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STRUCTURE COMPONENTS AND YIELDING CAPACITY OF *CAMELINA SATIVA* IN UKRAINE

SUMMARY

The results of three–year research on the influence of different fertilization levels and foliar fertilization with micronutrients and growth regulators on the formation of structure elements and yielding capacity of *Camelina sativa* variety Hirsky are presented, their parameters in the process of plant vegetation has been defined. The influence of mineral fertilizers and micro–fertilizers on the elements composing the structure and formation of *Camelina sativa* seed yield on low–fertile sod–podzolic soils of Precarpathians of Ukraine has been studied. It was found that application of mineral fertilizers increases yielding capacity of *Camelina sativa* by 56–87%, and together with three additional fertilizations of plants during vegetation period – almost by 4 times (up to 1.99 $t.ha^{-1}$, which is 0.96 $t\ ha^{-1}$ more than in the control).

Optimal parameters of cultivation technology elements of *Camelina sativa*, which allow to obtain seed yielding capacity at the level of 1.78–2.04 $t.ha^{-1}$, have been determined. On the basis of analysis of relation between yielding capacity and individual indices of *Camelina sativa* structure it was determined that the closest relation was between yielding capacity and the number of pods (R = 0.967). Therefore, it is the number of pods that allow the most accurate prediction

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of yielding capacity level for *Camelina sativa* a according to calculated regression equation.

Keywords: *Camelina sativa*, yield structure, seed yielding capacity, mineral fertilizers, micro–fertilizers

INTRODUCTION

Camelina sativa is a long–forgotten, uncommon, promising spring and winter oil crop of the *Brassicaceae* family of the genus *Camelina*. No wonder it is one of the oldest cultures, originating from Western Europe (Megaloudi and Fragkiska 2006; Hryhoriv *et al.*, 2020). Today, red and winter red are grown in almost all countries of the world, but each of them has its own leading oilseed crop. Today, Austria, Great Britain, Denmark, Germany, Russia, USA, Finland and France conduct active works on selection and agro–technics of *Camelina sativa* as oil plant, and the sown area under it is constantly growing (Madhav *et al.*, 2020; Landré *et al.*, 2020; Yakupoglu *et al.*, 2021; Hryhoriv *et al.*, 2021a).

Today, ryegrass is grown in Ukraine on small areas in the Polissya and Forest–Steppe zones – about 5–6 thousand hectares, which is only 3% of all oilseeds, but this crop has significant prospects for development as a highly productive oilseed crop. Although looking at the prospects of culture, it is safe to say that in the near future these areas may be increased by 3–4 times. Today, the leaders in growing ryegrass in Ukraine are Sumy, Chernihiv, Kyiv and Cherkasy regions, although there are all the prerequisites for expanding the area under its crops throughout Ukraine (Hamayunova, 2017; Long *et al.*, 2018; Hryhoriv *et al.*, 2021b; Tonkha *et al.*, 2021; Rieznik *et al*,. 2021). Recently, *Camelina sativa* has become the subject of various experiments aimed at assessing its future potential.

The culture is promising for growing in arid conditions of the steppe zone of our country, as it is undemanding to growing conditions, cold- and drought-resistant, has a unique resistance to oilseeds to disease and pests. It should be noted that the interest in *Camelina sativa* is explained by the fact that it successfully combines high potential of seed yielding capacity (2.0 $t.ha^{-1}$ in Canada, 2.1–2.2 $t.ha^{-1}$ in Ireland in 2013–2015) and unique properties and composition of *Camelina sativa* oil: healthy composition of fatty acids, high content of vitamins, high resistance to oxidation (Prianyshnykov, 1963; Volokh *at al.*, 2005; Hryhoriv *at al.*, 2020).

Currently, a very promising new direction of *Camelina sativa* use is being developed – to obtain environmentally friendly renewable fuel, biodiesel. *Camelina sativa* is promising for processing into biodiesel thanks to relatively high content of long–chain fatty acids (eicosenoic and erucic, in total up to 17–26%), which are characterized by high heat of combustion. Today, the world leader in rice cultivation is Russia, where over the past 7 years the area under it has increased from 12 thousand hectares to 540000 hectares, of which 463000 tons of rice oil per year. Most of the oil produced is a raw material for the production of aviation biodiesel. Finland is the main producer of biodiesel from Russian raw materials (aviation biokerosene), the buyer of which is Lauftganza (Putnam, 1993; Frohlich, 2005; Hamayunova, 2017; Lü *et al.*, 2019; Hryhoriv *et al.*, 2021c).

Not for nothing, *Camelina sativa* has many parameters which determine its commercial attractiveness as oil and industrial crop. First, it is a precocious crop that allow to increase seasonal load on combine harvesters, and its early harvesting creates conditions for struggle with littering of fields in the long post–harvest period and allows to prepare the soil for the next winter and spring crops. Secondly, cultivation of *Camelina sativa* is relatively low cost.

Resistance of *Camelina sativa* to diseases and pests can reduce the cost of insecticides by 2–3 times compared to other crops of the cabbage family (*Brassica napus*, *Barbaréa vulgáris*), which is a significant item of savings at current prices (Komarova, 2003; Hryhoriv *et al.*, 2021a).

MATERIAL AND METHODS

Field research was conducted on the research base of the Department of Technology of Growing, Seed Production and Biochemistry of Cruciferous Crops of the Precarpathian State Agricultural Research Station of the Institute of Agriculture of the Carpathian Region NAASU on sod podzolic soil during 2018–2021.

The soils of experimental plot are turf deep podzolic gleyed, by mechanical composition – coarse-grained heavy–clayed with strong humus horizon up to 75 cm and are characterized by the following indices: acidity, pH – 5.2, humus content (%) – 2.74, soil content of main nutrient elements (mg.kg^{-1}): nitrogen – 85, phosphorus – 47.0, potassium – 117.0.

Precursor – winter wheat. The sowing was carried out according to experimental scheme. For sowing was used a variety Hirsky, selection of institute AIP. Because scientists have found that *Camelina sativa* is not sensitive to potassium fertilizers (Poliakov, 2011; Hryhoriv *at al.*, 2020), so we studied the effects of only nitrogen and phosphorus fertilizers. In the experiment, mineral fertilizers in the form of nitrogen phosphorus and potassium, ammonium nitrate and granular superphosphate were applied to main soil tillage according to the following scheme:

Control – without fertilizers;
Background – ($N_0P_{45}K_{45}$);
Background – ($N_{30}P_{45}K_{45}$);
Background – ($N_{30}P_{45}K_{45}$) + N_{60};

Background – ($N_{30}P_{45}K_{45}$) + Vympel (500 g.ha^{-1}) + Oracul multicomplex (1 l.ha^{-1}) + Oracul colamine boron (1 l.ha^{-1}) + Oracul sulfur active (2 l.ha^{-1}).

The experiment was based on four repetitions; the area of accounting plot – 20 m^2. A variant without fertilizers was the control.

Fertilization of *Camelina sativa* crops was carried out with nitrogen fertilizers, micro–fertilizers and growth stimulants according to corresponding variants of experimental scheme in the rosette phase.

In the experiment was sown *Camelina sativa* variety Hirsky of selection Ivano–Frankivsk Institute AIP NAAS included in the State Register of varieties suitable for cultivation in Ukraine and adapted to the conditions of the Carpathians. The seed yield stated in the patent is on average 2.1 t.ha^{-1}, green mass – 40.5 t.ha^{-1} (Abramyk *et al.*, 2003; Karpenko *et al.*, 2019).

Agrotechnics of *Camelina sativa* cultivation on research sites was generally accepted for soil and climatic conditions of Prykarpattia, except for the studied factors (Syvyryn & Reshetnykov, 1988).

Weather conditions in Prykarpattia are formed under the influence of three main factors of geographical origin, air circulation and litter surface. An important climatic factor in this region is the Carpathians, which affect the spread of air currents near the earth's surface. Prykarpattia is a moderately warm and humid area. Natural and climatic conditions that have developed in Ivano–Frankivsk region contribute to development of agriculture and forestry, cultivation of main crops.

It should be noted that during the growing season of *Camelina sativa* during the study period, weather conditions in some months differed significantly from the average long-term data both in terms of temperature and rainfall.

However, analyzing the weather conditions, we see that the formation of the yield of *Camelina sativa* occurs with the appropriate satisfaction of plant needs, namely the optimal values of environmental factors, a significant proportion of which are meteorological values.

Thus, we found that during the 2018–2021 study, weather conditions differed slightly from the long-term average in terms of rainfall and temperature, but in some months we observed significant differences, which ultimately affected the level of crop productivity.

In the process of performing the work we used the following research methods: field – to study the interaction of the research subject with biotic and abiotic factors; laboratory – analysis of plants and soil in order to study the interaction between the plant and environmental conditions; measuring and weighing – to establish the level of yield of spring rye; mathematical and statistical – to establish the reliability of the results.

Mathematical processing of obtained analytical digital material was performed by the method of disperse and correlation analysis according to Dospekhov (1985) and Ushkarenko (2014) using the computer program Agrostat 2013.

RESULTS AND DISCUSSION

The structure of the crop is the ratio between main elements of yielding capacity: seeds and straw, aboveground part and root system, etc. And the level of crop yield depends on the number of plants per unit area, pods per plant, seeds and seed weight.

Taking into account the fact that individual elements of the structure are formed at different stages of plant ontogenesis, certain agrotechnical conditions are necessary for their successful development. From the level of providing plants with nitrogen in the phases of rosette formation, stemming, branching and its concentration in vegetative organs, the conditions for seed formation are improved. Fertilizers have a significant effect on the weight of 1000 seeds.

Important indicators that reflect the productivity of *Camelina sativa* are the number of branches, pods per plant, the number of seeds per pod per plant and the weight of 1000 seeds. It is with the help of these indicators you can determine the level of biological yield of the crop. In order to substantiate yield indices obtained under conditions created by the experimental variants, we analyzed yield structure of *Camelina sativa*.

It is known that the highest yield is formed at the optimal ratio of all structural elements. At the same time, with poor development of at least one of the structural elements of productivity, it can be partially compensated by other indicators. However, the productivity of such crops may not always be maximum. Therefore, agricultural techniques for growing crops should ensure uniform and optimal development of all elements of productivity, as only under this condition it is possible to obtain maximum results (Lykhochvor & Petrychenko, 2010).

Table 1. Influence of nutrient elements of camelina glabrata plants on the elements of camelina glabrata crop structure (average for 2018–2021)

Variant	Number of branches, pcs	Number of pods, pcs	Number of seeds per plant, pcs	Weight of 1000 seeds, g
Without fertilizers (control)	5	151	1661	1.01
$P_{45}K_{45}$	7	264	2485	1.06
$N_{30}P_{45}K_{45}$	10	384	3184	1.16
$N_{30}P_{45}K_{45}$+ N_{60}	14	418	3915	1.23
$N_{30}P_{45}K_{45}$+ micro–fertilizers	15	399	3904	1.19
$\bar{X} \pm S_{\bar{x}}$	0.2±3.8	33.1±5.2	0.2±4.5	0.02±7.2

The presented data show that application of mineral fertilizers had positive effect on the crop structure, one of which is the number of pods per plant. Thus, with increasing fertilizer dose, there was an increase in the number of pods per plant, as well as other indices. The studied doses of fertilizers in the experimental variants provided increase in the number of branches per plant from 5 to 15 pcs, the number of pods per plant from 151 to 418 pcs, the number of seeds per plant from 1661 to 3915 pcs, compared to the control without fertilizers. It was established that the number of seeds from a plant changes to the greatest extent from the structural elements of the formation of individual seed productivity, which was 2485-3915 pieces when fertilizers were applied. That is, the increase in control was 51-152%. Also, it should be noted that the application of nitrogen fertilizers leads to an increase in the number of pods on one plant, but no significant effect on the weight of 1000 seeds was noted. The increased number of seeds per 1 m^2 was caused by an increase in the number of pods per plant, but not by the number of seeds per pod. The level of yield of *Camelina sativa* seeds is directly proportional to the individual productivity of plants, which is determined primarily by the number of pods per plant, pod weight, seed weight per plant and weight of 1000 seeds. We have established that improving the conditions of mineral nutrition with the introduction of fertilizers significantly affects the formation of reproductive organs. Thus, with the introduction of different doses of nitrogen fertilizers in feeding, the number of pods on the plant varied from 418 pcs. – in the variant with application of $N_{30}P_{45}K_{45}$+N_{60}, up to 399 units/plant – in the variant with a dose of $N_{30}P_{45}K_{45}$+microfertilizer, which exceeded the indicator of the variant without fertilizers by 9% and 171%.

The weight of 1000 seeds did not change significantly under the influence of fertilizers 1.01 to 1.23 g.

Our results are also confirmed by the studies of Vakhnenko and Polyakov conducted in the Pidenny Steppe of Ukraine, which indicates that the use of biological preparations contributes to the growth of plant height, the number of pods on one plant, the weight of seeds from one plant and the weight of 1000 pcs. seed (Vakhnenko & Poliakov, 2010).

The results of research indicate that optimization of plant nutrition through the use of rational modern approaches to fertilization has had positive effect on such components of crop structure as the number of branches, the number of pods and seeds per plant and the weight of 1000 seeds. Our observations are confirmed by studies of Hamayunova (2017) conducted in the steppe zone.

A change in indicators of productivity elements led to a change in the yield level. A positive effect of mineral fertilizers and growth stimulants on this indicator was noted for all years of research. The effectiveness of their application was noted on all variants that gave an increase in productivity.

Thanks to optimization of growing conditions by appropriate combination of structural elements of technology, it is possible to achieve maximum realization of genetic variety potential in the economic harvest. As you know, yield is a determining indicator of the feasibility of growing crops and depends primarily on the genetic characteristics of the variety, its response, adaptation to soil and climatic conditions and technological measures of growing crops.

According to our research, the lowest yield of *Camelina sativa* seeds of variety Hirsky, as it was expected, has been noted in the variant without fertilizers (control) where it averaged 1.03 $t.ha^{-1}$ in 2018–2021 (Fig. 1).

Increasing the dose of mineral fertilizers to $N_{30}P_{45}K_{45}$ provided yield increase – by 0.75 $t.ha^{-1}$, or 69.9%. Further increase in doses of mineral fertilizers also contributed to increase of crop productivity. Thus, in the variant with application of mineral fertilizers at the dose of $N_{30}P_{45}K_{45}$+ N_{60} the crop yield increased to 2.04 $t.ha^{-1}$, which is by 1.01 $t.ha^{-1}$ higher than the control, and by 0.26 $t.ha^{-1}$ higher compared to the variant with $N_{30}P_{45}K_{45}$. On the fifth variant application of fertilizers in a dose of $N_{30}P_{45}K_{45}$ into main fertilization and in combination with micro–fertilizers and growth stimulants contributed to yield increase to 1.99 $t.ha^{-1}$, which is higher than the control by 0.96 $t.ha^{-1}$, and compared to the third variant ($N_{30}P_{45}K_{45}$) the yield increased by 0.21 $t.ha^{-1}$.

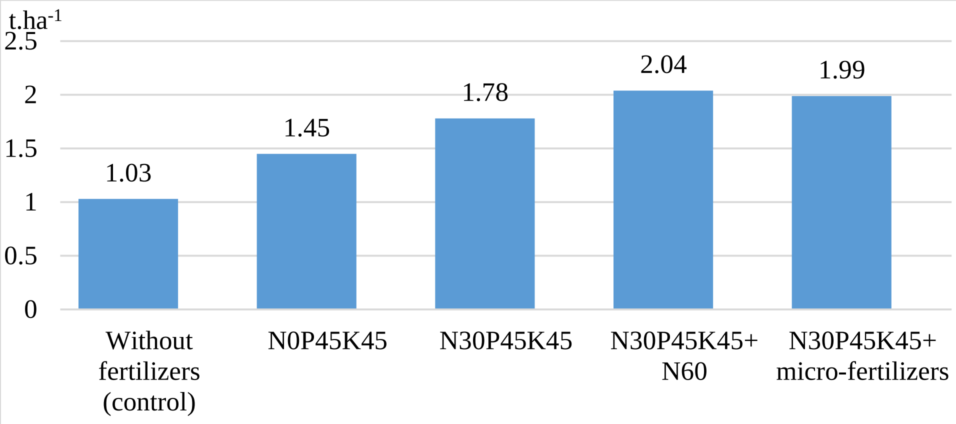

Figure 1. Yielding capacity of *Camelina sativa* depending on the level of mineral nutrition, $t.ha^{-1}$ (2018–2021)

Mathematical models have also been created that describe the relationship between spring rye yield and a set of structural indicators. These models make it possible to predict the yield level of a crop using the number of pods, the number of seeds in a pod in one equation.

In order to establish relation between yielding capacity and structure indices, we analyzed three–year experimental data (2018–2021) and created mathematical models based on correlation–regression analysis that are reliable at 95% probability according to Fisher's and Student's criteria (Table 2).

Table 2. Mathematical model of relation between yielding capacity and indices of *Camelina sativa* structure, average for 2018–2021

Regression equation	Multiple correlation coefficient, R	Determination coefficient, D, %
$Y = 0.4805–0.0305X_1+0,0031X_1^2$	**0.967**	**93.5**

Note: Y – yielding capacity, $t.ha^{-1}$; X_1 – number of pods, pcs.; X_2 – number of seeds per pod, pcs.; X_3 – field germination of seeds, %.

The average and close correlation of yielding capacity with the number of pods and the number of seeds per pod was established. It is evidenced by coefficients of correlation (R = 0.967) and determination (D = 93.5).

It should be noted that yielding capacity calculated by the number of pods was the closest to actual, and by the number of seeds per pod had some differences. And calculated yielding capacity in terms of field germination was almost the same in all variants of the experiment, which confirms the idea about weaker relation between these indices.

CONCLUSIONS

The study of obtained data allowed to establish that the decisive role in the formation of *Camelina sativa* seed yield belongs to the use of mineral fertilizers in main phases of the crop ontogenesis. On average for 3 years of research, the increase in yield from application of mineral fertilizers and micro–fertilizers was 0.42–1.01 $t.ha^{-1}$, and combination of this measure with foliar fertilization of micro–fertilizers three times during vegetation period generated seed yielding capacity in amount of 1.99 $t.ha^{-1}$.

It has been found that the level of yielding capacity is determined by the following elements of the structure: the number of branches on the plant, the number of pods, the number of seeds in them and the weight of 1000 seeds. It has been established that all these indices increase significantly under influence of mineral fertilizers.

Mathematical models created on the basis of experimental data (2018–2021) reflect peculiarities of dependence between these indices. Based on the analysis of relation between yielding capacity and individual indices of the structure of *Camelina sativa*, it has been determined that the closest relation was between yielding capacity and the number of pods ($R = 0.967$). Therefore, the most accurately prediction of yielding capacity level of *Camelina sativa* according to calculated regression equation can be done by the number of pods.

REFERENCES

Abramyk, M. I., Mazra, V. O., Kunychak, H. I. & Kozak, T.I. (2003). Catalog of varieties of Carpathian breeding. *Ivano–Frankivsk*, 58 p. [In Ukrainian]

Dospekhov, B. A. (1985). Methods of field experience (with fundamentals of statistical processing of research results). *Ed. 5th, ext. and rework, Moscow*, 350 p. [In Russian]

Frohlich, A. & Rice, B. (2005). Evaluation of *Camelina sativa* oil as a feedstock for biodiesel production. *Industrial Crops and Products*, 21 (1): 25–31. doi.org/10.1016/j.indcrop.2003.12.004.

Hamayunova, V. V. & Moskva, I. S. (2017). The yield formula and productivity of *Camelina sativa* Grantz on the Southern steppe of Ukraine. *Bulletin of Zhytomyr National Agroecological University*, 2 (61): 29–34. [In Ukrainian]

Hryhoriv, Ya. Ya., Butenko, S. O., Masyk, I. M., Onychko, V. I., Onychko, T. O., Pshychenko, O. I., Komar, V. I. & Berezniak, O.P. (2020). Influence of mineral fertilization level on productivity of *Camelina sativa* in the conditions of Prycarpattia. *Ukrainian Journal of Ecology*, 10 (2):28–32. doi: 10.15421/2020_59

Hryhoriv, Y., Butenko, A., Nechyporenko, V., Lyshenko, M., Ustik, T., Zubko, V., Makarenko, N. & Mushtai, V. (2021a). Economic efficiency of *Camelina sativa* growing with nutrition optimization under conditions of Precarpathians of Ukraine. *Agraarteadus*, 32 (2):232–238. DOI: 10.15159/jas.21.33

Hryhoriv, Ya., Butenko, Ye., Rozhko, V., Karpenko, O., Lychuk, A., Kudria, S., Sobran, I., Stavytskyi, A. & Tkachenko, O. (2021b). Formation of *Camelina sativa* yield depending on the level of mineral fertilization under conditions of Precarpathians. *Agricultural Mechanization in Asia*, 52 (1):2405–2413. https://www.shin-norinco.com/search-article

Hryhoriv, Ya. Ya., Butenko, A. O., Moisiienko, V. V., Panchyshyn, V. Z., Stotska, S. V., Shuvar, I. A., Kriuchko, L. V., Zakharchenko, E. A. & Novikova, A. V. (2021c). Photosynthetic activity of *Camelina sativa* plants depending on technological measures of growing under conditions of Precarpathians of Ukraine. *Modern Phytomorphology*, 15: 24–28. DOI: 10.5281/zenodo.5801099

Karpenko, O. Yu. *et al*. (2019). Postharvest siderates impact on the weed littering of maize. *Ukrainian Journal of Ecology*, 9 (3): 300–303. doi.org/10.15421/2019_745

Komarova, B. & Rozhkovan, V.V. (2003). *Camelina sativa* – is an alternative oil crop and prospects for its use. *Propozytsiia*, 1: 46–47. [In Ukrainian]

Landré, A., Cornu, S., Meunier, J., Guerin, A., Arrouays, D., Caubet, M. & Saby, N.P.A. (2020). Do climate and land use affect the pool of total silicon concentration? A digital soil mapping approach of frenchtopsoils. *Geoderma*, 364 p. DOI: 10.1016/j.geoderma.

Long, J., Cheng, H., Dai, Z. & Liu, J. (2018). The effect of silicon fertilizer on the growth of chives. IOP Conference Series: *Earth and Environmental Science*, 192: 1–6. DOI:10.1088/1755-1315/192/1/012065

Lü, H., Kang, J., Long, R., Xu, H., Chen, X., Yang, Q. & Zhang, T. (2019). Effects of seeding rate and row spacing on the hay yield and quality of alfalfa in saline-alkali land. *Acta Prataculturae Sinica*, 28 (3):164–174. DOI: 10.11686/cyxb2018153

Lykhochvor, V. V. & Petrychenko, V. F. (2010). Rape. *Lviv*: 117 p. [In Ukrainian]

Madhav Dhakal, Charles P. West, Carlos Villalobos, Philip Brown & Paul E. Green. (2020). Interseeding alfalfa into native grassland for enhanced yield and water use efficiency. *Agronomy Journal. Early View*. First published: 23 January, 22 p. DOI:10.1002/agj2.20147

Megaloudi & Fragkiska (2006). Plants and Diet in Greece from Neolithic to Classic Periods: the archaeobotanical remains. *Oxford: Archaeopress*, 145 p.

Prianyshnykov D. N. (1963). *Camelina*. Selected Works, T.II. *Moskva*, 418 p. [In Russian]

Putnam, D. & Budin, D. (1993). *Camelina*: Apromising low–input oilseed. *New York*, 314–322. https://hort.purdue.edu/newcrop/proceedings1993/V2-314.html

Rieznik, S., Havva, D., Butenko, A. & Novosad, K. (2021). Biological activity of chernozems typical of different farming practices. *Agraarteadus*, 32 (2): 307–313. DOI: 10.15159/jas.21.34.

Syvyryn, A. H. & Reshetnykov, V. N. (1988). Crop of saffron milk intensive technology. Industrial crops. *Moscow, Kolos*, 19 p. [In Ukrainian]

Tonkha, O., Butenko, A., Bykova, O., Kravchenko, Y., Pikovska, O., Kovalenko, V., Evpak, I., Masyk, I. & Zakharchenko, E. (2021). Spatial Heterogeneity of Soil Silicon in Ukrainian Phaozems and Chernozems. *Journal of Ecological Engineering*, 22 (2): 111–119. doi.org/10.12911/22998993/130884

Ushkarenko, V. O., Vozhehova, R. A., Holoborodko, S. P. & Kokovikhin, S. V. (2014). Method of field experiment. *Kherson, Hrin D.S.*, 448 p. [In Ukrainian]

Vakhnenko, S. & Poliakov, O. (2010). Productivity development in spring False Flax when applying biostimulators and plant growth regulators in South Steppe Ukraine. *Scientific and technical bulletin of the Institute of Oil Crops of the National Academy of Sciences,* 15: 2–7. [In Ukrainian]

Volokh, V. H., Dubrovetskyi, S. V., Kyiak, H. S. & Onyshchuk, D. M. (2005). Crop production: Textbook. *High school*, 382 p. [In Ukrainian]

Yakupoglu, T., Gundogan, R., Dindaroglu, T., Kusvuran, K., Gokmen, V., Rodrigo-Comino, J. Gyasi-Agyei, Y. & Cerdà, A. (2021). Tillage Impacts on Initial Soil Erosion in Wheat and Sainfoin Fields under Simulated Extreme Rainfall Treatments. *Sustainability,* 13: 789. DOI: 10.3390/ su13020789