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ECONOMIC EFFICIENCY OF *Camelina sativa* GROWING WITH NUTRITION OPTIMIZATION UNDER CONDITIONS OF PRECARPATHIANS OF UKRAINE

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ABSTRACT. The results of research conducted during 2015–2018 in a field experiment on sod-podzolic soils while studying the effect of different fertilizers on productivity of *Camelina sativa* and oil-bearing crops and, accordingly, economic efficiency and competitiveness of this crop growing have been presented. The dependence of elements of productivity and yielding capacity on the application of mineral fertilizers has been revealed. It has been found that the application of mineral fertilizers had a significant impact on the productivity of *Camelina sativa* seeds and the cost index and profitability of *Camelina sativa* seeds, accordingly. Depending on the studied elements in growing technology of little-known in Ukraine crop of *Camelina sativa*, the main indices of economic efficiency were determined. It has been found that with optimization of plant nutrition, regardless of the increase in cultivation costs, conditionally net profit and profitability level increased. This was facilitated by foliar fertilization with modern restrictive preparations or complex micro fertilizers in critical periods of crop vegetation. Depending on the variant of the experiment, the average conditionally net profit during growing years ranged from 471.78 to 688.48 € ha^{-1} (1 UAH = 0.032 €), and profitability level ranged from 178.8 to 222.0%.

Introduction

World experience shows that the way to overcome the crisis in the economy and agricultural sector, in general, lies primarily in the production, both for domestic and foreign markets, of competitive products which meet purchasing competence of consumers and at the same time is beneficial for producers. This can be achieved as a result of a complex approach to the production, practice and sale of crop products, and wide mastering of the latest scientific and technical research. At the same time, there is a need for more and more purposeful introduction into the production of crops with high yield potential which were tested by world and domestic practice and which, for one or another reasons, have not become properly widespread. *Camelina sativa* belongs to such crops in our country (Hryhoriv, 2012; Chețan *et al.*, 2021; Demydas *et al.*, 2021).

Currently, the sown area under oil-bearing crops in the world covers over 150 million hectares, and oil production is about 185 million tons. Recently, world consumption of oils and vegetable fats grew by 4% annually, and annual increase of oil production over the past decade is about 3.5 million tons. Crops of this family are grown in almost all countries of the world, but each of them has its leading oil crop. Today in Austria, Great Britain, Denmark, Germany, Russia, the USA, Finland and France work on selection and agrotechnical of red rice as an oil plant are actively conducted. In Ukraine, such main crops are sunflower and rapeseed, which are included in crop rotation structure of natural and climatic zones of the Steppe, Central and Eastern Forest-Steppe, and occupies over 70% of all cultivated oil-bearing crops in Ukraine (Havryliuk, 2008; Poliakov, 2011; Namayunova *et al.*, 2018; Madhav *et al.*, 2020; Yakupoglu *et al.*, 2021).

Reduction of sown area for rapeseed to a scientifically sound level replacing it by other, not less valuable oil-bearing crops, will improve sown area, increase oil assortment for various purposes (Hryhoriv *et al.*, 2020).

Solution of production problem for oil-bearing crops less widespread than rapeseed, such as mustard, and little widespread – *Camelina*, is closely connected with improvement of agrotechnologies setting parameters of basic agronomic measures for their growing, taking into account biological characteristics of varieties and specific properties of crops for obtaining high productivity. Therefore, the transition from extensive to adaptive-intensive methods with the successful combination of elements of intensification, resource-saving and biologization of crop production depending on climate, relief and soil conditions – is a progressive way in modern crop production (Demydas *et al.*, 2011; Moskva, 2016; Long *et al.*, 2018; Cerbari *et al.*, 2021).

Camelina sativa Grantz is a promising oil crop of the *Brassicaceae* family. Interest in *Camelina* is stipulated by the fact that successfully combines the high potential of seed yield (2.0 t ha^{-1} in Canada, 2.1–2.2 t ha^{-1} in Ireland in 2011–2013) (Hryhoriv *et al.*, 2020). And unique properties and composition of *Camelina* oils: healthy composition of fatty acids, high content of vitamins, high resistance to oxidation (Prianyshnykov, 1963; Volokh *et al.*, 2005; Hryhoriv *et al.*, 2020; Hryhoriv *et al.*, 2021). Despite all advantages of the crop, today in Ukraine, *Camelina* is grown only in large areas in the zones of Forest-Steppe and Polissya, although there are all conditions for expanding sown areas throughout the country (Hospodarenko, Rassadina 2015; Namayunova *et al.*, 2018).

The research was aimed to study the economic efficiency of *Camelina sativa* growing under conditions of Precarpathians of Ukraine.

Materials and Methods

Field research was conducted in technological crop rotation at the Department of Growing Technology, Seed Production and Biochemistry of Cruciferous Crops at Precarpathian State Agricultural Research Station of the National Academy of Agrarian Sciences of Ukraine on sod podzolic soil during 2015–2018 GPS binding: latitude 58^{0}56'55', longitude – 34^{0}41'45".

The soil of the experimental plot was the sod, deep podzolic gleyed soil. By mechanical composition, they were coarse-dusty heavy-gleyed with a strong humus horizon up to 75 cm and are characterized by the following indices: acidity, pH – 5.3, humus content 2.75%, soil provision with main nutrition elements: nitrogen – 82, phosphorus – 46.0 and potassium – 119.0 mg kg^{-1}.

A predecessor is winter wheat. The sowing was conducted according to the experimental scheme. A variety of Girsky of the selection of institute AIP was used for sowing. Taking into consideration the insensitivity of *Camelina sativa* to the application of potassium fertilizers (Poliakov, 2011; Hryhoriv, 2020; Kvitko *et al.*, 2021; Cerdà *et al.*, 2020), the effect of only nitrogen and phosphorus fertilizers was studied. In the experiment, mineral fertilizers in the form of ammonium nitrate and granular superphosphate were applied with main tillage according to the following scheme:

- Control – without fertilizers;
- Background – ($P_{45}K_{45}$);
- 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 sulphur active (2 l ha^{-1}).

The experiment was based on four repetitions; the area of the accounting plot was 20 m^2. The variant without fertilizers was used as control (absolute control), which is based on the natural soil fertility. Fertilization of *Camelina sativa* grass crops was carried out with nitrogen fertilizers, micro fertilizers and growth stimulators according to corresponding variants of the experimental scheme in the rosette phase.

In the experiment, was sown *Camelina sativa* variety Girsky of selection of Ivano-Frankivsk Institute AIP NAAS entered on the State Register of varieties suitable and adapted to the soil and climatic conditions in Ukraine. Potential seed yield is about 2.0 t ha^{-1}, green mass – 40.5 t ha^{-1} (Abramyk *et al.*, 2003). Growing technology of *Camelina sativa* in the experimental plots was generally accepted for soil and climatic conditions of Precarpathians, except the factors, studied (Syvyryn, Reshetnykov, 1988; Semenova *et al.*, 2005; Lü *et al.*, 2019; Landré *et al.*, 2020; Bulyhin *et al.*, 2021; Lys *et al.*, 2021).

The economic efficiency of spring ryegrass cultivation was calculated according to modern generally accepted methods, namely determined by technological maps. When determining production costs of the work, we included amount of wages, cost of soil tillage, herbicides, seeds, depreciation, maintenance and inspection, cost of fuel and lubricants, fertilizers, and cost of storing seeds. Calculations of economic efficiency of *Camelina sativa* growing are given in prices of 2020.

Evaluation of growing technologies for competitiveness was carried out according to the method of Garkavy, Petrychenko, Spirin (Garkavy *et al.*, 2003).

Weather and climatic conditions of the region are one of determining factors in the formation of productivity and quality of agricultural crop yields. It can be a decisive criterion for the expediency of growing crops and their implementation in a particular region, so much attention is paid to the analysis of weather conditions during the research period, which aimed to determine the economic efficiency of growing *Camelina sativa* depending on varietal characteristics and farming techniques under conditions of Precarpathians of Ukraine. Natural and climatic conditions which have developed in the Ivano-Frankivsk region contribute to the development of agriculture and forestry, growing of main crops. Analysis of hydrothermal conditions, which developed during the vegetation period of *Camelina sativa* during the years of research, was conducted according to Ivano-Frankivsk regional meteorological station. In the years of research, weather conditions differed significantly from the average long-term data both in terms of temperature and precipitation during the *Camelina sativa* growing season (Fig. 1).

Results and Discussion

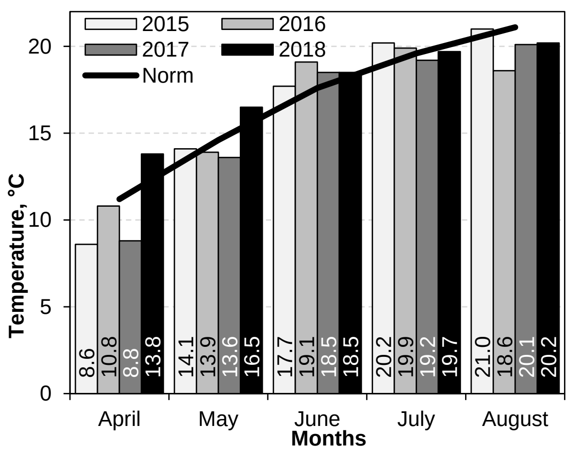
The main task of agricultural production in the process of growing *Camelina sativa* at the present stage is increasing its profitability with an increase of agricultural production with minimal energy and resources. The above mentioned is relevant especially in modern business conditions, when technology elements that are being developed and proposed for implementation in the production, first of all, have to reduce energy costs for growing crops, reduce costs for production unit and as a result – increase profits. In addition, modern technologies of growing crops must be competitive. It should be noted that the competitiveness of crop products depends on many different factors, including elements of growing technology. At the same time, the shortage of resource potential and pricing policy for main elements and tools, that are an integral part of the development of agronomic cultivation measures, requires certain revision of technological approaches to crop production. The cost of mineral fertilizers has increased significantly during recent years and organic fertilizers are almost not used because of the significant reduction in livestock breeding. This has led to further deterioration of soil quality, their content depletion concerning movable, available for plants nutrients. According to Gamayunova's research, it is established that nutrition optimization, depending on the use of biological products for seed treatment and sowing on the background of moderate fertilizer gives a relatively net profit of 534.74 to 2370.58 € ha^{-1}, which indicates the feasibility of growing spring rye in the south of Ukraine. Under such conditions, optimization of crop nutrition on measures of resource-saving becomes actual (Hryhoriv 2012; Peyraud *et al.*, 2016; Namayunova *et al.*, 2018; Tanchyk *et al.*, 2021).

It was found that studied doses of mineral fertilizers significantly affected economic efficiency indices of *Camelina sativa* growing (Table 1).

Calculations of economic efficiency of mineral fertilizers applied for *Camelina sativa* growing showed that the highest conditionally net profit – 688.38 € ha^{-1} on average for the years of research 2015–2018 was obtained on the variant with applying mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ in main fertilization and N_{60} in replenishment. Production cost in this variant was 998.40 €, total costs – 310.02 €, and the cost of 1 ton of seeds was 158.98 €, profitability level was 222%. Whereas according to the research of Mariusz *et al.* (2018) in Poland, the average income from ryegrass seeds is € 876.3 ha at a seed cost of 455.5 €.

We note that in the control (without fertilizers) was received conditionally net profit in the amount of 315.20 € ha^{-1}, at the cost of 1 ton of seeds – 183.65 €, general expenses – 176.32 € and profitability level – 178.8%.

Analyzing the structure of costs, it should be noted that with increasing fertilizer doses the share of costs for fertilizers also increased, while the share of costs for fuel, pesticides, and seeds decreased.



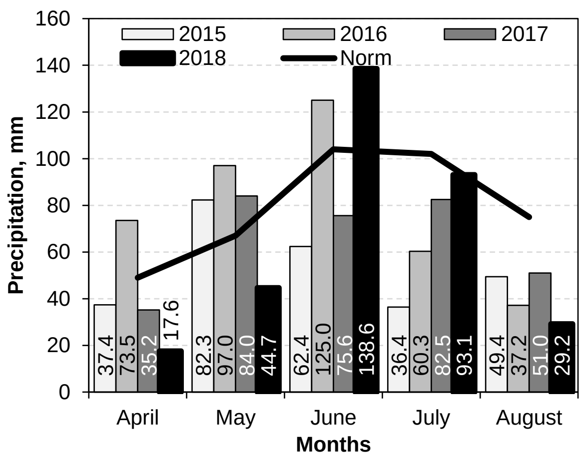


Figure 1. Air temperature and amount of precipitation during the growing season of *Camelina sativa* 2015–2018, ºC

Table 1. Economic efficiency of *Camelina sativa* growing technologies (average for 2015–2018)

Variant of fertilization	Yielding capacity, t ha^{-1}	Cost of the harvest, € ha^{-1}	Production costs, € ha^{-1}	Cost price of 1 t, €	Net profit, € ha^{-1}	Profitability level, %
Without fertilizers (control)	0.96	491.51	176.32	183.65	315.20	178.8
$N_0P_{45}K_{45}$	1.39	711.68	239.90	172.61	471.78	196.7
$N_{30}P_{45}K_{45}$	1.61	824.32	273.44	169.82	550.88	201.5
$N_{30}P_{45}K_{45}+N_{60}$	1.95	998.40	310.02	158.98	688.38	222.0
$N_{30}P_{45}K_{45}$+microfertilizers	1.86	952.32	290.78	156.32	661.54	227.5
$\bar{X} \pm S_{\bar{x}}$	1.55±0.08					
LSD_{05}	0.17					

1 UAH = 0.032 €

Table 2. Economic efficiency of technologies for growing spring oil-bearing crops (Hryhoriv *et al.*, 2014)

Crop	Yielding capacity, t ha^{-1}	Cost of the harvest, € ha^{-1}	Production costs, € ha^{-1}	Cost price of 1 t, €	Net profit, € ha^{-1}	Profitability level, %
Spring *Brassica napus*	2.23	927.68	473.92	212.51	453.76	95.7
Sinapis juncea	1.69	730.08	443.36	262.33	286.72	64.7
Sinapis alba	1.89	816.48	443.36	234.56	373.12	84.2
Camelina sativa	1.95	998.40	310.01	158.97	688.38	222.0
Linum usitatissimum	2.11	979.04	354.78	168.12	624.26	176.0

1 UAH = 0.032 €

Therefore, it is not for nothing that recently, in various EU projects (eg ITAKA, ICON, COSMOS), red rice has been reopened as a multi-purpose crop as a source of oil and protein (Righini *et al.*, 2016), using low costs and cost, and competitive agronomic management (Tonin *et al.*, 2018). Due to the great interest in this species in Europe and the driving force of this interest, the authors consider it necessary to gather all European knowledge about the cultivation of ryegrass to provide guidelines for the future sustainable development of this culture (Righini *et al.*, 2016).

It should be noted that the *Camelina sativa* alternative, first, is that no pests and diseases have been detected in this crop, unlike in other *Brassicaceae* plants. Therefore, *Camelina sativa* does not require the use of insecticides and fungicides during growing, which in practice will result in significant cost savings for chemical means of protection for *Camelina sativa* crops in comparison with other oil-bearing crops (Table 2).

Rapeseed, in contrast to *Camelina sativa*, is strongly damaged by pests: *Phyllotreta, (Meligethes aeneus* F.*), Ceuthorrhynchus*, *Aphidoidea*, *Dasineura brassicae* Winn. Therefore, rapeseed growing requires chemical protection with the application of effective insecticides from germination to budding, the cost of which by the prices of 2020 is 110.78 € ha^{-1}, which is 23% of all growing costs. In addition to all *Camelina sativa* advantages, the technology of its seed growing is environmentally friendly.

Researchers have also found that in milder Mediterranean environments, such as Spain (Martinez *et al.*, 2020) and Italy (Bacenetti *et al.*, 2017), red spring is well adapted to growing with the autumn cycle on marginal soils. Mauri *et al.* (2019) reported that spring red, sown in autumn in semi-arid conditions in central Spain, reached an average yield of 1 Mg DM ha^{-1} in a 2-year study. This value can be considered a reliable yield threshold for profitable cultivation on marginal or semi-marginal soils (Zanetti *et al.*, 2021)

It was found that the lowest production costs (310.01 and 354.78 €) were for growing *Camelina sativa* and *Linum usitatissimum*. Insecticides were additionally used three times in *Sinapis juncea* and *Sinapis alba* crops, so the costs increased to 443.36 €. The highest production costs were for growing *Spring Brassica napus* (473.92 €) because of two additional uses of fungicides and insecticides.

It should be noted that in the general growth of all oil-bearing crops was highly profitable. This is explained by relatively high yielding capacity in the experiments and high prices for the seeds of oil-bearing crops. Net profit from 1 ha was lower while growing species of *Sinapis* (286.72–373.12 €). *Camelina sativa* and *Linum usitatissimum* provided twice more profit – 688.38 and 61.06 €, respectively. The level of profitability is very high for *Camelina sativa* (222%) and *Linum usitatissimum* (176%). Other crops range from 64 to 95%.

It should be noted that red rice has an advantage as an alternative raw material for the production of biodiesel due to its low cost compared to commercial oils. Recently, jet fuel based on rye oil has been developed and test flights of various passenger aircraft, as well as fighters, have been successfully conducted (Moser, 2010). These facts indicate the suitability of rye oil for biofuel production. In addition, due to its unique nutritional properties, ryegrass flour has been recognized as a valuable animal feed (Pilgeram *et al.*, 2007). Thus, it has a high economic potential. Such a high economic value of rye meal has great potential in ensuring the economic efficiency of rye biodiesel.

As it is known, that the most promising growing technologies are considered to be the ones with energy costs reducing and energy efficiency coefficient increasing. It should be noted that the competitiveness of crop products depends on many different factors including elements of growing technology.

The basic technology for growing *Camelina sativa* was the variant of the experiment, where no mineral fertilizers were applied. Obtained results in determining coefficients of energy, integral evaluation and complex coefficient of competitiveness showed that they change depending on the doses of mineral fertilizers (Table 3).

Table 3. Competitiveness of *Camelina sativa* growing technologies

Variant of fertilization	Coefficient of energy evaluation, $К_{Ет}$[1]	Coefficient integral evaluation, J[2]	Complex coefficient of competitiveness $К_к$[3]
Without fertilizers (control)	2.04	0.80	0.87
$N_0P_{45}K_{45}$	1.45	0.78	0.93
$N_{30}P_{45}K_{45}$	0.83	0.71	0.96
$N_{30}P_{45}K_{45}+N_{60}$	0.72	0.69	1.32
$N_{30}P_{45}K_{45}$ +micro-fertilizers	0.75	0.61	1.27

[1]$К_{Ет} = \frac{Eu}{Et} = \frac{(\alpha o Uo + \alpha d Ud)}{Et}$, where *αo*, *αd* – respectively, the energy equivalent main and additional products, MJ kg^{-1}; Wow, Wood – respectively the harvest of the main and additional products, kg ha^{-1}; *Et* – total energy consumption technologies, MJ ha^{-1}.

[2]$J = \frac{Qn}{Qb}$, where *Qn*, *Qb* – the monetary expression of products produced per year per 1 hectare of area per 1 € of reduced costs, by the new and basic technology options.

[3]$К_к = \frac{Qq}{Qe}$, where *Qq* – quality parameters, *Qe* – economic parameters.

It was revealed that the application of the studied doses of mineral fertilizers leads to a decrease in the energy evaluation coefficient of *Camelina sativa* growing technology. Thus, when applying mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ in combination with foliar nitrogen fertilization at a dose of 60 kg ha^{-1}, the energy evaluation coefficient was 0.83. Whereas the variants without mineral fertilizers were noted the highest coefficient of energy assessment – 2.04.

The highest coefficient of integral evaluation of growing technologies was observed in the variants without mineral fertilizers, and which was respectively 0.80.

The maximum complex coefficients of competitiveness were observed in *Camelina sativa* – 1.32, and 1.27 was noted when growing *Camelina sativa* in the variants with mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ in combination with foliar nitrogen fertilization at a dose of 60 kg ha^{-1} and in the variant with stimulants of growth and micro fertilizers. In the variants where mineral fertilizers were not used, the minimum complex coefficients of competitiveness were noted, which were 0.87, respectively.

Conclusions

Under conditions of Precarpathians on sod-podzolic soils, the highest seed yield among spring oil-bearing crops was provided by spring rape (*Brassica napus* L.) – 2.23 t ha^{-1}. Slightly lower yields were provided by *Camelina* and *Linum usitatissimum* – respectively 1.95–2.11 t ha^{-1}. Other crops provided a much lower seed yield. The yielding capacity of *Camelina sativa* seeds under influence of mineral fertilizers increased from 0.96 t ha^{-1} in the variant without fertilizers to 1.95 t ha^{-1} in the variant with the application of $N_{30}P_{45}K_{45}$+ N_{60}, *i.e.* increased by 0.99 t ha^{-1} or 106.8%.

With intensive technology of growing *Camelina sativa*, variety Girsky, it is expedient to increase the dose of mineral fertilizers to $N_{30}P_{45}K_{45}$ + N_{60}, in this case, the net profit increases to 688.38 € from 1 hectare. The best indices of economic efficiency were obtained for growing *Camelina* and *Linum usitatissimum*: their profit was 688.38 and 624.26 € ha^{-1}, respectively, and the level of profitability was 222 and 176%.

So, when applying nitrogen fertilizers in a dose of 90 kg ha^{-1} on the background of phosphorus and potassium fertilizers ($P_{45}K_{45}$) there was a decrease in competitiveness coefficient ($К_к$), energy efficiency coefficient ($К_{Ет}$) and increase of integral evaluation coefficient (J) compared to the basic technology.

For the production of competitive products, increasing the yield and profitability of *Camelina sativa* cultivation in the conditions of Prykarpattia Ukraine on sod podzolic soil, it is recommended to obtain a yield of 2.23 t ha^{-1} to apply complete mineral fertilizer at a dose of $N_{30}P_{45}K_{45}$ with nitrogen fertilizers at a dose of N_{60} in the phase of socket formation. The results obtained in this study provide valuable information on the costs and cost-effectiveness of rice biomass production. However, further research is needed to verify the results of the study and further improve production technology, reduce costs, and increase the efficiency of seed collection (reduce losses during harvesting). This should in the future help increase the economic efficiency of rice production.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions

YH – study conception and design, drafting of the manuscript;
AB – analysis and interpretation of data and is the corresponding author;
ML – an author of the idea, guided the research;
TU, VZ, – acquisition of data, drafting of the manuscript;
NM – performed the literature data analysis and discussion of the results;
VM – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

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