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Influence of mineral fertilizers on yielding capacity and quality of soft spring wheat grain

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Abstract. The aim of the study is optimization of nutrition system for soft spring wheat plants through the use of mineral fertilizers in order to obtain high quality grain with simultaneous yield increase. Different doses of mineral fertilizers were tested in the study. The object of study was a variety of soft spring wheat 'Uliublena'. The structure of the crop was determined by the method of selecting sheaf samples from each accounting area. The leaf surface area was determined by calculation method. According to the results of research, yield capacity of soft spring wheat on average ranged from 2.43 to 4.51 t ha^{-1}. The highest index of gluten amount was obtained in the variant with fertilizers dose $N_{64}P_{64}K_{64}$ - 28.19%, which is higher than in the variants with fertilizer doses $N_{16}P_{16}K_{16}$ and $N_{32}P_{32}K_{32}$ by 6.11 and 0.15%. The highest increase in the yield of soft spring wheat grain (2.08 t ha^{-1}) was obtained with application of $N_{64}P_{64}K_{64}$, slightly lower yield increase was obtained with application of $N_{32}P_{32}K_{32}$ - 1.64 t ha^{-1}, and $N_{16}P_{16}K_{16}$ - 0.99 t ha^{-1} comparing with the control. With fertilizer dose of $N_{64}P_{64}K_{64}$ soft spring wheat provided the maximum yield - 4.51 t ha^{-1}, gluten content - 28.19% and protein content - 14.21%.

Key word: fertilization, ear, yield, protein, gluten.

INTRODUCTION

Attention to grain production is stipulated by its strategic importance within agro-industrial complex of Ukraine, as its products are critically important as key food for support of population lives (Klochan et al., 2018). Spring wheat is a crop with a fairly wide range of use. It is the only equivalent insurance crop in case of winter wheat loss

(Kolyuchiy, 2006). The quality of spring wheat grain is assessed by a number of features that together characterize its nutritional, physical and chemical, and technological properties (Kolyuchiy et al., 2007).

High potential of modern varieties of spring soft wheat can be realized by growing them in technologies that involve complex application of fertilizer. Exactly they should be the basis of modern environmentally friendly and resource-saving technologies for growing spring cereals (Polishuk & Antko, 2020). One of the ways to increase competitiveness of cereals can be achievement of high level of yield capacity and productive prime cost of spring cereals (Tomashevska & Shevchenko, 2019). Rational application of fertilizers allows to control the production process of wheat crops and get high yields, increase economic efficiency of growing crops (Mazur et al., 2020). Violation of cultivation technology leads to indivertible consequences such as loss of yield and grain quality. Many studies have shown that fluctuations in spring wheat yields are connected with its high sensitivity to environmental conditions (Kirichenko et al., 2009).

Adaptation of agricultural crops to conditions of growing, first of all, is determined by correctly chosen agrotechnological measures of cultivation - predecessors, soil tillage, sowing dates, sowing norms, fertilizers, varieties, etc (Popov et al., 2000; Muhamedyarova et al., 2020). Modern varieties of spring wheat have a high potential of yield capacity (in experiments up to 5.0–5.5 t ha^{-1}, under production conditions - about 3.0–3.5 t ha^{-1}). However, the average yield in recent years under conditions of Forest-Steppe was only 2.0–2.5 t ha^{-1}. One of the reasons for low yield capacity is insufficient study of the conditions for effective fertilizer application with taking into account the level of moistening and nutrient content of soils. Identification of regularities of mineral fertilizer influence on soil fertility and crop yield capacity - is an important condition for development of a scientifically substantiated fertilizer system (Sviderko et al., 2004; Melnyk et al., 2006).

It is determined that at the end of vegetation of spring grain crops the content of movable nutrients in the soil decreases significantly. It is connected with the usage of NPK for productivity formation of the studied crops and their partial redistribution in soil profile (Gamayunova et al., 2019). Application of mineral fertilizers contributes to increasing of microorganism number of main ecological-trophic, functional and systematic groups and rising of physiological and biochemical activity of representatives of certain microorganism groups (Malynovska, 2018).

Fertilizer equilibrium is important as high accumulation of nitrogen has a negative effect on the consumption of other nutrients, especially potassium (Hamnér et al., 2017). In its turn, potassium deficiency significantly reduces resistance of plants to drought. It is especially noticeable for genetically more tolerant varieties, 'as experimentally proved by Wei et al. (2013)'. 'The study by Yan Deng et al. (2018) also prove the presence of genotypic specificity of phosphorus consumption in different varieties of wheat at morphological, physiological and molecular level'. Nutrition of wheat with nitrogen is especially important as it can increase protein content without reducing yields (Gyuga et al., 2002; Balla et al., 2011; Litke et al., 2019).

Increasing of mineral fertilizer doses had a positive effect on increase of spring wheat yield capacity. It was also found that accumulation of movable compounds of nitrogen, phosphorus and potassium in the soil reduces negative impact of weather conditions and contributes to yield stabilization (Kochmarskiy et al., 2011). Most of experiments concerning the study of mineral fertilizer effect on nutritional regime of soil and yield capacity of spring wheat were conducted in Polissya area and, partially, under conditions of steppe irrigation (Lebid et al., 2006). An issue of growing spring wheat in the Forest-Steppe is still not fully studied.

The aim of the study is optimization of nutrition system for soft spring wheat plants through the use of mineral fertilizers in order to obtain high quality grain with simultaneous yield increase under conditions of the Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The research was conducted in 2016–2020 on the basis of educational and scientific production complex of Sumy National Agrarian University according to described methods of Dospekhov (1985) and Pidoprygora & Pisarenko (2003).

The object of the study was a variety of soft spring wheat Uliublena. Predecessor - soybeans. Sowing was carried out after physical readiness of soil at the temperature of 6–8 °C in the depth of 5 cm. with the help of seeder Klen - 1.5 to a depth of 3–4 cm. with sowing rate of 6.0 million similar seeds per 1 ha. Various doses of mineral fertilizers were tested. Mineral fertilizers were applied to pre-sowing cultivation in the form of nitroammophoska. Nitroammophoska is a complex nitrogen-phosphorus-potassium fertilizer. Mass fraction of nitrogen (N) 16%, phosphorus (P) 16%, potassium (K) 16%. Form of fertilizers - granular.

The total area of the plot was 50 m^2 (4.5 m × 11 m), accounting area was 30 m^2, repetition of the experiment - three times. The placement of plots is systematic.

Scheme of the experiment:

1. Without fertilizers (control);
2. 100 kg ha^{-1} ($N_{16}P_{16}K_{16}$ of active substance per 1 ha);
3. 200 kg ha^{-1} ($N_{32}P_{32}K_{32}$ of active substance per 1 ha);
4. 400 kg ha^{-1} ($N_{64}P_{64}K_{64}$ of active substance per 1 ha).

During phenological observations, the growth and development phase of spring wheat was considered to be beginning with appearance of at least 10% of plants, and the phase was considered to be complete with appearance of 75% of plants.

The dynamics of overground mass growing was determined in the main phases of growth and development by selecting 25 plants in typical places of the plots in two incompatible repetitions. The structure of the crop was determined by the method of selecting sheaf samples from each accounting area. The leaf surface area was determined by calculation method. Amount of gluten was determined according to STST 13586.1-68 Grain. Methods for determining quantity and quality of wheat gluten. Amount of protein was determined according to STST 10846-91 Grain and products of its processing. Method for determination of protein. Statistical analysis of experimental data was conducted according to Dospekhov (1985) with usage of Microsoft Excel.

The soil of experimental field is a typical powerful heavy-loamy and medium humus black soil, which is characterized by the following indices: humus content in arable layer (according to I.V. Tiuryn) - 4.0%, reaction of soil solution is close to neutral (pH 6.5), the content of easily hydrolyzed nitrogen (according to I.V. Tiuryn) 9.0 mg, movable phosphorus and exchangeable potassium (according to Ph. Chyrikov), accordingly, 14 mg and 6.7 mg per 100 g of soil.

Conditions in 2016 were characterized by a slightly higher average daily (average annual) air temperature, namely, 9.5 °C. That is 2.1 °C higher than the long-term index (7.4 °C). Its absolute maximum - 37.0 °C above zero was observed in the third decade of August, the minimum - 24.0 °C below zero was observed in the third decade of January. But amount of precipitation was 792.0 mm, that is 199.0 mm more than long-term norm (593 mm). In spring, average daily temperature was 2.1 °C higher than for many years (8.1 °C). Precipitation was 248.8 mm (188.0%) at a norm of 132 mm. The sum of active air temperatures above +10 °C for the spring period was 795 °C (long-term 620 °C). The average daily air temperature during summer was 21.5 °C, that is 2.1 °C higher than the long-term average one. Precipitation was 250.6 mm, that is 125% at a norm of 200 mm. Total number of days with precipitations for summer period was 25 while a long-term index is 40 days. The sum of active air temperatures above +10 °C during summer period was 1,982 °C, with a long-term index of 1,790 °C.

Conditions in 2017 were characterized by a slightly higher average daily (average annual) air temperature, namely 8.1 °C, that is 0.7 °C higher than the long-term index (7.4 °C). Its absolute maximum - 35.0 °C above zero was observed in the second decade of August, the minimum - 24.0 °C below zero was observed in the first decade of February. But precipitation amount was 449.0 mm, that is 144.0 mm less than the long-term norm (593 mm). In spring, the average daily temperature was 1.5 °C higher than the one for many years (8.1 °C). Precipitation was 54.4 mm (41.0%) at a norm of 132 mm. The sum of active air temperatures above +10 °C for spring period was 553 °C (long-term 620 °C). The average daily air temperature during summer was 21 °C, that is 1.7 °C higher than the long-term average one. Precipitation was 126.0 mm, that is 63% at a norm of 200 mm. Total number of days with precipitations for summer period was 22 while a long-term index is 40 days. The sum of active air temperatures above +10 °C during summer period was 1,937 °C, with a long-term index of 1,790 C°.

Conditions in 2018 were characterized by a slightly increased average daily (average annual) air temperature, namely, 9.4 °C, that is 2.0 °C higher than the long-term index (7.4 °C). Its absolute maximum - 35.0 °C above zero was observed in the second decade of August, the minimum - 22.0 °C below zero was observed in the third decade of February. But amount of precipitation was 539.0 mm, that is 54.0 mm less than the long-term norm (593 mm). During spring period, the average daily air temperature was 9.2 °C, that is 1.1 °C higher than the one for many years (8.1 °C). Precipitation was 150.6 mm (114%) at a long-term norm of 132 mm. The sum of active air temperatures above +10 °C for spring period was 920 °C (long-term - 620 °C). The average daily air temperature during summer was 22.4 °C, that is 3 °C higher than the long-term average one. Precipitation was 100.1 mm, that is 50% of a long-term index of 200 mm. Totally, there were 14 days of precipitation during summer. The sum of active air temperatures above +10 °C during summer period was 2,061 °C, with a long-term index of 1,790 °C.

Conditions in 2019 were characterized by a slightly higher average daily (average annual) air temperature, namely, 9.6 °C, that is 2.2 °C higher than the long-term index (7.4 °C). Its absolute maximum - 35.5 °C above zero was observed in the first decade of August, the minimum - 20.0 °C below zero - in the first decade of January. But amount of precipitation was 409.0 mm, that is 184.0 mm less than the long-term norm (593 mm). During spring period, the average daily air temperature was 10.7 °C, that is 2.6 °C higher than the one for many years (8.1 °C). Precipitation was 102 mm - 77% at a long-term norm of 132 mm. The sum of active air temperatures above +10 °C for spring period was 786 °C (long-term - 620 °C). The average daily air temperature during summer was 22.4 °C, that is 3.0 °C higher than the long-term average one. Precipitation was 78.7 mm, that is 39% at a norm of 200 mm. Totally, there were 14 days of precipitation during summer. The sum of active air temperatures above +10 °C during summer period was 2054 °C, with a long-term index of 1,790 °C.

Conditions in 2020 were characterized by a slightly higher average daily (average annual) air temperature, namely, 10.2 °C, that is 2.8 °C higher than the long-term index (7.4 °C). Its absolute maximum - 35.0 °C above zero was observed in the third decade of July, the minimum - 14.0 °C below zero - in the first decade of February. But amount of precipitation was 466.0 mm, that is 127.0 mm less than the long-term norm (593 mm). During spring period, the average daily air temperature was 8.9 °C, that is 0.8 °C higher than the one for many years (8.1 °C). Precipitation was 120 mm - 91% at a long-term norm of 132 mm. The sum of active air temperatures above +10 °C for spring period was 462 °C (long-term - 620 °C). The average daily air temperature during summer was 22.1 °C, that is 2.7 °C higher than the long-term average one. Precipitation was 126 mm, that is 63% at a norm of 200 mm. Totally, there were 13 days of precipitation during summer. The sum of active air temperatures above +10 °C during summer period was 2027 °C, with a long-term index of 1,790 °C.

In general, the most favorable years for the formation of crop yields were 2016, 2018, 2020. Drought conditions were observed in 2017 and 2019 and characterized by low precipitation amount and extreme deviation of air temperature during vegetation period.

RESULTS AND DISCUSSION

Germination phase is determinant one at quantity formation of productive stem-standing. As not all sown seeds give viable seedlings, it affects the index of field germination. 'Alimov & Shelestov, (1995) and others (Bebyakin et al., 2003; Altukhov, 2008) believe that one of the most important elements of crop sowing is the number of plants per unit of area. This number can vary during vegetation period'.

'The experiments of Kalens'ka & Suddenko (2016) revealed the influence of soft spring fertilizer system on the level of field germination and survival rate. Field germination of experimental varieties Elegiya myronivska and Simkoda myronivska increased by 0.7–4.0% depending on mineral nutrition. Plant survival rate increased from 1.7 to 4.8% depending on the system of fertilization and protection'.

The results of conducted research allowed to establish the fact that field germination of spring wheat seeds varied depending on a variant of experiment (Table 1). The lowest field germination was observed in the control 81.7%. The highest field germination of spring wheat seeds was observed in the variant with application of mineral fertilizers at sowing time in a dose of $N_{64}P_{64}K_{64}$ - 91.3%.

Plant standing density in the experiment increased from 490 to 548 pcs m^2. Thus, the lowest density of standing was formed in the control - 490 pcs m^2. The variant with fertilizer dose of $N_{16}P_{16}K_{16}$ is 17 pcs m^2 more than in the control. The variant with fertilizer dose of $N_{32}P_{32}K_{32}$ is 50 pcs m^2 more than in the control. The variant with fertilizer dose of $N_{64}P_{64}K_{64}$ is 58 pcs m^2 more than in the control.

Rate of plants preservation during vegetation period ranged from 70.8 to 76.6%. Thus, the highest preservation rate of plants was obtained in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 76.6%. In the control, preservation rate of plants during vegetation period was 70.8%, in the variant with fertilizer dose of $N_{16}P_{16}K_{16}$ - 75.5%, with fertilizer dose of $N_{32}P_{32}K_{32}$ - 75.4%. (Table 1).

Table 1. Standing density of soft spring wheat depending on fertilizer (average for 2016–2020)

Fertilizer dose	Field germination, %				Standing density, pcs m^2				Preservation rate of plants during vegetation period, %			
	I	II	III	average	I	II	III	average	I	II	III	average
Control (without fertilier)	82.4	80.1	82.6	81.7	482.0	495.0	493.0	490.0	70.9	71.3	70.1	70.8
$N_{16}P_{16}K_{16}$	86.0	83.1	84.4	84.5	512.0	501.0	508.0	507.0	74.6	75.0	75.2	75.0
$N_{32}P_{32}K_{32}$	89.1	91.8	89.1	90.0	536.0	548.0	536.0	540.0	75.0	74.8	76.3	75.4
$N_{64}P_{64}K_{64}$	92.6	90.2	91.1	91.3	556.0	544.0	544.0	548.0	76.6	76.6	76.6	76.6
LSD_{05}	-	-	-	2.6	-	-	-	12.5	-	-	-	1.0

It is known that crop yield amount depends on the efficiency of plant photosynthesis in crops. The largest and best quality crop yields can be obtained only in crops which have optimal leaf area size and processes of their formation (Gorodniy, 2004). The value of these indices is influenced by both biological characteristics of a variety and environmental conditions, which include light intensity, water and air regimes, temperature, as well as plant provision with nutrients (Zinchenko, 2005).

Therefore, it is necessary to create crops with optimal leaf area. Both with insufficient leaf area and under conditions of highly developed leaf area, a decrease in solar energy consumption is observed (Svydynyuk & Yula, 2004; Kolyuchiy et al., 2007). 'In the experiments of Kudriavytska (2016) it was established that application of mineral fertilizers significantly influenced the increase in leaf surface area of spring wheat plants. The highest index in leaf area increase of spring wheat (in amount of 51.8 thousand m^2 ha^{-1}) was determined in the variant where fertilizer norm Background + $N_{110}P_{120}K_{120}$ were applied on the background of manure aftereffect - 30 t ha^{-1}'.

The studies have shown that leaf area increase in the first vegetation period was slow. In the phase of tube entering intensity of its growth increased sharply and reached maximum before earing phase in all variants of the experiment (Fig. 1).

Thus, in the tillering phase, the largest leaf surface area of soft spring wheat was formed in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ and amounted to 9.5 thousand m^2 ha^{-1}. Leaf surface area decreased to 6.4 thousand m^2 ha^{-1} with fertilizer dose of $N_{32}P_{32}K_{32}$. It also decreased to 5.2 thousand m^2 ha^{-1} with fertilizer dose of $N_{16}P_{16}K_{16}$ and to 4.3 thousand m^2 ha^{-1} in the control (LSD_{05} = 0.6). These established differences persisted during the following vegetation phases of soft spring wheat. Thus, in the tube entering phase the area of leaf surface was: 40.4, 30.4, 25.2, 21.3 thousand m^2 ha^{-1}, accordingly (LSD_{05} = 1.8).

The largest leaf surface area was formed in the earing phase in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 43.2 thousand m^2 ha^{-1}. It is 7.8 thousand m^2 ha^{-1} more than in the variant $N_{32}P_{32}K_{32}$ (35.4 thousand m^2 ha^{-1}), 15.4 thousand m^2 ha^{-1} more than in the variant $N_{16}P_{16}K_{16}$ (27.8 thousand m^2 ha^{-1}), 16.7 thousand m^2 ha^{-1} more than in the control (26.5 thousand m^2 ha^{-1}) (LSD_{05} = 1.3) (Fig. 1).

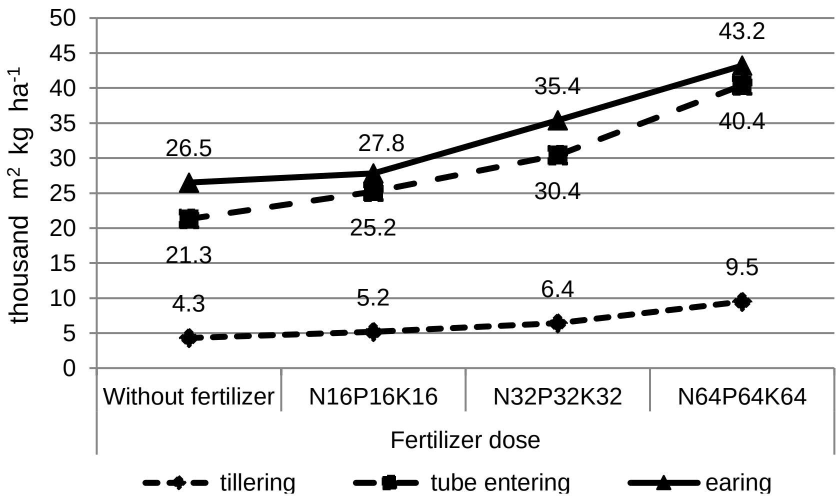

Figure 1. Leaf surface area of soft spring wheat by phases of development depending on fertilization (average for 2016–2020).

Plants of tall varieties have much larger leaf surface area, which provides better supply of assimilants into the ear and allows to form grain yield with lower level of mineral nutrition. It is established that the most favorable combination of morphological features and internal biological processes for the formation of high grain yield is in the plants with height of 85.2–97.8 cm.

In the tillering phase, the highest plant height was observed in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 28.8 cm. Slightly lower height was fixed in the variants with fertilizer dose of $N_{32}P_{32}K_{32}$ - 24.0 cm, with fertilizer dose of $N_{16}P_{16}K_{16}$ - 22.2 cm, in the control - 20,8 cm (LSD_{05} = 1.4).

In the phase of tube entering on average during the years of research, the maximum height was again obtained in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 65.4 cm. Smaller values of plant height were established both in the variants with fertilizer dose of $N_{32}P_{32}K_{32}$, $N_{16}P_{16}K_{16}$, and the control - 57.4, 49.5, 43.0 cm, accordingly (LSD_{05} = 3.7).

In the earing phase, on average during the years of research, the highest plant height was observed in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 97.8 cm, which is 12.6, 17.2, 25.0 cm higher (LSD_{05} = 4.0) than in the variants with fertilizer dose of $N_{32}P_{32}K_{32}$, $N_{16}P_{16}K_{16}$, the control, accordingly (Fig. 2).

'Insufficient provision of winter wheat plants with mineral nutrition in the studies of Zhuk (2016), assisted to reduce ear length (from 0.4 cm to 0.7 cm) of main and sidelong shoots. With deficiency of nutrition the number of grains in the ears of sidelong shoots decreases more significantly (from 7.0 to 8.0 grains) than in the main shoot (from 3.0 to 4.0 grains). It is primarily stipulated by reduction of lower and upper spikelets of the ear or flowers in them, underdevelopment of central grains of spikelet'.

According to the research, an average plant weight of soft spring wheat was from 1.8 to 2.7 g. The highest plant weight was observed in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 2.7 g. On average, during the years of research, maximum ear weight of soft spring wheat plants was in the variants with fertilizer doses of $N_{32}P_{32}K_{32}$ and $N_{64}P_{64}K_{64}$ - 1.7 g. Slightly less ear weight was determined in the control - 1.1 g, and in the variant with fertilizer dose of $N_{16}P_{16}K_{16}$ - 1.6 g.

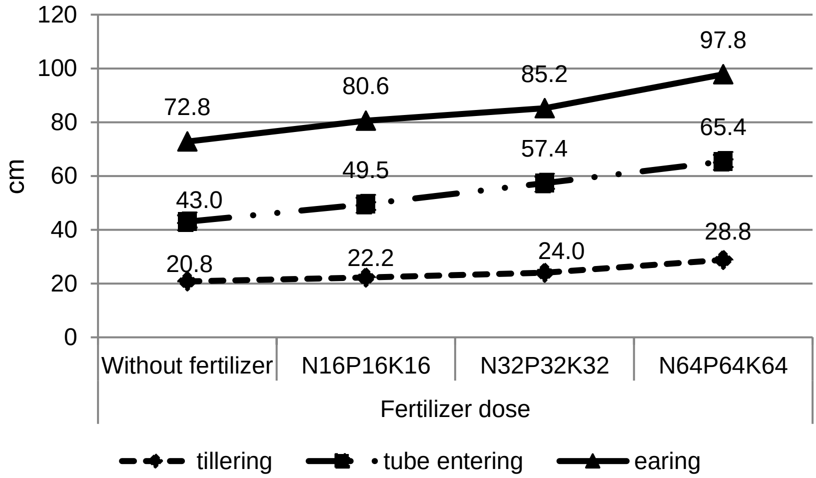

Figure 2. The height of soft spring wheat plants by phases of development depending on fertilizers (average for 2016–2020), cm.

Ear length of soft spring wheat also varied depending on the elements of cultivation technology. The largest index of ear length was obtained in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 9.8 cm and it decreased to 9.4 cm with fertilizer dose of $N_{32}P_{32}K_{32}$, to 9.0 cm with fertilizer dose of $N_{16}P_{16}K_{16}$ and to 8.1 cm in the control (Table 2).

Table 2. Weight of a plant and ear, ear length of soft spring wheat depending on fertilizers (average for 2016–2020)

Fertilizer dose	Plant weight, g				Ear weight, g				Ear length, cm			
	I	II	III	average	I	II	III	average	I	II	III	average
Control (without fertilier)	1.85	1.77	1.78	1.80	1.07	1.15	1.08	1.10	8.02	8.14	8.14	8.10
$N_{16}P_{16}K_{16}$	2.12	1.94	1.94	2.00	1.54	1.62	1.64	1.60	8.84	9.12	9.04	9.00
$N_{32}P_{32}K_{32}$	2.56	2.45	2.49	2.50	1.72	1.68	1.70	1.70	9.38	9.45	9.37	9.40
$N_{64}P_{64}K_{64}$	2.74	2.67	2.69	2.70	1.69	1.72	1.69	1.70	9.86	9.72	9.82	9.80
LSD_{05}	-	-	-	0.12	-	-	-	0.07	-	-	-	0.17

Determining factor for yield capacity is regulation of growth and development processes as important manifestations of organism vital activity. ‘According to the results of research conducted by Zhemela & Shakaliy (2012) it is established that the most rational norm of fertilizer application is - $N_{85}P_{96}K_{51}+N_{30}$. This norm contributes to effective increase of yield structure indices’.

As a result of the research it was found that the largest mass of grain in the ear of soft spring wheat plant was formed with fertilizer dose of $N_{64}P_{64}K_{64}$. The mass was 1.1 g. Slightly lower indices were obtained in the control - 0.7 g, in the variants with fertilizer dose of $N_{16}P_{16}K_{16}$ and $N_{32}P_{32}K_{32}$ - 0.9, 1.0 g, accordingly. The number of grains in the ear varied from 20.9 to 30.0 pieces. Sowing of soft spring wheat without fertilizers significantly reduced the number of grains per ear and amounted to 20.9 pcs. The highest number of grains per ear was obtained in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 30.0 pcs. This index is higher than in the variants with fertilizer doses of $N_{16}P_{16}K_{16}$ and $N_{32}P_{32}K_{32}$ by 3.9 and 2.3 pcs, accordingly (Table 3).

The weight of 1,000 pieces of grain plays a significant role in the formation of grain yield capacity, as this index correlates with the size of grain, which is a varietal trait, but depends on the influence of weather, soil and various technological factors. The plants have acquired optimal values when applying average fertilizer norms of $N_{45}P_{45}K_{45}$ - $N_{60}P_{90}K_{90}$ (Radchenko et al., 2018; Voloshchuk et al., 2019).

Depending on fertilizer dose, the weight of 1,000 grains differed significantly and varied from 34.48 to 36.67 g. The weight of 1,000 grains was trustworthy high depending on fertilization (LSD_{05} = 0.32). Thus, in the control, the mass of 1,000 grains was 34.48 g, in the variants with fertilizer dose of $N_{16}P_{16}K_{16}$ - 35.00 g, $N_{32}P_{32}K_{32}$ - 36.10 g, $N_{64}P_{64}K_{64}$ - 36.67 g. The largest mass of 1,000 grains was in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 36.67 g (Table 3).

Table 3. Structural indices of soft spring wheat plants depending on fertilization (average for 2016–2020)

Fertilizer dose	Mass of grains per ear, g				Number of grains per ear, pcs				Mass of 1,000 grains, g			
	I	II	III	average	I	II	III	average	I	II	III	average
Control (without fertilier)	0.68	0.75	0.67	0.70	21.6	20.2	20.9	20.9	34.75	34.28	34.41	34.48
$N_{16}P_{16}K_{16}$	0.92	0.87	0.91	0.90	26.7	25.9	25.7	26.1	34.92	35.15	34.93	35.00
$N_{32}P_{32}K_{32}$	1.02	0.99	0.99	1.00	27.8	28.0	27.3	27.7	36.21	36.02	36.07	36.10
$N_{64}P_{64}K_{64}$	1.13	1.07	1.10	1.10	29.6	30.2	30.0	30.0	36.78	36.52	36.71	36.67
LSD_{05}	-	-	-	0.08	-	-	-	1.05	-	-	-	0.32

Fertilization is one of the most effective and fast-acting factors of increasing wheat yield and improving its quality. Yield capacity increase occurs due to fertilizers by 50%, varietal properties by 25%, improvement of agrotechnology system by 20–25% (Zhemela, 1991).

Mineral fertilizers increase yield capacity of soft spring wheat under conditions of the Northern Forest-Steppe depending on the elements of cultivation technology on average from 0.1 to 1.0 t ha^{-1}. Application of $N_{30}P_{30}K_{30}$ in comparison with the variant without fertilizers promotes productivity increase by 15–16%, while increase of fertilizer dose to $N_{60}P_{60}K_{60}$ - promotes productivity increase by 4–15%, and increase of fertilizer dose to $N_{90}P_{90}K_{90}$ promotes productivity increase only by 2–7% (Antal et al., 2016).

According to the results of research, yield capacity of soft spring wheat ranged on average from 2.43 to 4.51 t ha^{-1} (LSD_{05} = 0.30). Analysis of yield data shows that the highest yield increase of soft spring wheat grain (2.08 t ha^{-1}) was obtained with application of fertilizer in a dose of $N_{64}P_{64}K_{64}$. Slightly lower yield increase was obtained with application of fertilizer in a dose of $N_{32}P_{32}K_{32}$ - 1.64 t ha^{-1}, the lowest yield increase was obtained in the variant with fertilizer dose of $N_{16}P_{16}K_{16}$ - 0.99 t ha^{-1} in comparison to the control (Fig. 3).

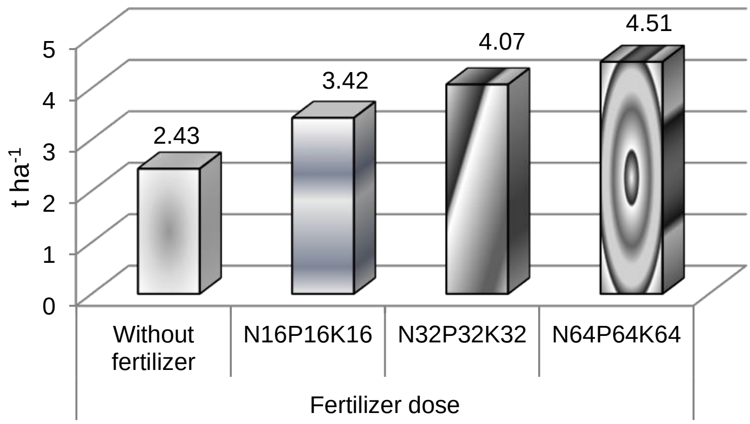

Figure 3. Yield capacity of soft spring wheat grain depending on fertilizer (average for 2016–2020), t ha^{-1}.

The quality of spring wheat grain is assessed by a number of features which together characterize its nutritional, physico-chemical and technological properties (Kolyuchiy et al., 2007; Kulyk et al., 2020). The greatest impact on the quality of wheat grain have mineral fertilizers, and especially nitrogen, its doses and timing of application, as well as ripening conditions and harvesting times. High-quality grain of strong wheat must be healthy and have high baking properties. It is established that the more gluten the grain contains the better baking properties the wheat has (Jula & Drozd, 2015).

Manifestation of quality characteristics is influenced not only by a variety but also by its ecological and geographical origin, in particular in Slovakia varieties from Austria and Hungary as well as varieties from Great Britain, Germany, Poland and Czech Republic dominated over the local ones (Mikulikova et al., 2009).

The content of gluten and protein in the grain of soft spring wheat was changed significantly from fertilization. With increasing doses of mineral fertilizers increases the content of gluten and protein in wheat grain.

The content of crude gluten in wheat grain during the years of research ranged from 18.13 to 28.19% (LSD_{05} = 0.42). In the variant without fertilizers gluten content was the lowest - 18.13%. The highest amount of gluten was obtained in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 28.19%, that is 6.11% more than in the variant with fertilizer dose of $N_{16}P_{16}K_{16}$ and 0.15% more than in the variant with fertilizer dose of $N_{32}P_{32}K_{32}$ (Table 4).

Table 4. Grain quality of soft spring wheat depending on mineral nutrition (average for 2016–2020)

Fertilizer dose	Gluten content, %				Protein content, %			
	I	II	III	average	I	II	III	average
Control (without fertilier)	18.52	18.00	17.87	18.13	10.83	10.08	10.65	10.52
$N_{16}P_{16}K_{16}$	22.15	21.88	22.21	22.08	11.92	11.48	11.61	11.67
$N_{32}P_{32}K_{32}$	27.95	28.09	28.08	28.04	14.38	14.10	14.12	14.20
$N_{64}P_{64}K_{64}$	28.22	28.13	28.22	28.19	14.25	14.12	14.26	14.21
LSD_{05}	-	-	-	0.42	-	-	-	0.56

The content of protein in wheat grain ranged from 10.52 to 14.21% (LSD_{05} = 0.56). The largest amount of protein in the grain of soft spring wheat was obtained in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$ - 14.21%. Slightly lower protein content was obtained in the other variants. Thus, in the variant without fertilizers it was 10.52%, in the variant with fertilizer doses of $N_{16}P_{16}K_{16}$ - 11.67%, and in the variant with fertilizer doses of $N_{32}P_{32}K_{32}$ - 14.20% (Table 4).

CONCLUSIONS

According to the results of research it was found that the best conditions for growth, development and crop formation of soft spring wheat were formed in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$. With this fertilizer dose, soft spring wheat provided maximum plant weight - 2.7 g, ear weight - 1.7 g, grain weight in the ear - 1.1 g and ear length - 9.8 cm. The number of grains in the ear was 30.0 pcs. with the weight of 1,000 grains - 36.67 g. The highest yield increase of soft spring wheat grain (2.08 t ha^{-1}) was obtained with application of $N_{64}P_{64}K_{64}$, slightly lower yield increase was obtained with application of $N_{32}P_{32}K_{32}$ - 1.64 t ha^{-1}, and with application of $N_{16}P_{16}K_{16}$ - 0.99 t ha^{-1} in comparison with the control.

The maximum amount of gluten - 28.19% with protein content of 14.21% in the grain of soft spring wheat was registered in the variant with fertilizer dose of $N_{64}P_{64}K_{64}$.

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