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ORIGINAL ARTICLE

Effect of mineral nutrition on winter wheat yield after sunflower in Ukrainian steppe zone

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The results of the long-term researches on determination of the effect of mineral fertilizers on the winter wheat yield after sunflower in the steppe zone of Ukraine are presented. The high efficiency of complete mineral fertilizer ($N_{90}P_{60}K_{60}$) application in pre-sowing cultivation that provides 2.29 t/ha increase in yield in comparison with control (without fertilizers) is established. $N_{60}P_{60}K_{60}$ norm of fertilization before sowing is also relevant especially in the case of optimal weather conditions and subsequent fertilization of crops with nitrogen. At the same time, the increase of applied nitrogen share up to $N_{120-180}$ as part of complete fertilizer does not lead to a significant yields increase compared to other variants, and in some years, in particular, it can even cause the yield decrease in drought conditions during grain swelling and formation. It has been proven that winter wheat sowing without any fertilizers application or applying small amount of fertilizers before sowing ($N_{16}P_{16}K_{16}$ та $N_{30}P_{60}K_{60}$) eventually causes a significant reduction in yield compared to better variants. In most cases that cannot be compensated by nitrogen fertilization in the first part of spring-summer vegetation.

Keywords: Mineral fertilizers, nitrogen fertilization, predecessor sunflower; winter wheat, yield.

Introduction

Over the past 10-15 years, Ukraine has significantly strengthened its position on the global cereal market and today it is among the group of leading countries with the highest potential of high-quality wheat grain production and which have the opportunity to remarkably increase their export and income. The demand for the food grain in the world is constantly growing and we can't deny that the global tendency of gross grain harvests increasing should be based on the principle of production intensification. At the same time, the increase of the wheat field productivity is the only way of food grain production intensification. There is no alternative to this (Gavrilyuk, 2016).

The mass cultivation of winter wheat (*Triticum aestivum* L.) after sunflower in the steppe zone of Ukraine has started very recently, about 15 years ago, when there was a significant demand for oil products in the world due to the expanding of fuel production from this type of raw material for internal combustion engines. With the increase of sunflower sown plots to 6.4 million hectares in Ukraine (2020), there was gradual replacement of the best winter cereals predecessors by this previous crop in recent years. The use of sunflower as a predecessor was possible due to the cultivation of early-maturing hybrids with earlier harvest dates. In addition, there was a high-performance complex technique that could prepare the soil for winter sowing after sunflower in very short term. The other equally important factor is the prolongation of autumn vegetation period, which is related to temperature rising. It often allows to get bushy plants at the beginning of the winter even under condition of late sowing.

This problem is especially relevant for the steppe zone. More than 70% of state sunflower crop production areas is located there and its share in the structure of crop rotations of individual farms is close to winter wheat ones. That further encourages grain producers to sow winter crops after this oil crop, which is very profitable and can provide more than 750 kg/ha oil output per unit area (Solodushko, 2016).

It is well know n that winter wheat is very demanding of nutritional conditions. This is due to the fact that its root system is characterized by a low ability to absorb nutrients from paringly soluble compounds in the soil. The absorption of nutrients by this crop depends on many factors, primarily on weather conditions, its yield and supply of minerals, especially nitrogen. Mineral nutrition is one of the determining factors that significantly affects the intensity and direction of physiological and biochemical processes and plant productivity (Marschner, 1986; Tkachuk et al., 1991; Masclaux-Daubresse et al., 2010; Maathus & Diatloff, 2013).

The results of field researches show that the current natural fertility of soils can provide no more than 2.0-2.5 t/ha of winter wheat yield. The application of mineral fertilizers increases yield after non-fallow predecessors by 1.0-1.5 t/ha, and in pairs-by 0.5-0.8 t/ha and also it significantly improves grain quality. Each kilogram of NPK active ingredient gives an increase of wheat grain on the bogary on average 3-5 kg, and on irrigation 10-12 kg. In general, due to fertilizers, the share of additional crops can be 30-40% (Marchuk, 2009; Netis 2011).

It is known that surplus of nitrogen at the beginning of plant ontogenesis can lead to the formation of tall and thickened crops, their lodging, high and inefficient moisture consumption, deterioration of winter hardiness and damage of plants by fungal diseases and reduction of their resistance to drought. Therefore, nitrogen fertilizers should be applied in critical periods for plants, in autumn in case there is poor deposit of mineral nitrogen in the soil at the rate of 20-30% of the total need (Timoshenko, 2004; Miroshnychenko et al., 2015; Maistruk, 2016; Likhochvor, 2016).

Until recently, this statement was undeniable, because winter wheat was grown after better predecessors in most areas, the global warming was not this intense, and sunflower was not regarded as a predecessor for winter crop, at least in the steppe zone.

In general, the impact of predecessors on winter wheat yield in the steppe of Ukraine is much stronger than in the forest-steppe and forest regions. That could be explained by limited deposits of moisture in the soil and as a result its impossible to get full-fledged seedlings after non-fallow predecessors every year. That significantly reduces winter crop yields especially after sunflower. This is particularly true for intensive varieties as their stage of development in the autumn is a decisive factor that determines their winter hardiness and yield. Moreover, when there is a lack of moisture in the spring, when the soil dries out, the applied nitrogen is concentrated in upper layers of the soil and becomes inaccessible to plants, which leads to their artificial nitrogen starvation, and at high doses-to general intoxication of plant organisms (Lebid et al., 2008; Pasichnyk & Marchuk, 2013; Solodushko, 2014).

At the same time the recent researches show that in modern conditions, relatively high winter wheat yields after sunflower can be achieved with certain tactical changes in the plant nutrition system-applying about 50% of nitrogen fertilizers during the pre-sowing period, which during the extended autumn vegetation and relatively warm winter allows to get undamaged and well-developed crops in early spring (Krivenko, 2018).

Moreover, this claim relates not only to the steppe region, but also to the southern regions of the forest-steppe. The researchers have shown that in conditions of insufficient and unstable moisture, split nitrogen fertilization at the different stages of winter wheat organogenesis has no advantages over single fertilization before sowing or pre-sowing fertilization in combination with early spring ones (Gorodniy et al., 2013).

There is no basis for the assumption about nitrogen leaching in deeper layers of soil after rain therefore it becomes inaccessible to plants, also the increased doses of nitrogen in the autumn can lead to overgrowth of winter wheat and decrease its winter hardiness. In the first case, it can be explained by the fact that the granulometric texture of black soil in the steppe zone is mainly average or coarse (Balyuk & Medvedev, 2016), the nitrate nitrogen leaching during autumn period is insignificant in case of light precipitation as it is known that 3 mm of precipitation can leach the nitrates on average 1 cm deep in this type of soil. If during the autumn vegetation there is about 110 mm of precipitation, nitrates are able to move to maximum 40 cm deeper than the place of their initial localization in the pre-sowing period.

As for winter hardiness of winter wheat which is grown after non-fallow predecessors, in particular after sunflower, it should be noted at for the last 15 years no case of physiological overgrowth of plants as a result of the high doses of nitrogen fertilizers was observed. Also, there were no critical low temperatures of the soil at the depth of tillering nodes of the plants (Table 1).

It is also significant that the level of mineral nutrition of plants plays a crucial role in increasing their resistance to stress factors, in particular, to drought (Marschner, 1995). In case of low and unbalanced nutrient concentrations in the soil, plants need to absorb more water to be able to get the same amount of minerals for their metabolism as they would get from the soil with optimal nutrient supply. On the other hand, plants are not able to receive optimal amounts of nutrients in conditions of insufficient moisture supply. That negatively affects the general condition of plants, especially their productivity and quality. Nitrogen is an important component of many structural, genetic and metabolic compounds of plants. About 80% of the total amount of nutrients absorbed by plant roots is nitrogen (Tisdale & Nelson, 1975; Hassan et al., 2005). The use and absorption of nitrogen by plants under water stress is very important for their normal growth and development, and therefore one of the means to minimize the harmful effects of drought is to increase the efficiency of soil moisture by improving plant nutrition with mineral fertilizers (Waraich et al., 2011).

It is also known that winter wheat absorbs large amounts of nitrogen at the early stages of development and retains it for use at later stages. In autumn, under favorable growing conditions, winter wheat consumes from 20-25% to 30% of nitrogen from all the amount of nitrogen consumed during the vegetation period (Morgun et al., 2009). Therefore, it is important to ensure sufficient nitrogen nutrition for plants in autumn to improve their growth and tillering. The crops must be provided with phosphorus and potassium, because the lack of these nutrients lead to slow tillering, weak root system and worse overwinter capability of the plants.

Table 1. Minimum soil temperature at the depth of winter wheat tillering node, ºC (according to the Dnipropetrovsk Regional Center of Hydrometeorology).

Vegetation Year	Month, Decade								
	December			January			February		
	1	2	3	1	2	3	1	2	3
2005/06	0.1	-2.0	-1.5	-8.0	-9.9	-13.5	-9.9	-7.3	-1.3
2006/07	0.1	-0.6	-2.0	-0.4	0,0	-2.6	-2.8	-1.5	-7.2
2007/08	0.2	-0.1	-0.7	-9.7	-9.9	-3.5	-3.2	-7.6	-5.0
2008/09	0.1	-5.0	-4.8	-5.5	-5.0	-1.4	-1.2	-0.9	-3.4
2009/10	-0.1	-4.7	-5.6	-9.3	-6.5	-9.8	-7.4	-3.0	0.1
2010/11	-4.6	-3.5	-4.6	-4.6	-4.0	-4.5	-2.2	-8.2	-8.1
2011/12	-0.4	-0.5	-0.9	-0.1	-1.7	-8.0	-10.7	-10.6	-4.3
2012/13	0.0	-10.0	-6.5	-4.5	-1.5	0.0	-0.1	-1.5	-4.5
2013/14	-1.1	-3.1	-1.4	-0.8	-3.0	-10.4	-6.7	-0.6	-0.5
2014/15	-3.8	-0.2	-1.6	-8.0	-0.6	-0.5	-2.5	-7.5	-0.3
2015/16	-1.0	-5.0	-3.8	-9.0	-0.8	-5.7	-2.0	-1.1	-0.1
2016/17	-4.5	-6.2	-3.7	-3.6	-4.7	-4.4	-4.4	-2.4	-0.8
2017/18	-0.3	-0.4	-1.0	-1.5	-5.7	-3.9	-2.0	-1.7	-5.7

2018/19	-3.6	-3.4	-2.6	-1.2	-1.2	-1.5	-0.7	-1.2	-4.1
2019/20	1.9	0.7	-0.2	-1.3	-1.0	-2.7	-5.7	-3.1	0.5

In this regard, there is a suggestion to improve the nitrogen nutrition system of winter wheat plants under the conditions of climate aridity increasing by applying nitrogen fertilizers, mainly in ammonium form, before sowing or in the autumn. That will increase efficiency and reduce non-target losses of an important nutrient (Mikhalska & Schwartau, 2018).

Given the lack of sufficient information on the technology of winter wheat growing after sunflower in the steppe zone and the existence of contradictory data on the impact of mineral fertilizers (including nitrogen) on its productive potential, the studies of certain elements of the plant nutrition system aiming at increasing the yield of this crop after such difficult predecessor are very important and relevant now.

Materials and Methods

The field trials were carried out on the site of the Synelnykivka selecting and research station of the State Institution Institute of Grain Crops of National Academy of Agrarian Sciences of Ukraine during 2006-2020 in the crop rotation of the laboratory of winter cereals agrobiological resources. The soil of the trial area is simple black soil. The average humus level in the plowing layer of the soil is 3.9%, the salt extract pH is 6.6. The content of mobile forms of phosphorus and potassium (according to Chirikov) is 23.0 mg and 13.8 mg per 100 g of absolute dry soil. The elementary accounting site plot is 50 m^2, 3 times replication.

The experiment studied winter wheat varieties with different levels of intensity: in 2006-2008-Selyanka variety (universal), in 2013-2015-Zira variety (semi-intensive), in 2018-2020-Kokhanka variety (semi-intensive). The following types of fertilizers were used: compound NPK fertilizer ($N_{16}P_{16}K_{16}$), ammonium nitrate ($N_{34.4}$), urea ($N_{46.2}$). The crop cultivation technology is standard for the northern part of the Steppe of Ukraine. The planting of winter wheat was carried out with a direct-connected planter CH-16 according to the trial scheme, without any time gap after pre-sowing cultivation. The sowing method-continuous row, depth of seed placement is 5-6 cm. The sowing period is optimal (September 15-25). The sowing rate is 5.5 million seeds/ha. The used equipment is Sampo-130 combine harvester.

Results and Discussion

The analysis of weather conditions during the research showed that they were quite diverse both in terms of temperature and rainfall and had a significant impact on the winter wheat productivity formation. That allowed us to obtain reliable information on the plants response to the action of abiotic factors and technological measures, in particular, the action of mineral fertilizers used in the process of winter wheat growing. The highest yields for the entire period of the experiment were in 2008, 2010, 2014-2020. The least favorable weather conditions were in 2007 and 2012, which were characterized by long rainless pre-sowing and autumn periods, difficult wintering, dry first half of spring-summer vegetation. The combination of all these weather factors negatively impacted winter wheat yield.

The results of the research have shown that plant nutrition system is extremely important in the technology of winter wheat growing after sunflower. The correct nutrition system is characterized by the appropriate norms application and timing of mineral fertilizers, taking into account nutrient reserves before sowing, biological characteristics of modern varieties, weather conditions during the growing season and a number of other factors.

In the course of the field trials it was determined that the main attention should be paid to creating an optimal nutrition for winter wheat during vegetation period. The per-sowing application of mineral fertilizers is preferable account taking into account the low nutrient deposits after sunflower and the fact that during the winter in conditions of higher temperature (that is common for steppe zone) the plants have the possibility to vegetate, spending the basic nutrients. The rapid rise of temperature in early spring and, as a result, the intense melting of snow and thawing of the soil do not allow grain producers to carry out the crops fertilization crops at this time. As a result, the plants cannot receive nitrogen in a timely manner, there was a backlog in growth and development, reduced productivity.

The agrochemical soil analysis, which was conducted during years of research before winter wheat sowing after sunflower and other predecessor such as black steam and peas showed that the lowest nitrogen deposits were observed on the site where sunflower was a predecessor-15 kg/ha in average, while the deposits on the site where black steam was a predecessor were 25 kg/ha (Table 2). Therefore, growing winter wheat after this predecessor it was necessary to apply more 45 and 75 kg/ha of active substance of nitrogen accordingly to provide background, for example, $N_{60}P_{60}K_{60}$ and $N_{90}P_{60}K_{60}$, which were also studied during experiments. Of course, this amount was not constant over the years of research and it is average, because the nitrogen content in the soil varied in a fairly wide range each year and depended on many factors, which must be taken into account when calculating the rate of complete mineral fertilizer in pre-sowing cultivation.

Table 2. The average nitrogen content of nitrates in the soil before sowing winter wheat after various predecessors, 2007-2019.

Predecessor	Nitrogen Amount, mg/kg, Absolutely Dry Soil	Nitrogen Deposits per 1 ha, kg	Nitrogen Amount That Will Be Used By Plants, kg/ha	Nitrogen to be Applied (kg/ha) for Background Providing*	
				$N_{60}P_{60}K_{60}$	$N_{90}P_{60}K_{60}$
Black fallow	41	123	25	35	65
Pea	35	105	21	39	69
Sunflower	24.6	73.8	15	45	75

*-without taking into account the share of plants nutrient use in the year of application (60%)

It is known that the largest increases in grain yield of winter wheat provides the use of mineral fertilizers for sowing, taking into account the sensitivity of the crop to their individual species and combinations in connection with the soil and climatic conditions, predecessors, variety properties and other agronomic factors (Pikush & Bondarenko, 1985).

Pre-sowing application of mineral fertilizers, designed for the initial period of plants nutrition, has great importance for their further plants' life. Under the favorable nutrient conditions, young plants form a stronger root system, develop faster and more easily tolerate the adverse effects of winter, possible drought in the spring, less damaged by pests and diseases, better inhibit the development of weeds.

Determining the effectiveness of different of mineral fertilizers for winter wheat growing after sunflower, it was found that during 2006-2010, each and every variant of the experiment, where fertilizers were used before sowing, provided a stable positive effect of yield growth. When sowing the Selyanka variety, the highest yield (3.88 t/ha) was obtained by applying complete mineral fertilizer $N_{120}P_{60}K_{60}$ in pre-sowing cultivation. The difference in yield between the best variant and the control, where fertilizers were not applied, was 2.37 t/ha (Table 3).

A similar effect of the pre-sowing fertilizers application was observed in other variants, where the proportion of nitrogen, as a rule, was dominant in compared to other nutrients. Although, given that the difference of winter wheat yield between variants $N_{90}P_{60}K_{60}$ and $N_{120}P_{60}K_{60}$, $N_{150}P_{60}K_{60}$ and $N_{180}P_{60}K_{60}$ was not significant, it can be considered that the most effective rate of complete mineral fertilizer is $N_{90}P_{60}K_{60}$ which provided an increase in yields by 2.29 t/ha compared to the control. A further increase of nitrogen in the fertilizer led to a slight increase of grain harvest (by 0.05-0.08 t/ha), which was not provided by the cost of applied nutrients.

Table 3. The yield of winter wheat Selyanka depending on the different norms of mineral fertilizers application during the pre-sow cultivation, 2006-2010. The predecessor is sunflower.

Variant of study	**Crop yield, t/ha**	**Increase, t/ha (+-)**	
		To Control	**To Background $N_{90}P_{60}K_{60}$**
Control (without fertilizers)	1.51	-	-2.29
$N_{30}P_{60}K_{60}$ in pre-sowing cultivation	2.16	+0.65	-1.64
$N_{60}P_{60}K_{60}$ in pre-sowing cultivation	3.45	+1.94	-0.35
$N_{90}P_{60}K_{60}$ in pre-sowing cultivation	3.80	+2.29	-
$N_{120}P_{60}K_{60}$ in pre-sowing cultivation	3.88	+2.37	+0.08
$N_{150}P_{60}K_{60}$ in pre-sowing cultivation	3.85	+2.34	+0.05
$N_{180}P_{60}K_{60}$ in pre-sowing cultivation	3.87	+2.36	+0.07
LSD_{05}, t/ha, 0,17-0,21			

Talking about the optimization of the use of mineral fertilizers on the winter wheat crops after sunflower in subsequent years under conditions of $N_{90}P_{60}K_{60}$ nitrogen fertilizers during the growing season we have studied the use of nitrogen fertilizers application was studied during the vegetation period of plants. According to the results of the research conducted in 2013-2015, the effectiveness of mineral fertilizers was largely determined by the time and norms of their application. At the same time, the yield of winter wheat varied significantly from year to year, which can be is explained not only by differences in plant nutrition, but also by different weather conditions during the vegetation period.

As in previous years, the conducted researches have shown extremely high efficiency of nitrogen, especially when applying it in autumn. Moreover, the application of nitrogen fertilizer N_{90} in pre-sowing cultivation had no negative impact on crops and didn't affect the results of winter wheat overwintering after sunflower even in 2012, when the autumn vegetation was favorable. This amount of nitrogen in combination with sufficient amount of phosphorus and potassium ($N_{90}P_{60}K_{60}$) during pre-sowing application provided the most favorable conditions for plant growth and development, which led to a significant increase in yield even without additional fertilization in spring and summer. Thus, compared to the control variant, where no pre-sowing nutrients were applied, only such nutrition allowed to obtain 2.04 t/ha increase of the grain yield (+72%) (Table 4).

Table 4. Yield of winter wheat Zira after sunflower depending on norms and terms of mineral fertilizers application, 2013-2015.

Terms And Norms Of Mineral Fertilizers Application	**Yield, t/ha**	**Increase To Control, ±**		**Increase To Background $N_{90}P_{60}K_{60}$, ±**	
		т/га	**%**	**т/га**	**%**
Control (without fertilizers)	2.85	-	-	-	-
Background $N_{90}P_{60}K_{60}$ (in pre-sowing cultivation)	4.89	2.04	41.7	-	-
Background+N_{30} in the autumn tillering phase of plants	5.18	2.33	45.0	0.29	12.5
Background+N_{30} in early spring on frozen-thawed soil	5.35	2.50	46.7	0.46	18.4
Background+N_{30} in the stem extension phase of plants	5.28	2.43	46.0	0.39	16.1
Background+N_{60} in the stem extension phase of plants	5.04	2.19	43.4	0.15	6.9
Background+N_{30} in early spring on frozen-thawed soil+N_{30} in the stem extension phase of plants	5.12	2.27	44.3	0.23	10.1
Background+N_{60} in early spring on frozen-thawed soil+N_{30}	4.81	1.96	40.7	-0.08	-4.1

in the stem extension phase of plants					
Background+N_{60} in early spring on frozen-thawed soil+N_{60} in the stem extension phase of plants	4.73	1.88	39.7	-0.16	-8.5
Background+N_{30} in the autumn tillering phase of plants+N_{30} in early spring on frozen-thawed soil+N_{30} in the stem extension phase of plants	4.88	2.03	41.6	-0.01	-0.5
LSD $_{05}$, t/ha, 0.13-0.17					

The greater grain yield (by 0.29-0.46 t/ha) was gained due to the combination of exiting background and additional nitrogen N_{30} winter wheat fertilization in the phase of autumn plants tillering, early spring frozen-thawed soil and in the phase of plants stem extension. That allowed to gain 5.18; 5.35; 5.28 t/ha of grain yield accordingly. The application of high doses of nitrogen as split fertilizing (90-120 kg/ha) during the winter wheat vegetation period didn't give the expected effect and led to yield decrease compared to the best variants by 0.45-0.62 t/ha. This usually occurred as a result of dry weather in the second half of the spring-summer vegetation and a critical decrease in productive moisture in the soil, the plants, creating a strong aboveground mass, formed small and slender grain in the absence of rain at this time. Such a phenomenon was observed in 2015. The researches have shown that winter wheat grown after sunflower is extremely sensitive to the nutrient level of the soil, especially in the first half of its vegetation period. Good development of the aboveground part and root system of plants with optimal and sufficient consumption of nutrients allow them to successfully withstand adverse conditions of winter and spring-summer periods and provide a fairly high yield.

It should be noted that the approach of using mineral fertilizers in some farms is limited to the application of 100 kg of compound NPK fertilizer (N:P:K=16:16:16), or a single N_{30} nitrogen fertilization in the spring, is erroneous and doesn't allow to receive grain yield more than 3,0 t/ha even under favorable weather conditions. This thesis is confirmed by the results of studies conducted during 2018-2020, when winter wheat was sown after sunflower with different soil preparations: without fertilizers (control), $N_{16}P_{16}K_{16}$ and $N_{60}P_{60}K_{60}$ with subsequent nitrogen crops fertilization in different doses during the spring-summer vegetation. By the way, the nitrogen amount in complete mineral fertilizer of the last background was N_{60}, but not N_{90} as it was in the previous experiment. That also did not prevent good results, which confirmed not only the high efficiency of pre-sowing application of mineral fertilizers in sufficient quantities, but also once again emphasized the significant role of nitrogen fertilizers in winter wheat yield forming after such a complex predecessor as sunflower.

The main fertilizer in the form of compound NPK fertilizer (16:16:16) and partially nitrogen fertilizer in the form of urea were applied during the pre-sowing cultivation. In the period of early spring vegetation ammonium nitrate was applied for fertilization on frozen-thawed soil and in the phase of plants stem extension. This modeling of production conditions made it possible to obtain clearly defined results of studies showing that compared to the control (1.87 t/ha) the higher yields (4.53 t/ha), as expected, were obtained by applying $N_{60}P_{60}K_{60}$ complete mineral fertilizer in pre-sowing cultivation (Table 5).

Table 5. The yield of winter wheat Kokhanka after the sunflower depending on the level of mineral nutrition, t/ha (2018-2020).

Mineral Background	**Control**	**N_{30} In Early Spring On Frozen-Thawed Soil**	**N_{30} In Early Spring On Frozen-Thawed Soil+N_{30} In The Stem Extension Phase**
Without fertilizers (control)	1.87	3.37	4.28
$N_{16}P_{16}K_{16}$	2.76	4.07	4.75
$N_{60}P_{60}K_{60}$	4.53	5.04	5.23
LSD_{05}, т/га, 0.06-0.11			

The yield difference between the variants was 2.66 t/ha (+142.2%). The pre-sowing N16P16K16 application also contributed to the yield increase, but the amount of its increase before the control was much smaller-0.89 t/ha, or 47.6%.

It is also interesting that the winter wheat crops nitrogen fertilization at the amount of 30 kg/ha applied on nonfertilized ground during the spring vegetation contributed to the growth of yield by 1.5-2.41 t/ha. Although it didn't exceed the one-time N60P60K60 complete mineral fertilizer in pre-sowing cultivation in its efficiency.

Moreover, with such degree of ground fertilization the additional single application of nitrogen fertilizers (N30) in early spring on the frozen-thawed soil, split fertilization on frozen-thawed soil or fertilization n the phase of plants stem extension allowed to get 5.04 and 5.23 t/ha of the grain harvest accordingly. That exceeded the control variant by 0.51 and 0.70 t/ha.

However, it should be added that the most positive effect of nitrogen fertilization was on the plots where no pre-sowing fertilizers were applied, or minimum amount were applied.

Conclusion

Thus, the system of plants mineral nutrition plays the critical role in the complex of technological measures for winter wheat growing after sunflower. It is the sufficient amount of nutrients in the soil at the time of sowing that allows to optimize the processes of growth and development of plants during the vegetation period, strengthens their adaptive capabilities and ensures the high yield formation.

The studies of the mineral fertilizers impact, in particular pre-sowing application of different rates and subsequent nitrogen fertilization for growing winter wheat after sunflower showed their high efficiency and proved that given the economic feasibility the highest yields were formed on the plots with the correct $N_{90}P_{60}K_{60}$ degree of ground fertilization. It was found that reducing the amount of nitrogen in the fertilizer to 60 kg/ha leads to a slight yield decrease compared to the best variant but can also provide good yields under optimal weather conditions and subsequent fertilization of crops with nitrogen yields. That was showed by the results of the studies during 2018-2020. The winter wheat sowing with no or small amount of fertilizers applied in pre-sowing cultivation ($N_{16}P_{16}K_{16}$ and $N_{30}P_{60}K_{60}$), ultimately causes a significant decrease in yield, which in most cases cannot be compensated by fertilizing of plants in the first half of spring-summer vegetation period. The increase of the applied proportion of nitrogen to $N_{120-180}$ in complete fertilizer does not provide a significant yield increase compared to other variants. And in some years it even causes yield decrease, in particular, under arid conditions during grain filling and formation.

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