ISSN 2226-3063 e-ISSN 2227-9555
Modern Phytomorphology 16: 15–20, 2022

RESEARCH ARTICLE

Economic and energy efficiency of growing *Camelina sativa* under conditions of precarpathians of Ukraine

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Received: 12.02.2022 | **Accepted:** 15.02.2022 | **Published:** 28.02.2022

Abstract

The article presents the results of research conducted during 2018-2021 in a field experiment on sod-podzolic soils on studying the efficiency of different fertilization variants on the productivity of *Camelina sativa* L. and, accordingly, the economic and energy efficiency of growing this crop.The dependence of productivity and yielding capacity elements on the application of mineral fertilizers has been revealed.It was found that the application of mineral fertilizers had a significant impact on the productivity of *Camelina sativa* L. seeds and the index of prime cost and profitability of *Camelina sativa* L. seeds accordingly. Depending on the studied elements in the technology of growing little-known in Ukraine crop of *Camelina sativa* L., the main indices of economic and energy efficiency were determined. It was found that optimization of plant nutrition, regardless of cultivation cost increase, provided an increase of conditionally net profit and profitability level. This was facilitated by foliar fertilization with modern regulators of growth and complex micro-fertilizers in critical periods of the crop vegetation. Depending on the variant of the experiment, conditionally net profit on average for the years of cultivation ranged from 14.899 UAH to 21.719 UAH/ha, and the level of profitability-from 172.8% to 197.4%. Under influence of the studied factors, the energy consumption of the yield, on the contrary, decreased compared to the control, which indicates expediency of different fertilization of plants in main periods of vegetation with the studied fertilizers and micro-fertilizers.

Keywords: *Camelina sativa* L., economic efficiency, energy efficiency, mineral fertilizers, micro-fertilizers.

Introduction

Camelina sativa L. is a promising oilseed crop, the yielding capacity potential of which has not yet been fully revealed. Interest in *Camelina sativa* L. has been restoring for recent years due to oversaturation of crop rotations with cereals, sunflower, as well as increase in demand for plant oils of various quality. It also attracts attention due to its simplicity, precocity, steady yielding capacity, high plasticity and suitability for different soil and climatic conditions (Hryhoriv et al. 2021; Volokh 2005).

Growing *Camelina sativa* L. in Ukraine has great prospects. Production technology, biological features, history of cultivation and sufficient level of yielding capacity under agro-climatic conditions of Ukraine indicate the necessity and prospects for crop development. Due to low-cost environmentally friendly cultivation and, consequently, insignificant impact on the environment, *Camelina sativa* L. is becoming a favourite crop for the production of organic products (Hryhoriv et al. 2020; Demydas et al. 2011). The use of *Camelina sativa* L. oil in food and other industries has a huge market potential. In addition, *Camelina sativa* L. oil contains large number of essential polyunsaturated acids, including linolenic (up to 31%) and linoleic (up to 18%). These substances are not synthesized in the human body, so they were called essential (irreplaceable). The wide application of *Camelina sativa* L. oil in food, cosmetics and perfume industries, as well as in medicine, makes *Camelina sativa* L. an agricultural crop of the future (Frohlich 2005; Putnam 1993; amayunova 2017; Hryhoriv et al. 2021).

Camelina sativa L. culture is valued for its high content (up to 45%), omega-3 fatty acids, which are rare in other plant sources. More than 50% of fatty acids in cold-pressed *Camelina sativa* L. oil are polyunsaturated. The main components are alpha-linolenic acid-C 18:3 (omega-3 fatty acids), about 35%-45% and linoleic acid-C 18: 2 (omega-6 fatty acids), about 15%-20%. The oil is also very rich in natural antioxidants. It has 1%-3% erucic acid. The content of vitamin E in *Camelina sativa* L. oil is about 110 mg per 100 g. Its seeds contain up to 50% of low-drying oil (iodine value 127-150), 30% of crude protein, up to 17-18% of carbohydrates. The nutritional value of *Camelina sativa* L. is due to the high content of phosphatides, sterols, vitamins (A, B, E, K), linoleic and linolenic acids and polyunsaturated fatty linoleic acid, which can accelerate the metabolism of cholesterol esters in the body (Demydas et al. 2011; Hryhoriv et al. 2020).

Despite all advantages of the crop, currently in Ukraine *Camelina sativa* L. is grown only in large areas in the Forest-Steppe and Polissia, although there are all conditions for expanding sown areas throughout the country (amayunova et al. 2018; Hospodarenko, Rassadina 2015; Hryhoriv et al. 2021).

Economic methods of assessing technologies of growing crops are to some extent insufficient as they have significant fluctuations which are primarily stipulated by pricing policy. Energy analysis makes it possible to largely avoid these fluctuations and obtain a more objective description of the technological processes of growing crop plants. Thus, energy and economic assessments of technological processes of growing crops complement each other and are relevant for the modern agricultural production of Ukraine (Hryhoriv 2012; Karbivska et al. 2021).

Materials and Methods

Field research was conducted in technological crop rotation of the Department of Growing Technology, Seed Production and Biochemistry of Cruciferous Crops at Precarpathian State Agricultural Research Station of National Academy of Agrarian Sciences of Ukraine on sod podzolic soil during 2018–2021, GPS binding: latitude 58056'55', longitude–34041'45".

The soils of the 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): nitrogen-85, phosphorus–47.0, potassium– 117.0.

Precursor–winter wheat. The sowing was carried out according to the experimental scheme. For sowing was used a variety of Hirsky, selection of institute AIP. Taking into consideration the insensitivity of *Camelina sativa* L. to the application of potassium fertilizers (Poliakov 2011; Hryhoriv et al. 2020), the effect of only nitrogen and phosphorus fertilizers was studied. 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–($P_{45}K_{45}$); 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) + Oracul multicomplex (1 l/ha) + Oracul colamine boron (1 l/ha) + Oracul sulfur active (2 l/ha).

The experiment was based on four repetitions; the area of accounting plot–20 m². A variant without fertilizers was the control. Fertilization of *Camelina sativa* L. crops was carried out with nitrogen fertilizers, micro-fertilizers and growth stimulants according to corresponding variants of the experimental scheme in the rosette phase.

In the experiment was sown *Camelina sativa* L. variety Hirsky of selection Ivano-Frankivsk Institute AIP NAAS included in the State Register of varieties suitable for cultivation in Ukraine. The potential yielding capacity of the seeds is about 2.1 t/ha, green mass-40.5 t/ha (Abramyk et al. 2003; Karpenko et al. 2019; Demydas et al. 2021).

The technology of growing *Camelina sativa* L. on the experimental plots was generally accepted for soil and climatic conditions of Precarpathians, except for the factors studied (Syvyryn and Reshetnykov 1988).

Natural and climatic conditions that have developed in the Ivano-Frankivsk region contribute to the development of agriculture and forestry, cultivation of major crops. It should be noted that during the vegetation period of *Camelina sativa* L. in the research period weather conditions differed significantly from the average long-term data both by temperature indices and amount of precipitations.

It has been established that spring has become 0.8°C warmer in the last two decades, it is provided mainly by March, while in autumn air temperature has changed insignificantly. However, as a result of natural anomalies, acceleration of flowering in spring and premature flowering in autumn take place. This significantly affects the vegetation period of crops and their productivity in general.

The Economic and energy efficiency of growing *Camelina sativa* L. was determined according to modern generally accepted methods, namely with the help of technological maps. Energy efficiency evaluation of production technology elements was carried out according to Ushkarenko, recommendations of Medvedovsky and Ivanenko. Economic efficiency was determined by technological maps and prices prevailing on December 1, 2021. Mathematical processing of obtained analytical digital material was performed by the method of dispersal and correlation analysis according to Dospekhov (1985) and Ushkarenko and others (Ushkarenko et al. 2008), using the computer program "Agrostat".

Experimental design is usually used at the point of greatest impact to reduce design costs by speeding up the design process, reducing the complexity of the material and labor. Experimental design is also a powerful tool for achieving production cost savings by minimizing process variations and reducing recycling, shortages, and the need for verification.

When developing the experiment, we pay special attention to four potential dangers that can create experimental difficulties:

- In addition to measurement error, other sources of error or unclear variations may overshadow the results;
- Uncontrolled factors that cause changes in normal operating conditions are called "Noise Factors". These factors, such as numerous machines, several changes, raw materials, humidity, etc., can be built into the experiment so that their variations are not combined into obscure or experimental errors;
- Correlation can often be confused with causation. Two factors that change together can be highly correlated without one causing the other-both can be caused by a third factor;
- Combined effects or interactions between factors should be carefully considered before conducting an experiment. It was found that the increased amount of water increases the growth of the crop, but there is a time when additional water leads to root rot and has a detrimental effect. Similarly, additional fertilizer has a beneficial effect to the point that too much fertilizer burns the roots. To this complexity of the main effects are added interactive effects-too much water can nullify the benefits of fertilizers, washing it away.

Results and Discussion

The main task of agricultural production in the process of growing any crop, including *Camelina sativa* L., is to increase its profitability with minimal costs of energy and resources (Hryhoriv et al. 2021; Karbivska et al. 2021). This is especially current in modern economic conditions when technology elements, which are developed and proposed for implementation in the production, primarily have to reduce energy costs of growing crops, reduce the prime costs of the production unit and, consequently, provide profit increase. In addition, modern technologies of growing crops must be competitive. At the same time, the shortage of resource potential and pricing policy for the main elements and means, which are an integral component in the development of agronomic cultivation measures, require certain revision of technological approaches to crop production. In recent years, as it is known, the cost of mineral fertilizers has increased significantly, and organic fertilizers are practically not applied due to a significant reduction of public livestock breeding. This has led and continues to lead to deterioration of soils, depletion of movable, available for plants nutrients in their content. Under such conditions, optimization of crop nutrition on resource-saving measures becomes very topical (Hryhoriv et al. 2021; Mauri et al. 2019).

It has been found that the studied doses of mineral fertilizers significantly affected the economic efficiency of growing *Camelina sativa* L. (Tab. 1).

Calculations of economic efficiency of applying mineral fertilizers for growing *Camelina sativa* L. showed that the highest conditionally net profit–21719 UAH/ha on average for the years of research (2018–2021) was obtained in the variant with the application of mineral fertilizers in a dose of $N_{30}P_{45}K_{45}$ as main fertilization and N_{60} as an additional one. The cost of production amounted to 32840 UAH, total costs– 11041 UAH, and the prime cost of 1 ton of seeds–5461 UAH, the level of profitability–197.4%. While in Poland growing of *Camelina sativa* L. seeds provide an average income of 876.3 €/ha with the prime cost of seeds of 455.5 € (Mariusz et al. 2018).

We have to note that in the control variant (without fertilizers) was obtained conditionally net profit in the amount of 6630 UAH/hectare at a prime cost of 1 ton of seeds–6151 UAH, total costs–6336 UAH and profitability level of 104.7%.

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

Therefore, it is not strange that recently, within limits of various EU projects (e.g. ITAKA, ICON, COSMOS), *Camelina sativa* L. has been reopened as a multi-purpose crop as a source of oil and protein (Righini et al. 2016), using low costs and expenditures, and competitive agronomic management (Tonin et al. 2018). Due to great interest in this species in Europe and the driving force of

Table 1. Economic efficiency of *Camelina sativa* L. growing technologies (average for 2018-2021).

Fertilization variant	Yielding capacity, t/ha	Harvest cost, UAH/ha	Production costs, UAH/ha	Prime cost of 1 t, UAH	Net profit, UAH/ha	Profitability level, %
Without fertilizers (control)	1.03	16480	6336	6151	6630	104.7
$P_{45}K_{45}$	1.47	23520	8621	5864	14899	172.8
$N_{30}P_{45}K_{45}$	1.83	29280	9926	5311	19354	195
$N_{30}P_{45}K_{45}$ + N_{60}	2.04	32840	11041	5461	21719	197.4
$N_{30}P_{45}K_{45}$ + micro-fertilizers	1.99	31840	10450	5251	21390	204.7
$\overline{X} \pm s_{\overline{x}}$	1.68 ± 0.07					
LSD_{05} general	0.15					

Table 2. Bioenergy efficiency of *Camelina sativa* L. growing technologies, average for 2018-2021.

Fertilization variant	Gross energy outcome, MJ/ha	Energy costs, MJ/ha	Coefficient of Energy efficiency
Without fertilizers (control)	60732	49335	1.22
$N_0P_{45}K_{45}$	52176	69551	0.77
$N_{30}P_{45}K_{45}$	52863	78696	0.68
$N_{30}P_{45}K_{45}$ + N_{60}	54176	87894	0.62
$N_{30}P_{45}K_{45}$ + micro-fertilizers	52197	83158	0.65

this interest, the authors consider it necessary to gather all European knowledge about the cultivation of *Camelina sativa* L. to provide guidelines for future sustainable development of this crop (Righini et al. 2016; Tonkha et al. 2021).

It is not a secret that the main task of agricultural production in the process of growing *Camelina sativa* L. at present is to increase the profitability of production by increasing agricultural production volume with minimal energy consumption and costs of resources. The estimation of energy efficiency indices is absolutely stable and unchanging. To do this, it is necessary to determine the arrival of energy with the harvest, its costs for growing crops and by the difference between these indices get energy increase. All these indices are stable, they do not change over time, do not depend on pricing policy and so on, as all the components are calculated in megajoules. We have defined main indices of energy efficiency in the cultivation of *Camelina sativa* L., namely nutrition optimization of this little-widespread crop based on resource-saving (Tab. 2).

As a result of the research, it was found that the highest energy outcome was observed in the variant without application of mineral fertilizers (control), which was–60732 MJ/ha. Energy outcome with the harvest increased significantly with the application of mineral fertilizers on average from 1979 MJ/ha to 6556 MJ/ha according to fertilizer variant. Thus, the highest indices were obtained in the control–60732 MJ/ha, while in the variant with the application of $N_{30}P_{45}K_{45}$ + N_{60}–54176 MJ.

We have to note that energy costs for cultivation grew, however insignificantly compared to its income with the harvest. Thus, determined indices of energy growth from the studied factors when growing *Camelina sativa* L. are quite high.

Simultaneously with already mentioned indices of energy efficiency components, changed coefficient of energy efficiency, as it is determined by the ratio of energy income with the harvest and the costs of agro-technological measures provided for cultivation of the studied crop. It was found that optimization of *Camelina sativa* L. plant nutrition, and this was the application of different doses of mineral fertilizers, provided an increase of energy efficiency coefficient compared to the control. Thus, if it was 1.22 in the control without fertilizers, with the application of mineral fertilizers 0.62–0.77, then for foliar nutrition with biological preparations and growth stimulants it increased to 0.65. Our results are confirmed by the studies of Keshavarz-Afshar and Chen, which found a very high coefficient of energy efficiency in the production of *Camelina sativa* L. seeds in the variant without nitrogen fertilizers (10.4), which decreased to 4.4 and 3.7 with an increase in nitrogen fertilizer norms to 45 and 90 kg/ha respectively (Keshavarz-Afshar et al. 2015). And average energy efficiency of *Camelina sativa* L. seed production in another three-year study in the system of arid land in central Montana was 4.2 and ranged from 2.0 to 5.5 in different years of the study (Keshavarz-Afshar et al. 2015).

Conclusions

Analysis of economic efficiency of the studied nutrition optimization elements determined that depending on the application of mineral fertilization conditionally net profit by the variants of experiment ranged from 14.899 UAH/ha to 21.719 UAH/ha, the prime cost of the harvest unit decreased, and the level of profitability changed from 172.8% to 197.4%, i.e. it is high and indicates the expediency of growing *Camelina sativa* L. in Precarpathians of Ukraine using our developed resource-saving approaches to optimization of this crop nutrition.

From the point of view of energy efficiency, *Camelina sativa* L. production was characterized by higher energy gain and low energy consumption of seed production. Under influence of the studied factors, harvest energy consumption, on the contrary, decreased compared to the control, which indicates expediency of fertilizing plants with the studied fertilizers and micro-fertilizers in main vegetation periods of the crop.

Results obtained in this study provide valuable information on the input resources, energy and economic efficiency of *Camelina sativa* L. This information can also be used in other regions of Europe and the world with the aim to improve energy balance and comparance of economic efficiency of *Camelina sativa* L. biomass production. It is shown, that from the point of view of economic and energy efficiency, *Camelina sativa* L. biomass production in a large scale is expedient. However, further research is needed to verify the results of our study and for further improvement of the production technology, reduction of energy consumption and the costs, as well as increase of seed collection efficiency (reduction of losses during harvesting). In the future, this has to help increasing energy and economic efficiency of *Camelina sativa* L. production.

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