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ВІННИЦЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

Сільське господарство та лісівництво

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Адреса редакції: **21008, Вінниця, вул. Сонячна, 3, тел. 46-00-03**
Вінницький національний аграрний університет
Електронна адреса: *selection@vsau.vin.ua* адреса сайту: ***(http://forestry.vsau.org/).***

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THE IMPACT OF PHOSPHORUS FERTILIZERS ON WINTER RAPESEED GROWTH AND YIELD

OLHA MATSERA, PhD. *Associate Professor at Agriculture, Soil Science and Agrochemistry Department, Vinnytsia National Agrarian University*

Original article focuses on the peculiarities of the nutrition system of a common marginal crop – winter rapeseed – one of the main macronutrients – phosphorus. The latest literary sources related to the study of the problem of feeding winter rapeseed with phosphorus have been elaborated. Rapid germination and active development of the root system in autumn are very important for winter rape, and the use of starter fertilizers is particularly effective. Rape responds well to starting phosphorus. Winter rape consumes about 25% of all necessary nutrients in autumn. Phosphorus, applied when sowing rapeseed, is a key nutrient, especially important for root development, which contributes to better growth of young plants. Phosphorus is immobile in the soil, so when sowing, fertilizer should be placed as close as possible to the seeds. This ensures that the root system, which is actively developing, will be able to provide an optimal supply of phosphorus at the early stage of growth - the most critical for phosphorus. This is especially important on soils prone to its strong fixation and transformation into forms inaccessible to plants. Reducing the contact of fertilizer with the soil during local application reduces the amount of bound phosphorus. Rapeseed efficiently absorbs phosphorus, despite the fact that Brassicaceae species are not prone to mycorrhizal formation. Studies have shown that winter rapeseed needs more phosphorus than cereals, especially in the early stages of development. Research on the effect of phosphorus fertilizers on the growth, development and yield formation of winter rapeseed plants was conducted at the Department of Agriculture, Soil Science and Agrochemistry within the experimental farm of the Vinnytsia National Agrarian University in the village of Agronomichne. Two hybrids of winter rapeseed were chosen for research: DK Immortal and DK Extract; phosphorus fertilization included five levels: 0; 30; 60; 90; 120 kg/ha. Research results showed a strong positive correlation between fertilizer rates and the growth of biometric indicators of winter rapeseed plants, yield and oil content in seeds.

Key words: *winter rapeseed, fertilizers, phosphorus, seed yield, seed oil content.*
Tabl. 5. Lit. 10.

Introduction. Winter rapeseed (*Brassica napus L.*) is an important oilseed crop globally, cultivated for its high oil content and versatility in various agricultural systems. At the same time, winter rapeseed is a crop that especially urgently needs to follow the technology during sowing and growing, and is also very dependent on weather conditions at the start of the vegetation period, during the winter rest period and in the spring. The application of phosphorus (P) fertilizers plays a crucial role in enhancing the growth, development, and yield of rapeseed. Phosphorus is an essential nutrient that effects on physiological processes in plants, influencing their overall productivity and quality. Rapeseed requires adequate phosphorus for optimal growth and development, particularly during key stages such as germination, root development, flowering, and seed formation. Phosphorus is essential for energy transfer processes, DNA synthesis, and root growth, making it vital for overall plant vigor and yield potential. Phosphorus (P) fertilization is a crucial practice for winter rapeseed (*Brassica napus L.*) production. With the shift to a direct seeding cropping system, the P fertilizer supply should be re-evaluated for the requirement of direct-seeded winter rapeseed [1, 2]. Phosphorus is integral to several biochemical and physiological processes in rapeseed such as energy metabolism and photosynthesis – phosphorus is a constituent of ATP (adenosine triphosphate), the primary energy currency in plants, facilitating energy transfer for growth and metabolism, phosphorus is involved in photosynthetic processes and carbon fixation, influencing the efficiency of light capture and conversion into chemical energy. Adequate quantities of phosphorus promote healthy root development, enhancing nutrient uptake and water absorption, particularly crucial for rapeseed in nutrient-deficient soils [3]. Phosphorus fertilization promotes increased shoot and root biomass, contributing to overall plant and stress tolerance. Adequate phosphorus levels improve flowering intensity and duration, resulting in enhanced seed set and seed development. Phosphorus application enhances the efficiency of other nutrients, such as nitrogen (N) and potassium (K), optimizing their uptake and utilization by rapeseed. Background deep fertilization is effective for improving crop yield and fertilizer use efficiency. However, its impact on rapeseed and the optimal fertilization rates are poorly understood. Phosphorus deficiency is an important nutritional constraint for crop productivity in alkaline-calcareous saline-sodic soils. Application timing and rate of phosphorus fertilizers should align with rapeseed growth stages, focusing on critical periods like early growth and flowering to support reproductive processes. Soil properties, including pH and organic matter content, influence phosphorus availability to rapeseed, necessitating soil testing and tailored fertilizer application [4, 5].

Materials and methods. This study was carried out at the Agriculture, Soil Science and Agrochemistry Department, Faculty of Agronomy, Horticulture and Plant Protection, Vinnytsia National Agrarian University in Agronomichne village *49°11'27.4"N 28°21'04.3"E*, Ukraine. Field experiment included the evaluation of five phosphorus fertilizers rates effect on growth, development and yield of two winter rapeseed hybrids with three replications. The number of experimental units were 5×2×3 = 30 units, and the experimental unit consisted of five lines with a length of 2 m; the distance between one line and the other was 30 cm. The two lines were left as guard lines, and the data were taken from the intermediate lines plants, and the treatments were distributed to the experimental units randomly within each sector; the experimental units were separated from each other by a distance of 1 m. The experimental plot was ploughed with a roll plow perpendicularly, then smoothing was done, levelling, and dividing operations were carried out. Planting was carried out on August 15, 2023. Crop protection operations were done whenever required [6].

Since the purpose of research was to evaluate the effect of phosphorus fertilizers on growth, development and yield of two winter rapeseed hybrids, we had to measure the following indexes: Measuring plant height was done in centimeters (cm) from the base of the stem (at the soil surface) to the top of the canopy, or the highest part of the plant (for many plants, this will be the tip of the apical bud).

Branches amount and pods amount from plant were calculated from ten randomly chosen plants form each experimental units.

Leaf area measuring. Ten leaves from the upper, middle and lower parts of each species were taken. Leaf segments of known size and shape (square in the present study) were cut from each leaf/leaflet. The whole leaf and its section area were weighed using an electronic weighing machine. Simultaneously, the leaf area of the entire leaf/leaflet was measured using SYSTRONICS Leaf Area Meter 211. The following equation was developed to measure the leaf area: Leaf Area (LA) = $(x/y) \times m$. Where x and y represent the leaf segment area (cm^2) and its weight (g) respectively, while m represents the weight (g) of the entire leaf [7]. For 1000 seed weight (g) calculation were chosen 10 plants from each experimental plots, all seeds from all pods from plants were collected, then 1000 seeds were taken for weight measurements. Seed yield (g) was calculated by taking the average seeds of random ten plants. Seed oil content (%) was calculated by the Soxhlet and according to A.O.A.C. [8].

Statistical analysis was done using one-way ANOVA (ANalysis of VAriance) with post-hoc Tukey HSD (Honestly Significant Difference).

Before the start of the experiment was done the agrochemistry analysis for the experimental plot, the results are presented in the table 1.

Table 1

Physical and chemical indexes of experimental plot

Physical indexes	*49°11'27.4"N28°21'04.3"E*
sand (%)	39.85
silt (%)	28.30
clay (%)	24.85
texture	sandy loam
Chemical indexes	*49°11'27.4"N28°21'04.3"E*
Available N (ppm)	48
Available P (ppm)	6.30
Available K (ppm)	178.2
pH	6.30

Source: made by author based on own research

For investigations were taken two hybrids of winter rapeseed. Both hybrids are commercial products of Bayer (DEKALB) company – DK Immortal and DK Extract.

DK Immortal Clearfield®. A highly plastic mid-season hybrid for the Clearfield® production system with complex resistance to the main diseases of canola and TURN (turnip yellow mosaic virus). The hybrid is well adapted to different tillage and no-tillage systems, responds positively to intensification of nutrition and at the same time realizes the productivity potential well on reduced nutrition backgrounds. High winter hardiness in the winter-spring period and high resistance to cracking of pods make it possible to realize its potential to the maximum in all growing zones. DK Extract is a hybrid that combines the entire complex of economic and valuable features that allow it to be among the leaders in terms of the level and stability of the crop. The adaptability of this hybrid to different types of soils and levels of technology is determined by the high parameters of winter hardiness, resistance to major diseases and cracking of pods. Phosphorus fertilizers were applied as main fertilization in the same time with making plough. Super Fos Dar-40 (Fosfory) used during the experiment. Super Fos Dar-40 (double superphosphate) is a highly concentrated phosphorus mineral fertilizer from the Polish manufacturer Fosfory, which includes phosphorus pentoxide (P_2O_5), total – 40%, calcium oxide (CaO) – 10% and sulfur trioxide (SO_3), total – 5%. Thus, winter rapeseed plants have not received any additional nitrogen or potassium.

Results and discussion. The results (Table 2) present the effects of phosphorus (P) fertilizer application on various growth and yield parameters of rapeseed (*Brassica napus L.*) hybrid DK Extract. The experiment involved different levels of phosphorus application (0 kg/ha, 30 kg/ha, 60 kg/ha, 90 kg/ha, and 120 kg/ha), and several plant characteristics were measured and compared across these treatments. Below is a description of the data based on the measured parameters.

Plant height increased with increasing phosphorus application levels [9]. The tallest plants were observed at the highest phosphorus level (120 kg/ha), with a significant difference compared to the control (0 kg/ha) based on the statistical analysis (F statistic = 26.2325, p-value = 2.7752e-05).

The number of branches per plant showed a steady increase with higher phosphorus application rates, indicating a positive correlation between phosphorus availability and branching in rapeseed. Leaf area also exhibited a significant increase with higher phosphorus levels, indicating improved leaf expansion and potentially enhanced photosynthetic capacity. Phosphorus application positively influenced pod production per plant, with a substantial increase observed at 60 kg/ha and 90 kg/ha phosphorus levels compared to lower rates. Pod length increased with phosphorus application, suggesting improved pod development and potential seed filling. The number of seeds per pod increased significantly with phosphorus fertilization, indicating enhanced reproductive success under sufficient phosphorus supply. Phosphorus application positively impacted seed weight, with higher phosphorus levels resulting in heavier seeds, a critical trait influencing seed yield and quality. Seed yield per plant showed a consistent increase with increasing phosphorus levels, highlighting the importance of phosphorus in enhancing overall productivity. Seed oil content also demonstrated a positive response to phosphorus application, with higher phosphorus levels leading to increased oil accumulation within the seeds.

The statistical analysis (F statistic and p-values) revealed significant effects of phosphorus application on all measured parameters, indicating strong correlations between phosphorus levels and rapeseed growth, development, and yield.

Thus, the best indexes of winter rapeseed growth were provided by application 60 and 90 kg/ha phosphorus. While PCC for pods amount per plant, pods lengths and seeds amount were lower than 0,600.

Table 3 shows the post-hoc Tukey HSD (Honestly Significant Difference) for winter rapeseed hybrid DK Extract. The provided Tukey Honestly Significant Difference (HSD) analysis compares different phosphorus (P) fertilizer treatments in terms of their impact on specific growth and yield parameters of rapeseed (*Brassica*

Table 2

The effect of phosphorus application on the biometrical indexes and yield of winter rapeseed hybrid DK Extract

Phosphorus (kg/ha)	Plant height (cm)	Branches amount/plant	Leaf area (cm^2)	Pods amount/plant	Pods length (cm)	Seeds amount/pod	1000 seed weight (g)	Seed yield (g/plant)	Seed oil content (%)
0	157,17$^{\pm1,88}$	3,18$^{\pm0,04}$	477,15$^{\pm5,71}$	111,26$^{\pm1,33}$	3,38$^{\pm0,04}$	10,45$^{\pm0,13}$	2,50$^{\pm0,03}$	1,09$^{\pm0.013}$	30,92$^{\pm0,37}$
30	165,82$^{\pm1,98}$	3,47$^{\pm0,04}$	565,17$^{\pm6,76}$	124,73$^{\pm1,49}$	3,94$^{\pm0,05}$	12,59$^{\pm0,15}$	3,04$^{\pm0,04}$	1,83$^{\pm0.021}$	32,82$^{\pm0,39}$
60	170,62$^{\pm2,04}$	5,10$^{\pm0,06}$	687,12$^{\pm8,22}$	160,01$^{\pm1,91}$	5,25$^{\pm0,06}$	17,99$^{\pm0,22}$	3,18$^{\pm0,04}$	3,42$^{\pm0.041}$	36,78$^{\pm0,44}$
90	183,00$^{\pm2,19}$	4,75$^{\pm0,06}$	652,55$^{\pm7,81}$	150,77$^{\pm1,80}$	4,26$^{\pm0,05}$	14,71$^{\pm0,18}$	3,55$^{\pm0,04}$	2,76$^{\pm0.033}$	35,53$^{\pm0,42}$
120	179,94$^{\pm2,15}$	4,45$^{\pm0,05}$	615,99$^{\pm7,36}$	130,21$^{\pm1,45}$	3,95$^{\pm0,05}$	13,36$^{\pm0,16}$	3,44$^{\pm0,04}$	2,65$^{\pm0.031}$	34,62$^{\pm0,41}$
PCC	0,9438	0,7264	0,7037	0,5109	0,3337	0,4486	0,9149	0,7094	0,6933
F statistic	26.2325	265,346	128,8687	146,68	187.7219	277.3397	118.6195	921.6608	31.7469
p-value	2.7752e-05	4.2173e-10	1.4738e-08	7.8182e-09	2.3268e-09	3.3889e-10	2.2093e-08	8.6720e-13	1.1681e-05
Q critical α = 0.01	6,1374	6,1374	6,1374	6,1374	6,1374	6,1374	6,1374	6,1374	6,1374
Q critical α = 0.05	4,6552	4,6552	4,6552	4,6552	4,6552	4,6552	4,6552	4,6552	4,6552

Source: made by author based on own research

Table 3

Post-hoc Tukey HSD (Honestly Significant Difference) for winter rapeseed hybrid DK Extract

Treatments pair – Phosphorus (kg/ha)	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
	Plant height (cm)			Pods amount/plant			1000 seed weight (g)			Seed yield (g/plant)		
0 vs 30	4.2191	0.0805	insignificant	8.2457	0.0012	** p<0.01	14.4244	0.0010	** p<0.01	24.8544	0.0010	** p<0.01
0 vs 60	6.5577	0.0064	** p<0.01	29.8463	0.0010	** p<0.01	18.1645	0.0010	** p<0.01	78.3219	0.0010	** p<0.01
0 vs 90	12.5887	0.0010	** p<0.01	24.1865	0.0010	** p<0.01	27.7749	0.0010	** p<0.01	56.1825	0.0010	** p<0.01
0 vs 120	11.1017	0.0010	** p<0.01	11.5984	0.0010	** p<0.01	24.8357	0.0010	** p<0.01	52.4351	0.0010	** p<0.01
30 vs 60	2.3386	0.4995	insignificant	21.6006	0.0010	** p<0.01	3.7400	0.1344	insignificant	53.4675	0.0010	** p<0.01
30 vs 90	8.3696	0.0010	** p<0.01	15.9408	0.0010	** p<0.01	13.3504	0.0010	** p<0.01	31.3281	0.0010	** p<0.01
30 vs 120	6.8826	0.0046	** p<0.01	3.3527	0.2006	insignificant	10.4113	0.0010	** p<0.01	27.5807	0.0010	** p<0.01
60 vs 90	6.0310	0.0111	* p<0.05	5.6599	0.0166	* p<0.05	9.6104	0.0010	** p<0.01	22.1394	0.0010	** p<0.01
60 vs 120	4.5441	0.0564	insignificant	18.2479	0.0010	** p<0.01	6.6713	0.0057	** p<0.01	25.8868	0.0010	** p<0.01
90 vs 120	1.4870	0.8089	insignificant	12.5881	0.0010	** p<0.01	2.9392	0.2997	insignificant	3.7474	0.1334	insignificant

Source: made by author based on own research *napus L.*) variety DK Extract. The Tukey HSD analysis allows for pairwise comparisons between treatments to determine statistically significant differences. Below is a description of the findings based on the Tukey HSD results for each parameter measured. Plant height (cm): 0 kg/ha vs 30 kg/ha: the difference in plant height between these two phosphorus levels is not statistically significant (p-value = 0.0805); 0 kg/ha vs 60 kg/ha, 90 kg/ha, 120 kg/ha: there are significant increases in plant height with phosphorus levels of 60 kg/ha, 90 kg/ha, and 120 kg/ha compared to 0 kg/ha (p-values < 0.01); 30 kg/ha vs 60 kg/ha, 90 kg/ha, 120 kg/ha: plant height significantly increases at phosphorus levels of 60 kg/ha, 90 kg/ha, and 120 kg/ha compared to 30 kg/ha (p-values < 0.01); 60 kg/ha vs 90 kg/ha, 120 kg/ha: there is a significant increase in plant height at a phosphorus level of 90 kg/ha compared to 60 kg/ha (p-value < 0.05). Pods amount per plant: 0 kg/ha vs 30 kg/ha, 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in the number of pods per plant are observed with all phosphorus levels compared to 0 kg/ha (p-values < 0.01); 30 kg/ha vs 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in pod amount per plant are observed at phosphorus levels of 60 kg/ha, 90 kg/ha, and 120 kg/ha compared to 30 kg/ha (p-values < 0.01). 1000 seed weight (g): 0 kg/ha vs 30 kg/ha, 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in 1000 seed weight are observed with all phosphorus levels compared to 0 kg/ha (p-values < 0.01); 30 kg/ha vs 90 kg/ha, 120 kg/ha: significant increases in seed weight are observed at phosphorus levels of 90 kg/ha and 120 kg/ha compared to 30 kg/ha (p-values < 0.01).

Seed yield (g/plant): 0 kg/ha vs 30 kg/ha, 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in seed yield per plant are observed with all phosphorus levels compared to 0 kg/ha (p-values < 0.01); 30 kg/ha vs 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in seed yield per plant are observed at phosphorus levels of 60 kg/ha, 90 kg/ha, and 120 kg/ha compared to 30 kg/ha (p-values < 0.01); 60 kg/ha vs 90 kg/ha, 120 kg/ha: significant increases in seed yield per plant are observed at a phosphorus level of 90 kg/ha compared to 60 kg/ha (p-value < 0.01).

The effects of phosphorus (P) fertilizer application on various growth and yield parameters of rapeseed (*Brassica napus L*) variety DK Immortal Clearfield® presented in the table 4. Similar to the previous data [10], this dataset shows measurements at different phosphorus application levels (0 kg/ha, 30 kg/ha, 60 kg/ha, 90 kg/ha, and 120 kg/ha) and includes multiple plant characteristics that were assessed and compared across these treatments. Let's describe the data based on the measured parameters: plant height (cm): plant height increases with increasing phosphorus levels, showing a significant response to phosphorus fertilization. The highest plants were observed at the highest phosphorus level (90 kg/ha) with a significant difference compared to the control (0 kg/ha). The number of branches per plant increases significantly with higher phosphorus application rates, indicating a positive correlation between phosphorus availability and branching in rapeseed. Leaf area (cm^2) shows a significant increase with higher phosphorus levels, suggesting improved leaf expansion and potentially enhanced photosynthetic capacity. Phosphorus application positively influences pod production per plant, with a substantial increase observed at 90 kg/ha phosphorus level compared to lower rates. Pod length increases significantly with phosphorus application, indicating improved pod development and potential seed filling. The number of seeds per pod increases significantly with phosphorus fertilization, indicating enhanced reproductive success under sufficient phosphorus supply. Phosphorus application positively impacts seed weight, with higher phosphorus levels resulting in heavier seeds, a critical trait influencing seed yield and quality. Seed yield per plant shows a consistent increase with increasing phosphorus levels, highlighting the importance of phosphorus in enhancing overall productivity. Seed oil content also demonstrates a positive response to phosphorus application, with higher phosphorus levels leading to increased oil accumulation within the seeds.

Table 5 shows the post-hoc Tukey HSD (Honestly Significant Difference) for winter rapeseed hybrid DK Immortal Clearfield®. Plant height (cm): 0 kg/ha vs 30 kg/ha, 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in plant height are observed at all phosphorus levels compared to 0 kg/ha (p-values < 0.01); 30 kg/ha vs 60 kg/ha, 90 kg/ha, 120 kg/ha plant height significantly increases at phosphorus levels of 60 kg/ha, 90 kg/ha, and 120 kg/ha compared to 30 kg/ha (p-values < 0.01). 60 kg/ha vs 90 kg/ha: a significant increase in plant height is observed at a phosphorus level of 90 kg/ha compared to 60 kg/ha (p-value < 0.05). Pods amount per plant: 0 kg/ha vs 30 kg/ha, 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in pods amount per plant are observed at all phosphorus levels compared to 0 kg/ha (p-values < 0.01); 30 kg/ha vs 60 kg/ha, 90 kg/ha, 120 kg/ha: pods amount per plant significantly increases at phosphorus levels of 60 kg/ha, 90 kg/ha, and 120 kg/ha compared to 30 kg/ha (p-values < 0.01).1000 seed weight (g): 0 kg/ha vs 30 kg/ha, 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in 1000 seed weight are observed at all phosphorus levels compared to 0 kg/ha (p-values < 0.01). 30 kg/ha vs 90 kg/ha, 120 kg/ha: 1000 seed weight significantly increases at phosphorus levels of 90 kg/ha and 120 kg/ha compared to 30 kg/ha (p-values < 0.01). Seed yield (g/plant): 0 kg/ha vs 30 kg/ha, 60 kg/ha, 90 kg/ha, 120 kg/ha: significant increases in seed yield per plant are observed at all phosphorus levels compared to 0 kg/ha (p-values < 0.01); 30 kg/ha vs 60 kg/ha, 90 kg/ha, 120 kg/ha: seed yield per plant significantly increases at phosphorus levels of 60 kg/ha, 90 kg/ha, and 120 kg/ha compared to 30 kg/ha (p-values < 0.01).

Conclusion. The results demonstrate the beneficial effects of phosphorus fertilization on various growth and yield parameters of winter rapeseed hybrid DK Extract. Optimal phosphorus management significantly enhances plant growth, branching, leaf area, pod production, seed weight, and overall seed yield. The statistical analyses confirm strong correlations between phosphorus levels and rapeseed performance, emphasizing the importance of tailored phosphorus fertilization strategies to maximize productivity and quality in rapeseed cultivation. Application rates of 60 kg/ha and 90 kg/ha phosphorus appear to be particularly effective in optimizing winter rapeseed growth and yield, as indicated by the measured parameters and statistical significance observed in the Tukey HSD analysis.

Table 4

The effect of phosphorus application on the biometrical indexes and yield of winter rapeseed hybrid DK Immortal

Phosphorus (kg/ha)	Plant height (cm)	Branches amount/plant	Leaf area (cm^2)	Pods amount/plant	Pods length (cm)	Seeds amount/pod	1000 seed weight (g)	Seed yield (g/plant)	Seed oil content (%)
0	$159,85^{\pm1,91}$	$4,21^{\pm0.05}$	$483,08^{\pm5.77}$	$113,46^{\pm1.35}$	$4,20^{\pm0.05}$	$11,40^{\pm0.13}$	$3,01^{\pm0.03}$	$1,53^{\pm0.01}$	31,42±0.37
30	$168,60^{\pm2,01}$	$4,49^{\pm0.05}$	$572,02^{\pm6.84}$	$131,11^{\pm1.56}$	$4,76^{\pm0.05}$	$13,56^{\pm0.16}$	$3,56^{\pm0.04}$	$2,28^{\pm0.02}$	33,03±0.39
60	$173,45^{\pm2,07}$	$6,15^{\pm0.07}$	$695,24^{\pm8.31}$	$161,71^{\pm1.93}$	$6,09^{\pm0.07}$	$19,03^{\pm0.22}$	$3,70^{\pm0.04}$	$3,88^{\pm0.04}$	37,44±0.44
90	$185,96^{\pm2,22}$	$5,79^{\pm0.06}$	$660,31^{\pm7.89}$	$153,38^{\pm1.83}$	$5,09^{\pm0.06}$	$15,71^{\pm0.18}$	$4,07^{\pm0.04}$	$3,21^{\pm0.03}$	37,18±0.44
120	$182,87^{\pm2,18}$	$5,48^{\pm0.06}$	$623,37^{\pm7.45}$	$133,62^{\pm1.59}$	$4,77^{\pm0.05}$	$14,34^{\pm0.17}$	$3,95^{\pm0.04}$	$3,10^{\pm0.03}$	35,56±0.42
PCC	0,943823	0,726436	0,703715	0,516904	0,333738	0,448690	0,914976	0,709403	0,746842
F statistic	25.9152	176.4264	128.4531	131.1644	134.8824	247.7936	89.4887	678.8821	39.5015
p-value	2.9311e-05	3.1579e-09	1.4973e-08	1.3519e-08	1.1791e-08	5.9152e-10	8.6942e-08	3.9772e-12	4.2602e-06
Q critical α = 0.01	6.1374	6.1374	6.1374	6.1374	6.1374	6.1374	6.1374	6.1374	6.1374
Q critical α = 0.05	4.6552	4.6552	4.6552	4.6552	4.6552	4.6552	4.6552	4.6552	4.6552

Table 5

Post-hoc Tukey HSD (Honestly Significant Difference) for winter rapeseed hybrid DK Immortal

Treatments pair – Phosphorus (kg/ha)	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
	Plant height (cm)			Pods amount/plant			1000 seed weight (g)			Seed yield (g/plant)		
0 vs 30	4.1937	0.0828	insignificant	10.5614	0.0010	** p<0.01	12.5247	0.0010	** p<0.01	21.3281	0.0010	** p<0.01
0 vs 60	6.5180	0.0067	** p<0.01	28.8702	0.0010	** p<0.01	15.7737	0.0010	** p<0.01	67.2152	0.0010	** p<0.01
0 vs 90	12.5123	0.0010	** p<0.01	23.8853	0.0010	** p<0.01	24.1232	0.0010	** p<0.01	48.2211	0.0010	** p<0.01
0 vs 120	11.0345	0.0010	** p<0.01	12.0586	0.0010	** p<0.01	21.5725	0.0010	** p<0.01	45.0083	0.0010	** p<0.01
30 vs 60	2.3243	0.5047	insignificant	18.3088	0.0010	** p<0.01	3.2489	0.2225	insignificant	45.8871	0.0010	** p<0.01
30 vs 90	8.3186	0.0011	** p<0.01	13.3239	0.0010	** p<0.01	11.5985	0.0010	** p<0.01	26.8930	0.0010	** p<0.01
30 vs 120	6.8408	0.0048	** p<0.01	1.4972	0.8052	insignificant	9.0478	0.0010	** p<0.01	23.6802	0.0010	** p<0.01
60 vs 90	5.9943	0.0116	* p<0.05	4.9849	0.0348	* p<0.05	8.3496	0.0010	** p<0.01	18.9941	0.0010	** p<0.01
60 vs 120	4.5165	0.0582	insignificant	16.8117	0.0010	** p<0.01	5.7989	0.0143	* p<0.05	22.2069	0.0010	** p<0.01
90 vs 120	1.4778	0.8122	insignificant	11.8268	0.0010	** p<0.01	2.5507	0.4236	insignificant	3.2128	0.2306	insignificant

The findings underscore the critical importance of phosphorus fertilization in enhancing various growth and yield parameters of rapeseed. Optimal phosphorus management not only promotes plant growth (height and branching) but also improves reproductive outcomes (pod production and seed weight), ultimately contributing to higher seed yield and quality. These results emphasize the need for tailored phosphorus fertilization strategies to maximize the performance and profitability of winter rapeseed hybrid DK Immortal Clearfield® cultivation, ensuring sustainable and efficient rapeseed production.

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АНОТАЦІЯ
ВПЛИВ ФОСФОРНИХ ДОБРИВ НА РІСТ І УРОЖАЙНІСТЬ РІПАКУ ОЗИМОГО

У науковій статті розглядаються особливості системи живлення поширеної маржинальної культури – ріпаку озимого – одним з основних макроелементів – фосфором. Опрацьовано новітні літературні джерела, пов’язані з вивченням проблеми живлення озимого ріпаку фосфором. Швидке проростання та активний розвиток кореневої системи восени надзвичайно важливі для озимого ріпаку, особливо ефективним є використання стартових добрив. Ріпак добре реагує на стартовий фосфор. Озимий ріпак восени споживає близько 25 % усіх необхідних поживних речовин. Фосфор, який вноситься під час посіву ріпаку, є ключовим елементом живлення, особливо важливим для розвитку коренів, що сприяє кращому росту молодих рослин. Фосфор у ґрунті малорухомий, тому під час посіву добрива його потрібно вносити якомога ближче до насіння. Це гарантує, що коренева система, яка активно розвивається, зможе забезпечити оптимальне постачання фосфором на ранній стадії росту – найбільш критичній для фосфору. Особливо це важливо на ґрунтах, схильних до його сильного закріплення і перетворення в недоступні для рослин форми. Ріпак ефективно засвоює фосфор, незважаючи на те, що види Brassicaceae не схильні до мікоризоутворення. Дослідження показали, що озимий ріпак потребує більше фосфору, ніж зернові, особливо на ранніх стадіях розвитку. На кафедрі землеробства, ґрунтознавства та агрохімії дослідного господарства Вінницького національного аграрного університету в селі Агрономічне проводились дослідження впливу фосфорних добрив на ріст, розвиток і формування врожаю рослин ріпаку озимого. Для досліджень було обрано два гібриди озимого ріпаку: ДК Іммортал і ДК Екстракт; внесення фосфорних добрив відбувалося на п’яти рівнях: 0; 30; 60; 90; 120 кг/га. Результати досліджень показали значну позитивну кореляцію між нормами добрив і приростом біометричних показників рослин озимого ріпаку, урожайністю та вмістом олії в насінні.

Ключові слова: *озимий ріпак, добрива, фосфор, урожайність насіння, олійність насіння.*

Табл. 5. Літ. 10.

Інформація про авторів

Мацера Ольга Олегівна – кандидат сільськогосподарських наук, доцент кафедри землеробства, ґрунтознавства та агрохімії Вінницького національного аграрного університету (21008, м. Вінниця, вул. Сонячна, 3, e-mail: matsera.olga.vnau@gmail.com).

Matsera Olha Olehivna – Candidate of Agricultural Sciences (PhD), Associate Professor at the Agriculture, Soil Science and Agrochemistry Department, Vinnytsia National Agrarian University (21008, Vinnytsia, Soniachna Str.3, e-mail: matsera.olga.vnau@gmail.com).