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EFFICIENCY OF WINTER WHEAT CULTIVATION AFTER SPRING BARLEY IN THE NORTHERN STEPPE OF UKRAINE

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Abstract

The influence of environmental conditions and mineral fertilizers on the efficiency of growing winter wheat after spring barley was revealed. It was found that nitrogen feedings after stubble previous crop in the spring-summer period of growing season does not lead to an increase in plant productivity in dry years. In favorable years in terms of moisture supply yields and economic indicators of cultivation increased. Thus, on average for 2016-2018, the highest yield and net income from the growing winter wheat after spring barley were obtained in the experimental variants, where feeding with ammonium nitrate N_{60} on the background of $N_{60}P_{60}K_{30}$ was carried out on freeze-thawed soil or in two terms: N_{60} on freeze-thawed soil and N_{30} locally at the end of the tillering stage of plants. According to the fertilization variant, the yield and net income varied within 4.78-5.47 t/ha and 16,041-19,949 UAH/ha, as well as 5.03-5.62 t/ha and 16,752-21,347 UAH/ha.

Key words: *winter wheat, variety, previous crop - spring barley, nitrogen feedings, yield, economic efficiency.*

INTRODUCTION

Under contemporary social and economic conditions, one of the significant tasks for the Ukrainian agricultural sector is the increase and stabilization in grain yield, mainly for the principal food crop - winter wheat *(Triticum aestivum* L.). Its harvest is influenced by the number of factors. Among the uncontrollable factors one can name as follows: solar radiation, air temperature, rainfall, the autumn vegetation period duration, the time of spring vegetation resumption, etc. (Zhemela & Musatov, 1989).
The last years in the Ukrainian Northern Steppe zone saw mostly unfavourable conditions for winter wheat in pre-sowing and after-sowing periods of vegetations. High air temperatures and insufficient rainfall at these periods resulted in air and soil droughts, which prevented winter wheat seedlings from appearing timely and delayed the development of these plants. The conditions were more severe for those winter wheat which had been sown after such non-fallow previous crops as stubble crops and oil cultures since they reduce the opportunities for moisture accumulation and preservation within the soil before sowing. This moisture is necessary for obtaining even stands of seedlings and further sufficient development of plants (Cherenkov et al., 2015).
According to the researchers, good seedlings of winter wheat require that the productive moisture reserves in the soil layer of 0-20 cm deep is to be at least 20 mm (Lichikaki, 1958), while that of 0-10 cm is to possess at least 10 mm (Kulyk, 2008). At the lower values of soil productive moisture, the decreases both in the sustainability of seedlings and in their even stands at the beginning of the plant development are observed. It is determined that depending on hydro and thermal conditions, the period between sowing and seedlings to appear varies from 6 days to 90 days in different years, according to the researches (Klimov & Povzik, 1980). Moreover, it is defined that the moisture shortage is not cured by wider range of the mineral fertilizers, plant growth stimulators and pesticides (Zubets et al., 2010).
The better developed plants in autumn, the more resistant they are to droughts and they grow higher yield. Late seedlings, poorly developed seedlings, seedlings without tillering since

autumn are usually of low productiveness. Under conditions of the Southern Steppe, the years of dry autumns have registered the 8.2-18.0% decrease in winter wheat yield as compared against the years with favorable autumns. Further, at early spring, the wheat plants have longer tillering, develop crown roots and ensure sufficient grain yield even if sowing has been late. The late spring produces an adverse effect on the poorly developed seedlings: their even stands gradually become less frequent and form low grain yield (Netis & Onufran, 2016).

Along with the mentioned, the researchers consider that the scientifically grounded approaches towards the choice of the wheat variety, the soil cultivation, the previous crop, the sowing time, the fertilizing system and the protection against pests and diseases are capable of increasing the wheat productivity significantly and respectively wheat growing even under disadvantageous conditions (Cherenkov et al., 2015; Mykhalska & Shvartau, 2018; Solodushko, 2021).

Furthermore, one of the most important techniques of obtaining excellent yields of winter wheat grains along with their high-quality is proved to be the right choice of the previous crop for the certain crop. The long-term research carried out at Institute of Grain Crops of National Academy of Agrarian Sciences of Ukraine has pointed out black fallow, full fallow, leguminous crops, perennial grasses as the best previous crops (Hodulian & Bardunova, 1967; Pikush et al., 1992). However, the last years sharply decreased the share of these previous crops in the Ukrainian Steppe zone and increased the sowing areas for winter wheat after stubble crops, sunflowers, sorghum for grain, which drastically deplete soil taking away its moisture, nutrients and other components (Zubets et al., 2010; Cherenkov et al., 2018). This means that the conditions for winter wheat seed germination, their development in the autumn period and vegetation period deteriorate, the frost-resistance and the winter hardiness in wheat reduce, which results in less dense seedling stands and lower grain yield.

The yield and the quality of winter wheat grains considerably depend on the availability of the mineral elements for the plants during the whole period of their vegetation. When applying the fertilizers for winter wheat plants one also should take into account the previous crop, soil and climate conditions, and the specific character of the interrelation effect of the weather conditions in a certain case (Maadi et al., 2012; Netis, 2011). Fertilizers are one of the most expensive components for winter wheat growing that is why the determination of their rational norms to be applied is the urgent task of the contemporary science.

The aim of the current research is to define the impact of the weather and the mineral nutrition on the yield and the economic efficiency for winter wheat growing after spring barley under conditions of the Ukrainian Northern Steppe.

MATERIALS AND METHODS

The reported research is the long-term studies on winter wheat sown after spring barley as a previous crop on common black soil, low in humus, full cross-section. The research has been carried out at State Establishment Institute of Grain Crops NAAS of Ukraine. The sowing time was optimal for Northern Steppe zone - 20 September, the rate of seeding was 5,000,000 viable seeds/ha, the depth of seed wrapping was 5-6 cm. The norm for fertilizers applied was $N_{60}P_{60}K_{30}$. During the years of the research, on the background of pre-sowing fertilizer, spring-summer nitrogen feedings were introduced by the fertilizers as follows: ammonium nitrate, urea ammonium nitrate mixture (UAN-32), carbamide. Ammonium nitrate was put randomly on the soil surface and locally by means of the seeders; carbamide and UAN-32 were introduced by spraying of vegetative plants with backpack sprayers.

The field experiments and wheat grain quality determination were performed in accordance with the applicable standards and approved methods (DSTU 3768-2019; Volkodav, 2001). Wheat plant development and growth were monitored directly by phenological observations. The yield was determined via continuous threshing with “Sampo-500” combine on each plot and weighing with the subsequent calculation per 1 ha (Dospekhov, 1985).

The economic efficiency on the variations in nitrogen supplements for winter wheat growing was defined by utilizing the average price information on resources and grain in the years of the research. The principal criteria of economic efficiency were determined with yield indicators and we also took into account the grain quality after each agricultural technique application. The calculation and monitoring were performed based on the typical flow charts of wheat growing and conventional techniques (Cherenkov et al., 2017; Hyrka et al., 2019).

RESULTS AND DISCUSSIONS

In Steppe zone, the best productivity and frost resistance have been shown by those winter wheat plants, which managed to acquire 3-5 shoots before completing autumn vegetation. For obtaining such a number of shoots, the autumn period of the plant growing and development should be within the range of 55-65 days, while the sum of the effective temperatures (> 5°C) - 250-300°C. The duration of the indicated period is rather long for the wheat plants to accumulate the sufficient amount of plastic substances and as the result the plants become more capable of resisting the unfavorable conditions of winter period as well as those in spring and summer periods (Cherenkov et al., 2021).

Moreover, apart from the mentioned, the necessary constituent of winter wheat growing is availability of the productive rainfall during the period of plant vegetation in autumn. During the many years, the average amounts of the rainfall in the zone of our research for the period from sowing to vegetation completion in autumn (sowing date of 20 September and the average autumn vegetation is 60 days) have been approximately 80 mm.

The analysis on the last 13 years of the research has shown the significant differences in weather conditions between them in terms of the duration of autumn vegetation, the sum of the accumulated effective temperatures for the period and moisturizing conditions. The term of the autumn vegetation final completion was varying from 6th November (early completion of vegetation in 2011 and 2018) to 1st December and 4th December (respectively, late term of vegetation completion in 2010 and 2012). Further, the sum of the effective temperatures not always was dependent on the duration of autumn vegetation period. Thus, in 2018, the sum of the effective temperatures was 316.4°C with autumn vegetation period of 47 days, while, for instance, in 2010, the dedicated period was 25 days longer, but the sum of the effective temperatures was 295.9°C. The highest values of this parameter were in 2020 - 420.8°C, in 2012 - 389.6°C and in 2019 - 325.1°C. The lowest value was in 2016 and totaled - 181.7°C (Table 1).

Table 1. Hydro and thermal conditions of winter wheat autumn vegetation in 2010-2022

Year	The date of the final termination of autumn vegetation	Term of the duration of autumn vegetation, days	The sum of the effective temperatures during the period «sowing-termination of autumn vegetation», °C	The rainfall amount during the period «sowing-termination of autumn vegetation», mm
2010	1st December	72	295.9	132.1
2011	6th November	47	240.1	16.2
2012	4th December	75	389.6	104.4
2013	26th November	67	204.0	118.0
2014	16th November	57	215.1	88.5
2015	24th November	65	294.1	41.7
2016	11th November	52	181.7	140.7
2017	15th November	56	265.0	78.9
2018	6th November	47	316.4	44.9
2019	16th November	57	325.1	96.7
2020	11th November	52	420.8	70.1
2021	10th November	51	200.2	24.3
2022	26th November	67	297.2	138.9

As it has mentioned before, even at the sufficiently encouraging temperature regime, the moisture shortage within the soil during autumn vegetation is capable of producing the adverse effect on the conditions of winter wheat seed germination, its seedling growth and development.

During the years of the observation, the least rainfall during autumn vegetation were in 2011 and totaled only 16.2 mm. Not high was this value in the following years: in 2021 - 24.3 mm, in 2015 - 41.7 mm and in 2018 - 44.9 mm.

In case of poorly developed plants, the crucial in significance for their further development and growth are the conditions of winter period and spring-autumn period. Under advantageous weather conditions, the state of the plants could notably improve and allow good grain yield. The most severe was the winter time for 2011/2012 growing season. The winter wheat sown after spring barley was in the stage of the third leaf and the beginning of tillering at completing its autumn vegetation. The crops were not dense in their stand and were uneven but their state was estimated as sufficient.

In December and at the beginning of January, it was predominantly warm, frequent fogs and rainfall, that hampered plant hardening, caused the losses in the nutrient substances and the decrease in their winter hardiness. The 15 last days of February were very cold and dry. The average daily air temperature on the coldest days was within -11 ... -24°C, that is 6-19°C lower than the normal meteorological one. At the coldest nights, the air temperature went down to -25 … -30°C.

The steady recovery of winter wheat vegetation in 2012 was registered on 3 April, somewhat later than the conventional terms. The supplies of the productive moisture were enough for the non-fallow previous crops. However, in the period from 24 April to the end of June, the season progressed with abnormally hot weather and the lack of rainfall. This speeded up the winter wheat plant development stages. The plants exhibited early yellow leaves on the bottom, poor formation of reproductive organs and worsening crop state due to the drought. The high temperatures caused early ripening of winter wheat and subsequent reduction in the yield was registered, especially after non-fallow previous crops, and in our study it was detected after spring barley. Thus, the complex of the disadvantageous hydro and thermal factors during 2011/2012 growing season impacted the considerable loss in winter wheat grain after all the previous crops.

The following growing seasons (2012/2013 and 2013/2014) were generally good for winter wheat and this influenced the yields. Thus, the average yield per the wheat variety after spring barley as the previous crop on the background of soil conditioning with complete $N_{60}P_{60}K_{30}$ fertilizing but without nitrogen feedings was 2.37 t/ha in 2012, while in 2013 - 4.17 t/ha, in 2014 - 4.73 t/ha (Table 2).

Nitrogen feedings for the plants at their spring-summer vegetation were attributed to the losses in certain cases and rather low economic efficiency with the wheat varieties as compared to the control groups. However, during the next years to come, winter wheat growing with nitrogen feedings allowed higher grain yields and the net incomes.

Table 2. The economic efficiency of winter wheat growing depended on the previous crop and nitrogen feedings under various weather conditions of the seasons under study

Previous crop	2011/2012		2012/2013		2013/2014	
	No feeding - control	Nitrogen feedings	No feeding - control	Nitrogen feedings	No feeding - control	Nitrogen feedings
Spring barley (background $N_{60}P_{60}K_{30}$)	Yield, t/ha					
	2.37	2.24-2.39	4.17	4.38-4.70	4.73	4.98-5.28
	Net income, UAH/ha					
	1,681	-256-620	4,305	5,003-6,331	6,767	6,771-7,982
	Profitability, %					
	28.8	-3.5-9.5	67.6	63.5-80.0	104.5	84.8-99.6
Black fallow (background $P_{60}K_{30}$)	Yield, t/ha					
	3.87	3.95-4.27	6.69	6.73-7.40	6.77	6.90-7.23
	Net income, UAH/ha					
	5,306	5,361-5,920	7,193	7,758-8,704	7,195	7,762-8,701
	Profitability, %					
	82.6	68.5-83.3	160.4	150.1-172.8	163.5	150.8-169.4

Growing winter wheat after black fallow (on $P_{60}K_{30}$ background) permitted the plants to develop greater vegetative masses and better root systems, even in unfavorable 2012, the yield in the control group was 3.87 t/ha. This result was 1.5 t/ha higher than that obtained under the same condition but after spring barley, though the mineral background was more intensive after the non-fallow previous crop. It worth mentioning that the increases in the yield and economic efficiency were registered even in this disadvantageous year in the trials with nitrogen feedings into black fallow. The yield grew up to 3.95-4.27 t/ha, gross operating profits went up from 5,306 UAH/ha to 5,361-5,920 UAH/ha. The next years were good with their weather conditions (2013 and 2014), the yields after black fallow in the control group were respectively 6.69 t/ha and 6.77 t/ha. The nitrogen feedings during spring-summer vegetation permitted the increase up to 6.73-7.40 t/ha and 6.90-7.23 t/ha, respectively. In these years, considerably higher were the gross operating profit values and profitability values both in the control group and in the variations with nitrogen feedings as compared against 2012-year data.

Moreover, it should be mentioned that in 2013 and 2014 there were obtained the highest net income values from growing winter wheat after spring barley. This result was achieved with $N_{60}P_{60}K_{30}$ as a background and the plants were given the supplement of nitrogen fertilizers (ammonium nitrate) in two steps: N_{30} to the thawing frozen ground and N_{30} locally at the completion of tillering phase. After black fallow (on the background of $P_{60}K_{30}$), the values of this indicator were the highest in such fertilizering variations: $N_{30\text{-}60}$ (ammonium nitrate) or N_{30} of UAN-32 at the end of plant tillering. The lowest results were attributed to those fertilizering variations where carbamide supplement was employed to the plants at their stage of heading and this did not allow the sharp increase in the yeild.

Quite unfavorable were also the weather conditions in autumn 2015. In spite of a rather lengthy period of autumn vegetation (65 days) and the sufficient sum of effective temperatures (294.1°C), the rainfall amount in this season was only 41.7 mm that is not enough for growing timely winter wheat seedlings after non-fallow previous crops, and, in particular after spring barley. During the winter period, the winter wheat seeds sown after stubble previous crop were at the stage of swelling and subsequent germination, while the sustainable seedlings appeared only in February at thawing periods. However, the specific character of 2015/2016 growing season was very good hydro and thermal conditions right after quite early spring vegetation recovery (1 March): they permitted the winter wheat plants to root well, to develop the sufficient leaf surfaces and above-ground vegetative masses and to produce rather good grain yield even after conventionally disadvantageous non-fallow previous crops.

The weather conditions of the following 2016/2017 and 2017/2018 growing seasons showed their specific character but in general were encouraging for the winter wheat grain yield, including the cases of sowing after spring barley. 2016 autumn period was rather cold but wet, while that in 2017 was on the contrary warm with the insufficient rainfall.

Should be noted that it was cold and frosty at nights but very wet in April in 2016/2017 growing season. In May, the weather was changeable with late frost. In spite of the mentioned, the state of the wheat improved at the end of May. In 2017/2018 growing season, the plants recovered their vegetation on 31 March, at the timing close to the climatic norm. March in 2018 was abnormally wet, the amount of the snow and rain precipitations totaled 145 mm, that was 4 times higher than the average values observed during the many years. In April, May and June, high air temperatures predominated, but the shortage of rainfall was also registered. In general, the moisturizing conditions in 2016-2018 were favorable during the spring vegetation of winter wheat, but they were unstable per months and wheat development stages.

The notable shortage of rainfall and insufficient sum value of the effective temperatures were also the characteristics of 2021/2022 autumn vegetation. This especially had the impact on winter wheat sown after non-fallow previous crops. However, moisture availability in April was considerably higher than the meteorological norms of the region and this contributed to the improvement in poorly developed wheat seedlings and enhanced their potential to sufficient productivity.

The research results point to the fact that 2016-2018 yields of winter wheat sown after spring barley depended on the winter wheat varieties and the fertilizing variation applied. The highest yield was observed with Pylypivka variety, strong in its grain quality, then followed the yield value obtained with Kokhanka variety. The variety of Misia Odeska in the above-mentioned years was inferior in the yield to others in all fertilizing variants of the research (Table 3).

Table 3. The economic efficiency of nitrogen feedings for winter wheat growing after spring barley, 2016-2018

Nitrogen feedings	Yield, t/ha	Grain class (DSTU 3768-2019)	Net income, UAH/ha	Profitability, %
Pylypivka				
No feeding - control (background $N_{60}P_{60}K_{30}$)	4.46	4	14,269	126.4
N_{30} in early spring on freeze-thawed soil	5.08	3	18,337	151.0
N_{60} in early spring on freeze-thawed soil	5.47	3	19,949	155.0
N_{30} at the end of plant tillering	4.97	3	17,613	144.3
N_{30} in early spring on freeze-thawed soil + N_{30} at the end of plant tillering	5.32	3	18,993	146.9
N_{60} at the end of plant tillering	5.25	3	18,564	143.5
N_{60} in early spring on freeze-thawed soil + N_{30} at the end of plant tillering	5.62	2	21,347	156.9
Kokhanka				
No feeding - control (background $N_{60}P_{60}K_{30}$)	4.26	4	13,139	116.6
N_{30} in early spring on freeze-thawed soil	4.91	3	17,319	142.6
N_{60} in early spring on freeze-thawed soil	5.31	3	18,986	147.5
N_{30} at the end of plant tillering	4.74	3	16,264	133.6
N_{30} in early spring on freeze-thawed soil + N_{30} at the end of plant tillering	5.16	3	18,030	139.4
N_{60} at the end of plant tillering	5.08	3	17,545	135.6
N_{60} in early spring on freeze-thawed soil + N_{30} at the end of plant tillering	5.46	3	19,147	140.7
Misia Odeska				
No feeding - control (background $N_{60}P_{60}K_{30}$)	3.88	4	11,122	100.1
N_{30} in early spring on freeze-thawed soil	4.45	4	13,558	113.5
N_{60} in early spring on freeze-thawed soil	4.78	3	16,041	126.9
N_{30} at the end of plant tillering	4.24	4	12,340	103.2
N_{30} in early spring on freeze-thawed soil + N_{30} at the end of plant tillering	4.60	3	14,921	117.7
N_{60} at the end of plant tillering	4.54	3	14,546	114.6
N_{60} in early spring on freeze-thawed soil + N_{30} at the end of plant tillering	5.03	3	16,752	124.8

The nitrogen supplements of ammonium nitrate depended on the doses and the time of their application, they contributed to the Pylypivka yield increase, namely from 4.46 to 4.97-5.62 t/ha; Kokhanka variety - from 4.26 to 4.74-5.46 t/ha, while Misia Odeska - from 3.88 to 4.24-5.03 t/ha. The highest increases in grain yield compared against the control group were ensured by applying nitrogen fertilizer of N_{60} on freeze-thawed soil in two stages: N_{60} on freeze-thawed soil + N_{30} locally at the end of plant tillering.

Further, as compared with the control group, the winter wheat grain quality was better in the variations where nitrogen feedings were applied and mainly those of the 4th and the 3^{d} class. With Pylypivka variety, the grain of the 2nd class was obtained. Furthermore, according to the Ukrainian standard on soft wheat (DSTU 3768-2019) the 1st class of wheat is the highest grade, followed in quality degrading by the 2nd and the 3d class, and the 4th is the lowest class. Therefore, the 1st class grain is the most expensive for selling, while the 4th class is the cheapest.

When determining the economic efficiency for winter wheat growing (as we mentioned before) we took into account both the yield and the grain quality. The costs of the mineral fertilizers in the years of long-term studies are among the main constituents of the operational costs of winter wheat growing. The expenses spent at various agricultural practices were also considered in the estimation: they were the introduction of fertilizers, preventive measures against diseases, pests and weeds, crop gathering, crop delivery to the elevators and others.

The analysis on the experimental data has revealed that the highest yields and net incomes of winter wheat sown after spring barley in 2016-2018 were obtained in variations where along with $N_{60}P_{60}K_{30}$, the ammonium nitrate (N_{60}) supplement was introduced on freeze-thawed soil or in two stages: N_{60} on freeze-thawed soil and N_{30} locally at plant tillering phase. With the described fertilizing, Pylypivka variety produced 5.47 t/ha and 5.62 t/ha, Kokhanka variety - 5.31 t/ha and 5.46 t/ha, the variety of Misia Odeska - 4.78 t/ha and 5.03 t/ha.

The net income with Pylypivka variety compared with the other varieties under study was the highest and was attributed to above-mentioned supplement variations: 10,049 UAH/ha and 21,347 UAH/ha, Kokhanka variety - 18,986 UAH/ha and 19,147 UAH/ha, Misia Odeska - 16,041 UAH/ha and 16,752 UAH/ha.

Wheat grain growth profitability in control groups (without nitrogen feedings during the period of spring vegetation) was the lowest: within 100.1-126.4 % depending on the variety.

The introduction of nitrogen feedings facilitated the increase in this value: 17.1-30.5 % higher profitability with Pylypivka, 17.0-30.9 % - Kokhanka, 13.4-24.7 % - Misia Odeska.

CONCLUSIONS

Based on the long-term research to have been carried out under conditions of Ukrainian Northern Steppe, the specific character of winter wheat growing after spring barley has been described and it has been determined that feeding with nitrogen fertilizers does not ensure higher productivity of the plants if there was drought at their spring-summer vegetation. In a number of cases, winter wheat growing in such years at the plots where nitrogen feedings were introduced into the soil was unprofitable, while the control variants (without application of nitrogen fertilizers) provided the highest net income and the profitability.

When moisturizing was sufficient in the described period of time, the mineral fertilizers dissolved within the ground and were better consumed by the plants, the yield and the economic efficiency of wheat growing increased. The highest values of the yield and the net income were obtained from winter wheat growing after stubble previous crop on average in 2016-2018 with those variations, where on the background of $N_{60}P_{60}K_{30}$ we applied ammonium nitrate (N_{60}) supplement introduced on freeze-thawed soil or in two stages: N_{60} on freeze-thawed soil and N_{30} locally at plant tillering phase. These data were varying respectively to the fertilizing variations within 4.78-5.47 t/ha and 16,041-19,949 UAH/ha, 5.03-5.62 t/ha and 16,752-21,347 UAH/ha. Among the varieties of Kokhanka, Misia Odeska and Pylypivka, the maximal economic efficiency was registered with the variety of Pylypivka, which had the highest yield and the best grain quality.

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