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Efficiency of Use of Macronutrients by Spring Rapeseed Plants

Abstract. The relevance of this study is determined by the need to optimize the production process of agrocenoses of spring rapeseed and establish the regularities of the dynamics of macroelements in the soil under the influence of different rates of mineral fertilisers. In this regard, the purpose of this paper was to cover the regularities of changes in the content of macroelements in typical low-humus chernozems at different stages of spring rapeseed culture development in the conditions of the Right Bank Forest Steppe of Ukraine. Field, laboratory, analytical, and statistical research methods were used in the study. It was established that the highest content of macroelements in the soil at all levels of mineral fertiliser is in the phase of leaf rosette formation by spring rapeseed plants (BBCH 15-18). As plants grow through the phases, it decreases and reaches minimum values in the ripening phase (BBCH 85-88). The highest content of nitrogen mineral compounds was noted in BBCH 15-18: 52.0-60.2 mg/kg of soil depending on the fertiliser variant, the content in the variant without fertiliser application – 49.8 mg/kg of soil. It was found that the maximum content of mobile phosphorus compounds in the soil was recorded in the first half of the growing season. It was found that the content of mobile potassium in the soil is dictated by the amount of applied mineral fertilisers. The highest content was noted at the beginning of the vegetation of spring rapeseed, with a gradual decrease until the seed ripening phase (BBCH 85-88). A close correlation was established between the accumulation of dry matter in the BBCH 55-58 period and the yield level (r=0.91). The materials of this paper are of practical value for the improvement of processes related to the development of the productivity of spring rapeseed crops in the conditions of the Forest Steppe of Ukraine, as well as the rational use of mineral fertilisers on typical low-humus chernozems

Keywords: *Brassica napus* L., mineral nutrition, application rates of mineral fertilisers, dry matter, productivity

INTRODUCTION

The high competitiveness of spring rapeseed in the international market makes this crop promising due to the growing demand for oils characterised by a high content of oleic acid. Thanks to this argument, agrarians will have the opportunity to receive added profits, as well as for the cultivation of high-oleic sunflower, provided that certain technological elements of crop cultivation are optimised to use the soil and climatic conditions of Ukraine more effectively [1].

In the coming years, the promising high-oleic segment will grow in Ukraine according to world trends and ensuring demand in Europe [2]. In France, the area under winter rapeseed makes up over 50% of the area under winter rapeseed, while in Ukraine, this indicator is at 10-15%. The increase in the area sown under rapeseed allows stabilising the energy independence of Ukraine due to the increase in the gross collection of seeds for processing into biodiesel [3; 4]. Furthermore, the situation on the world oil market can substantially affect the economic attractiveness of spring rapeseed cultivation [5].

Regulation of crop productivity formation processes encompasses the influence of many factors, both regulated and unregulated. Particular attention is paid to certain abiotic factors and certain elements of cultivation technology. Among abiotic factors, the main attention is paid to water and temperature regimes. Of the technological processes, the selection of the variety (hybrid), plant density, and feeding conditions are of immense importance [6; 7]. The emergence of many promising hybrids with high-yield potential on the market causes a problem related to their adaptation to growing conditions. Just as the rapid growth of the genetic potential of modern varieties and hybrids cannot be ensured at the proper level by abiotic factors [8]. A wide range of changes in biotic and abiotic environmental factors and the ability to adapt to them determines the degree of adaptability of modern hybrids [9].

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Rapeseed belongs to crops that react extremely sensitively to changes in mineral nutrition conditions. That is why due attention is paid to the regulation of the mineral nutrition regime for the cultivation of rapeseed [10].

Rapeseed cultivation technology, despite its prospects and wide distribution, still raises many questions aimed at individual technological processes, namely mineral nutrition intended to increase productivity and identify its impact on oil quality indicators.

Over the past decades, the issue of reproduction of fertility and preservation of soil cover has become relevant. One of the key factors in the fertility of soils is their provision of mobile forms of the main nutrients, which is carried out through the introduction of organic and mineral forms of fertilisers [11].

The increase in rapeseed yield, depending on the dose of mineral fertilisers, is 46-60% [12]. On chernozem soils of Ukraine, the greatest yield increase is obtained from the application of nitrogen fertilisers (about 30-40%) [1]. Phosphorous and potash fertilisers are less effective. Thus, in the conditions of the north-eastern part of Germany, full potassium nutrition increases the yield of rapeseed by 0.2-0.3 t/ha [13]. Moreover, the effectiveness of nitrogen fertilisers increases after stubble precursors, especially in wet years. Retail application of nitrogen fertilisers in conditions of insufficient soil moisture is ineffective, especially on soils with a heavy granulometric composition [1].

The analysis of literary sources indicates an increase in the yield of rapeseed under increased rates of nitrogen fertilisation, with possible lodging of plants [11; 13]. The use of nitrogen in the amount of 120-180 kg/ha causes a decrease in added production per 1 kg of nitrogen. Therewith, an increased accumulation of nitrates is noted in the obtained crop.

On chernozem soils, with insufficient application of nitrogen forms of fertilisers, the deficiency of the element is partially eliminated due to the natural reserves of the element in the soil. The analysis of earlier studies shows a direct dependence between the content of available forms of nitrogen in the soil and the amount of fertilisers applied [14].

Nitrogen, unlike phosphorus and potassium, is the most mobile, and therefore it is vital to monitor the nitrogen nutrition of crops, adjust the nitrogen dose in a timely manner and give plants the opportunity to form the highest and full-quality crops [15].

Based on this, it is of great interest to investigate the content and dynamics of typical ammonium and nitrate nitrogen in chernozems, i.e., mobile forms of nitrogen that are most available to plants.

Phosphorus is one of the main elements of plant nutrition. To obtain high and stable crops of superior quality, balanced mineral nutrition of spring rapeseed plants is necessary, where nitrogen and phosphorus play a significant role [1]. The supply and use of nitrogen by plants is related to the level of their phosphorus supply since phosphorus metabolism in plants is closely related to carbohydrate-protein and energy metabolism [13].

An essential indicator of soil fertility is its availability of phosphorus, which is an organic and mineral soil compound. In plant nutrition, the main role belongs to mineral compounds of phosphorus, which are represented by the remains of apatite, phosphorite, salts of phosphoric acids. The content of phosphorus available to plants depends on the characteristics of the soil, the methods, and terms of applying fertilisers and their forms [16].

The assimilation of phosphorus compounds by the plant is characterised by two periods. The first period is the time of seed germination. There is a close connection between the growth processes of plants and the presence of phosphorus compounds in the soil. This is showed by the high concentration of the element in tissues where growth occurs. The second period corresponds to the seed ripening phase. In the seeds of plants, phosphorus compounds are in a storage form, which is phytin, the content of which can be 1-3%. In the vegetative organs of plants, phytin is absent or present in insignificant amounts [11].

Potassium reserves in the soil are a determining factor in the development of crop productivity under intensive cultivation technologies. Together with phosphorus, it helps reduce the adverse effect of excessive consumption of nitrogen by plants. An insufficient amount of potassium causes a decrease in photosynthetic activity, exposure to harmful organisms and disruption of the main processes of the plant organism [1].

Potassium fertilisers, upon interacting with the soil, are subjected to various transformations, which cause the formation of compounds of different mobility and availability for the plant organism. Potassium is one of the indispensable elements of the plant organism, which can enhance growth processes, respiration, and nitrogen exchange. Its role in the water regime of plant tissues is also important. Potassium deficiency manifests itself as early as at the initial stages of plant development, restraining their growth [13].

The need of spring rapeseed plants for potassium is observed most in the initial periods of its vegetation, contributing to the growth of plant resistance to adverse environmental factors and harmful organisms. With the optimal supply of plants with all nutrients, excluding potassium, the synthesis, and dissimilation of carbohydrates are inhibited, proteins are consumed for respiration, and the activity of enzymes ceases [11]. The supply of spring rapeseed plants with potassium at the proper level helps increase nectar production and improve seed quality indicators [17]. Under the conditions of optimal provision of the element during the growing season, friendly flowering of the crop, increased resistance to lodging, improvement of water exchange processes and, as a final result, increased productivity are observed.

Mobile potassium is the most available form for plants, which ensures the processes of their nutrition.

Potassium, in other forms, can be used under the condition of a number of chemical and physical transformations in the soil, such as mineralisation, destruction of minerals and microorganisms, which lead to the transition of insoluble compounds in the solution [16].

The purpose of this study was to identify the influence of different nutritional conditions created by fertiliser options on the development of the productivity of spring rapeseed agrocenoses and the dynamics of the main elements of mineral nutrition in the soil and plants in the conditions of the Right Bank Forest Steppe of Ukraine.

MATERIALS AND METHODS

Field experiments were carried out in the production unit of the NULES of Ukraine "Agronomic Research Station" in the stationary crop rotation of the Department of Plant Breeding during 2010-2013 and 2015-2017 on typical low-humus chernozems (humus content – 4.38-4.53%, pH_{saline} – 6.9-7.3). Laboratory analyses were carried out in the laboratory of analytical research of the crop production department.

The territory of the experimental station belongs to the moderately warm, moderately humid agro-climatic sub-district of the Kyiv Oblast. The total amount of precipitation during the calendar year corresponds to an average of 543 mm, while for the period with temperature indicators above +5°C – 372 mm. Precipitation is unevenly distributed during the growing season [18].

The conditions of 2010, 2011 and 2016 can be characterised as conditions close to the average long-term indicators and favourable for the development of spring rapeseed.

The calculation of the coefficients of the substantiality of deviations (Cs) of the amount of precipitation and average temperatures indicates that the vast majority of months of crop vegetation belong to years with conditions close to normal (the first group of gradation).

The vegetation period of 2016 was characterised by the sum of effective temperatures exceeding the long-term indicators. The sum of the effective temperatures in April corresponded to 275°C, exceeding the long-term indicators by 115.4°C. This was reflected in the formation of shoots and the development of culture in the initial stages, speeding up their progress. May indicators were typical for this region. The summer months were characterised by exceeding the long-term indicators by 43-62.8°C.

The weather conditions in 2012 were close to the average long-term indicators. However, their distribution by months and decades at the initial stages of crop development did not meet the requirements of oil crops of the Brassicaceae family of the spring type of development, which was reflected in the formed productivity of the crop. The year 2012 was characterised by a lack of moisture during May and elevated temperature indicators in April-June. The weather conditions of 2013 were unfavourable for the development of rapeseed, which caused the lowest crop yield in the experiment.

The indicators of the sum of effective temperatures in 2015 exceeded the long-term average by 429.7°C and amounted to 3,302.7°C. In April and May, the sum of effective temperatures exceeded 37.9°C and 40.5°C, respectively. During the summer months, the sum of effective temperatures was within 633-685.1°C, with less precipitation compared to multiyear values. At the initial stages of rapeseed development, its soil reserves compensated the moisture deficit. June was characterised by drought and elevated temperatures. Weather conditions in 2017 were even more difficult and were characterised by a moisture deficit during the rapeseed growing season and stressful conditions caused by frost in the third decade of April. April's total effective temperatures were 49.9°C higher than the annual average. May turned out to be typical for this region, which ensured the early onset of the growing season. Excess of temperature indicators in June and July corresponded to 58°C and 28°C, respectively.

The subject under study was the Yura spring rapeseed hybrid. The technology used for the research was generally accepted for the Forest Steppe zone. Individual technological processes differed according to the scheme of the experiment. The predecessor is spring barley.

Scheme of the experiment – fertilisation options:

1. Without fertilisers (control).
2. $N_{30}P_{20}K_{35}$.
3. $N_{60}P_{40}K_{70}$.
4. $N_{90}P_{60}K_{105}$.
5. $N_{120}P_{80}K_{140}$.

Fertiliser rates were determined according to the balance method for the planned yield, considering the content of the main nutrients in the soil. The area of the accounting plot was 25 m^2. Repetition – four times. Placement of variants was sequential. Field, laboratory, analytical, and statistical methods of scientific research were used for this study [19-21].

The content of easily hydrolysed nitrogen compounds was found according to the Tyurin-Kononova method, ammonium nitrogen – colorimetrically, using the Nessler reagent; mobile phosphorus and potassium – according to the Chirikov method [22]. The content of the main nutrients in dry plant samples was determined by first ashing them according to the method of K. Ginzburg *et al.* [22]: nitrogen – according to the photocolorimetric method using Nessler's reagent; phosphorus – photocolorimetrically according to the Denizhe method in the A. Levytskyi's modification [22]; potassium – using a flame photometer [19; 22].

RESULTS AND DISCUSSION

The obtained results indicate that the application of mineral fertilisers increases the content of nitrogen, phosphorus, and potassium in the soil: their content increases with an increase in the rates of fertilisation. The conducted studies established that the increase in nitrogen fertilisation rates leads to an increase in the concentration of mineral compounds in the soil.

The highest content of nitrogen compounds in the soil is noted in the leaf rosette phase of spring rapeseed (BBCH 15-18) and, depending on the fertiliser option, it varies from 52.0 to 60.2 mg/kg of soil, while the content in the control option without fertilisation is 49.8 mg/kg of soil (Table 1). As the spring rapeseed plants grow and develop, the nitrogen content in the soil decreases: during the ripening period of the seeds (BBCH 85-88), it changes from 26.0 to 30.1 mg/kg of soil, compared to 20.1 mg/kg in the control version.

Analysis of the data in Table 1 shows that the highest content of mobile phosphorus compounds was noted in the first half of the growing season of the crop, which is associated with insignificant assimilation by plants in this period. During the period of formation of the leaf rosette (BBCH 15-18), the highest content of mobile phosphorus compounds in the arable layer of the soil was noted for $N_{120}P_{80}K_{140}$ and was 92.9 mg/kg of soil against 61.1 mg/kg of soil in the control variant without fertiliser.

Table 1. Dynamics of the macronutrient content in the soil during the cultivation of spring rapeseed, mg/kg of soil (average for 2010-2013)

Stages of growth and development of spring rapeseed plants	Nutrition element	Unit of measurement	Fertiliser options				
			Without fertiliser (control)	$N_{30}P_{20}K_{35}$	$N_{60}P_{40}K_{70}$	$N_{90}P_{60}K_{105}$	$N_{120}P_{80}K_{140}$
BBCH 15-18	N	Content, mg/kg of soil	49.8	52.0	53.7	56.4	60.2
	P_2O_5		61.1	62.9	76	84.7	92.9
	K_2O		94.5	107.5	108.5	119.5	137.5
BBCH 55-58	N		38.2	41.9	43.8	45.3	48.5
	P_2O_5		49.9	52.1	68.2	72.1	82.6
	K_2O		82.4	95.4	98.4	102.4	113.4
BBCH 65-68	N		26.6	32.1	35.2	38.1	40.7
	P_2O_5		29.1	48.2	51.9	56.4	60.0
	K_2O		58.8	67.1	76.3	79.6	88.7
BBCH 85-88	N		20.1	26.0	27.2	28.8	30.0
	P_2O_5		21.1	36.0	42.4	51.1	54.1
	K_2O		45.5	49.6	56.5	57.5	59.7
LSD_{05}	N	0.35					
	P_2O_5	0.63					
	K_2O	0.96					

The rate of application of mineral fertilisers directly affects the content of mobile potassium in the soil. Its highest content was noted at the beginning of the vegetation of spring rapeseed. Until the phase of full maturity (BBCH 85-88), it gradually decreased due to intensive use by plants. The maximum content of mobile potassium was noted in the rosette phase (BBCH 15-18) with the application of $N_{120}P_{80}K_{140}$ and was 137.5 mg/kg of soil, and in microstages BBCH 85-88, its content was 59.7 mg/kg of soil in this variant.

Thus, the application of mineral fertilisers positively affects the content of macronutrients in the soil. It was established that their number depends on both the application rate and the stage of development of spring rapeseed. In all variants of the experiment, the highest content was noted in microstage BBCH 15-18 (phase of leaf rosette formation). During plant growth and development, the content decreases and the minimum value is observed in BBCH 85-88 (ripening phase of spring rapeseed).

The assimilation of mineral nutrients is closely related to the accumulation of dry matter. Deficiency in nutrition leads to a decrease in yield, including due to a decrease in stress resistance of the culture, which is also confirmed by other researchers [23]. Under conditions of intensive farming, the increase in the yield of agricultural crops is accompanied by an increase in the removal of mineral nutrients from the soil [24; 25].

It is known that 13 nutrients, primarily macronutrients, play a vital role in optimising plant nutrition [26].

Research results indicate that with an increase in the amount of applied mineral fertilisers, the content of nutrients in plants increases at all stages of plant growth and development. This trend can be observed in all variants of fertiliser application. In the stemming phase (BBCH 35-38), the highest content of potassium was found in the plant material, the content of which varied depending on the rates of fertiliser application from 5.24% to 5.99%, while the content in the variant without fertiliser application was 4.93% (Table 2). Notably, as the phases of growth and development of rapeseed plants changed and, accordingly, the growth of vegetative mass and dry matter increased, the content of the main nutrients in plants gradually decreased.

Table 2. Dynamics of the content of mineral nutrients in spring rapeseed plants by growth phase, % of dry matter (average for 2015-2017)

Fertiliser options	Stages of growth and development of spring rapeseed plants											
	BBCH 35-38			BBCH5-58			BBCH 65-68			BBCH 80-83		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Without fertiliser (control)	2.76	1.02	4.93	1.71	0.71	2.99	1.1	0.48	2.51	1.02	0.31	1.79
$N_{30}P_{20}K_{35}$	2.98	1.08	5.24	1.9	0.79	3.54	1.23	0.6	2.69	1.28	0.39	1.91
$N_{60}P_{40}K_{70}$	3.26	1.13	5.55	2.0	0.85	3.96	1.51	0.65	2.77	1.36	0.5	1.97
$N_{90}P_{60}K_{105}$	3.35	1.22	5.87	2.13	0.88	4.18	1.67	0.71	2.89	1.48	0.53	2.06
$N_{120}P_{80}K_{140}$	3.59	1.26	5.99	2.27	0.92	4.59	1.81	0.73	3.1	1.54	0.6	2.14
LSD_{05}	0.06	0.04	0.15	0.04	0.04	0.9	0.06	0.03	0.09	0.05	0.03	0.12

The content of nitrogen in plants is lower: it varied from 2.98% to 3.59%, compared to 2.76% in the control version. Phosphorus content in spring rapeseed plants with fertilisers varied from 1.08% to 1.26%, while it was 1.02% in the case without fertilisers.

In the later stages of growth and development of spring rapeseed, a decrease in the content of all nutrients was observed, as evidenced by the research results. The positive effect of increased rates of mineral fertiliser application is confirmed by the results of research conducted in the north-eastern part of the Forest Steppe of Ukraine [27].

The conducted correlation-regression analysis of research results indicates a close correlation between the accumulation of dry matter in the BBCH 55-58 period and the level of productivity (r=0.91) (Fig. 1).

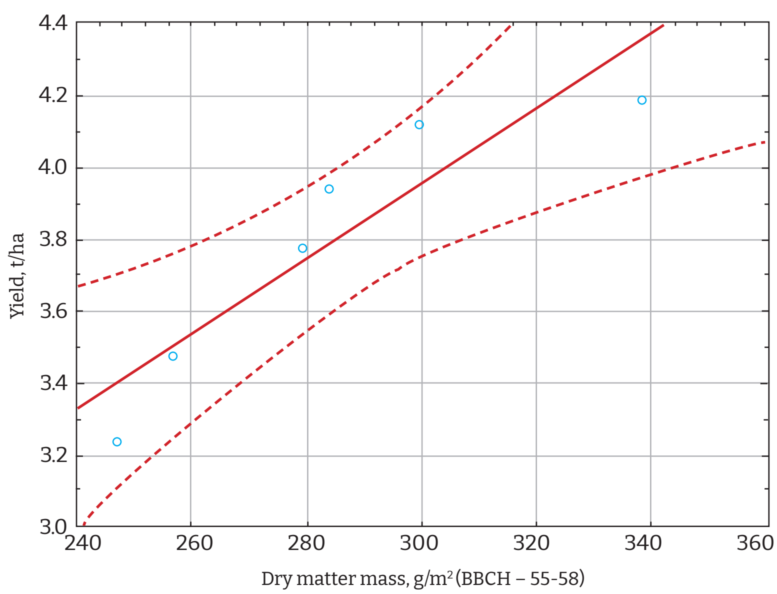

Figure 1. Correlation between yield (y) and dry matter mass (x) of spring rapeseed in BBCH microstages BBCH 55-58 (average for 2010-2013)

The resulting dependencies are described by the equations: Yield, t/ha=0.80369+0.01050 x mass of dry matter, g/m^2 (BBCH 55-58). Some scientists have obtained similar research results indicating an increase in accumulated dry matter by 7-32% under the influence of fertiliser application rates [1; 10; 17]. Use of mineral fertilisers in experiments by L. Harbar [1] positively affected the accumulation of dry matter during the entire vegetation period of rapeseed, which improved its productivity.

CONCLUSIONS

Based on the analysis of the current state of research in agronomic science on the cultivation of spring rapeseed, it was established that the application of mineral fertilisers in the maximum rates provides the best conditions for the formation of its crop.

Research established that the highest content of mineral nutrition elements in the soil is noted in the phase of spring rapeseed leaf rosette formation (BBCH 15-18) and gradually decreases towards the phase of full seed maturity (BBCH 85-88) due to their intensive use by plants. The maximum content of nitrogen compounds in the soil in BBCH 15-18 and depending on the fertiliser variant varies from 52.0 to 60.2 mg/kg of soil, mobile phosphorus compounds – 92.9 mg/kg of soil (after $N_{120}P_{80}K_{140}$), mobile potassium – 137.5 mg/kg of soil (for $N_{120}P_{80}K_{140}$). It can be argued that the content of macroelements in the soil is dictated by the rate of application of mineral fertilisers: increased application rates positively affect the accumulation of basic nutrients in the soil. Crop productivity and dry matter accumulation largely depend on the fertilisation system. A close correlation was established between the accumulation of dry matter in the BBCH 55-58 period and the yield level (r=0.91).

The issue of the content of mineral nutrition elements in the post-harvest residues of spring rapeseed requires further study, including in the root system and investigating the effect of applied mineral fertilisers on the yield of subsequent crops in crop rotation. The question of obtaining ecologically safe products of crop production at high rates of application of mineral fertilisers is still unresolved.

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Ефективність використання макроелементів рослинами ріпаку ярого

Анотація. Актуальність досліджень зумовлена необхідністю оптимізації продукційного процесу агроценозів ріпаку ярого та встановлення закономірностей динаміки макроелементів у ґрунті за впливу різних норм внесення мінеральних добрив. В зв'язку з цим дана стаття спрямована на розкриття закономірностей зміни вмісту макроелементів в чорноземах типових малогумусних за різними стадіями розвитку культури ріпаку ярого в умовах Правобережного Лісостепу України. У процесі наукових пошуків за цією проблемою застосовували польовий, лабораторний, аналітичний та статистичний методи досліджень. Встановлено, що найвищий вміст макроелементів у ґрунті за всіх рівнів мінерального удобрення – у фазі формування рослинами ріпаку ярого розетки листків (BBCH 15–18). У міру проходження фаз росту рослин він зменшується й у фазі дозрівання (BBCH 85–88) досягає мінімальних значень. Найвищий вміст мінеральних сполук азоту відмічено у BBCH 15–18: 52,0–60,2 мг/кг ґрунту залежно від варіанту удобрення, вміст у варіанті без внесення добрив – 49,8 мг/кг ґрунту. З'ясовано, що максимальний уміст рухомих сполук фосфору в ґрунті зафіксований у першій половині вегетаційного періоду. Встановлено, що вміст рухомого калію в ґрунті визначається кількістю внесених мінеральних добрив. Найвищий вміст відмічений на початку вегетації ріпаку ярого з поступовим зниженням до фази дозрівання насіння (BBCH 85–88). Встановлено тісний кореляційний зв'язок між накопиченням сухої речовини у період BBCH 55–58 та рівнем урожайності (r=0,91). Матеріали статті становлять практичну цінність для вдосконалення процесів, пов'язаних з формуванням продуктивності посівів ріпаку ярого в умовах Лісостепу України, а також раціональному використанню мінеральних добрив на чорноземах типових малогумусних

Ключові слова: *Brassica napus* L., мінеральне живлення, норми внесення мінеральних добрив, суха речовина, врожайність