average, the increase in grain yield was 0.47 t/ha and 0.99 t/ha for the fourth rotation, respectively, and 0.57 and 1.16 t/ha for the fifth rotation. It

Table 3. Yield of winter wheat after peas depending on the long-term fertilisation system in the crop rotation, t/ha

Year	Nutrition background *			Effect of fertilisers, t/ha		% to control	
	C	O	OM_{30}	O	OM_{30}	O	OM_{30}
Fourth crop rotation							
2004	5.15	5.65	5.78	0.50	0.63	109.7	112.2
2005	6.49	7.40	7.35	0.91	0.86	114.0	113.3
2006	0.28	0.38	0.63	0.10	0.35	135.7	225.0
2007	5.80	6.05	7.37	0.25	1.57	104.3	127.1
2008	7.94	8.27	8.36	0.33	0.42	104.2	105.3
2009	3.53	4.57	6.35	1.04	2.82	129.5	179.9
2010	2.86	2.87	3.15	0.01	0.29	100.3	110.1
2011	4.95	5.88	6.81	0.93	1.86	118.8	137.6
2012	3.91	4.12	4.04	0.21	0.13	105.4	103.3
Average	4.55	5.02	5.54	0.47	0.99	110.3	121.8
Fifth crop rotation							
2013	5.13	5.82	6.24	0.69	1.11	113.5	121.6
2014	6.65	7.19	7.59	0.54	0.94	108.1	114.1
2015	7.03	7.11	7.25	0.08	0.22	101.1	103.1
2016	3.89	4.32	4.96	0.43	1.07	111.0	127.5
2017	4.45	5.04	6.41	0.59	1.96	113.2	144.0
2018	3.16	4.62	5.39	1.46	2.23	146.2	170.6
2019	5.37	5.77	6.37	0.40	1.00	107.4	118.6
2020	6.54	6.82	7.40	0.28	0.86	104.3	113.1
2021	6.60	7.24	7.64	0.64	1.04	109.7	115.8
Average	5.42	5.99	6.58	0.57	1.16	110.5	121.4
Average for 2004–2021	4.98	5.50	6.06	0.52	1.07	110.4	121.6
LSD_{05}, t/ha: nutrition background – 0,16; year – 0,24; interaction – 0,41							

** Note: C – control (no fertilisers); O – organic background; OM_{30} – organic-mineral background (aftereffect of manure + $N_{30}P_{30}K_{30}$).*

should be noted that not in all years the application of complete mineral fertiliser on the background of manure was effective because the difference in yield between the variants was not significant.

Over two rotations (on average for 2004–2021), increase in grain yield on the organic background and with additional application of $N_{30}P_{30}K_{30}$ was 0.38 and 0.66 t/ha after black steam, 0.52 and 1.07 t/ha after peas, while the yield on the control was 5.79 and 4.98 t/ha, respectively.

Thus, if the grain yield on the unfertilised background is taken as 100 %, the comparative effectiveness of the organic system by rotations in cultivation after the black fallow was 102.4 and 110.3 %, or an average of 106.4 % for the entire period of research; in the organic-mineral system, this indicator was higher by 2.6 and 6.6 %, respectively, and averaged 111.0 %. After peas for grain, the effect of fertilisers during both rotations was significantly higher and amounted to 110.4 % on the organic background and 121.6 % on the organic-mineral background, which is 4.0 and 10.6 % higher, respectively, compared to the black fallow. At the same time, after both predecessors, patterns in the increasing yield under the influence of fertilisers at the end of the fifth rotation compared to the fourth were noted.

Since mineral nitrogen is the most important in the nutrition system of winter wheat, the effectiveness of foliar nitrogen feeding at rates of N_{20}, N_{40} and N_{60} was studied in 2015–2018, depending on soil fertility and background of the basal fertilisation. Weather conditions during the research were dry in autumn and varied significantly during the spring and summer period. The growing season in 2014/15 and 2016/17 were more favourable for the growth, development and formation of plant productivity, and less favourable in 2015/16 and

2017/18. The effectiveness of application of different nitrogen doses largely depended on the crop condition in autumn and the amount of precipitation during the growing season of a particular year.

According to the results of research in 2015–2018, a significant increase in the grain yield of winter wheat was found due to the basal fertilisation and root application of ammonium nitrate in the tillering stage (Table 4). The grain yield after black fallow on organic and organic-mineral background (aftereffect of manure + $N_{30}P_{30}K_{30}$) averaged 6.55 and 7.02 t/ha, which is 0.78 and 1.22 t/ha higher than the control. Nitrogen feeding in rates of N_{20}, N_{40} and N_{60} on the background without the basal fertilisation provided an increase in grain yield of 0.69, 0.89 and 0.96 t/ha (12.0–16.6 %) with a yield of 5.77 t/ha in the control. On the background of manure + $N_{30}P_{30}K_{30}$, the increase was 1.65, 1.99 and 2.10 t/ha (28.6–36.4 %), respectively, which was 7.5–15.3 % higher than in the organic background. The highest grain yield on the control variant was 6.89 t/ha in 2015.

Table 4. Yield of winter wheat depending on the predecessor and fertilisation system, t/ha *

Variant of fertilisation (B)	Total fertiliser quantity, a. i.	Year of research				Average	Effect of fertilisers		Payback of 1 kg a.i. by grain, kg
		2015	2016	2017	2018		t/ha	%	
predecessor – black fallow (A)									
Control	–	6.89	5.10	5.30	5.80	5.77	–	–	–
N_{20}	20	7.27	5.68	6.85	6.04	6.46	0.69	12.0	34.5
N_{40}	40	7.31	5.83	7.26	6.23	6.66	0.89	15.4	22.3
N_{60}	60	7.23	5.99	7.50	6.17	6.73	0.96	16.6	16.0
Background (manure)	90	7.18	5.93	6.29	6.79	6.55	0.78	13.5	8.7
Manure + $N_{30}P_{30}K_{30}$	180	7.27	6.60	7.18	7.04	7.02	1.22	21.1	6.8
Manure + $N_{30}P_{30}K_{30}$ +N_{20}	200	7.58	6.87	7.91	7.33	7.42	1.65	28.6	8.3
Manure + $N_{30}P_{30}K_{30}$+ N_{40}	220	7.84	7.27	8.37	7.58	7.76	1.99	34.5	9.0
Manure + $N_{30}P_{30}K_{30}$+ N_{60}	240	8.02	7.38	8.55	7.52	7.87	2.10	36.4	8.8
predecessor – peas for grain									
Control	–	7.03	3.89	4.45	3.16	4.63	–	–	–
N_{20}	20	7.26	4.26	5.12	3.55	5.05	0.42	9.1	21.0
N_{40}	40	7.36	4.71	5.52	3.87	5.36	0.73	15.8	18.3
N_{60}	60	7.32	5.01	5.86	4.02	5.55	0.92	19.9	15.3
Background (manure)	90	6.96	5.01	4.62	4.29	5.22	0.59	12.7	6.5
Manure + $N_{30}P_{30}K_{30}$	180	7.25	4.96	6.41	5.39	6.00	1.37	29.6	7.6
Manure + $N_{30}P_{30}K_{30}$ +N_{20}	200	7.16	5.50	7.12	5.71	6.37	1.74	37.6	8.7
Manure + $N_{30}P_{30}K_{30}$+ N_{40}	220	7.45	6.02	7.36	5.89	6.68	2.05	44.2	9.3
Manure + $N_{30}P_{30}K_{30}$+ N_{60}	240	7.59	6.26	7.58	5.92	6.84	2.21	47.7	9.2

$LSD_{05,}$ t/ha for factors:				
A – predecessor	0.14	0.13	0.11	0.12
B – fertilisation	0.18	0.21	0.24	0.19
AB – interaction	0.32	0.36	0.30	0.24

*Note *– average by Statna, Smuhlianka, Epokha odeska varieties.*

At the same time, nitrogen feeding in rates of N_{20}, N_{40} and N_{60} on the unfertilised background provided increases in grain yield of 0.38, 0.42 and 0.34 t/ha, while on the organo-mineral background increases were higher by 0.31, 0.53 and 0.79 t/ha, respectively, and significantly varied by variants. So, after black fallow, the most effective was the application rate of N_{40}, which on the background without the basal fertilisation provided an increase in yield by 0.89 t/ha, and on the organo-mineral background by 1.99 t/ha. Over four years, on average, a similar dependence of yield on nitrogen feeding was recorded after the peas for grain, with a higher level on the organic-mineral background. The increase in grain yield was 0.59 t/ha against the background of manure aftereffect, and with additional application of $N_{30}P_{30}K_{30}$ – 1.37 t/ha or 29.6% compared to the control. Nitrogen feeding in rates of $N_{2}0$, N_{40} and N_{60} in crop rotation provided an increase in grain yield of 0.42, 0.73 and 0.92 t/ha (9.1–19.9 %), and in the organic-mineral background – 1.74, 2.05 and 2.21 t/ha (37.6–47.7 %). At the same time, on the fertilised background with nitrogen feeding variants, increases in grain yield were higher by 0.37, 0.68 and 0.84 t/ha, respectively, or by 8.0–18.1 % compared to the unfertilised background.

The highest grain yield (7.03 t/ha) was recorded in 2015, however, the grain yield in the variants with nitrogen feeding was the lowest and amounted to 0.23–0.33 t/ha on the unfertilised background, and 0.13–0.56 t/ha on the fertilised background. (LSD_{05}=0.18 t/ha). In 2016, an unfavourable year, the highest increases in grain yields were to 0.37, 0.82 and 1.12 t/ha in terms of nitrogen rates, respectively, against a unfertilised background, and 1.61, 2.13 and 2.37 t/ha in terms of organic-mineral fertilisation. Consequently, higher and more reliable increases in grain yield were obtained in the variants with nitrogen feeding with ammonium nitrate on the background of manure + $N_{30}P_{30}K_{30}$ compared to the control. The most cost-effective rate for root feeding of weak crops was $N_{60.}$

The experiments showed a high payback of nitrogen fertilisers by grain that largely depended on the predecessor, nutrition background and rate of nitrogen feeding. Therefore, after black fallow on an unfertilised background of ammonium nitrate application in rates of N_{20}, N_{40}, N_{60}, 34.5, 22.3 and 16.0 kg of grain per 1 kg of nit-rogen were obtained, and after peas - 21.0, 18.3 and 15.3 kg, respectively. This high payback of nitrogen fertilisers is explained by the rapid action of nitrogen compounds after feeding the poor crops. A similar pattern was observed in the variants of the specified nitrogen rates against the background of the aftereffect of manure + $N_{30}P_{30}K_{30}$, but a significant decrease in their payback by grain was noted due to an increase in the total rate of fertiliser. The payback of 1 kg of NPK by the increase in grain yield in accordance with the nitrogen rates was 8.3, 9.0 and 8.8 kg after black fallow, 8.7, 9.3 and 9.2 kg after peas, respectively.

The high yield of winter wheat after black fallow is achieved by observing scientifically based crop rotation, and after peas – by applying organic and organic-mineral fertilizer systems; the economically feasible rate of mineral fertilizers for the organic-mineral system of the basal fertilization is $N_{30}P_{30}K_{30}$.

Conclusions. It was found that the observance of crop rotation during 1991–2001 against the background of systematic organic-mineral fertilisation led to the preservation and improvement of soil fertility. On the crop rotation background (without fertilisers), easily hydrolysable nitrogen content was low, and mobile phosphorus and exchangeable potassium content was medium and high, which resulted in a yield of 5.79 t/ha after black fallow and 4.98 t/ha after peas. Against the background of manure + $N_{30}P_{30}K_{30}$, the increase in grain yield after black fallow was 0.66 t/ha, and after peas - 1.07 t/ha due to high content of phosphorus and potassium in the soil. Additional root nitrogen feeding in the tillering stage provided an increase in grain yield of 28.6–36.4 % after black fallow, and 37.6–47.7 % after peas. The highest payback of nitrogen fertilisers by grain was from 15.3 to 34.5 kg of grain per 1 kg of nitrogen due to feeding crops on unfertilised background. On the background of manure + $N_{30}P_{30}K_{30}$, the payback of 1 kg of NPK by grain, depending on the predecessor, was 8.3–9.2 kg.

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Попов С. І., Гутянський Р. А., Кузьменко Н. В., Авраменко С. В. Урожайність пшениці озимої залежно від довготривалого застосування добрив у сівозміні та родючості ґрунтів.

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Інститут рослинництва імені В.Я. Юр'єва НААН, пр. Героїв Харкова, 142, м. Харків, 61060, Україна

Актуальність. Проблема ефективного використання поживних речовин органічних і мінеральних добрив залежно від насичення ними ґрунту має особливо важливе значення для агроформувань, які запроваджують інтенсивні технології. На цей час, у більшості господарств має місце значна різниця між необхідною та фактичною дозою внесення добрив, що, в свою чергу, викликає високу вірогідність недобору прогнозованих урожаїв. У зв'язку з цим, питання оптимізації раціонального використання добрив при вирощуванні пшениці озимої стають першочерговими. Оцінюючи стан вивчення даної проблеми, важливо дослідити, як гній, повне мінеральне удобрення й азотне підживлення посівів впливають на родючість ґрунту та рівень урожайності зерна залежно від місця розміщення культури в сівозміні. **Мета досліджень.** Встановити вплив тривалого застосування різних систем удобрення на родючість ґрунту та закономірності формування врожайності сучасних сортів пшениці озимої. **Методи.** Польовий, вимірювально-ваговий та статистичний. **Результати.** Встановлено, що за 30 років досліджень у варіантах основного внесення $N_{30}P_{30}K_{30}$ та $N_{60}P_{60}K_{60}$ на фоні гною вміст у ґрунті обмінного калію (16,4–17,9 мг/100 г ґрунту) та рухомого фосфору (18,9–20,2 мг) відповідав високому й дуже високому рівню, а легкогідролізованого азоту (16,3–17,6 мг) – низькому та середньому. У середньому за 2004–2021 рр., на органічному фоні та за додаткового внесення $N_{30}P_{30}K_{30}$ надбавки зерна після чорного пару становили 0,38 і 0,66 т/га, а після гороху – 0,52 і 1,07 т/га відповідно. Азотне підживлення посівів у дозах N_{20}, N_{40} та N_{60} на фоні без добрив після чорного пару забезпечило приріст урожаю зерна 12,0–16,6 %, а на фоні гною + $N_{30}P_{30}K_{30}$ – 28,6–36,4 %. Після попередника горох на зерно за фонами живлення приріст зерна склав 9,1–19,9 % і 37,6–47,7 % відповідно. Найвищу окупність азотних добрив зерном одержано за підживлення посівів на неудобреному фоні – від 15,3 до 34,5 кг зерна на 1 кг азоту. На фоні гною + $N_{30}P_{30}K_{30}$ окупність 1 кг NPK зерном залежно від попередника склала 8,3–9,2 кг. **Висновки.** Дотримання сівозміни протягом 1991–2001 рр. на фоні систематичного органо-мінерального удобрення зумовило збереження та підвищення родючості ґрунту. Після чорного пару високу врожайність пшениці озимої можливо отримати за рахунок дотримання науково обґрунтованої сівозміни, а після гороху – за використання органо-мінеральної системи удобрення.

Ключові слова: *сівозміна, родючість ґрунту, фон живлення, азотне підживлення, урожайність, ефективність, окупність*