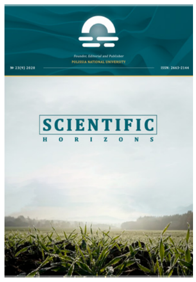
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua/en

Scientific Horizons, 25(2), 55-64



UDC 633.31

DOI: 10.48077/scihor.25(2).2022.55-64

Energy Aspects of Alfalfa Seed Production in Southern Ukraine

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Article's History:

Received: 20.04.2022

Revised: 21.05.2022

Accepted: 22.06.2022

Suggested Citation:

Antypova, L. (2022). Energy aspects of alfalfa seed production in Southern Ukraine. *Scientific Horizons*, 25(2), 55-64.

Abstract. This paper presents the findings of the study on determining the energy efficiency of alfalfa seed production in the first year of life in the south of Ukraine using various technologies, which is relevant for their adequate assessment in conditions of energy conservation of non-renewable resources. The purpose of the study was to determine the most energy-efficient technology for growing alfalfa varieties for seeds. Methods of observation, comparison, and field experiment were used. The study investigated the varieties Nadezhda, Veselka, and Unitro for cultivation using conventional technology (without manual and chemical weeding), which included manual weeding without herbicides and a chemical method to reduce crop contamination. It is established that the production of alfalfa seeds requires a significant expenditure of energy-intensive non-renewable resources for the reliable protection of crops from weeds. It was found that the energy intensity of the technology with chemical weeding of alfalfa crops in the first year of life increased by 32.1-32.4% compared to the control (without weed destruction). Energy consumption reached 13,706 MJ/ha (Nadezhda grade, yield 1.46 centner/ha) against 10374 MJ/ha (yield 0.43 centner/ha) in the control. At the same time, due to the introduction of herbicides, 2.6 times less energy was consumed per 1 centner of seeds (9,388 MJ) compared to the control (24,126 MJ). The energy efficiency coefficient (K_{ee}) for chemical weeding of crops increases from 1.28 to 2.99 (Nadezhda variety) and from 1.35 to 3.13 (Unitro variety). Labour costs are reduced by 2.9 or more times due to chemical weeding of crops. Thus, in the control areas, 25.3 (Nadezhda variety) – 23.3 person-hours were consumed per 1 centner of seeds (Unitro variety), and with the introduction of herbicides, this indicator decreases to 8.8, 8.4 person-hours, respectively. The practical significance of the study lies in the proposal of an energy-saving technology for growing alfalfa for seeds

Keywords: alfalfa for seeds, herbicides, manual weeding of crops, energy efficiency

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INTRODUCTION

Energy analysis in agricultural research is important since it allows substantiating various options for experiments in terms of both profitability and energy-saving, which occupies a special place in terms of economic profit in the market (Zhuchenk *et al*., 1983; Kalashnikova *et al*., 1986). The bioenergy method has become popular in practice as a universal method for assessing anthropogenic energy flows in agroecosystems. It allows expressing all the diversity of both human and mechanic labour in uniform indicators according to the "CI" system in Joules (J). Determining the balance of energy, both consumed for production and produced, allows for quantifying the energy efficiency of growing various crops (Medvedovsky & Ivanenko, 1988; Poisa *et al*., 2016).

Perennial grasses are plants that not only provide farm animals with high-protein feed, but also play a very important role in the biologisation of agriculture, because they have a positive impact on soil fertility and the state of the environment, replenish the soil with organic and biologically environmentally friendly nitrogen, and therefore energy. The activation of biological processes in the soil during the production of perennial grasses should be significant enough to leave a certain reserve to prevent the negative impact of any anthropogenic factor on the environment. Alfalfa is one of the crops that can improve the production of high-quality feed to provide animals with the necessary proteins and at the same time contribute to the biologisation of agriculture (Pachev, 2014; Kvitko *et al*., 2021; Vasileva & Antipova 2021).

An important biological feature of alfalfa is the structure of the root system, which plays a crucial role in the nutrition system. In the process of its ontogenetic development, this plant forms a root system up to 3, and sometimes up to 5 meters deep. At the same time, alfalfa poorly utilises nutrients from such a deep soil profile, because it is poorly supplied with nutrients (Holoborodko & Tyshchenko, 2011).

The most significant factor for choosing a legume perennial grass is drought resistance, since the development of the root system significantly affects this property of the crop and determines the level of its productivity. A.P. Tkachuk study found that alfalfa roots penetrate deeply into the soil and are placed horizontally (Tkachuk, 2021). Alfalfa has a large root neck thickness and many lateral roots. These features contribute to the plasticity, durability, and productivity of its crops.

In the experiments by N.M. Galchenko, energy efficiency coefficient (K_{ee}) for the production of green alfalfa mass was 5.4-6.6, haylage – 4.3-6.1. This figure was highest for growing alfalfa for hay – from 6.2 to 7.6. When using brome grasses, K_{ee} decreased by 30.3-33.3 %, because nitrogen fertilisers were used, which are quite energy-intensive (Halchenk, 2016).

The purpose of the study is to establish regularities of changes in the coefficient of energy efficiency of growing individual varieties of alfalfa for seed purposes based on energy analysis of various technologies of its production in non-irrigated conditions.

LITERATURE REVIEW

A literature review shows that to determine the effectiveness of both individual elements and crop cultivation technologies, it is important to carry out not only energy calculations of total energy consumption for production, but also energy calculations for the energy intake with the crop. Thus, in the experiments of R.A. Vozhehova *et al*. (2019) on the dark chestnut soils of the experimental field of the Institute of irrigated agriculture of the NAAS of Ukraine, when comparing energy indicators, it was found that the energy intensity of white sweet clover of the annual Pivdennyi variety is less than the use of the Donetskyi variety. When sowing the Pivdennyi variety, the energy coefficient value was higher in the variant without mineral fertilisers. This indicator ranged from 1.59-1.77. Fertilisation caused its deterioration.

Application of phosphorus-potassium fertilisers ($P_{120}K_{180}$) to alfalfa under irrigation conditions with a high sensitivity of the crop to phosphorus-potassium nutrition and low energy equivalent contributed to a significant reduction in energy costs for the production of 1 centner of seeds. This figure was 3,276 MJ for alfalfa in the first year of fruiting, 5,266 MJ in the second year, and 7,514 MJ in the third (Holoborodko & Tyshchenko, 2011).

N.M. Halchenko (2016) found that alfalfa cultivation (*Medicago sativa* L.) mixed with medium wheatgrass (*Elytrigia intermedia* Host.) and a boneless bonfire (*Bromus inermis* Leyss) contributed to an increase in the energy efficiency coefficient (K_{ee}) to the level of 4.3-5.9. Since this indicator is significantly higher than 1, this indicates a high efficiency of feed production from perennial grasses in a grass mixture with alfalfa.

A.S. Shpakov *et al*. (2001) proved that perennial grasses provide cheap fodder. The total energy consumption for their cultivation and mowing was 6.8 GJ/ha per mixture of clover and timothy. Kee reached the level of 9.9 in terms of yield of 67.3 GJ/ha of exchange energy. At the same time, it was noted that perennial grasses are an important source of soil replenishment with organic matter and nitrogen. Thus, the legume-cereal mixture provided an average of 94 centners/ha of organic biomass, that is, 21% more than the single-species agrophytocenosis of legumes.

Researchers of the Institute of Feed Research and Agriculture of Podillya of the NAAS have found that the yield of legume seeds strongly depends on the environmental factor (52-75%). Diseases and pests account for 10-15%, and varieties – 15-25%. It is indicated that the "outsized" use of phosphorus and potash fertilisers for three years was more effective than their annual application in a dose of $P_{60}K_{60}$ and provided an increase in yield in the range of 20-28% (Antoniv *et al*., 2018).

Researchers claim that for the surface improvement of meadows and pastures in the conditions of floodplain mountain meadows of the Carpathians, it is mandatory to apply various types of fertilisers and seeds to the sod of mixtures of cereals and legumes that are long-lasting (Kurhak *et al*., 2021). The productivity of grass stands depends on the methods of soil treatment (Karbivska *et al*., 2020).

I. Nikolova & N. Georgieva (2019) emphasise that alfalfa prevents wind and water erosion, improves agrophysical indicators of soil fertility, and is the best precursor of many agricultural crops due to the fixation of environmentally safe biological nitrogen in the atmosphere.

During studies in the northern part of the forest-steppe of Ukraine, it was found that symbiotic nitrogen accumulates the most in alfalfa plants (1.91-2.66 centner/ha), and the least – in meadow clover plants (Kurhak *et al*., 2020).

V.H. Didora & M.M. Kluchkevych (2021) determined that in the Polissya region, up to 3.57-4.00 centner/ha of biological nitrogen are fixed from the air by soybean plants, while up to 1.17-1.60 centner/ha remain in the soil profile.

An important factor that significantly reduces the "nitrogen fixation activity of legume-rhizobial symbiotic systems" is insufficient water supply (Kots *et al*., 2021).

In the experiments by A.V. Tishchenko *et al.* (2020) conducted in the steppe zone (Inguletsky irrigated Massif), irrigated alfalfa of the second year of vegetation (Zoryana variety) formed 3.02 centner/ha of seeds, and the Unitro variety – significantly more (3.91 centner/ha) and accumulated air-dry root mass at the level of 51.40 and 51.00 centner/ha; symbiotic fixation of 2.05 and 2.00 centner/ha, respectively.

At the same time, insufficient research has been conducted on the energy efficiency of alfalfa seed production, which is one of the main forage crops among perennial legumes.

MATERIALS AND METHODS

A study to determine the most energy-efficient technology for growing alfalfa for seed purposes in non-fertile agrophytocenoses of arid conditions was conducted in the southern massif of Ukraine, in a branch of the Mykolaiv National Agrarian University. The sown area was 50 m^2, and accounting area – 30 m^2.

Soils – southern chernozems are residual slightly saline, heavy loamy, containing humus (according to Tyurin, DSTU 7855:2015) in the arable layer of 0-30 cm on average 2.9%. The reaction of the soil solution is close to a neutral value: the pH of the salt extract ranges from 6.8. 100 g of soil is provided on average with: nitrates – 1.2 mg, mobile phosphorus – 8.5 mg, and exchange potassium –18 mg.

The density of 0-60 cm soil layer is 1.25 g/cm^3, wilting humidity – 11.4%. Underground water lies deeper than 20 m and does not affect the process of soil formation. An average of 400 mm of precipitation falls per year, and the hydrothermal coefficient is 0.7-0.8.

The predecessor of alfalfa was winter barley, and after harvesting it, stubble was cleaned. In autumn, the soil was loosened with a KPE-3,8 cultivator to a depth of 12-14 cm.

Alfalfa varieties Nadezhda, Veselka, and Unitro were studied. All these varieties are suitable for growing in non-irrigating conditions. They are included in the State register of plant varieties of Ukraine.

In the spring, mineral fertilisers were applied (nitroammofoska – 1 centner/ha) and pre-sowing cultivation was carried out by harrowing with the KPS-4G cultivator. Varieties without cover were sown in the third decade of March 2018, 2019, and 2020 with row spacing of 70 cm. The depth of seed embedding is 2-3 cm, the seeding rate is 3 kg/ha.

Weeding (chemical) was carried out with the herbicide pivot manually with a satchel sprayer at the rate of 1 l/ha in the phase of the 1st trigeminal leaf in alfalfa on plots according to the experimental design.

After the appearance of full shoots in the experiment, row-to-row tillage with a KRN-4.2 cultivator was carried out on the entire array. Working bodies – razors.

Weeding of crops manually was carried out twice: the first time, when weeds grew en masse, and the second time – 2 weeks after the first only in areas for manual weeding according to the experimental design.

The second row-to-row loosening of the soil in the entire experiment was carried out during the period of mass germination of weeds. Desiccation of crops was carried out by Reglon Super, and the seed yield was accounted for by the Sampo-500 combine. Before desiccation, sheaf samples were taken at all sites of the experiment to determine the crop structure.

Weather conditions varied over the years. 2018 was more favourable for the grass yields. In March, 75.5 mm of precipitation fell, and in April-July, another 179.4 mm was added. The average daily air temperature during April-July ranged from 10.2-23.3°C. 2020 turned out to be the driest. The above indicators are listed at the level of 8.5 mm, 118.0 mm, 10.4-24.2°C. In August 2020, there was no rain at all, which adversely affected the productivity of alfalfa.

The experiments were conducted according to generally accepted methods, considering the publications "Fundamentals of scientific research in agronomy" and "Methodology of field experience" by B.O. Dospekhov (Yeshchenko *et al*., 2005; Dospekhov, 1985).

The energy efficiency was analysed using technological maps and energy equivalents (Eeq), defined by Medvedovsky A.K., Ivanenko P.I. for machinery, electricity, fuel, fertilisers, pesticides, transportation, processing, and storage of agricultural products, labour costs, etc. (Medvedovsky & Ivanenko, 1988).

To calculate labour productivity, the direct labour costs of tractor drivers, combine harvesters, workers, etc. were taken into account.

Energy efficiency coefficient (K_{ee}) is calculated by equation (1):

$$K_{ee} = OE : \sum E \quad (1)$$

where OE – exchange energy of the crop, MJ; $\sum E$ – amount of total energy spent on growing alfalfa, MJ.

The obtained data were processed by the method of variance analysis, which was carried out using the software and information complex Agrostat (Ushkarenko *et al*., 2008).

RESULTS AND DISCUSSION

High and stable yields of alfalfa seeds are obtained only when all innovative agronomic measures are applied to the seedlings, developed considering the biological characteristics of this plant. Neglecting at least one of the planned types of work can reduce total energy costs, but at the same time, it can lead to a significant decrease in the productivity of alfalfa for seed purposes.

Main soil treatment methods play an important role in energy saving. In previous years, experiments were conducted to investigate the influence of this factor on alfalfa seed productivity (Antypova, 2008). The experiment scheme is shown in Table 1. Calculations indicate the energy efficiency of shallow (12-14 cm) loosening of the soil with an anti-erosion cultivator (KPE-3.8), that is, without a barrow. The use of this option in the autumn period leads to a decrease in energy consumption in the production of alfalfa seeds. This method should be attributed to energy-saving agrotechnical in comparison with the conventional shelf with a depth of 28-30 cm, which was taken as control. At the same time, the total energy intensity of labour resources decreases from 57.7 to 29.0 MJ/ha, that is, almost twice.

***Table 1**. Energy intensity of basic cultivation methods for alfalfa**

Main soil treatment		Output for 1 person – hour, ha	Energy intensity, MJ/ha			
Methods	Depth, cm		Labour resources	Fuel	Total	± to control
Control – tillage	28-30	1.06	57.7	1,006.5	1,064.2	0
Tillage	22-24	1.08	56.7	901.5	958.2	-106.0
Without tillage	28-30	1.37	44.7	758.4	803.1	-261.1
Tillage	22-24	1.41	43.4	663.0	706.4	-357.8
Tillage	12-14	2.11	29.0	357.8	386.8	-677.5

***Note:** calculated by the author based on technological map and energy equivalents for machinery, fuel, and labour costs*

It was found that during shallow sweep tillage, fuel consumption is 13.6 kg/ha less compared to deep ploughing. The cost of such a non-renewable resource as fuel, which is an energy carrier, is reduced from 1006.5 (control) to 357.8 MJ/ha, that is, by 2.81 times, and the total cost of total energy, which includes labour with fuel, is reduced by 2.75 times (from 1064.2 to 386.8 MJ/ha, respectively).

Considering the fact that there was no significant difference in seed productivity between the considered options, it can be concluded that among the methods of basic tillage, sweep tillage to a depth of 12-14 cm is preferred in terms of energy efficiency. Alfalfa seed production also requires a significant expenditure of energy-intensive non-renewable resources (in particular fuel and herbicides) to reliably protect crops from weeds. The spread of unwanted plants in the agrophytocenosis significantly reduces the productivity of crops, especially in the first year of life of alfalfa seeds, when it grows slowly and cannot compete with weeds.

The highest yield of alfalfa seeds and dry matter was formed in 2018 due to more favourable weather conditions for plant growth and development. On average, 1.24 centner/ha of seeds and 15.9 centner/ha of dry matter were collected in the experiment in 2018. For drier weather conditions in 2020, these indicators are in the range of 1.11 and 12.9 centner/ha, respectively (Table 2).

***Table 2**. Yield of alfalfa for seed purposes depending on the studied factors*

Technology (factor A)	Variety (factor B)	Yield by year, centner/ha			
		2018	2019	2020	Average
Seeds					
Without herbicides and manual weeding	Control – Nadezhda	0.49	0.42	0.38	0.43
	Veselka	0.51	0.44	0.41	0.45
	Unitro	0.50	0.49	0.42	0.47
Manual weeding	Nadezhda	1.61	1.57	1.43	1.54
	Veselka	1.64	1.61	1.49	1.58
	Unitro	1.74	1.67	1.54	1.65
Application of herbicide	Nadezhda	1.50	1.48	1.40	1.46
	Veselka	1.56	1.58	1.42	1.52
	Unitro	1.61	1.59	1.48	1.56
Average in the experiment		1.24	1.21	1.11	1.18

Table 2, Continued

Dry matter					
Without herbicides and manual weeding	Control – Nadezhda	7.1	5.2	4.8	5.7
	Veselka	7.2	5.3	4.9	5.8
	Unitro	7.5	5.7	4.8	6.0
Manual weeding	Nadezhda	19.9	19	16.6	18.5
	Veselka	20.3	19.1	17.3	18.9
	Unitro	21.4	19.7	17.7	19.6
Application of herbicide	Nadezhda	19.2	16.8	16.2	17.4
	Veselka	19.9	16.8	17	17.9
	Unitro	20.5	17.5	16.9	18.3
Average in the experiment		15.9	13.9	12.9	14.2

On average, over three years of study, in areas without herbicides and without manual removal of competing plants, the seed yield ranged from 0.43-0.47 centner/ha. Due to the introduction of herbicides, the contamination of crops decreased, and the yield increased to 1.46-1.56 centner/ha. The best protection of crops from weeds is manual weeding. According to this model of seed production, the highest yield was obtained (1.54-1.65 centner/ha). The Unitro variety had an advantage in this indicator. The Veselka variety has fewer seeds per unit of sown area.

Due to the existing shortage of energy resources and high prices for agrochemicals and modern agricultural machinery, it is necessary to justify the efficiency of crop production technologies not only from the standpoint of economic feasibility but also based on accounting for energy equivalents (Misiuk, 2013).

The energy analysis shows that with the chemical weeding of alfalfa crops in the first year of life, the energy intensity increases by 32.1-32.4% compared to the control, where the crop was not protected from weeds by either herbicide or manual weeding. Energy costs reached 13,706 MJ/ha (Nadezhda variety) — 13,758 MJ/ha (Unitro variety) against 10,374-10,395 MJ/ha, respectively, for varieties on control plantings (Table 3).

***Table 3**. Energy costs for the production of alfalfa seeds in the first year of life, depending on the studied factors (on average for 2018-2020)*

Technology (factor A)	Variety (factor B)	Yield, centner/ha		Energy costs, MJ	
		Seeds	Dry matter	Per 1 hectare	Per 1 centner seeds
Without herbicides and manual weeding	Control – Nadezhda	0.43	5.7	10,374	24,126
	Veselka	0.45	5.8	10,384	23,076
	Unitro	0.47	6.0	10,395	22,117
Manual weeding	Nadezhda	1.54	18.5	15,341	9,962
	Veselka	1.58	18.9	15,362	9,723
	Unitro	1.65	19.6	15,447	9,362
Application of herbicide	Nadezhda	1.46	17.4	13,706	9,388
	Veselka	1.52	17.9	13,737	9,038
	Unitro	1.56	18.3	13,758	8,819
LSD_{05}, centner/ha for factor A		0.03	0.54	–	–
LSD_{05}, centner ha for factor B		0.03	0.54	–	–
LSD_{05}, centner/ha for AB interaction		0.05	0.94	–	–

It was found that energy costs for seed production significantly decreased due to the introduction of the herbicide (in the range of 2.5-2.6 times) and amounted to 8,819 MJ/centner (for the Unitro variety) — 9,388 MJ/centner (for the Nadezhda variety) compared to the control plots (herbicide-free technology), where fluctuations in this indicator were recorded in the range of 22,117 and 24,126 MJ, respectively, for the above-mentioned varieties. Due to the higher productivity of alfalfa sowing for seed purposes using herbicides, that is, by reducing the number of weeds, the content of energy accumulated by plants in the studied crop increases 3.1 times compared to the control and averages 42,060 MJ/ha for factor A. This indicator was slightly higher (3.3 times) when manually weeding crops — 44,689 MJ/ha (Table 4).

Table 4. *Energy accumulation of alfalfa seeds in the first year of life, depending on the factors studied (on average for 2018-2020)*

Technology (A)	Variety (B)	Energy content in the crop from 1 ha, MJ				
		Seeds	Dry matter	Total	Average for factor A	Average for factor B
Without herbicides and manual weeding	Nadezhda – control	869	12,443	13,312	13,643	32,581
	Veselka	909	12,661	13,570		33,389
	Unitro	949	13,098	14,047		34,422
Manual weeding	Nadezhda	3,111	40,386	43,497	44,689	
	Veselka	3192	41,259	44,451		
	Unitro	3,333	42,787	46,120		
Application of herbicides	Nadezhda	2,949	37,984	40,933	42,060	
	Veselka	3,070	39,076	42,146		
	Unitro	3,151	39,949	43,100		

Most of the energy was generated by Unitro plants during manual weeding of crops (46,120 MJ/ha). On average, for factor B in the production of seeds of this variety, 34,422 MJ/ha of energy was accumulated in the yield, which is 5.7% more than the control variety Nadezhda (standard).

According to S.P. Holoborodko & A.V. Tyshchenko, (2011), the production of alfalfa seeds in the South of Ukraine in the average dry (within 75%) and dry (within 95%) years without irrigation during the growing season led to significant expenditures of total energy for growing 1 centner of seeds, which caused the unprofitability of seed production. Energy consumption for seed production (Khersonskaya 7 variety) under natural conditions of moisture in the first year of fruiting (second year of life) was 11,144 MJ/ha and 20,262 MJ/centner of seeds, and Nadezhda variety – 11,144 MJ/ha and 16,151 MJ/centner of seeds, respectively. The implementation of vegetation irrigation once in the period from the beginning of regrowth to the beginning of budding increases energy consumption by 2,255 MJ/ha. At the same time, the energy intensity of 1 centner of seeds decreases by 4,768 and 3,774 MJ, respectively, for the above-mentioned varieties. These figures are considerably better when watered twice during the growing season. Notably, the energy efficiency coefficient (Kee) for chemical weeding of crops increases from 1.28 to 2.99 (for the Nadezhda variety) and from 1.35 to 3.13 (Unitro variety). Consequently, the energy costs of applying herbicides contribute to the conservation and more efficient use of total energy (Fig. 1).

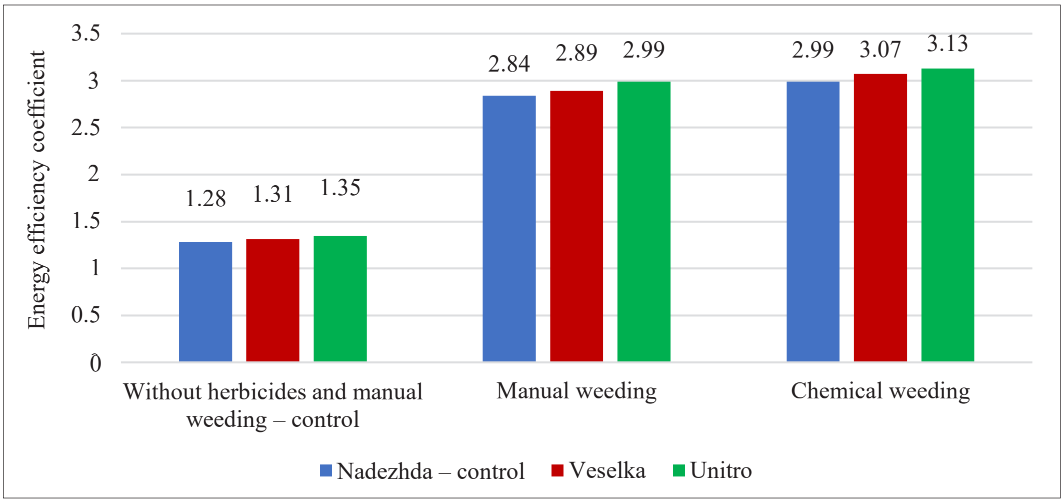

Figure 1. *Coefficients of energy efficiency (Kee) of alfalfa seed production in the first year of life, depending on the studied factors (on average for 2018-2020)*

When manually weeding the agrophytocenosis, the coefficient of energy efficiency of seed production of the studied alfalfa varieties of the first year of life was slightly lower compared to chemical weed control. For plants of the Nadezhda variety, it fluctuated on average over three years of research at the level of 2.84, and for the production of Unitro seeds, it increased by 0.15 units, or by 5.3%. As for the Veselka variety, it had minor advantages over the Nadezhda variety, but they were not reliably confirmed.

It is appropriate to calculate labour productivity, that is, the ability of a particular type of work when growing alfalfa to form a certain amount of products (seeds) in one working hour. This indicator may increase if alfalfa seed production increases by one working hour, or if labour costs per unit of the generated crop are reduced. Labour costs were expressed in person-hours. During the production of agricultural products, in this case, alfalfa seeds, direct labour costs of tractor drivers, combine harvesters, workers, etc. are determined.

According to the technology with the use of herbicides, the highest level of labour productivity was observed: 11.89 (Unitro variety), 11.66 (Veselka variety), 11.30 (Nadezhda variety) kg of seeds/person-hour were obtained compared to the control: 3.96, 4.13, 4.30 kg of seeds/person-hour, respectively (Fig. 2).

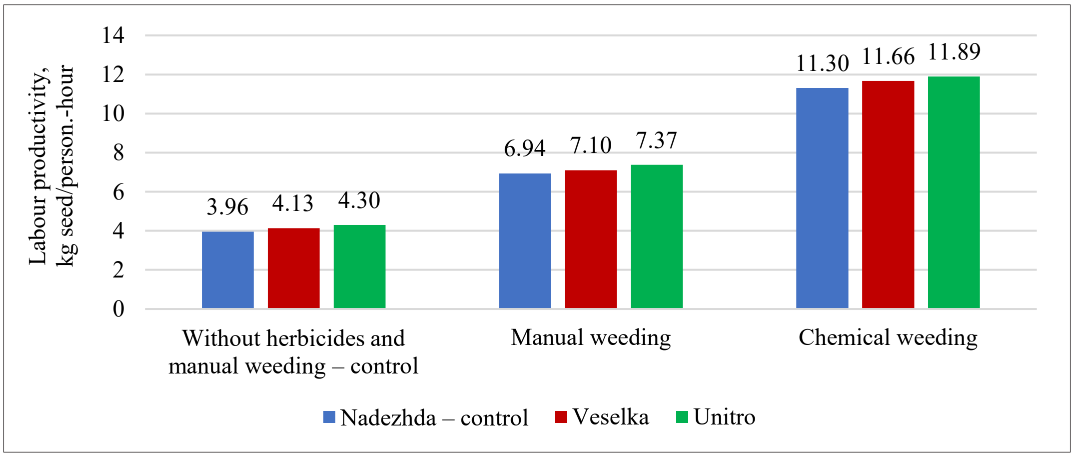

Figure 2. *Labour productivity for the production of alfalfa seeds of the first year depending on the studied factors (on average for 2018-2020), kg of seeds/person-hour*

The technology, which includes manual weeding, is 1.6 times inferior to the chemical weeding model in terms of the above indicator, but labour productivity was 1.7 times higher compared to the control: 6.94-7.37 kg of seeds were obtained per 1 person-hour.

The analysis of the data in Figure 3 indicates that labour costs are reduced by 2.9 or more times due to chemical weeding of crops. Thus, in the control areas, 25.3 (Nadezhda variety) — 23.3 (Unitro Variety) person-hours were consumed per 1 centner of seeds. With the introduction of herbicides, this indicator decreases to 8.8 (Nadezhda variety), 8.6 (Veselka variety), 8.4 (Unitro variety) person-hours.

When using the technology with manual weeding of crops, the energy intensity increases by 11.9 % (up to the level of 15,341 MJ/ha), labour intensity of the percentage of seeds for growing Nadezhda variety increases from 8.8 to 14.4 person-hours and in the Unitro variety – from 8.4 to 13.6 person-hours compared to the technology that is based on the use of chemical weed control. The growth of Kee shows the advantages of chemical weeding technology, especially in the Unitro variety, over other seed production technologies studied.

It should be noted that biological nitrogen enters the soil during the cultivation of alfalfa, which causes a replenishment of the meter layer with total energy.

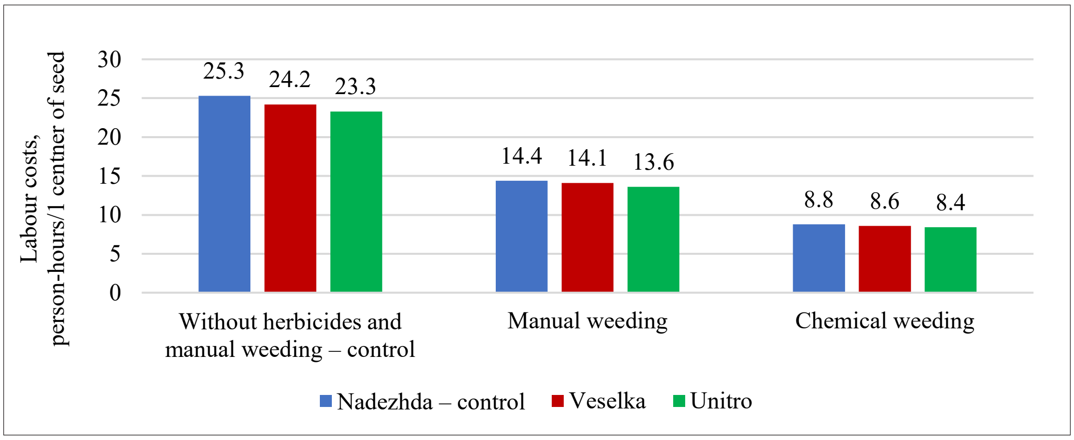

Figure 3. *Labour costs for the production of alfalfa seeds in the first year of life, depending on the factors studied (on average for 2018-2020), person-hour/ centner of seeds*

As evidenced by the results of research by Bulgarian researchers I. Nikolova and N. Georgieva 2019, alfalfa most of all fixes nitrogen against the control (untreated) crop with combined treatment with biological preparations Agricol with Nagro and Litovit, which were used for spraying crops against aphids. The increase in nitrogen fixation was 2.77 and 2.95 kg/kg of dry matter.

N.V. Tsurkan (2014) determined the coefficient of conversion of alfalfa hay crop to nitrogen (K_N), which gets into the soil. This indicator in the conditions of the Southern Steppe for recalculation is 0.025. Considering the above-mentioned coefficient for the transfer of the formed alfalfa hay yield to the nitrogen recorded and trapped in the soil, the intake of this element, and therefore energy, into the soil profile of the root layer, was determined.

The study calculated that as a result of nitrogen fixation, the soil was most replenished with environmentally friendly nitrogen (51.48 kg a.s./ha) using a technology based on manual weeding of alfalfa crops in the first year (Table 5).

***Table 5**. Energy supply to the soil depending on the studied factors (average for 2018-2020)*

Technology (factor A)	Variety (factor B)	Entered the soil per 1 ha					
		Nitrogen, kg of active substance			Total energy, MJ		
		Total	Average for factor A	Average for factor B	Total	Average for factor A	Average for factor B
Without herbicide and manual weeding	Control – Nadezhda	15.33	15.71	37.53	1,330	1,363	3,257
	Veselka	15.63		38.45	1,356		3,338
	Unitro	16.18		39.65	1,404		3,442
Manual weeding	Nadezhda	50.10	51.48		4,348	4,468	
	Veselka	51.20			4,444		
	Unitro	53.13			4,611		
Application of herbicides	Nadezhda	47.15	48.45		4,093	4,206	
	Veselka	48.55			4,214		
	Unitro	49.65			4,310		

***Note**: the energy equivalent (Kee) of 1 kg of active substance of nitrogen fertilisers is 86.8 MJ (Medvedovsky & Ivanenko, 1988)*

For chemical weeding of crops, this indicator was slightly lower – 48.45, and in crops that were not protected from weeds, nitrogen fixation was even lower (15.71 kg of active substance of nitrogen per 1 ha).

There is a tendency for greater nitrogen fixation by plants of the Unitro variety – 39.65 kg a.s./ha, which is 2.12 kg a.s./ha more compared to the control Nadezhda variety.

An identical pattern was established in the flow of total energy into the soil conditioned by nitrogen fixation. This property of alfalfa plants should be considered when calculating both the energy and economic efficiency of its production.

The results of the analysis of the energy structure show that when growing alfalfa for seeds without weeding and herbicides (control), the share of fuel (in conditions of acute energy shortage) reaches 41.5%, and mechanisms – 27.7% (Fig. 4).

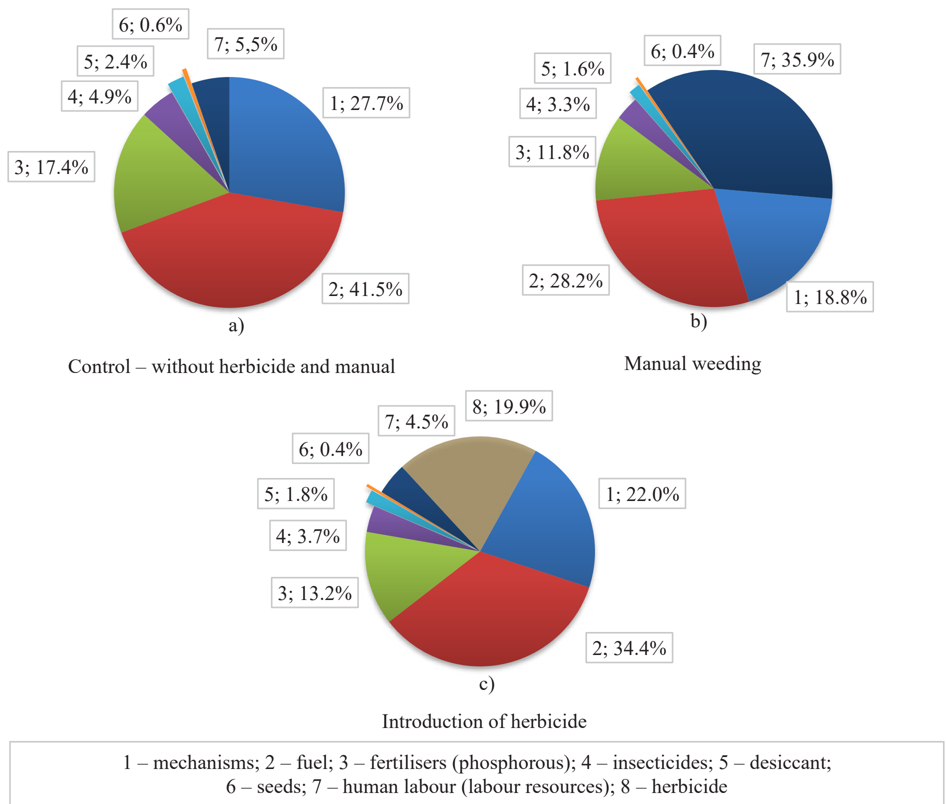

***Figure 4**. Specific weight of energy consumption by alfalfa seed cultivation technology in the first year of growth*

A smaller part is spent on mineral fertilisers (17.4%), insecticides (4.9%), and desiccants (2.4%).

Although the share of human labour using this technology is reduced to 5.5%, the development of the crop, as noted above, was the worst compared to the areas that were cleared of weeds.

The share of fuel and equipment in the structure of energy consumption during manual weeding with wide-row sowing decreases to 28.2 and 18.8%, respectively. At the same time, the main energy consumption falls on labour resources (35.9%), which does not justify a slight increase in seed productivity of the crop compared to chemical weeding.

CONCLUSIONS

The level of energy consumption per unit of production depends primarily on the year of growth, technologies that are implemented, and the equipment used in growing and harvesting alfalfa for seeds.

With sweep tillage to a depth of 12-14 cm, 13.6 kg/ha less fuel is consumed, the total energy costs of human labour are reduced by almost 50%, and the total energy costs (labour resources + fuel) are 2.75 times less compared to deep ploughing by 28-30 cm for sowing alfalfa for seeds.

The formation of crop productivity significantly depends on weather conditions during the growth and development of alfalfa.

When using herbicides, the productivity of alfalfa for seed purposes increases from 0.43 (control without herbicides and manual weeding) to 1.46 entner/ha of seeds, especially with the Unitro variety (from 0.47 to 1.56 centner/ha). Due to the release of crops from the weed component by chemical method, the collection of dry matter also underwent changes and amounted to 5.7, 17.4, 6.0, and 18.3 centner/ha, respectively.

Since manual weeding of the agrophytocenosis accounts for the main share of energy costs in labour resources (35.9%), this technology should not be offered to production. Energy consumption for the production of 1 centner of seeds during chemical weeding is reduced by 2.5-2.6 times compared to the control (without herbicides and weeding), and Kee is 2.99-3.13 against the control level of 1.28-1.35.

The change in the energy efficiency coefficient from 1.28 (for the technology without weeding of the Nadezhda variety, which is taken as a control) to 3.13 (for the technology of growing alfalfa for seed purposes of the Unitro variety with the introduction of herbicides) indicates the advantages of the latter model based on energy analysis of various technologies for the production of seed material in non-irrigated conditions.

During the production of alfalfa seeds of the Unitro variety in the first year, protected from weeds by chemical weeding of crops, 49.65 kg of active substance of nitrogen/ha accumulates in the soil, which is 3.2 times more compared to the control. The property of alfalfa plants to accumulate nitrogen in the soil should be taken into account when calculating both the energy and economic efficiency of its products.

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Енергетичні аспекти виробництва насіння люцерни на півдні України

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Анотація. У цій роботі представлені результати досліджень щодо визначення енергетичної ефективності виробництва насіння люцерни першого року життя на півдні України за різними технологіями, що є актуальним для адекватної їх оцінки за умов енергозбереження непоновлюваних ресурсів. Метою досліджень було визначення найбільш енергоефективної технології вирощування сортів люцерни на насіння. Використовували методи спостереження, порівняння та польового експерименту. Досліджували сорти Надєжда, Веселка, Унітро за вирощування з використанням традиційної технології (без ручного і хімічного прополювання), яка включала ручне прополювання без внесення гербіцидів і технології з застосуванням хімічного методу зменшення забур'яненості посівів. Встановлено, що виробництво насіння люцерни потребує значних витрат енергоємних невідновлюваних ресурсів для надійного захисту посівів від бур'янів. З'ясовано, що енергоємність технології з хімічним прополюванням посівів люцерни першого року життя зросла на 32,1–32,4 % порівняно з контролем (без знищення бур'янів). Витрати енергії досягли 13706 МДж/га (сорт Надєжда, урожайність 1,46 ц/га) проти 10374 МДж/га (урожайність 0,43 ц/га) на контролі. Водночас завдяки внесенню гербіцидів на 1 ц насіння було витрачено енергії у 2,6 рази менше (9388 МДж) порівняно з контролем (24126 МДж). Коефіцієнт енергетичної ефективності (КЕЕ) за хімічного прополювання посівів збільшується з 1,28 до 2,99 (сорт Надєжда) та з 1,35 до 3,13 (сорт Унітро). За рахунок хімічної прополки посівів витрати праці зменшуються у 2,9 і більше разів. Так, на контрольних ділянках на 1 ц насіння витрачалося 25,3 (сорт Надежда) – 23,3 люд/год. (сорт Унітро), а з внесенням гербіцидів цей показник зменшується до 8,8, 8,4 люд./год. відповідно. Практична цінність дослідження полягає в пропозиції енергозберігаючої технології вирощування люцерни на насіння

Ключові слова: люцерна на насіння, гербіциди, ручна прополка посівів, енергоефективність