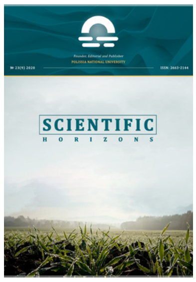
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 28(2), 55-62



UDC 635.15:631.82/85:631.53.01/.02
DOI: 10.48077/scihor2.2025.55

Formation of sowing qualities of oil radish seeds depending on the nutrition system in the Western Forest-Steppe

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Article's History:
Received: 18.10.2024
Revised: 07.01.2025
Accepted: 22.01.2025

Abstract. The reasons for the limited distribution of oil radish include the lack of seeds caused by the imperfection of the elements of cultivation technology, which requires additional research. The purpose of this study was to improve the technology of growing oil radish varieties through the plant nutrition system. Methodological research was based on general scientific and special methods. The study was conducted at the experimental base of the Department of Seed Production and Seed Science of the

Suggested Citation:
Voloshchuk O., Panakhyd, H., Voloshchuk, I., Hlyva, V., & Bilonizhka, K. (2025). Formation of sowing qualities of oil radish seeds depending on the nutrition system in the Western Forest-Steppe. *Scientific Horizons*, 28(2), 55-62. doi: 10.48077/scihor2.2025.55.

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Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine. Based on the results obtained in 2022-2024, it was substantiated that the low natural fertility of grey forest surface-gleyed soils of the Western Forest-Steppe and the insufficient supply of microelements in them cause low yields and seed quality of the crop under study. This problem can be solved by developing a balanced nutrition system for oil radish based on innovative macro- and microelements. Under effective pre-sowing seed treatment with microfertilisers in combination with insecticidal and fungicidal seed treatment with Modesto preparation, 48% FC (12.5 l/t) and against the background of mineral fertilisers in the norm of $N_{30}P_{90}K_{100}$ with nitrogen fertilisation + N_{50} (main growth stage and developmental stages – BBCH 14-16) + N_{30} (BBCH 52-53), the statistically significant yield increases were 0.23-0.36 t/ha. Balanced plant nutrition contributed to the improvement of sowing qualities of seeds, specifically, the thousand-kernel-weight, germination energy, and laboratory germination. The improved nutrition system for oil radish, considering the introduction of mineral fertilisers and chelated micronutrients into the cultivation technology, can be used by agricultural enterprises and farms engaged in growing the crop for seeds, which will increase the production of seed material to expand the sown areas in the region

Keywords: oil radish; variety; seeds; mineral fertilisers; micronutrient fertilisers; yield; sowing qualities

INTRODUCTION

Currently, agribusiness is focused on growing marketable, high-yielding oilseeds. Among the biological range and agrotechnical possibilities, oil radish plays a significant role. This previously well-known crop can be used as a fodder crop in the context of climate change, and its spring post-mowing and post-harvest sowings are a valuable source of green fodder in the conveyor production system. It can be grown in monoculture and in grass mixtures. During a short growing season (40-50 days), it produces 30-70 t/ha of leaf mass with an optimum content of digestible protein. Its great value lies in restoring the fertility of depleted soils, as well as in its use as a substitute for organic fertilisers when ploughing biomass. According to H.S. Hereshko *et al.* (2021), the significant agrotechnical value of this crop resides in the fact that the plant cleanses the soil from nematodes, wireworms, pathogens, enriching it with a complex of useful substances (organic matter, nitrogen, phosphorus, potassium, trace elements), prevents root rot, and is antagonistic to malicious wheatgrass.

Producers of this crop are offered different varieties for cultivation, created in distinct soil and climatic zones, with differences in morphological characteristics and economic qualities. However, S.V. Nrigorenko (2019) and Ya. Tsytsyura (2020) noted that the technological spread of the crop itself is conditioned by the limited varietal resources, with an urgent problem of using it for feed and seed purposes. From both theoretical and practical standpoints, it is vital to investigate the reaction of the variety to concrete growing conditions and the proposed elements of technology, which allows selecting the most environmentally friendly and plastic ones for different zones, subzones, and levels of management (Karamushka & Moroz, 2018).

In recent years, climate change has become evident, affecting vital functions under unfavourable environmental conditions, and therefore obtaining high and stable yields and qualities of oil radish seeds depends on the resistance of plants during the growing season, according to Bilonizhka (2023). It is with a balanced macro- and microelements nutrition system that their negative impact can be levelled. Kh.V. Bilonizhka (2024) reported that optimum nutrition of oil radish varieties conditioned by the application of mineral fertilisers and micronutrient fertilisers contributes to an increase in the morphological parameters of plants, namely: plant height, number of stems per plant, pods, seeds in the pod and per plant, increases the weight of seeds per plant, and the thousand-kernel-weight, which affects their productivity.

According to A.V. Yunyk and I.V. Trifonov (2020), to form 1 tonne of dry matter, oil radish consumes 35-40 kg of nitrogen, 12-19 kg of phosphorus, 48-50 kg of potassium, and 16-20 kg of calcium. The soils of the Carpathian region are characterised by a low supply of available forms of macro- and microelements and therefore obtaining high yields and sowing qualities of oil radish seeds is somewhat problematic and requires scientific substantiation. Scientific publications on the technology of growing this crop are limited and do not fully cover the innovative elements of today.

The purpose of the present study was to improve the plant nutrition system of oil radish varieties through the main application of mineral fertilisers and pre-sowing seed treatment with microfertilisers for the formation of yield and sowing characteristics in the Western Forest-Steppe zone.

MATERIALS AND METHODS

Experimental research was conducted at the Department of Seed Production and Seed Science of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences (49°47′07″ N, 23°52′07″ E, 314 m above sea level) in 2022, 2023, and 2024. Varieties (factor B) of oil radish were used for the research: Zhuravka – originated by the Carpathian State Agricultural Research Station of the Institute of Agriculture of the Carpathian Region of NAAS, and

Fakel – Institute of Oilseeds of NAAS. The grey forest, surface-gleyed, light loamy soil of the experimental plots was characterised by a very low supply of nitrogen and potassium, medium supply of phosphorus, and a slightly acidic reaction of the soil solution (pH_{salt} – 5.4). The content of trace elements was as follows: boron (B) – 0.67 mg/kg soil (average supply), manganese (Mg) – 21.99, cobalt (Co) – 0.56, copper (Cu) – 1.68 (low), and high in zinc (Zn) – 0.59 mg/kg soil.

In all variants of the experiment, seeds were treated with insecticidal-fungicidal seed preparation Modesto, 48% FC (12.5 l/t). The experimental scheme included microfertilisers (factor A): 1. Without microfertilisers – control, 2. Oracle seed (1.0 l/t), 3. YaraVita Brasitrel Pro (1.0 l/t), 4. Vitazim (1.0 l/t). The level of mineral nutrition was $N_{30}P_{60}K_{70}$ + N_{40} (BBCH 14-16) + N_{20} (BBCH 52-53). The study was conducted using the methodology by S. Tkachyk (2016). The field experiments were set up and conducted according to the generally accepted methodology of research work – statistical analysis of the results was performed using the analysis of variance according to the method of V.O. Ushkarenko *et al.* (2014). The correlation between yield and seed quality was determined considering: from 0 to 0.33 – weak, from 0.33 to 0.66 – medium, from 0.66 to 1.00 – strong, 1.00 – complete, both for direct and inverse correlation (r), with reliability at the 5% statistical significance level. Sowing qualities of seeds were determined in the laboratory according to the thousand-kernel-weight, germination energy, and laboratory germination according to the methods of DSTU 4138-2002 (2004).

According to the standard, the thousand-kernel-weight was determined by two weights of 500 kernels each, after which it was converted to the thousand-kernel-weight and the average weight was calculated to the nearest 0.1 g. If the deviation of the weight of two samples from the average thousand-kernel-weight exceeded 0.5 %, a third sample was deducted and weighed. The calculated average thousand-kernel-weight was adjusted to a standard moisture content of 8% using the following formula:

$$W = \frac{W1x(100-m)}{100-Sm}, \quad (1)$$

where W_1 is the thousand-kernel-weight, g; *m* is the moisture content, %; *Sm* is the standard moisture content, 14%.

The germination energy and laboratory germination of seeds were determined in a certified laboratory of agrochemistry and analytical research of the Institute of Agriculture of the Carpathian region of NAAS by germinating each variety in Petri dishes on filter paper under optimum conditions of 25°C in a dry-air thermostat TS-80. The ratio of seeds that germinated to the total number (100 pcs.) was used to determine the germination energy on Day 3, and the laboratory germination of seeds on Day 6. The seed yield was determined by continuous threshing with a Sampo-130 combine harvester from each plot, after which the seeds were weighed and recalculated to a standard moisture content of 8%.

The weather conditions during the years of research were characterised by higher monthly air temperatures and slightly lower precipitation compared to the long-term average. Figure 1 shows the hydrothermal coefficient (HTC), i.e., the moisture availability of the territory during the growing season of oil radish varieties. For the Western Forest-Steppe of Ukraine, the norm is 1.1-1.6; in 2022, the HTC was insufficient on average (0.87), in 2023 – excessive (1.66), and in 2024 – optimum (1.16).

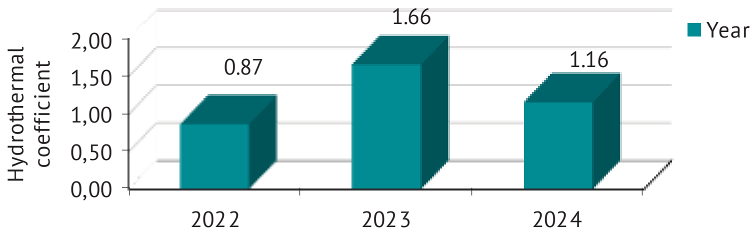

***Figure 1**. Moisture level (2022-2024)*
***Source:** compiled by the authors of this study*

The total area of the experimental plot was 60 m^2, and the accounting area was 50 m^2. The variants were placed systematically, with three replications: Zhuravka, Fakel is generally accepted in this zone. Soil cultivation includes primary tillage to a depth of 10-12 cm and ploughing to a depth of 20-22 cm. The previous crop was winter wheat. Sowing was performed in the third decade of April. The seeding rate of oil radish (*Raphanus sativum d. var. oleifera* Metrg.) varieties was 2.0 million germinating seeds per hectare. The seeds were treated with Modesto seed preparation, 48% FC (insecticidal-fungicidal action, 12.5 l/t). The seeding depth was 2-4 cm, and the sowing method was conventional row seeding (15 cm). Herbicides: Roundup, 48% AS (2-3 weeks before ploughing), Butyzan, 40% SC (1.75-2.50 l/ha); insecticides against pests – Calypso, 48% SC (0.25-0.40 l/ha). The study followed the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

Against the background of mineral nutrition of plants with $N_{30}P_{60}K_{70}$ + N_{50} (4-6 leaves) + N_{20} (peduncle of the main shoot) and pre-sowing treatment of seeds of Zhuravka and Fakel varieties with microfertilisers, the average yield of oil radish ranged from 3.33 t/ha in the control variant (without microfertilisers) to 3.69 t/ha when applying YaraVita Brasitrel Pro (1.0 l/t), which provided an increase of 0.36 t/ha. A slightly lower result, 3.62 t/ha, was obtained with the Vitazim microfertiliser (1.0 l/t), and the lowest result, 3.56 t/ha, was obtained with the Oracle Seeds (1.0 l/t) (Fig. 2). At $LSD_{0.05}$ = 0.10 t/ha, there was no significant difference between these variants. According to the statistical processing of the data, the greatest influence on the yield of oil radish seeds was as follows: 35% (A) – microfertilisers, 24 – variety (B), 8 – their interaction (AB), 33% – weather conditions (residual) (Fig. 3).

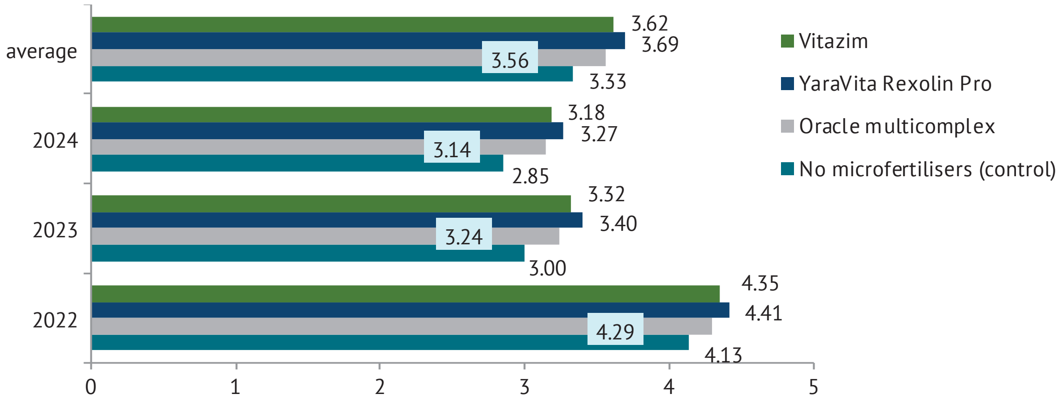

***Figure 2**. Average seed yield of oil radish varieties depending on pre-sowing treatment with microfertilisers (2022-2024), t/ha*

***Source:** compiled by the authors of this study*

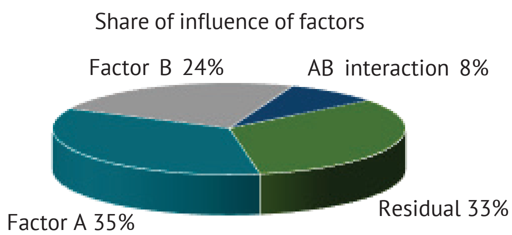

***Figure 3**. Share of influence of factors on the yield of oil radish seed varieties (2022-2024), %*

***Source:** compiled by the authors of this study*

Microfertilisers contributed to the formation of seeds with high sowing qualities, specifically, the thousand-kernel-weight (Table 1). The average indicators for the years of research suggest an increase in this indicator by 0.19 g compared to the control (without microfertilisers) when using Oracle Seeds (1.0 l/t), and the best effect was observed when using Vitazim (1.0 l/t) and YaraVita Brasitrel Pro (1.0 l/t), with increases of 0.27 g and 0.35 g, respectively. The highest thousand-kernel-weight (9.50-9.93 g) was provided by favourable weather conditions in 2022.

***Table 1**. Effect of pre-sowing seed treatment with microfertilisers on the thousand-kernel-weight of oil radish varieties (2022-2024), g*

Pre-sowing treatment of seeds with microfertilisers	Application rate, l/t	Year			Average	± to control	
		2022	2023	2024			
No microfertiliser (control)	–	9.50	9.20	8.90	9.20	–	–
Oracle Seed	1.0	9.71	9.33	9.12	9.39	0.19	–
YaraVita Brasitrel Pro	1.0	9.93	9.52	9.21	9.55	0.35	0.16
Vitazim	1.0	9.84	9.41	9.15	9.47	0.27	0.08
*$LSD_{0.05}$		0.11	0.08	0.09			

***Note:** *LSD – least significant difference*

***Source:** compiled by the authors of this study*

A direct strong correlation between the thousand-kernel-weight and yield was found (Table 2). In the control (without microfertilisers), this indicator was 0.816 and increased with their application to 0.943-0.963.

Table 2*. Correlation (r) between the thousand-kernel-weight and the yield of oil radish depending on pre-sowing treatment with microfertilisers (2022-2024)*

Seed treatment with microfertilisers before sowing	Microfertiliser application rate, l/ha	Thousand-kernel-weight, g	Seed yield, t/ha	r
No microfertiliser (control)	-	9.20	3.33	0.816
Oracle Seed	1.0	9.39	3.56	0.943
YaraVita Brasitrel Pro	1.0	9.55	3.69	0.961
Vitazim	1.0	9.47	3.62	0.963

Source: *compiled by the authors of this study*

The formed thousand-kernel-weight under the influence of optimum plant nutrition in favourable weather conditions provided a high percentage of germination energy of the collected seeds (Fig. 4). If in the control (without microfertilisers) it was 90.6%, then under their influence it increased by 0.6-1.7%. It was the highest in 2022 – 91.8-93.5%, and the lowest in 2024 – 89.5-91.4%. The rate of laboratory germination of harvested oil radish seeds in all years was high in 2022 – 95.2-96.8%, in 2023 – 94.5-95.9%, in 2024 – 93.8-94.8% (Fig. 5).

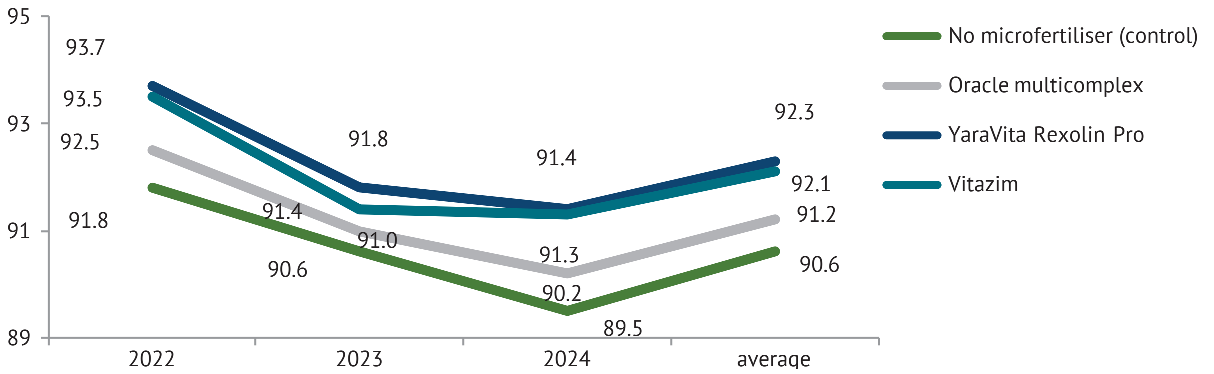

Figure 4*. Influence of pre-sowing seed treatment with microfertilisers on the germination energy of oil radish varieties (2022-2024), %*

Source: *compiled by the authors of this study*

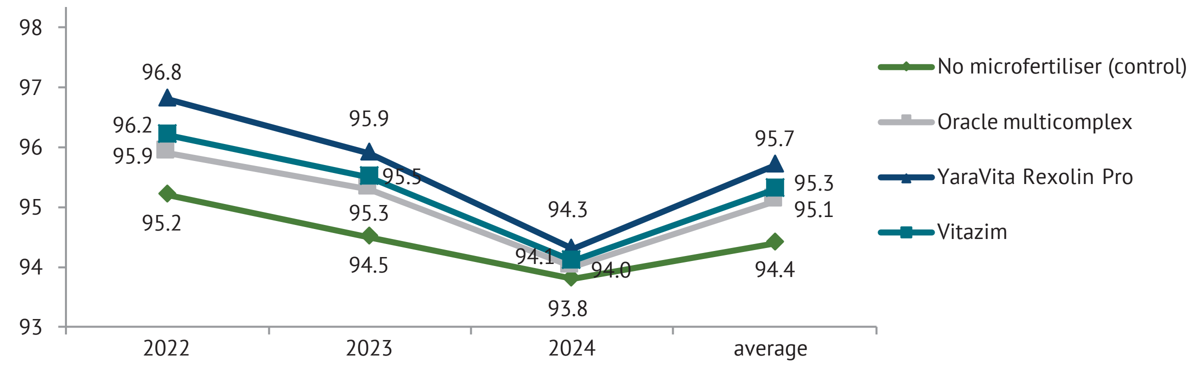

Figure 5*. Average laboratory germination rate of oil radish seeds depending on pre-sowing treatment with microfertilisers (2022-2024), %*

Source: *compiled by the authors of this study*

The effect of the studied microfertilisers was estimated at 0.6-1.2% compared to the control variant (without microfertilisers). The greatest influence on the formation of yield, thousand-kernel-weight, germination energy, and laboratory germination was observed during pre-sowing treatment with YaraVita Brasitrel Pro microfertiliser.

S. Verma *et al.* (2022) noted that the average yield of oil radish seeds in Ukraine is lower than in the leading EU countries due to insufficient fulfilment of the genetic potential of the crop varieties. To increase the yield by 40% or more, the reaction of the variety to the plant nutrition system is of great significance, meeting the nutrient needs of plants not only at the initial stages but throughout the entire plant life cycle. In this regard, R. Mondal *et al.* (2020) emphasised the expediency of using microfertilisers, which allows quickly eliminating nutrient deficiencies and compensating for the effects of abiotic and biotic stresses. To increase the efficiency of fertiliser use in advanced oilseed cultivation technologies, it is advisable to apply nitrogen in stages (Mishchenko *et al.,* 2020; Lövgren, 2022).

P. Banerjee *et al.* (2019) emphasised the significance of finding ways to increase the yield of mustard seeds through foliar feeding with macro- and microfertilisers with a harmonious combination of different types, which will help to solve the problem of crop competitiveness and its attractiveness for production. The effectiveness of microfertilisers in pre-sowing seed treatment against mineral fertilisers has been pointed out by many scientists. V.V. Gamayunova and R.V. Zadyrko (2024) found that pre-sowing seed treatment with Bast Complex (0.5 l/t) and treatment of crops in the 'herringbone' phase with microelements – Boron (1 l/ha), Organic D-2M (2 l/ha), Bast Complex (1.5 l/ha) against the background of the main application of mineral fertilisers in the norm of $N_{15}P_{15}K_{15}$ contributed to an increase in the yield of oil flax seeds by 0.51-0.58 t/ha, which is 49.5-56.3%.

Y.G. Tsytsyura and Yu.O. Kovalchuk (2019) pointed to the recommended micronutrient fertilisers for the group of cruciferous crops containing boron, manganese, and zinc – NutriVant Plus Oilseed, Granubor Natur, Ecolist Micro RB, Ecolist Monobor, Rostok Oilseed, etc., which are reliable sources of trace elements that help maintain the balance of growth processes and ensure the qualitative differentiation of plant parts in a harmonious combination. V.M. Sendetsky (2018) substantiated the sunflower yield of 3.6 t/ha and oil yield of 2.03 t/ha under the condition of combined use of pre-sowing seed treatment and double spraying of plants during the growing season with Vermiodis at 4 l/ha.

M.Yu. Voloshchuk (2024) pointed out that providing white mustard plants with the necessary nutrients during the growing season is significant, and therefore the fertilisation system should be based on knowledge of the biological characteristics of the variety and the soil and climatic conditions of the growing zone. The largest increase in seed yield compared to the control (without fertiliser) – 2.46 t/ha – was achieved at the rate of mineral fertiliser application $N_{30}P_{90}K_{100}$ + N_{50} (BBCH 14-16) + N_{30} (BBCH 52-53), due to a 1.85 g greater thousand-kernel-weight. S.O. Butenko and J. PeiPei (2022) found that in the conditions of the northeastern Forest-Steppe of Ukraine, it is advisable to use a complex of growth regulators Bioforge and Fast Start to obtain seeds of white mustard of the White Princess variety with high quality indicators, which allows obtaining more than 2.2 t/ha of seeds and 0.6 t/ha of oil. For the Felicia grey mustard variety, the most effective is the use of growth regulators Anti-Stress, Agrinos, and Regoplan, which ensured the highest seed yield (1.86-1.89 t/ha) and oil yield (0.73-0.74 t/ha). Scientists say that with an optimum plant nutrition system that promotes the productivity of varieties, high economic performance can be achieved.

Thus, the research findings obtained by scientists allow the manufacturer to identify the most effective elements of oil radish cultivation technology that will not only increase yields but also ensure high sowing quality of the grown seeds of different generations. The nutrition system of an agronomically valuable crop, considering the latest innovative fertiliser developments, is narrow and insufficiently covered in scientific papers, which prompted this comprehensive research.

CONCLUSIONS

On grey forest surface-gleyed soils of the Western Forest-Steppe zone of Ukraine, on the background of $N_{30}P_{90}K_{100}$ with nitrogen fertilisation with N_{50} (BBCH 14-16) + N_{30} (BBCH 52-53), pre-sowing seed treatment with microfertilisers in combination with insecticidal-fungicidal preparation Modesto, 48% FC (12.5 l/t) was an effective agricultural measure in the technology of oil radish cultivation. The trace elements in the studied microfertilisers were in a chelated form available to plants, which, when they got into the seed, contributed to the activation of enzymes, improved its viability, as well as increased germination energy, and development intensity. This helped to increase the resistance of oil radish plants to adverse environmental conditions. Thanks to the humic substances contained in the micronutrient fertiliser, the plants intensified root formation, increased water and nutrient supply, which led to an increase in leaf surface area and increased net photosynthetic productivity. A balanced system of nutrition with mineral fertilisers at the rate of $N_{30}P_{90}K_{100}$ + nitrogen fertilisation + N_{50} (BBCH 14-16) + N_{30} (BBCH 52-53) and pre-sowing seed treatment with microfertilisers provided higher plant structure indicators, which contributed to yield increases. In 2022, the seed yield of oil radish varieties was 4.13-4.41 t/ha, in 2023 – 3.00-3.40, and in 2024 – 2.85-3.18 t/ha. The most effective microfertiliser was YaraVita Brasitrel Pro (1.0 l/t), which significantly exceeded Oracle Multicomplex (1.0 l/t) by 0.13 t/ha and insignificantly exceeded Vitazim (1.0 l/t) by 0.04 t/ha in terms of seed yield.

Favourable weather conditions during the years of research and optimum supply of varieties: Zhuravka, Fakel oil radish with nutrients, due to the rate of mineral fertilisers $N_{30}P_{90}K_{100}$ with additional fertilisation with nitrogen fertilisers N_{50} (BBCH 14-16) + N_{30} (BBCH

52-53) and pre-sowing treatment with microfertilisers together with insecticidal-fungicidal treating agent Modesto, 48% FC (12.5 l/t) contributed to the formation of harvested seeds of high sowing qualities, specifically, greater by 0.19-0.35 g – thousand-kernel-weight, 0.6-1.7% – germination energy and 0.6-1.2% – laboratory germination. Research on the effects of new forms of microfertilisers in pre-sowing seed treatment is particularly relevant for growing oil radish varieties on poor and acidic soils with natural fertility.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Формування посівних якостей насіння редьки олійної залежно від системи живлення в умовах Західного Лісостепу

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Анотація. Причинами обмеженого розповсюдження редьки олійної є недостатня кількість насіння через недосконалість елементів технології вирощування, що потребує додаткових наукових досліджень. Мета досліджень було вдосконалення технології вирощування сортів редьки олійної за рахунок системи живлення рослин. Методологічні дослідження базувалися на загальнонаукових і спеціальних методах. Дослідження здійснювали на експериментальній базі відділу насінництва та насіннєзнавства Інституту сільського господарства Карпатського регіону Національної академії аграрних наук України. За результатами отриманих у 2022-2024 рр. обґрунтовано, що низька природня родючість сірих лісових поверхнево-оглеєних ґрунтів Західного Лісостепу та недостатня забезпеченість у них форм мікроелементів зумовлюють низьку врожайність та якість насіння досліджуваної культури. Цю проблему можна вирішити, розробивши збалансовану систему живлення редьки олійної на основі інноваційних макро- і мікроелементів. За ефективної передпосівної обробки насіння мікродобривами сумісно з інсектицидно-фунгіцидною обробкою насіння протруйником Модесто, 48 % т. к. с. (12,5 л/т) та фоні внесення мінеральних добрив у нормі $N_{30}P_{90}K_{100}$ з підживленням азотними + N_{50} (основні стадія росту та фази розвитку – ВВСН 14-16) + N_{30} (ВВСН 52-53) достовірні прирости врожайності становили 0,23-0,36 т/га. Збалансоване живлення рослин сприяло поліпшенню посівних якостей насіння, зокрема маси 1000 насінин, енергії проростання та лабораторної схожості. Удосконалена система живлення редьки олійної з урахуванням внесення в технологію вирощування мінеральних добрив і хелатних мікродобрив може бути використана сільськогосподарськими підприємствами та фермерськими господарствами, які займаються вирощуванням культури на насіння, що дозволить збільшити виробництво насіннєвого матеріалу для розширення посівних площ у регіоні

Ключові слова: редька олійна; сорт; насіння; мінеральні добрива; мікродобрива; урожайність; посівні якості