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Yield and quality of rolled cereal from spelt wheat grain depending on the duration of irradiation with an ultrahigh-frequency electromagnetic field

Abstract. Spelt wheat has great prospects in the technology of manufacture of products of the highest biological value. In the technology of rolled cereal, water-heat treatment is energy-consuming. Therefore, the study of technological parameters of ultrahigh-frequency electromagnetic field irradiation in the technology of spelt wheat cereal is relevant. The purpose of the study is to examine the yield and quality of rolled spelt wheat depending on the duration of exposure to an ultrahigh-frequency electromagnetic field. The study used laboratory (determination of croup yield) and statistical methods. It was identified that the total yield of cereal with the use of the grain of the Holikovs`ka variety substantially increased to 97.3% with the use of irradiation for 60-80 seconds. The yield of premium rolled cereal is the highest with irradiation for 80-100 seconds. Water-heat treatment of cereal from the Holikovs`ka variety grain did not substantially increase the yield of cereal. The highest total yield of rolled cereal was obtained in the LP 1152 line with a duration of irradiation of 100-120 seconds – 93.2-94.9%. The highest yield of rolled cereal of the highest grade was obtained with an irradiation duration of 120-140 seconds. Notably, water-heat treatment substantially affected the yield of cereal (96.0-96.1%). In the technology of production of rolled cereal from spelt wheat of the Holikovs`ka variety using an ultra-high frequency electromagnetic field, the duration of irradiation is 80-100 seconds without moistening. When using cereal No. 1 from spelt wheat of the LP 1152 line, it is necessary to moisten it by 0.5% with an irradiation duration of 120-140 seconds. The duration of cooking of premium rolled cereal is 10.7-11.3 minutes. The materials of the study are of practical value for low-productivity cereal enterprises in the production of spelt wheat cereal products. If the electromagnetic field is used in the technological process, it is possible to use improved modes

Keywords: microwave oven, cooking time of cereal, peeling index, cooking time, grain crop

INTRODUCTION

According to FAO (Food and Agriculture..., 2021), wheat is the main cereal crop with a gross grain production of about 765 million tonnes. Evidently, wheat grain is the main raw material for food production. Spelt wheat has great prospects in the technology of manufacture of products of the highest biological value. In addition, it has a number of advantages during cultivation. Modern spelt wheat varieties are characterised by the highest resistance to major fungal diseases and are able to form a grain crop on low-fertile soils. The grain forms a higher protein content, which is more balanced in amino acid composition. Therefore, research on expanding the range of grain products and improving the technological modes of their production is relevant.

Cereal products are an important component of nutrition and raw materials for the production of other products. Among them, rolled cereals are the most popular, especially in the technology of fast-cooking cereals or cereals that do not require cooking. Thus, according to the State Statistics Service of Ukraine (State Statistics

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Service..., 2022), 165.28 thousand tonnes of rolled cereal were produced in 2021, while rice – 11.70, and other types of cereal – 49.43 thousand tonnes.

Water-heat treatment is performed in overpressure apparatuses with a continuous or periodic principle of operation. Notably, this process is energy-intensive, which increases capital investment. In addition, depreciation operations during the technological process are high, and the danger to service personnel increases (Schmidt *et al.*, 2018). Thus, the study on the effectiveness of using new methods of water-heat treatment of raw materials in the technology of cereal products is relevant. Especially for processing grain that has the highest biological value.

Ultrahigh-frequency electromagnetic field radiation (UHF-EMR) exposure is quite common in food technology. In addition, it is a promising method of conducting water-heat treatment in the technology of cereal products. Its use affects the physical and chemical parameters of raw materials. Usually, UHF-EMR increases the temperature of the grain and causes denaturation of its biochemical components, while reducing the number of microorganisms (Lamacchia *et al.*, 2016). The efficiency of UHF-EMR depends on the technological properties of raw materials, their humidity, the duration of irradiation, the power of the electromagnetic field, and its frequency (Qu *et al.*, 2017).

Currently, in the technology of rolled cereal, water-heat treatment with water vapour under pressure is used. It is performed using the steaming and infrared radiation. Therewith, the humidity of the finished product increases substantially. After the precedure, it is necessary to use drying. An ultrahigh-frequency electromagnetic field causes internal heating of materials due to fluctuations in electric charges. The key dipole is water. When the grain is heated, some of the moisture converts into a gaseous state. Due to this, the grain volume increases and a certain part of the moisture evaporates (Lucas, 2018).

UHF-EMR exposure does not affect the amount of protein in the grain. At high temperatures (>65-75°C), thermal denaturation of glutenin proteins occurs in the grain (Ma & Baik, 2021). After tempering the grain with infrared radiation at a temperature of 102°C for 90 seconds, there is a substantial decrease in the activity of vitamin B_2 (Aguilar *et al.*, 2019). After keeping the grain at a temperature close to 100°C, processes similar to cooking occur. This increases the nutritional value of the product and the absorption of nutrients (Ma & Baik, 2021).

Currently, the demand for a sparsely distributed tetraploid type of wheat – spelt wheat, is growing intensively (*Triticum dicoccum* Schuebl (Schrank.)) due to the highest biological value of grain and a number of economically valuable properties during cultivation. In scientific sources, it is known as hulled wheat and emmer. Marketing of producers of this crop contributes to an increase in demand. They offer it as an alternative to soft wheat (de Sousa *et al.*, 2021). The emphasis is reduced to the following advantages: the highest content of protein, vitamins, microelements, and the possibility of using it for people with allergy to gluten group protein (Lindfors *et al.*, 2019). Although it is warned that with celiac disease, it should be excluded from the diet. For the most part, spelt wheat is grown in organic farming. This is facilitated by high tolerance to certain diseases, unpretentiousness to the soil, and the ability to grow in mountainous areas (Dubois *et al.*, 2017).

The growing popularity of spelt wheat as an environmentally friendly product with increased nutritional value actively encourages researchers to examine possible applications to obtain food products of improved quality (Silletti *et al.*, 2019). Now spelt wheat grain is a raw material for the production of flour (varietal and whole grain) and many types of cereal. One of the options for processing spelt wheat grain is the production of rolled cereal. This type of cereal has gained popularity among the population as a full breakfast. They are made in different sizes and from a variety of grain raw materials: oats, triticale, spelt, buckwheat, corn. Spelt wheat cereals are known to have excellent taste properties. Semolina has better culinary properties compared to soft wheat and is similar to durum wheat (Dhanavath & Prasada Rao, 2017). In general, the culinary quality of spelt wheat cereals has certain characteristic features: a well-defined smell and taste that differs from conventional wheat cereal and a crumbly consistency of porridge with yellow or cream colour. Due to the properties of the shells, there is no need for strict grain peeling modes (Liubych *et al.*, 2020). However, to improve the functional properties of spelt wheat grain, it is better to remove a certain number of shells since their surface contains bacterial and fungal microflora and soil particles adversely, and they affect the work of the gastrointestinal tract of a person with chronic diseases. It is known that a decrease in the content of shells in grain negatively affects the yield of cereal, including rolled ones (Liubych *et al.*, 2022).

Thus, spelt wheat has prospects for obtaining high-quality grain products. Therewith, the use of UHF-EMR irradiation in cereal technology has not been sufficiently investigated. Therefore, it is necessary to conduct more detailed studies in the laboratory to examine the effectiveness of the UHF field.

The purpose of the study is to determine the effect of the duration of ultrahigh-frequency electromagnetic field irradiation and water-heat treatment on the yield of spelt wheat cereal products.

MATERIALS AND METHODS

The experimental part of the study was conducted in the educational-scientific laboratory of the Department of Food Technologies "Assessment of the quality of grain and its processed products" of the Uman National University of Horticulture during 2020-2021. Spelt wheat of the Holikovs`ka variety (spring type of development) and the LP 1152 line (winter type) grown in the Right-Bank Forest-Steppe were used. The grain of both samples had a vitreous endosperm (≥70%), the grain moisture content was 12.5%, and the protein content was 14.3 and 15.2%, respectively.

Experiment scheme

The experiment scheme was developed in accordance with the Rules for organizing and conducting the technological process at the cereal factories (Kroshko *et al.*, 1998), which included the technological components shown in Fig. 1. The experiment is repeated three times.

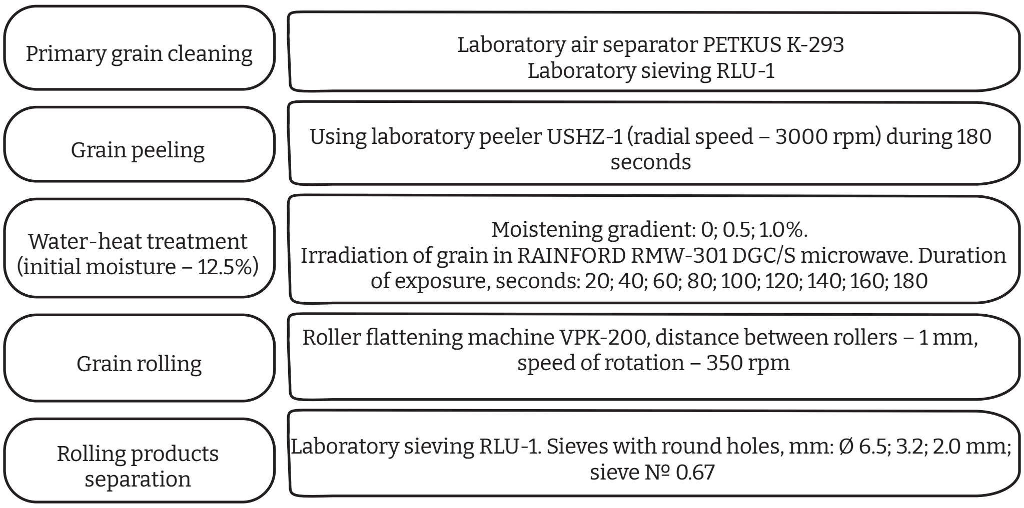

Figure 1. Experiment scheme

Grain peeling

After peeling the grain in the laboratory husker USHZ-1, whole cereal from spelt wheat No. 1 was obtained. The weight of the peeling sample was 150 g. The separation of flour from the pile was conducted on laboratory sieving RLU-1 (sieve No. 0.67). The grain peeling index was 13-15%.

Conducting water-heat treatment of whole wheat spelt cereal No. 1

Water-heat treatment (WHT) of grain was conducted by drip method, and the amount of water was determined by the formula (1):

$$В = 3 \cdot \left(\frac{100-А}{100-Б}\right) - 1 \quad (1)$$

where W is the required mass of water for water-heat treatment of grain, g; G – grain weight during analysis, g; M – grain moisture before processing, %; R – required grain moisture, %.

Water-heat treatment and flattening of whole spelt wheat cereal No. 1

Raw materials were irradiated with an electromagnetic field in a RAINFORD RMW-301 DGC/S microwave oven with a rated power of 1000 W and a microwave frequency of 2450 MHz. The sample weight in the studies was 100 g. The sample was evenly distributed (layer thickness <1 cm) on a round plate (245 mm). After processing, the raw material was rolled, while it was not allowed to cool down. For flattening, a VPK–200 roller flattening machine was used, the distance between the rolls was 1 mm. Rifled rolls (grooved slope 4°, relative position – horizontal), rotation speed 350, 450 rpm.

Determining the yield of cereal

Cereal products were cooled in a ventilated box to room temperature. The cereal products were then separated by RLU-1 sieving. For this purpose, sieves of different sizes were used. As a result, five varieties of the product were obtained (Table 1).

Table 1. Characteristics of products after flattening

Product name	Sieves sizes	Flake diameter, mm
stuck together grains	Sieves with 6.5 mm holes	1%
premium rolled groats	sieve passage with 6.5 mm holes sieve descent with 3.2 mm holes	6.5-3.2
first grade rolled groats	sieve passage with 3.2 mm holes sieve descent with 2.0 mm holes	3.2-2.0

Table 1, Continued

Product name	Sieves sizes	Flake diameter, mm
(grits) crumb	sieve passage with 2.0 mm holes sieve descent with No. 0.67 holes	2.0-0.67
feed flour	screen passage with holes No. 0.67	>

Culinary evaluation of cereal

The culinary evaluation was performed by cooking cereal in measuring cylinders. Since the duration of irradiation did not affect the smell and taste of porridge, the duration of its cooking was determined. The readiness of porridge was determined organoleptically.

The competence of the commission was determined based on a previously improved methodology (Liubych *et al.*, 2020). The commission that conducted the culinary assessment of cereal products included four experts. The overall competence of the commission was 82 points. Therefore, it can be argued that the competence of the commission was very high.

Statistical analysis

Statistical analysis was performed using the STATISTICA 12 programme (StatSoft, Inc., USA). Variance analysis of the results was performed by the least squares method using the Student's criterion. Differences were considered statistically substantial if the probability exceeded 95% ($p<0.05$). All analyses were performed in three repetitions. Experimental results are expressed as mean ±SD (standard deviation).

RESULTS AND DISCUSSION

Yield of rolled croup by UHF-EMR irradiation

Modelling of the process of water-heat treatment by irradiation with a UHF-EMR field is conducted using specialised laboratory equipment or household appliances. Structurally, they differ from industrial equipment. In addition, especially in household microwave ovens, there is no possibility of a perfect study of all the parameters of the technological process. However, the yield trend and the quality of the finished product will correspond to the production parameters. In addition, investigating the effectiveness of UHF-EMR on industrial equipment requires substantial costs (Mazima *et al.*, 2018).

The results of statistical processing indicate that with an increase in the duration of exposure to UHF-EMR from 20 to 80 seconds, the total yield of cereal products substantially increased (from 93.8 to 97.3%) (Table 2). With an increase in the duration of irradiation to 100-180 seconds, this indicator substantially decreased to 85.5-95.3% compared to the option where cereal was treated for 80 seconds. The decrease in the yield of cereal is due to an increase in the yield of crumb and flour. Moistening of cereal No. 1 before irradiation substantially reduced the yield of cereal products by 0.5% compared to options where no moistening was performed. The exception was the irradiation of cereal for 20-40 seconds. The yield of cereal was at the level of options without moistening. Notably, the moistening of cereal No. 1 before irradiation by 1.0% had a similar trend compared to options where humidity increased by 0.5%. During the moistening of cereal No. 1 from spelt wheat, the total yield of cereal products decreased due to a substantial increase in the yield of crumb and flour.

Table 2. Yield of cereal from spelt wheat depending on the duration of irradiation and water-heat treatment (Holikovs`ka variety), %

Duration of exposure, seconds	Yield of cereal products				Flour
	Rolled groats, variety		Crumb	total	
	higher	first			
Without moistening					
20	3.4±0.2	45.4±0.7	45.0±1	93.8±0.3	6.2±0.3
40	24.3±1.1	54.7±0.9	16.1±0.5	95.1±0.2	4.9±0.2
60	67.0±1.2	23.2±0.9	7.1±0.4	97.3±0.2	2.7±0.2
80	82.1±0.7	12.5±0.6	2.7±0.1	97.3±0.2	2.7±0.2
100	77.8±0.5	12.4±0.5	5.1±0.2	95.3±0.2	7.6±0.3
120	68.7±0.1	14.9±0.7	8.8±0.4	92.4±0.3	7.6±0.3
140	58.4±1.5	18.2±0.9	13.7±0.6	90.4±0.5	9.6±0.5
160	44.8±0.9	25.7±1.2	16.0±0.3	86.5±0.6	13.5±0.6
180	39.6±2.4	23.6±1.0	22.2±0.9	85.5±0.5	14.5±0.5

Table 2, Continued

Duration of exposure, seconds	Yield of cereal products				Flour
	Rolled groats, variety		Crumb	total	
	higher	first			
Moistening of cereal No. 1 by 0.5%					
20	20.4±1.1	53.1±1.6	20.7±0.6	94.2±0.3	5.8±0.3
40	43.8±2.0	39.3±1.7	12.0±0.5	95.0±0.2	5.0±0.2
60	62.0±1.6	26.7±1.3	6.4±0.3	95.1±0.2	4.9±0.2
80	78.7±0.7	10.9±0.6	5.0±0.3	94.6±0.4	5.4±0.4
100	73.8±0.7	12.2±0.6	6.9±0.3	92.9±0.2	9.6±0.3
120	66.8±0.7	14.9±0.7	8.8±0.4	90.4±0.3	9.6±0.3
140	57.0±1.9	21.3±1.0	10.2±0.4	88.5±0.6	11.5±0.6
160	43.2±2.2	20.8±0.9	19.8±0.8	83.8±0.5	16.2±0.5
180	36.7±1.7	19.1±0.9	25.7±1.1	81.5±1.1	18.5±1.1
Moistening cereal No. 1 by 1.0%					
20	19.7±0.9	53.0±1.5	2.0±0.9	94.7±0.1	5.3±0.1
40	40.4±2.1	38.1±1.9	16.4±0.5	94.9±0.3	5.1±0.3
60	60.1±1.9	24.5±1.7	10.1±0.5	94.7±0.1	5.3±0.1
80	79.2±0.7	14.1±0.5	3.5±0.2	96.8±0.1	3.2±0.1
100	71.5±1.2	16.5±0.6	6.5±0.4	94.5±0.4	8.7±0.2
120	66.1±1.0	17.8±0.8	7.4±0.4	91.3±0.2	8.7±0.2
140	60.0±1.7	21.6±1.0	9.1±0.4	90.7±0.4	9.3±0.4
160	54.4±2.0	22.1±1.0	11.3±0.5	87.8±0.5	12.2±0.5
180	47.8±1.9	23.4±1.1	13.9±0.6	85.1±0.5	14.9±0.5

The yield of premium rolled cereal varied differently. Thus, the lowest yield was provided by irradiation for 20 seconds – 3.4%. The highest yield was provided by irradiation for 80 seconds – 82.1%. Therewith, exposure for 100 seconds substantially reduced this indicator to 77.8%, but it was substantially higher compared to exposure for 60 seconds. Moistening of cereal No. 1 substantially increased the yield of rolled cereal of the highest grade during the duration of irradiation for 20-40 seconds. With an increase in the duration of exposure, the yield of premium rolled cereal was substantially lower compared to non-moistening options. A similar trend was identified when moistening cereal No. 1 by 1.0%. The yield of first grade rolled cereal, the yield of flour and crumb was inversely proportional to the indicator of premium cereal products.

Thus, in the technology of rolled cereal from shelled spelt wheat of the Holikovs`ka variety, the duration of irradiation for 60-80 seconds is sufficient, provided that the total yield of cereal products is high without moistening. It is necessary to irradiate the peeled grain with a duration of 80-100 seconds without moistening to obtain a high yield of rolled cereal of the highest grade.

The yield of cereal (highest and first grade) from cereal No. 1 spelt wheat of the Holikovs`ka variety can be expressed by a multiple nonlinear models (2, 3):

$$\text{for highest grade} = -15.4208+1.6357\,x + 6.4776\,y-0.0075x^2-0.0291\,xy + 0.1186y^2 \quad (2)$$

$$\text{for first grade} = 68.8229-0.9049\,x-6.6215\,y+0.0036x^2 + 0.0108\,xy + 5.5779y^2 \quad (3)$$

where x – the duration of grain irradiation in a microwave oven, seconds; y – water-heat treatment mode, %.

The highest total yield of cereal products (94.9%) in the LP 1152 line was obtained by irradiation for 120 seconds, provided that no moistening is conducted (Table 3). With the extension of the duration of exposure, this indicator substantially decreased to 89.5-92.3%. In this scenario of water-heat treatment, the yield of cereal was at the level of 50.7-64.3%.

Table 3. Yield of spelt wheat cereal depending on the duration of irradiation and water-heat treatment (LP 1152 line), %

Duration of exposure, seconds	Yield of cereal products				Flour
	Rolled groats, variety		Crumb	total	
	higher	first			
Without moistening					
20	3.6±0.2	47.3±1.7	40.3±1.1	91.2±0.5	8.8±0.5
40	8.7±0.4	44.3±1.5	39.7±0.9	92.7±0.3	7.3±0.3
60	13.5±0.4	40.4±2.0	39.1±1.3	93.0±0.3	7.0±0.3
80	20.7±0.7	44.1±1.9	28.8±1.0	93.5±0.2	6.5±0.2
100	44.9±1.9	29.9±1.3	18.4±0.7	93.2±0.2	6.8±0.2
120	64.3±0.7	18.5±0.9	12.1±0.5	94.9±0.3	5.1±0.3
140	50.7±1.4	27.7±1.3	13.9±0.5	92.3±0.3	7.7±0.3
160	42.3±1.7	32.4±1.4	17.0±0.6	91.7±0.3	8.3±0.3
180	30.5±1.3	40.3±0.4	18.7±0.8	89.5±0.7	10.5±0.7
Moistening of cereal No. 1 by 0.5%					
20	19.9±0.4	43.3±1.9	29.7±1.2	92.9±0.3	7.1±0.3
40	30.1±1.4	40.2±0.7	24.3±0.8	94.6±0.2	5.4±0.2
60	41.4±2.2	36.6±1.6	17.2±0.5	95.2±0.2	4.8±0.2
80	51.1±1.3	28.9±1.1	15.5±0.8	95.5±0.2	4.5±0.2
100	61.7±1.6	17.5±0.7	16.8±0.7	96.0±0.2	4.0±0.2
120	70.5±1.4	15.1±0.7	10.5±0.5	96.1±0.2	3.9±0.2
140	64.6±1.6	19.3±0.9	8.8±0.4	92.7±0.3	7.3±0.3
160	42.2±1.7	38.9±1.0	9.4±0.4	90.5±0.4	9.5±0.4
180	33.1±1.6	42.2±1.8	11.3±0.5	86.6±0.6	13.4±0.6
Moistening cereal No. 1 by 1.0%					
20	24.4±0.5	40.1±0.4	28.7±0.6	93.2±0.3	6.8±0.3
40	35.1±1.8	32.3±1.9	26.1±1.2	93.5±0.3	6.5±0.3
60	46.3±1.0	28.6±1.1	18.8±0.9	93.7±0.3	6.3±0.3
80	60.2±0.9	19.5±0.9	15.3±0.6	95.0±0.3	5.0±0.3
100	68.8±0.8	17.4±0.7	8.0±0.3	94.2±0.2	5.8±0.2
120	73.1±0.3	12.4±0.5	7.4±0.3	92.9±0.3	7.1±0.3
140	62.4±0.6	22.8±0.9	5.9±0.3	91.1±0.4	8.9±0.4
160	44.5±0.7	34.5±1.5	10.5±0.3	89.5±0.4	10.5±0.4
180	36.6±0.5	38.2±1.6	11.8±0.7	86.6±0.8	13.4±0.8

Notably, moistening cerealubstantially increased the yield of products to 19.9-70.5% with the duration of irradiation for 20-140 seconds. Increasing the duration of irradiation did not substantially affect the yield of this grain. Therewith, the total yield of cereal products was substantially higher with irradiation for 20-120 seconds.

The highest yield of premium rolled cereal was obtained during the duration of UHF-EMR irradiation for 120-140 seconds. The yield of rolled cereal increased due to a decrease in the yield of first grade cereal, crumbs, and flour.

Moistening of cereal No. 1 from spelt wheat by 1.0% did not substantially affect the overall yield of cereal products compared to options where moisture was increased by 0.5%. Therewith, the yield of rolled cerealubstantially increased during the duration of irradiation for 20-120 seconds – 24.4-73.1%. The highest yield of this cereal was obtained for the duration of irradiation for 100-120 seconds – 68.8-73.1%.

Thus, in the technology of production of rolled cereal from spelt wheat of the LP 1152 line using UHF-EMR, the duration of irradiation for 120-140 seconds is sufficient with moistening of cereal No. 1 by 0.5% and without water-heat treatment. If cereal No. 1 is moistened by 1.0%, the duration of irradiation can be 100-120 seconds.

The yield of cereal from the LP 1152 line is described by the following multiple models:

$$\text{For higher grade} = -33.5914+1.3257\,x + 58.087\,y-0.0053x^2-0.1701\,xy-21.9329y^2 \quad (4)$$

$$\text{For the first grade} = 69.2838-0.7404\,x-18.5229\,y + 0.0033x^2+0.0822\,xy + 1.5036y^2 \quad (5)$$

where x – the duration of grain irradiation, seconds; y – water-heat treatment mode, %.

Results of the examination of the effect of microwave processing and moistening on the yield of spelt wheat groats

Using the methods of dispersion analysis, a reliable effect ($p<0.05$) of varietal characteristics, the duration of irradiation in a microwave oven and the WHT on the total yield of cereal and the yield of rolled cereal of the highest grade was established (Fig. 2, Fig. 3).

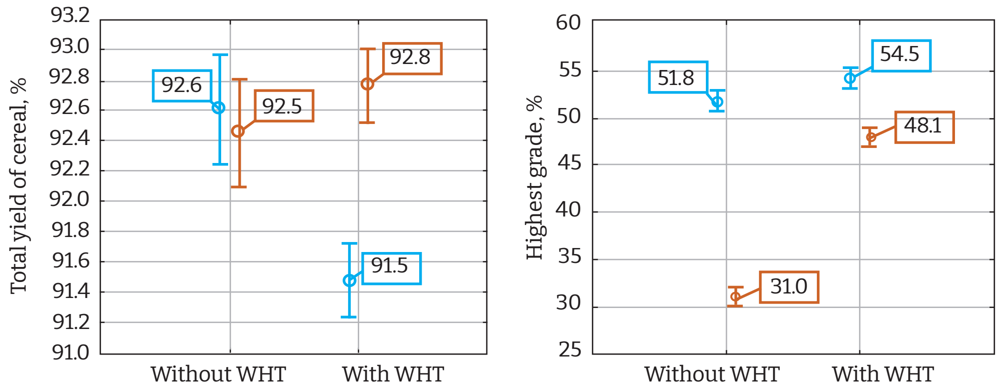

Figure 2. Variance analysis of the influence of technological parameters on the yield of cereal (vertical bars indicate a 0.95 confidence interval)

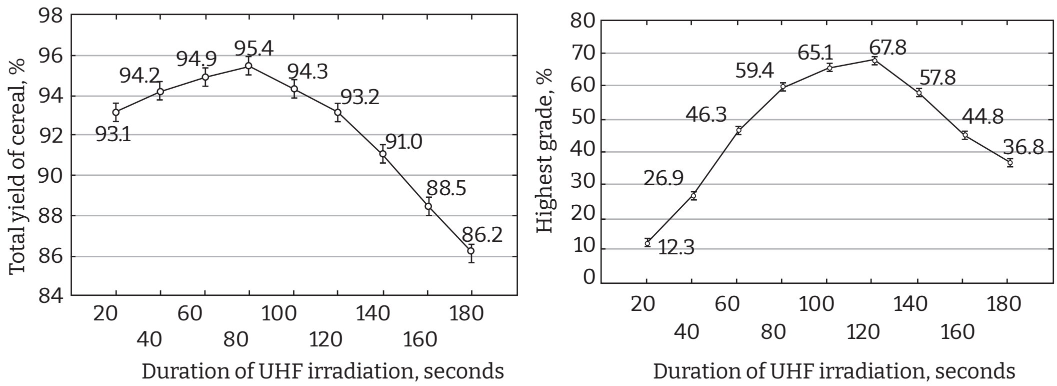

Figure 3. Results of variance analysis of the dependence of the influence of technological parameters on the yield of cereal (vertical bars indicate a 0.95 confidence interval)

The total yield of cereal products when using spelt wheat of the LP 1152 line and the Holikovs`ka variety without the WHT did not differ substantially. The moisture content of cereal No. 1 had different effects depending on the variety or line. Thus, the total yield of cereal when using the LP 1152 line increased, but when using the Holikovs`ka variety, it decreased. The reason for the opposite effect is the morphological features of the grain. There was an increase in the yield of premium rolled cereal after moistening for both varieties.

Exposure to the UHF electromagnetic field for 60-100 seconds provided the highest total yield of cereal products (94.3-95.4%). However, to obtain the highest yield, rolled cereal of the highest grade should be irradiated for 80-120 seconds. An increase in the duration of irradiation (>120 seconds) led to an increase in the grinding of flakes, as a result – a decrease in the yield of premium cereal and cereal in general.

Notably, the total yield of cereal depended more on the variety, and moistening had a low level of influence (η^2=0.53). But the yield of rolled cereal of the highest grade depended most substantially on the duration of exposure to the microwave field. Varietal characteristics were affected the least by strong exposure levels (η^2=0.87). These judgments are confirmed by Pareto diagrams ($p<0.05$) (Fig. 4).

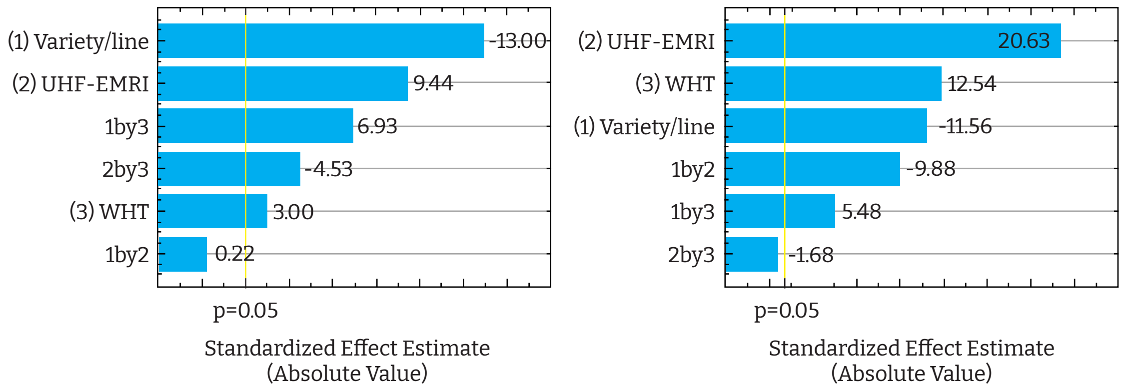

Figure 4. Pareto diagram showing the influence of varietal characteristics, duration of UHF-EMR irradiation and WHT on the total yield of cereal and premium cereal

The results obtained indicate that the efficiency of water-heat treatment depends on the technological parameters of spelt wheat grain. Thus, if the grain of spelt wheat of the Holikovs`ka variety is processed using UHF-EMR, it is not necessary to moisten cereal No. 1. When producing rolled cereal from spelt wheat of the LP 1152 line, moistening cereal No. 1 substantially increases the yield of cereal products, especially premium rolled cereal. During the irradiation of cereal No. 1, changes occur with biochemical components that contribute to the development of flakes and retain their shape after cooling. This statement is proved in the papers of other researchers (Aguilar *et al.*, 2018; Mobolade *et al.*, 2019). In addition, it was identified that the yield of cereal varies depending on the operation parameters of the UHF-EMR equipment itself. This changes the structure of the final product.

In the research of other researchers (Liangchen *et al.*, 2022; Wang *et al.*, 2018), it is proved that the yield of rolled cereal can depend on the protein content in the grain. The protein is able to form strong complexes that have the ability to retain endosperm pstudys after its flattening. Especially if the cereal is low in moisture before rolling. Thus, in the studies, the protein content in the grain of spelt wheat of the Holikovs`ka variety was substantially lower compared to the grain of the LP 1152 line. In addition, it is known that the effectiveness of UHF-EMR also depends on the moisture content of the grain, starch content, fibre, hardness, and thermophysical parameters of the grain.

The efficiency of water-heat treatment can also vary depending on the rate of penetration of free moisture into the grain. Therefore, the effectiveness of moistening can also vary depending on the variety of spelt wheat, which is confirmed in the work (Ding *et al.*, 2018; Barba *et al.*, 2020). In addition, the technological properties of wheat grains of sparsely distributed species differ substantially from soft wheat and durum wheat (Mefleh et al., 2019).

In addition to the protein content, other technological parameters of the grain may affect the efficiency of water-heat treatment using UHF-EMR. Therefore, further research will be aimed at investigating such features to develop optimal UHF-EMR modes regardless of the spelt wheat variety. This is especially important for large batches of grain of this crop, since it can include several varieties.

Culinary evaluation of premium rolled cereal

An important technological indicator of the culinary quality of cereal is the duration of its cooking (Lamacchia *et al.*, 2016). Due to irradiation in a microwave oven, the product is heated. As (Wang *et al.*, 2018) state, heating causes an intense transition of water to a gaseous state, loosening the internal structure of the endosperm. The result of these processes is a change in the duration of cooking cereal (Figure 5). After processing in a microwave oven for 20 seconds without WHT, the cooking time of rolled cereal of the highest grade was 18.3 minutes for the Holikovs`ka variety and 17.7 minutes for the LP 1152 line. An increase in the duration of irradiation (up to 180 seconds) led to a reduction in the cooking time to 15 and 13.7 minutes, respectively. Moistening also led to a reduction in the cooking time by 6-15%.

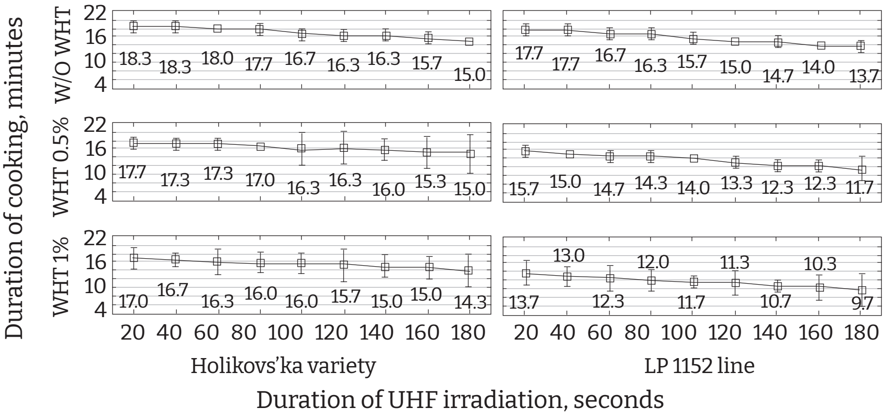

Figure 5. Duration of cooking of rolled cereal of the highest grade, depending on the variety and mode of water-heat treatment

Notably, cereal made from spelt wheat of the LP 1152 line were characterised by a shorter cooking time of 2-3 minutes compared to the Holikovs`ka variety. The duration of cooking rolled cereal (LP 1152 line) of the highest grade after 180 seconds of irradiation coincides with the results obtained after rolling a similar whole cereal after steaming and moistening for 3 minutes (grain peeling index 11.6%) (Liubych *et al.*, 2022).

Changes in the duration of microwave exposure and moistening did not affect organoleptic parameters and overall culinary assessment. However, the culinary quality of cereal depended on the varietal characteristics of spelt wheat. Similar patterns were obtained by other researchers (Barba *et al.*, 2020). According to (Liubych *et al.*, 2020), increasing the protein content of wheat grains improves the smell and taste of the finished product. The results obtained are similar to the known results of the study. Thus, rolled cereal from spelt wheat of the LP 1152 line prevailed by 1 point in taste, smell, colour, and consistency during chewing. Porridge from both varieties had a very high overall culinary rating (8.2-9 points).

Since organoleptic parameters do not change depending on the duration of irradiation in a microwave oven, it is worth choosing production modes that will provide the highest yield of cereal of the desired variety.

Although the study has certain disadvantages, namely the low level of investigating of the parameters of the microwave electromagnetic field and the frequency of processing raw materials, which is due to the specific features of the laboratory installation. However, the results obtained indicate a reliable and positive effect of UHF-EMR on the yield of rolled cereal, regardless of the grade of processed raw materials. Therefore, a more detailed study of the parameters of grain processing in the microwave electromagnetic field and its testing under production conditions are promising.

The results obtained and presented in the paper are of practical importance for production. The use of the proposed method in the conditions of existing production facilities of low productivity will substantially reduce costs for depreciation and maintenance of hot air conditioning systems, and abandon the use of energy carriers (fuel or gas). For the design of new enterprises, the absence of the need for moistening after grain processing in the microwave electromagnetic field substantially reduces the cost of construction, and therefore, the risk of capital investment. Notably, the duration of irradiation may vary depending on the level of moisture content of the cereal. This makes it necessary to determine the optimal modes during UHF-EMR. Further research of economic indicators related to the integration of this technology is required.

CONCLUSIONS

As a result of the study, optimal UHF-EMR modes of cereal No. 1 from spelt wheat were determined. The influence of the duration of irradiation and moistening on the yield and duration of cooking rolled cereal of two varieties of spelt wheat was identified. It was determined that during the production of rolled cereal from spelt wheat of the Holikovs`ka variety, moisture did not substantially affect its yield. Therewith, the total yield of cereal products was also the highest. Moistening of cereal No. 1 from spelt wheat of the LP 1152 line substantially increased the total yield of cereal products and premium rolled cereal. Therewith, for 0.5% moistening, irradiation for 120-140 seconds was effective, and for 1.0% – 100-120 seconds.

Changing the duration of treatment in a microwave oven did not affect the culinary quality. The duration of cooking of rolled cereal depends on the duration of exposure in the microwave, the moisture index, and varietal characteristics. Spelt wheat groats of the LP 1152 line are characterised by a shorter cooking time.

In the technology of production of rolled cereal from spelt wheat of the Holikovs`ka variety, when using UHF-EMR, the duration of irradiation is 80-100 seconds without moistening. The use of such parameters provides a yield of premium rolled cereal of 77.8-82.1%, first grade – 12.4-12.5%, crumb – 2.7-5.1%, and flour – 2.7-7.6%. The duration of cooking of premium rolled cereal is 16.0 minutes. When using cereal No. 1 from spelt wheat of the LP 1152 line, it is necessary to moisten it by 0.5% with an irradiation duration of 120-140 seconds. At such parameters of UHF-EMR, the yield of premium rolled cereal is 64.6-70.5%, first grade – 15.1-19.3%, crumb – 8.8-10.5%, and flour – 3.9-7.3%. The duration of cooking of premium rolled cereal is 10.7-11.3 minutes.

Promising areas are the research of the use of irradiation with whole grain No. 1 obtained from spelt wheat varieties, which have technological properties different from the Holikovs`ka variety and the LP 1152 line. In addition, it is necessary to establish the duration of storage of spelt wheat cereal products exposed to radiation. The research on ways to store such cereal is promising.

REFERENCES

[1] Aguilar, C.N., Ruiz, H.A., Rios, R.A., Chávez-González, M., Sepúlveda, L., Rodríguez-Jasso, R.M., Loredo-Treviño, A., Flores-Gallegos, A.C., Govea-Salas, M., & Ascacio-Valdes J.A. (2019). Emerging strategies for the development of food industries. *Bioengineered*, 10(1), 522-537. doi: 10.1080/21655979.2019.1682109.

[2] Aguilar, C.N., Ruiz, H.A., Rubio Rios, A., Chávez-González, M., Sepúlveda, L., Rodríguez-Jasso, R.M., Loredo-Treviño, A., Flores-Gallegos, A.C., Govea-Salas, M., & Ascacio-Valdes, J.A. (2019). Emerging strategies for the development of food industries. *Bioengineered*, 10(1), 522-537. doi: 10.1080/21655979.2019.1682109.

[3] Barba, A.A., Naddeo, C., Caputo, S., Lamberti, G., d'Amore, M., & Dalmoro, A. (2020). Microwave treatments of cereals: Effects on thermophysical and parenchymal-related properties. *Foods*, 9(6), article number 711. doi: 10.3390/foods9060711.

[4] De Sousa, T., Ribeiro, M., Sabença, C., & Igrejas, G. (2021). The 10,000-year success story of wheat! *Foods*, 10(9), article number 2124. doi: 10.3390/foods10092124.

[5] Dhanavath, S., & Prasada Rao, U.J.S. (2017). Nutritional and nutraceutical properties of *Triticum dicoccum* wheat and its health benefits: An overview. *Journal of Food Science*, 82(10), 2243-2250. doi: 10.1111/1750-3841.13844.

[6] Ding, J.Z., Hou, G.G., Dong, M.Y., Xiong, S., Zhao, S., & Feng, H. (2018). Physicochemical properties of germinated dehulled rice flour and energy requirement in germination as affected by ultrasound treatment. *Ultrasonics Sonochemistry*, 41, 484-491. doi: 10.1016/j.ultsonch.2017.10.010.

[7] Dubois, B., Bertin, P., Muhovski, Y., Escarnot, E., & Mingeot, D. (2017). Development of TaqMan probes targeting the four major celiac disease epitopes found in α-gliadin sequences of spelt (*Triticum aestivum ssp. spelta*) and bread wheat (*Triticum aestivum ssp. aestivum*). *Plant Methods*, 13, article number 72. doi: 10.1186/s13007-017-0222-2.

[8] Food and Agriculture Organization of the United Nations. (2021). Crops and livestock products. Retrieved from http://www.fao.org/faostat/en/#data/QC.

[9] Kroshko, H., Levchenko V., Nazarenko L. (1998). *Rules for organizing and conducting the technological process at the cereals factories*. Kyiv.

[10] Lamacchia, C., Landriscina, L., & D'Agnello, P. (2016). Changes in wheat kernel proteins induced by microwave treatment. *Food Chemistry*, 197, 634-640. doi: 10.1016/j.foodchem.2015.11.016.

[11] Liangchen, Z., Linchun, D., & Taiyuan, S. (2022). Effects of pulsed light on germination and gamma aminobutyric acid synthesis in brown rice. *Journal of Food Science*, 87(4), 1601-1609. doi: 10.1111/1750-3841.16087.

[12] Lindfors, K., Ciacci, C., Kurppa, K., Lundin, K.E.A., Makharia, G.K., Mearin, M.L., Murray, J.A., Verdu, E.F., & Kaukinen, K. (2019). Coeliac disease. *Nature Reviews Disease Primers*, 5(1), article number 3. doi: 10.1038/s41572-018-0054-z.

[13] Liubych, V., Mostoviak, I., Novikov, V., Leshchenko, I., Belinska, S., Kirian, V., Tryhub, O., Pykalo, S., Petrenko, V., & Tverdokhlib, O. (2022). Improving electromagnetic field exposure regimes in the production of flattened spelt groats. *Eastern-European Journal of Enterprise Technologies*, 4(118), 15-22. doi: 10.15587/1729-4061.2022.262102.

[14] Liubych, V., Novikov, V., Zheliezna, V., Prykhodko, V., Petrenko, V., Khomenko, S., Zorunko, V., Balabak, O., Moskalets, V., & Moskalets, T. (2020). Improving the process of hydrothermal treatment and dehulling of different triticale grain fractions in the production of groats. *Eastern-European Journal of Enterprise Technologies*, 3(105), 55-65. doi: 10.15587/1729-4061.2020.203737.

[15] Lucas, J. (2018). Microwave radiation. In *CIRP Encyclopedia of production engineering*. doi: 10.1007/978-3-642-35950-7_6488-4.

[16] Ma, F., & Baik, B.K. (2021). Influences of grain and protein characteristics on *in vitro* protein digestibility of modern and ancient wheat species. *Journal of the Science of Food and Agriculture*, 101(11), 4578-4584. doi: 10.1002/jsfa.11100.

[17] Mazima, J.K., Johnson, A., Manasseh, E., & Kaijage, S. (2018). An overview of electromagnetic radiation in grain crops. *Food Science and Technology: An International Journal (FSTJ)*, 1(1), 21-32.
[18] Mefleh, M., Conte, P., Fadda, C., Giunta, F., Piga, A., Hassoun, G., & Motzo, R. (2019). From ancient to old and modern durum wheat varieties: interaction among cultivar traits, management, and technological quality. *Journal of the Science of Food and Agriculture*, 99(5), 2059-2067. doi: 10.1002/jsfa.9388.
[19] Mobolade, A.J., Bunindro, N., Sahoo, D., & Rajashekar, Y. (2019). Traditional methods of food grains preservation and storage in Nigeria and India. *Annals of Agricultural Sciences*, 64(2), 196-205. doi: 10.1016/j.aoas.2019.12.003.
[20] Official website of the State Statistics Service of Ukraine. (n.d.). Retrieved from http://www.ukrstat.gov.ua.
[21] Qu, C., Wang, H., Liu, S., Wang, F., & Liu, C. (2017). Effects of microwave heating of wheat on its functional properties and accelerated storage. *Journal of Food Science and Technology*, 54(11), 3699-3706. doi: 10.1007/s13197-017-2834-y.
[22] Schmidt, M., Zannini, E., & Arendt, E.K. (2018). Recent advances in physical post-harvest treatments for shelf-life extension of cereal crops. *Foods*, 7(4), article number 7040045. doi: 10.3390/foods7040045.
[23] Silletti, S., Morello, L., Gavazzi, F., Gianì, S., Braglia, L., & Breviario, D. (2019). Untargeted DNA-based methods for the authentication of wheat species and related cereals in food products. *Food Chemistry*, 271, 410-418. doi: 10.1016/j.foodchem.2018.07.178.
[24] Wang, S.M., Wang, J.F., & Guo, Y.B. (2018). Microwave irradiation enhances the germination rate of tartary buckwheat and content of some compounds in its sprouts. *Polish Journal of Food and Nutrition Sciences,* 68(3), 195-205. doi: 10.1515/pjfns-2017-0025.

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Вихід і якість плющеної крупи із зерна пшениці полби залежно від тривалості опромінення електромагнітним полем надвисокої частоти

Анотація. Пшениця полба має велику перспективу в технології виробництва продуктів вищої біологічної цінності. У технології плющеної крупи водотеплове оброблення є енерговитратним. Тому дослідження технологічних параметрів опромінення електромагнітним полем надвисокої частоти у технології крупи із зерна пшениці полби є актуальними. Мета дослідження – вивчення виходу та якості плющеної крупи із пшениці полби залежно від тривалості опромінення електромагнітним полем надвисокої частоти. У дослідженнях використано лабораторний метод (визначення виходу круп) і статистичний. Встановлено, що загальний вихід крупи за використання зерна сорту Голіковська достовірно зростав до 97,3 % за опромінення впродовж 60-80 с. Вихід крупи плющеної вищого сорту найвищий за опромінення впродовж 80-100 с. Водотеплове оброблення крупи із зерна сорту Голіковська достовірно не підвищувало вихід крупи. Найвищий загальний вихід плющеної крупи отримано в лінії LP 1152 за тривалості опромінення впродовж 100-120 с – 93,2-94,9 %. Найвищий вихід плющеної крупи вищого сорту отримано за тривалості опромінення 120-140 с. Слід відзначити, що проведення водотеплового оброблення достовірно впливало на вихід крупи (96,0-96,1 %). У технології виробництва плющених круп з пшениці полби сорту Голіковська за використання електромагнітного поля надвисокої частоти тривалість опромінення становить 80-100 с без проведення зволоження. За використання крупи №1 із пшениці полби лінії LP 1152 необхідно проводити зволоження на 0,5 % з тривалістю опромінення 120-140 с. Тривалість варіння крупи плющеної вищого сорту становить 10,7-11,3 хв. Матеріали статті мають практичну цінність для круп'яних підприємств малої продуктивності під час виробництва круп'яних продуктів із пшениці полби. За умови використання електромагнітного поля в технологічному процесі можливе застосування удосконалених режимів

Ключові слова: мікрохвильова піч, тривалість варіння крупи, індекс лущення, тривалість варіння, зернова культура

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Dynamics of soil fertility indicators in the Chernivtsi region

Abstract. Agrochemical assessment of soils is important for the development of measures for the rational use of soils. The purpose of the study was to establish the dynamics of changes in soil fertility indicators in the Chernivtsi region during 2011-2020. Laboratory and field methods, analysis, and generalisation were used. The reaction of the soil, humus content, the nitrogen content of easily hydrolysed compounds, mobile phosphates, and exchangeable potassium were determined in soil samples. It was identified that the acidity of the soil solution in the region is dominated by soils close to neutral (31.8%) and neutral (36.5%). The weighted average salt pH is 5.8, which corresponds to a close to the neutral reaction of the soil solution. Compared to the previous round of the examination (2011-2015), the weighted average pH indicator did not change in terms of the level of humus supply, soils with an average humus content (66.7%) predominate, and the weighted average humus content in the region is 2.7%. Compared to the previous round of the examination, the weighted average humus content increased by 0.1% in terms of nitrogen content, which is easily hydrolysed, most lands have very low (48.3%) and low (48.7%) indicators. The weighted average content of easily hydrolysed nitrogen for the reporting period is 106.4 mg/kg of soil, which corresponds to the low availability of this element. Compared to the previous round of the examination, the weighted average content of easily hydrolysed nitrogen increased by 0.9 mg/kg of soil. The region is dominated by land with an average content of mobile phosphorus compounds (31.5%), and the weighted average content of mobile phosphorus compounds is 56 mg/kg, which corresponds to the average availability. Compared to the previous round of the examination, the weighted average phosphorus content increased by 4.0 mg/kg. The content of mobile potassium compounds is dominated by soils with a very high content of potassium (51.5%), although the weighted average content of mobile potassium compounds is 78 mg/kg, which corresponds to the average availability of this macronutrient. Compared to the previous round of the examination, the weighted average phosphorus content increased by 15.4 mg/kg. The results of the paper can be used in the process of training specialists in soil science and agronomy, and will also be useful for land users of the Chernivtsi region when planning measures for the rational use of soils

Keywords: soil reaction, soil humus content, easily hydrolysed nitrogen compounds, mobile phosphorus, exchangeable potassium, agrochemical examination

INTRODUCTION

The rational use and protection of land resources are one of the most important socio-economic issues of the present time. Its multidimensional nature determines a systematic approach to solving practical problems of organising the effective and integrated use of the main national wealth – land. For practical solutions to problems of preserving soil fertility, it is necessary to have objective and reliable information about their ecological-agrochemical state (Bandurovych *et al.*, 2017; Hryshchenko *et al.*, 2019). That is why in Ukraine, to

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timely establish the nature and dynamics of changes in the soils of agricultural land, protect them, and restore fertility in accordance with the Law of Ukraine "On Land Protection" (2003), it is necessary to conduct their ecological-agrochemical certification. Ultimately, the data obtained allow for establishing the state of soil fertility and its changes and developing agrotechnical, agrochemical, technological, and economically justified measures to preserve and restore soil fertility.

Bulygin *et al.* (2020) note that the quality of soils can be assessed by the totality of their properties, which can be both positive and negative, which is associated with the specific features of their use.

Balyuk *et al.* (2018) indicate that the most pressing issues of modern times are those that ensure an increase in the level of the information content of data on the soil cover of Ukraine, its formation under the influence of both natural and anthropogenic factors.

Soil degradation processes are developing over large areas and the current state of land resources in Ukraine is of concern. The main reasons are non-compliance with an ecologically balanced ratio of agricultural land, forest-covered areas, reservoirs, and a substantial increase in anthropogenic load on soil cover in recent decades, which has negatively affected the sustainability of agricultural landscapes (Berezhniak *et al.*, 2020). Losses of humus and nutrients in Ukraine were recorded in 43% of all areas (Truskavets'kyy & Tsapko, 2016). The importance of soils is noted in supporting food production and providing ecosystem services, but the soils are under pressure due to population growth, higher demand for food, and competition in land use. For the sustainable use of soil resources, there is a growing demand for up-to-date soil information (Chen *et al.*, 2022).

With the introduction of Soil Day (World Soil Day..., 2021) in December 2013, the term soil health is gaining popularity. Healthy soil is a dynamic living system that can ensure the cultivation of plants, breeding of animals, maintain their health, improve water and air quality, control the availability of nutrients, accumulate carbon in the soil, etc. Soil health is considered the foundation of plant health and productivity, and the basis of sustainable agricultural production (Handayani & Hale, 2022). The fact that land use should be conducted based on land use stabilisation by optimising natural components, introducing adaptive farming systems, and the latest technologies for realising the high biological potential of modern crop varieties is also mentioned by Novakovs'kyy & Novakovs'ka, (2017).

Dem'yanyuk & Boyko (2019) note that the issue of soil condition for various reasons on the land territories of Ukraine is currently being considered insufficiently. Soils need a comprehensive assessment of their condition for forecasting and timely prevention of degradation processes, protection, and rational use of land (Balyuk *et al.*, 2017; Graham, 2021; Hunchak, 2022;).

Cherlinka V. et al. (2019) indicate that in the current conditions, there is a growing need for updated land taxation methods based on accurate information about the ground cover. Ukraine has a large area of land, so field examinations often do not cover the entire territory, which can lead to errors in determining soil varieties and their properties. That is why the examination of indicators of effective soil fertility in a particular territory is relevant, which is what the paper is devoted to.

Smaha & Kazimir (2013) note that various genetic soil types are common in the Chernivtsi region. Sod-brown-earth and podzolic brown-earth soils were formed on eluvial-diluvial deposits, and in foothill areas, 25 thousand hectares are occupied by brownish-podzolic soils. In the forest-steppe districts of the region, 68.3 thousand hectares are occupied by light grey and grey forest soils, 90.8 thousand hectares – by dark grey forest soils. Podzolic chernozems cover an area of 41.9 thousand hectares and are confined to plateaus and shallow slopes of slightly hilly terrain. Such soils as light grey, grey, dark grey forest, podzolic chernozems, semi-hydromorphic meadow-chernozem and hydromorphic meadow-swamp are common in all administrative regions with the exception of Vyzhnytsia and Putyla districts. Brown mountain-forest soils are common in Storozhynets, Vyzhnytsia, and Putyla districts, sod-brown-earth and brown-earth-podzolic soils are typical for the Putyla district, and brown-earth-podzolic soils are common for Hertsa, Storozhynets, and Vyzhnytsia districts.

The purpose of the study – examine agricultural land, assess the state of the main indicators of soil fertility in the Chernivtsi region, and determine the dynamics of changes in these indicators for 2011-2020.

MATERIALS AND METHODS

The Chernivtsi branch of the state institution "Institute of Soil Protection of Ukraine" researched soils to determine the main indicators of soil fertility. The study was conducted in 2016-2020 according to the methods described in the methodology for agrochemical certification of agricultural land (Yatsuk *et al.*, 2019).

Soil samples were taken from a depth of 0-30 cm in accordance with DSTU 4287:2004 (2005). The combined sample consisted of 20-25 point samples weighing about 500 g. If there are two soil types or agricultural production groups of soils within the same basic site, point samples were taken from the type that prevailed in terms of area. If the areas of the two types were equivalent, then two samples were taken. When taking soil samples on agricultural land, a distance of at least thirty meters from buildings, forests, forest belts, warehouses of organic and mineral fertilisers, roads, and other linear objects was observed. In addition, when selecting combined samples, agricultural crops that were grown in the fields were considered: combined samples were taken for each crop. The average sample is made from an area of 50 hectares, provided that the granulometric composition is uniform. If the granulometric composition was different, two or more averaged samples were taken for each soil type. Soil samples were dried for analysis. An average sample from at least 5 different locations was taken with a spatula from the dried soil sample. They determined the humus content by the Tyurin method (DSTU 4289:2004, 2005), the reaction of the soil medium according to DSTU ISO 10390:2007 (2007), the content of easily hydrolysed nitrogen compounds according to DSTU 7863:2015 (2015), mobile phosphates and exchangeable potassium according to DSTU 4115-2002 (2003).

During the period from 2016 to 2020, the Chernivtsi branch of the state institution "Institute of soil protection of Ukraine" examined 182.4 thousand hectares of agricultural land in Vyzhnytsia, Hertsa, Hlyboka, Zastavna, Kelmentsi, Kitsman, Novoselytsia, Putyla, Sokyriany, Storozhynets, and Khotyn districts.

RESULTS AND DISCUSSION

Figure 1 shows that in the Chernivtsi region, the largest areas are occupied by soils with a neutral and close to neutral reaction of the soil environment.

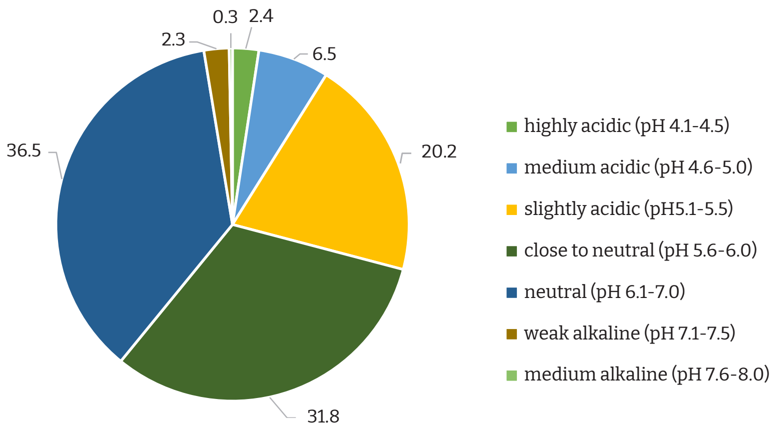

Figure 1. Distribution of the area of agricultural land in Chernivtsi region by the reaction of soil solution, %

Based on the results of the analysis of the reaction of the soil medium (salt pH), the areas under study were distributed as follows (Fig. 1): very highly acidic soils with a pH of less than 4.0 are absent in the area, highly acidic lands with a pH of 4.1-4.5 occupy 4.5 thousand hectares, which is 2.4% of the land area under study, medium acidic with pH 4.6-5.0 – 11.9 thousand hectares (6.5%), slightly acidic (pH 5.1-5.5) – 36.8 thousand hectares (20.2%), close to neutral (pH 5.6-6.0) – 57.9 thousand hectares (31.8%), neutral (pH 6.1-7.0) – 66.6 thousand hectares (36.5%), weak and medium alkaline (water pH 7.1-8.0) – 4.6 thousand hectares (2.6%). The weighted average pH of salt in the 11th round of examinations was 5.8, which corresponds to a close to neutral reaction of the soil solution.

Compared to the previous round of the examination (20112015), the weighted average pH value did not change (Fig. 2). However, there was a decrease in the area of acidic soils by 6%. The area of land with a close to neutral reaction of the soil environment increased by 3.7%, and neutral land decreased by 0.2%. Analysing the results of the study of the reaction of the soil environment in the context of districts, it was identified that in the Hertsa district, the weighted average pH indicator decreased by 0.2 compared to the previous round of the examination, and in the Kitsman and Hlyboka districts – by 0.1 units. This is due to the lack of measures for liming acidic soils. As for Kelmentsi, Zastavna, Storozhynets, and Putyla districts, their weighted average pH indicator remained at the level of the previous round. In Novoselytsia, Vyzhnytsia, Sokyriany, and Khotyn districts, there is a slight increase in the pH value.

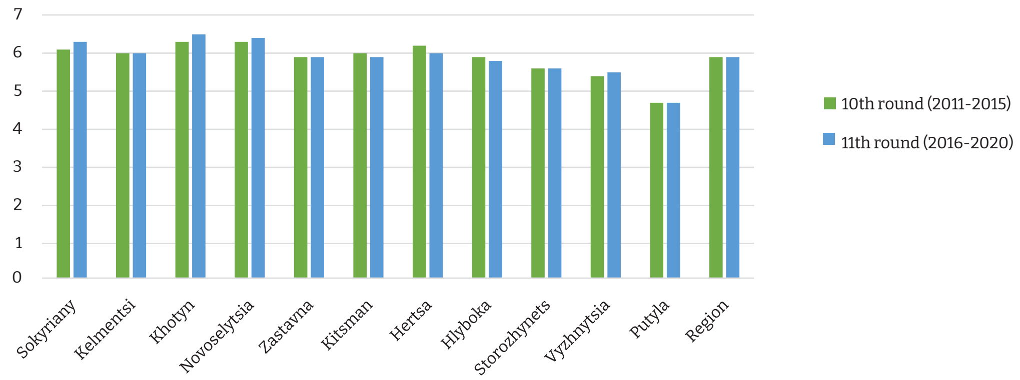

Figure 2. Dynamics of changes in the reaction of the soil (salt pH) of the lands of the Chernivtsi region for the 10th-11th round of agroecological examinations

Soil organic matter (SOM) is an important indicator of its fertility since changes in its content can indicate the presence or absence of soil degradation processes. SOM directly or indirectly improves soil health. That is why efforts must be made to persuade farmers or other land users to increase resource efficiency and the ability to preserve soil to maximise the benefits of agriculture (Sharma *et al.*, 2021; Yu *et al.*, 2022). Humus is the main component of SOM and its importance, first of all, lies in the fact that it serves as a reserve fund of the soil in relation to nitrogen, which, as is known, is not part of mineral compounds. In addition, 40-80% of all phosphorus is also located in its organic matter. Humus also affects the physico-chemical, biological, agrochemical properties of soils, and their water and air regimes, on which the productivity of agricultural crops depends. The weighted average humus content in the region is 2.7%, which corresponds to reserves of 81 tons per 1 ha (Fig. 3).

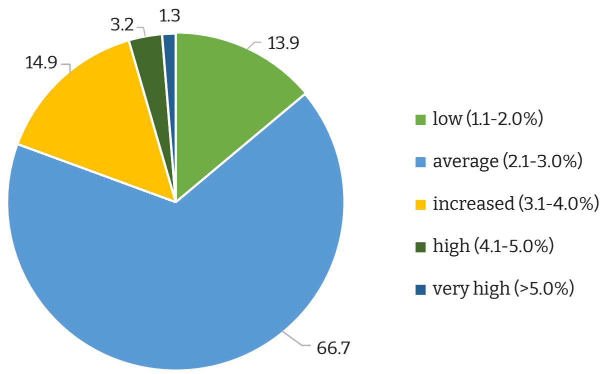

Figure 3. Distribution of the area of agricultural land in Chernivtsi region by humus content, %

In terms of humus content, the soils of the Chernivtsi region were distributed as follows: soils with a very low humus content in the region are absent, with a low content occupy 25.3 thousand hectares (13.9%), with an average – 121.5 thousand hectares (66.7%), with increased content – 27.2 thousand hectares (14.9%), with a high content – 5.9 thousand hectares (3.2%), with a very high content – 2.4 thousand hectares (1.3%). Thus, the region is dominated by soils with an average humus content. Thus, two-thirds of the soils of the region have an average potential fertility in terms of humus content, which is why it is necessary to pay special attention to the preservation of organic matter in the soil and prevent the development of dehumification processes in the soils. Therewith, 19.4% of the land is characterised by a humus content of more than 3%.

In general, the weighted average humus content in the region increased by 0.1%, which indicates effective land use and зrevention of losses of organic matter in soils (Fig. 4).

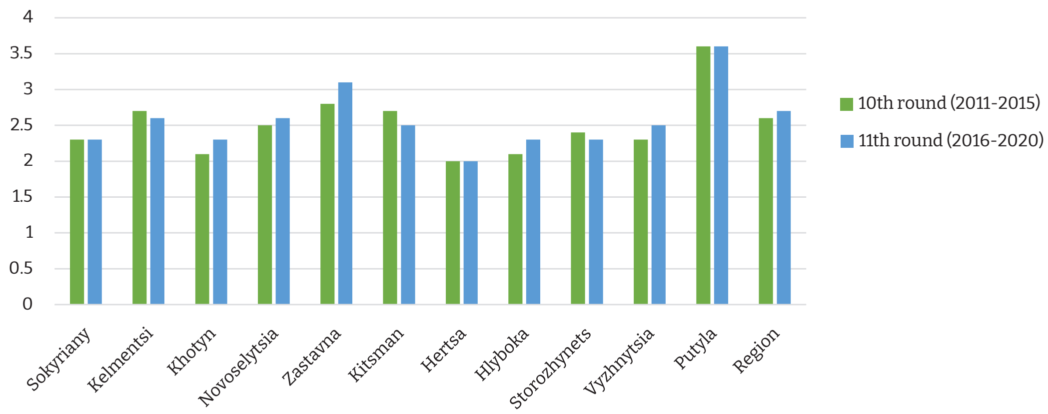

Figure 4. Dynamics of changes in humus content indicators of the examined lands of the Chernivtsi region for the 10th-11th round of agroecological examinations, %

The largest increases in humus content were observed in Zastavna (+0.3%), Hlyboka, Vyzhnytsia, and Khotyn (+0.2%) districts. However, there are areas where a decrease in the weighted average humus content was recorded: in Kitsman district, the decrease was 0.2%, and in Kelmentsi and Storozhynets districts – 0.1%. This indicates an irrational use of soil. Yatskiv (2008) indicates a decrease in the humus content in the soils of the

Chernivtsi region from 2003 to 2008 by 0.1% from 2.5 to 2.4. Poznyak *et al.* (2020) note that the most productive soils with a high content and reserves of humus, a sufficient level of supply of nutrients, and favourable physical properties are used as arable land, the share of which in the Chernivtsi region is 60.2%. The reasons for the decrease in humus content are an increase in the area of row crops sown against the background of an insufficient number of perennial grasses, etc. In addition, the removal of crop by-products from the fields and an unbalanced crop fertilisation system lead to soil dehumification. Therewith, the introduction of straw provides an increase in the stability of soil aggregates and bacterial diversity (Tonkha *et al.*, 2019). A decrease in the percentage of areas with low humus content and an increase in areas with medium and very high humus content is present in the region.

Nitrogen is one of the main elements of plant nutrition, which is necessary for their growth and development. The level of nitrogen nutrition determines the size and intensity of the synthesis of proteins and other nitrogenous organic compounds in the plant, which substantially affect the growth processes. Insufficient nitrogen supply delays plant growth, reduces the size of the assimilation surface of leaves, the duration of their functioning in the active state, and the level of yield and worsens its quality (Tonkha *et al.*, 2019; Tsentylo & Tsyuk, 2019). According to the nitrogen content of compounds that are easily hydrolysed, the area of the examined land is distributed as follows: land with a very low nitrogen content – 88.1 thousand hectares (48.3%), with a low – 88.7 thousand hectares (48.7%), with an average – 2.0 thousand hectares (1.1%), and with an increased nitrogen content – 3.5 thousand hectares (1.9%) (Fig. 5).

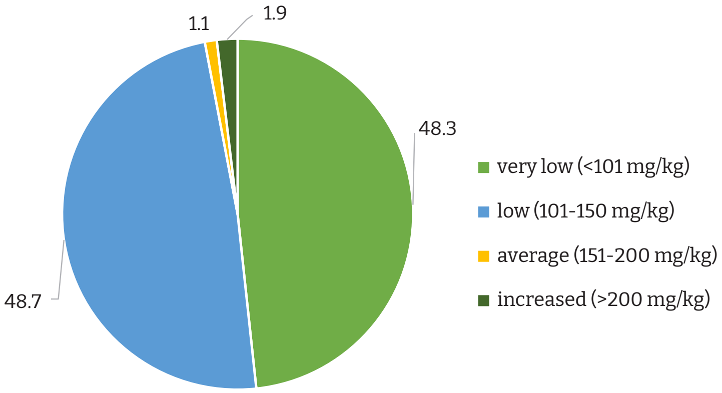

Figure 5. Distribution of the area of agricultural land in Chernivtsi region by nitrogen content, which is easily hydrolysed, %

The weighted average content of easily hydrolysed nitrogen for the period of 2016-2020 is 106.4 mg/kg of soil, which corresponds to reserves of 319 kg/ha. During the two rounds of examinations, the weighted average content of easily hydrolysed nitrogen increased by 0.9 mg/kg (Fig. 6). The greatest increase in easily hydrolysed nitrogen content was observed in Kelmentsi (+14 mg/kg), Hlyboka (+12 mg/kg), and Novoselytsia (+11 mg/kg) districts. A decrease in the weighted average indicator was identified in Putyla (-18 mg/kg), Khotyn (-14 mg/kg), and Vyzhnytsia (-9 mg/kg) districts.

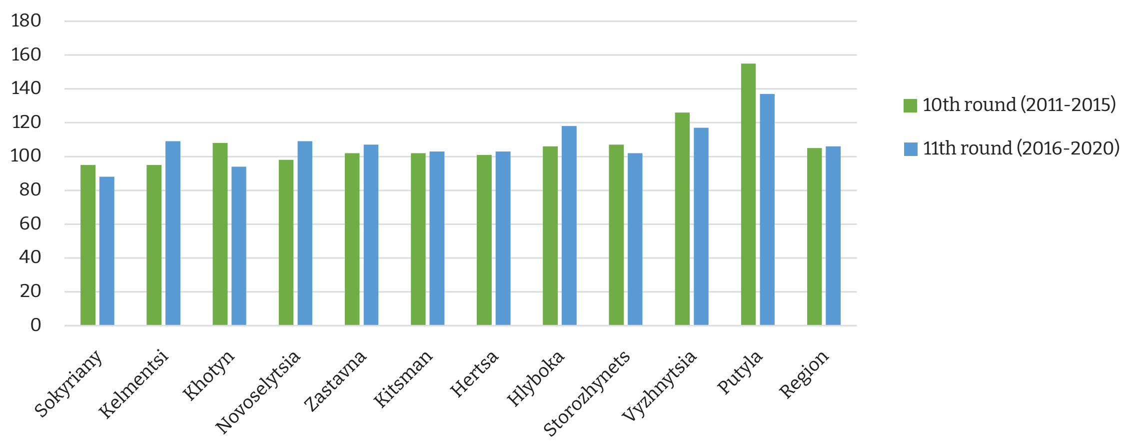

Figure 6. Dynamics of changes in the content of nitrogen, which is easily hydrolysed in the soils of Chernivtsi region according to the 10th–11th round of agroecological examinations, mg/kg

The effective fertility and effect of fertilisers are influenced by the phosphorous regime of the soil. The level of providing the soil with phosphorus mobile compounds is an important indicator of effective fertility since this element is involved in metabolic processes, and is part of DNA, RNA, and other substances, which is why its content in soils affects crop yields. A special feature of phosphorus is that in most varieties of soils, it is in poorly soluble mineral and organic forms inaccessible to plants (Yaliang *et al.*, 2022; Kramariov *et al.*, 2015).

According to the results of the agrochemical examination of agricultural land in the region, the content of mobile phosphorus compounds is distributed as follows: with a very low content – 4.5 thousand hectares (2.5%), with a low content – 21.9 thousand hectares (12.0%), with an average content – 57.5 thousand hectares (31.5%), with an increased content – 52.3 thousand hectares (28.7%), with a high content – 33.6 thousand hectares (18.4%), with a very high content – 12.5 thousand ha (6.9%) (Fig. 7) the weighted average content of mobile phosphorus compounds is 56 mg/kg. Compared to the previous round of the examination (2011-2015), the weighted average phosphorus content increased by 4.0 mg/kg (Fig. 8).

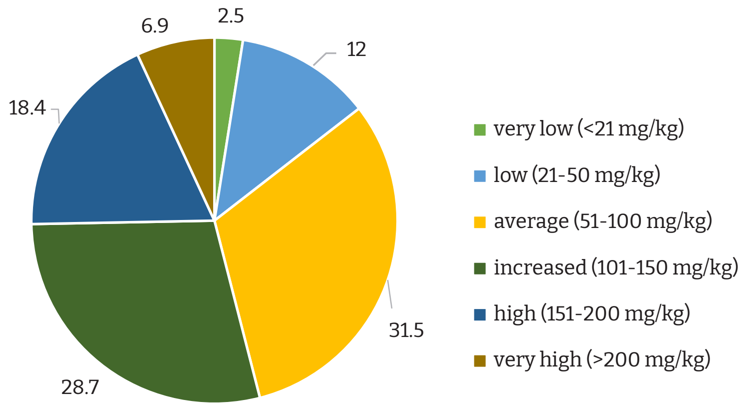

Figure 7. Distribution of the area of agricultural land in Chernivtsi region by the content of mobile phosphorus compounds, %

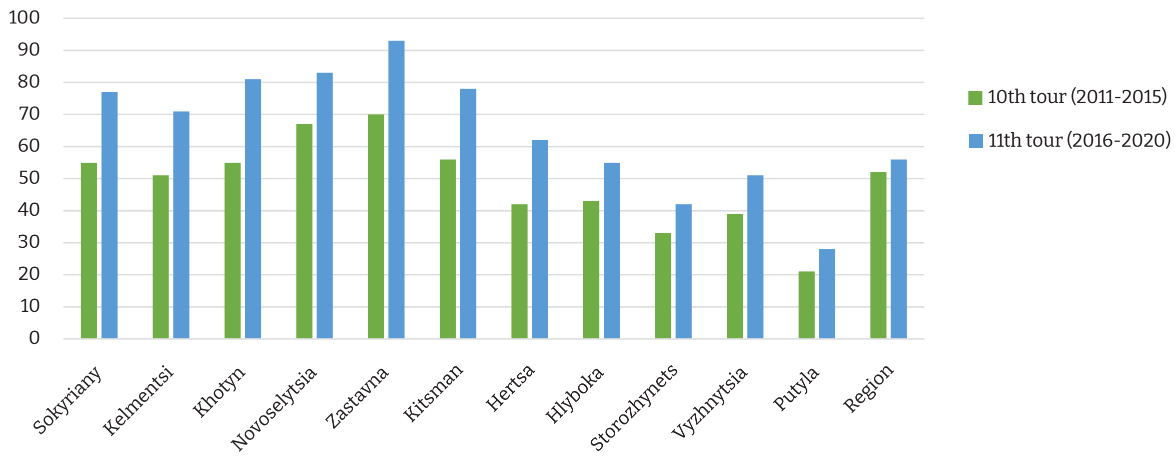

Figure 8. Dynamics of changes in the content of mobile phosphorus compounds in the soils of Chernivtsi region according to the 10th-11th round of agroecological examinations, mg/kg

In general, the content of mobile phosphorus compounds increased in all districts of the region, but most of all in Khotyn (+26 mg/kg), Zastavna (+23 mg/kg), Kitsman, and Sokyriany (+22 mg/kg) districts.

According to the results of an agrochemical examination, agricultural land in the region is distributed according to the content of exchangeable potassium compounds as follows: with very low content and low content – absent. With an average content – 12.2 thousand hectares (6.7%), with an increased content – 21.3 thousand hectares (11.7%), with a high content – 54.9 thousand hectares (30.1%), with a very high content – 93.9 thousand hectares (51.5%) (Fig. 9). The weighted average content of exchangeable potassium compounds is 78 mg/kg.

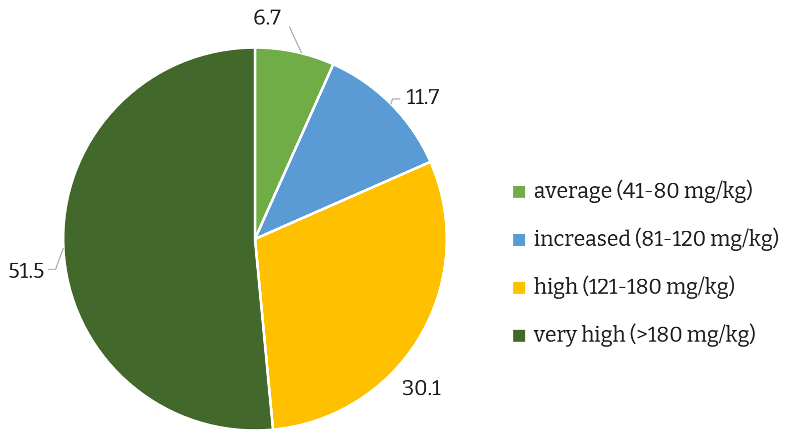

Figure 9. Distribution of the area of agricultural land in Chernivtsi region by the content of mobile potassium compounds, %

The weighted average potassium content increased by an average of 15.4 mg/kg in the region (Fig. 10). In general, the content of mobile potassium compounds increased in all districts of the region, but the largest increase is observed in Sokyriany (+21 mg/kg), Zastavna, Vyzhnytsia (+19 mg/kg), and Kelmentsi (+17 mg/kg) districts.

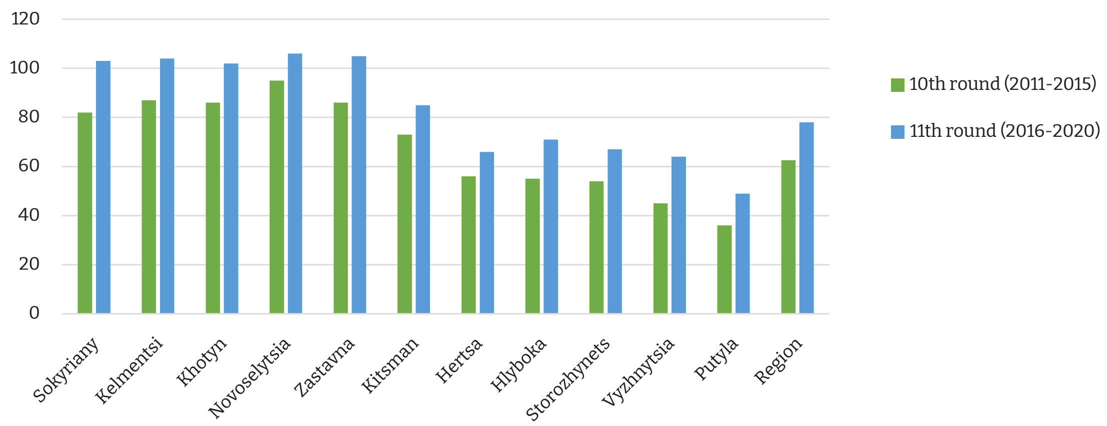

Figure 10. Dynamics of changes in the content of mobile potassium compounds in the soils of Chernivtsi region according to the 10th-11th round of agroecological examinations, mg/kg

Khrystenko (2016) notes that the low availability of mobile phosphates in the arable land of the Chernivtsi region in 2016 amounted to 37 mg of P2O5/kg of soil and is due to the high acidity of brown-earth-podzolic soils. The researcher draws attention to the fact that often the assessment of soil fertility, due to under-examination of the least fertile soils, is somewhat overestimated. In the study, the weighted average value of mobile phosphates was 56 mg/kg for the period from 2016 to 2020, which indicates a positive trend.

CONCLUSIONS

1. According to the results of agrochemical examinations of agricultural land in the Chernivtsi region, it was identified that the reaction of the soil environment in the region is dominated by soils close to neutral (31.8%) and neutral (36.5%).

2. In terms of humus content soils with a humus content of 3.1-4% account for 66.7% of the total, and the weighted average for the region is 2.7%.

3. In terms of easily hydrolysed nitrogen content, most lands have very low (48.3%) and low (48.7%) nitrogen content. 31.5% of all lands have an average phosphorus content, and the weighted average content of this macronutrient is 56 mg/kg of soil. In terms of the content of exchange potassium, lands with a very high content of potassium (51.5%) predominate with a weighted average of 78 mg/kg of soil.

The research on a comprehensive assessment of land quality in the Chernivtsi region based on bonitet points and the development of measures to protect and restore soil fertility is considered promising.

REFERENCES

[1] Baliuk, S.A., Medvedev, V.V., Vorotintseva, L.I., & Shymel, V.V. (2017). Problems of degradation of soils and measures on reaching its neutral level. *Bulletin of Agricultural Science*, 95(8), 5-11. doi: 10.31073/agrovisnyk201708-01.

[2] Baliuk, S.A., Miroshnychenko, M.M., & Medvediev, V.V. (2018). Scientific bases of stable management of soil resources of Ukraine. *Bulletin of Agricultural Science*, 11, 5-12. doi: 10.31073/agrovisnyk201811-01.

[3] Bandurovych, Yu.Yu., Fandaliuk, A.V., Romanova, S.A., & Polichko, V.S. (2017). Ecological and agrochemical evaluation of the soils of Zakarpattia. *Agroecological Journal*, 4, 46-52. doi: 10.33730/2077-4893.4.2017.219728.

[4] Bulygin, S.Yu., Vitvitskyy, S.V., Kucher, L.I., & Vitvitska, O.I. (2020). Concept of quality assessment and protection of land in Ukraine. *Plant and Soil Science*, 11(2), 30-38. doi: 10.31548/agr2020.02.030.

[5] Berezhniak, E.M., Berezhniak, M F., & Ivaniya, D.A. (2020). The evaluation of environmental sustainability of gray forest soils under different uses. *Plant and Soil Science*, 11(1), 52-61. doi: 10.31548/agr2020.01.052.

[6] Chen, S., Arrouays, D., Leatitia Mulder, V., Poggio, L., Minasny, B., Roudier, P., Libohova, Z., Lagacherie, P., Shi, Z., Hannam, J., Meersmans, J., Richer-de-Forges, A.C., & Walter, C. (2022). Digital mapping of GlobalSoilMap soil properties at a broad scale: A review. *Geoderma,* 409, article number 115567. doi: 10.1016/j.geoderma.2021.115567.

[7] Cherlinka, V., Dmytruk, Y., & Barabas, D. (2019). Methods of verification of soils prediction maps: A case study from Chernivtsi region, Ukraine. *Geographia Cassoviensis*, 13(2), 141-160. doi: 10.33542/GC2019-2-04.

[8] Demianiuk, O.S., & Bojko, A.L. (2019). Land demands strategic analysis. *Bulletin of Agricultural Science*, 2, 82-85. doi: 10.31073/agrovisnyk201902-11.

[9] DSTU 4115-2002 "Soils. Determination of mobile compounds of phosphorus and potassium according to the modified Chirikov method". (2003). Kyiv: Derzhspozhyvstandart Ukrainy.

[10] DSTU 4287:2004 "Soil quality. Sampling of samples". (2005). Kyiv: Derzhspozhyvstandart Ukrainy.

[11] DSTU 4289:2004 "Soil quality. Methods for determining organic matter". (2005). Kyiv: Derzhspozhyvstandart Ukrainy.

[12] DSTU 7863:2015 "Soil quality. Determination of easily hydrolyzed nitrogen by the Kornfield method". (2016). Kyiv: Derzhspozhyvstandart Ukrainy.

[13] DSTU ISO 10390:2007 "Soil quality. Determination of pH". (2009). Kyiv: Derzhspozhyvstandart Ukrainy.

[14] Graham, F. (2021). COP26: Glasgow climate pact signed into history. *Nature*. doi: 10.1038/d41586-021-03464-9.

[15] Handayani, I.P., & Hale, C. (2022). Healthy soils for productivity and sustainable development in agriculture. *IOP Conference Series: Earth and Environmental Science,* 1018, article number 012038. doi: 10.1088/1755-1315/1018/1/012038.

[16] Hryshchenko, O.M., Zapasnyi, V.S., Yarmolenko, Ye.V., & Shylo, L.H. (2019). Dynamics of soil fertility in the Pereyaslav-Khmelnytsky district of the Kyiv region. *Agroecological Journal*, 3, 35-41. doi: 10.33730/2077-4893.3.2019.183469.

[17] Hunchak, M.V. (2022). Dynamics of humus content in soils of Chernivtsi region. In *International scientific conference "Problems and prospects of implementation and implementation of interdisciplinary scientific achievements"* (pp. 129-131). Vinnytsia: European Scientific Platform.

[18] Khrystenko, A.O. (2016). Expert evaluation of the supply of arable lands of Ukraine with plant nutrition macronutrients. *Herald of Agrarian Science,* 1, 18-22.

[19] Kramariov, S.M., Kramarov, O.S., Khrystenko, A.O., Tokmakova, L.M., Zhuchenko, S.I., Syrovatko, V.A., & Tsova, Yu.A. (2015). Comparative assessment of the content of mobile phosphorus in different genetic horizons of ordinary chernozem. *Bulletin of the Poltava State Agrarian Academy*, 1-2, 29-31. doi: 10.31210/visnyk2015.1-2.04.

[20] Law of Ukraine No. 962-IV "On Land Protection". (2003, June). Retrieved from https://zakon.rada.gov.ua/laws/show/962-15#Text.

[21] Novakovskyi, L.Ya., & Novakovska, I.O. (2017). Ecological, economic and legal problems of land protection. *Bulletin of Agricultural Science*, 95(11), 61-70. doi: 10.31073/agrovisnyk201711-10.

[22] Pozniak, S., Pankiv, Z., Yamelynets, T., & Havrysh, N. (2020) Investment attractiveness of the soils of the Carpathian region of Ukraine. *Ukrainian Geographical Journal*, 1(109), 26-34. doi: 10/15407/ugz2020.01.026.

[23] Sharma, M., Kaushal, R., Kaushik, P., & Ramakrishna, S. (2021). Carbon farming: Prospects and challenges. *Sustainability,* 13(19), article number 11122. doi: 10.3390/su131911122.

[24] Smaha, I.S., & Kazimir, I.I. (2013) Current qualitative state of soils of Chernivtsi region. *Geodesy, Cartography and Aerial Photography*, 78, 222-225.

[25] Tonkha, O., Balaev, A., Pikovska, O., & Tarasenko, D. (2019). Microbiological evaluation of the chernozem regraded by different fertilizer systems. *Plant and Soil Science,* 10(2), 54-61. doi: 10.31548/agr2019.02.054

[26] Tonkha, O., Pikovska, O., Balaev, A., Kovalyshyna, G., Zavgorodniy, V., & Kovalenko, V. (2019). Monitoring of the microbiological condition of virgin chernozem under different management. In *Monitoring 2019 conference: Monitoring of geological processes and ecological condition of the environment.* doi: 10.3997/2214-4609.201903256.

[27] Truskavetskyy, R.S., & Tsapko, Yu.L. (2016). *Fundamentals of soil fertility management*. Kharkiv: FOP Brovin O.V.
[28] Tsentylo, L.V., & Tsyuk, O.A. (2019). Nitrogen regime of typical chernozem depending on fertilization and tillage. *Bioresources and Nature Management*, 11(1-2), 107-114. doi: 10.31548/bio2019.01.012.
[29] World Soil Day is celebrated on December 5. (2021). Retrieved from https://minagro.gov.ua/news/5-grudnya-vidznachayetsya-vsesvitnij-den-gruntu.
[30] Yaliang, L., Yan, G., Chunsheng, W., Hongxiang, Z., Wenhe, H., Chen, X., & Xifeng, C. (2022). Short-term straw returning improves quality and bacteria community of black soil in Northeast China. *Polish Journal of Environmental Studies,* 31(2), 1869-1883. doi: 10.15244/pjoes/142480.
[31] Yatskiv M.Yu. (2008) Assessment of the ecological situation of the Chernivtsi region. *Environmental Ecology and Life Safety*, 4, 43-51.
[32] Yatsuk, I.P., & Baliuk, S.A. (2019). Methodology for agrochemical certification of agricultural lands: Regulatory document. Kyiv.
[33] Yu, Q., Xu, L., Wang, M., Xu, S., Sun, W., Yang, J., Shi, Y., Shi, X., & Xie, X. (2022). Decreased soil aggregation and reduced soil organic carbon activity in conventional vegetable fields converted from paddy fields. *European Journal of Soil Science,* 73(2), article number 13222. doi: 10.1111/ejss.13222.

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Динаміка показників родючості ґрунтів Чернівецької області

Анотація. Для розробки заходів з раціонального використання ґрунтів важливою є агрохімічна оцінка ґрунтів. Метою досліджень було встановлення динаміки змін показників родючості ґрунтів Чернівецької області протягом 2011-2020 рр. В роботі були використані лабораторні, польові методи, аналіз та узагальнення. У зразках ґрунту визначали реакцію ґрунтового середовища, вміст гумусу, вміст азоту сполук, що легко гідролізують, рухомих фосфатів та обмінного калію. Встановлено, що за кислотністю ґрунтового розчину в області переважають землі близькі до нейтральних (31,8 %) та нейтральні (36,5 %). Середньозважений показник pH сольове – 5,8, що відповідає близькій до нейтральної реакції ґрунтового розчину. В порівнянні із попереднім туром обстеження (2011-2015 рр.) середньозважений показник pH не змінився За рівнем забезпечення гумусу переважають ґрунти з середнім його вмістом (66,7 %), а середньозважений уміст гумусу по області становить 2,7 %. В порівнянні з попереднім туром обстеження середньозважений уміст гумусу збільшився на 0,1 % За вмістом азоту, що легко гідролізується найбільше земель мають дуже низький (48,3 %) та низький його вміст (48,7 %). Середньозважений показник умісту азоту, що легко гідролізується за звітний період становить 106,4 мг/кг ґрунту, що відповідає низькій забезпеченості даним елементом. При порівнянні з попереднім туром обстеження середньозважений показник умісту азоту, що легко гідролізується збільшився на 0,9 мг/кг ґрунту. В області переважають землі з середнім вмістом рухомих сполук фосфору (31,5 %), а середньозважений показник умісту рухомих сполук фосфору становить 56 мг/кг, що відповідає середній забезпеченості. В порівнянні з попереднім туром обстеження середньозважений показник умісту фосфору збільшився на 4,0 мг/кг. За вмістом обмінних сполук калію переважають землі з дуже високим його вмістом (51,5 %), хоча середньозважений показник їх вмісту складає 78 мг/кг, що відповідає середній забезпеченості макроелементом. В порівнянні з попереднім туром обстеження середньозважений показник умісту фосфору збільшився на 15,4 мг/кг. Результати роботи можуть бути використані у процесі підготовки фахівців з ґрунтознавства та агрономії, а також будуть корисними для землекористувачів Чернівецької області при плануванні заходів з раціонального використання ґрунтів

Ключові слова: реакція ґрунтового середовища, вміст гумусу у ґрунті, легкогідролізовані сполуки азоту, рухомий фосфор, обмінний калій, агрохімічне обстеження

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Dynamics of the average fruit weight and the ratio of kernels to pulp in cherry fruits grown in the Southern Steppe zone of Ukraine

Abstract. The popularity of sweet cherries among consumers is due to the high taste qualities of fruits with an attractive appearance and the early ripening period. Among external quality indicators, the mass of sweet cherries and the kernel-to-pulp ratio are of the greatest importance for consumers, which affects the market value. The purpose of the study was to examine the average fruit weight and kernel weight of 33 cherry varieties of three maturation periods, both promising and common in Ukraine, and identify varieties and variety samples that have scientific and practical value in terms of the considered parameters. Determining the average fruit weight, kernel weight, and kernel-to-pulp ratio in cherry fruits was conducted during the period of economic ripeness. Sampling and preparation of samples for analysis were conducted in accordance with DSTU ISO 874-2002. The average weight of the fruit in sweet cherries grown in the conditions of the Southern Steppe zone of Ukraine was at the level of 8.41 grams, the average weight of the kernel was 0.56 grams. The optimal fruit weight was provided by the fruits of the sweet cherry group of the late ripening period (7.27-12.18 g). The most stable, with minimal coefficients of variation in the indicators under study in the context of early-ripening varieties in terms of fruit and kernel mass, were the varieties Sweat earlies and Rubinova rannia. Among the group of varieties of medium ripening, the most stable mass of fruits and kernels were the fruits of the varieties Temp and Vynka. In late ripening varieties, the lowest variability in the content of fruit and kernel weight was recorded in the Regina variety. It was identified that the dominant influence for the formation of fruit mass in all groups of varieties was exerted by the weather conditions of years of research, and for the formation of kernel mass in all groups of varieties – varietal features. The results of the study will be useful when choosing cherry varieties of different maturation periods that are suitable for selling fruits and further processing them

Keywords: ripeness, regression analysis, bone mass, variation of indicators

INTRODUCTION

Sweet cherries belong to the most popular kernel crops among consumers of fruit products (Tolstolik, 2021; Ivanova *et al.*, 2022). Such popularity of this fruit crop is due to the high taste qualities of fruits with an attractive appearance, and an early ripening period (Bak *et al.*, 2010; Alrgei *et al.*, 2016; mézes *et al.*, 2017). Cherry fruits begin to ripen in the third decade of may and thus open the period of consumption of fresh fruit (Turovtseva & Turovtsev, 2014). According to the Ukrainian Association of agricultural exports, Ukrainian producers annually grow 133 thousand tonnes of sweet cherry fruits (Ukraine ranks second..., 2022), and according to FAO (Food and Agriculture..., 2022) statistics over the past 10 years, the level of sweet cherry fruit production in the

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world is within 2 million tonnes, which led to an acute shortage and high sales prices for it (Ivanova *et al*.., 2019). Keserović *et al*. (2014), and others note that about 70% of the world's total sweet cherry is produced by European countries (Bouhadidaa *et al*., 2009; Barac *et al*., 2014; Gaudet *et al*., 2019), followed by Asia – 20% and North America – 10% (Sanderson *et al*., 2019; mezhenskyj *et al*., 2020).

The increase in fruit production is due to a number of reasons: variety renewal and introduction of new high-quality fruit varieties (Mir *et al*., 2021; Shevchuk *et al*., 2021; Shevchuk *et al*., 2021); progress in agriculture and fruit processing technology (Bell *et al*., 2017). The popularity of fruit consumption is confirmed by numerous studies of the content of biologically active substances in fruits (Ivanova *et al*., 2021) and their therapeutic and preventive health effects (Miloševic & Miloševic, 2012; Eslami *et al*., 2022). Blando & Oomah (2019) notes that the consumption of sweet cherries has a positive effect on human health, namely, it counteracts oxidative stress, reduces inflammation, regulates blood glucose levels and improves cognitive function, promotes faster recovery from muscle damage caused by exercise. Many studies are devoted to the examination of the biochemical composition of sweet cherries by species and varietal characteristics. A study of the fruit content of four species of the *Prunus* genus conducted by Cao *et al*. (2015) in China determined the suitability of *Prunus cesarus* for processing due to the high content of ascorbic acid and anthocyanins.

According to biological characteristics, sweet cherries grow best in moderately warm climates, in Ukraine, the vast majority of the plantings are concentrated in the Southern region, in particular, in the Zaporizhzhia, Dnepropetrovsk, Odesa, Kherson, and Mykolaiv regions (Kishchak, 2014; Ivanova *et al*., 2021; Ivanova *et al*., 2021).

The productivity of varieties is investigated by many indicators, in particular: maturation periods, storage periods, logistics of transportation, commercial qualities of fruits, the content of biologically active substances in them, methods of influencing the marketability of fruits, yield, the possibility of manufacturing processed products from cherry fruits, etc. Thus, Grandi *et al*. (2017) note the dependence of the taste qualities of sweet cherries on the date of fruit harvesting. They highlight the need to determine the physiological date of ripening of fruits on the tree and not reduce it due to commercial or marketing necessity. The paper by Zhang *et al*. (2017) is devoted to the examination of the influence of product quality on the selling price, transportation conditions to maintain high quality, especially in express logistics. The authors proposed a dynamic monitoring and quality assessment system (DMQAS), based on multisensors to reduce the quality loss of fresh cherry fruits in express logistics. The paper by Chockchaisawasdee *et al*. (2016) presents the development of methods for post-harvest processing of sweet cherry fruits to extend the terms of their storage and transportation and provides data on biologically active components of sweet cherry fruits.

The purpose of the study was to assess the average weight of fruits and the ratio of pulp and kernel in the fruits of cherry varieties of Ukrainian and foreign selection grown in the conditions of the Southern Steppe of Ukraine.

LITERATURE REVIEW

In the context of the problem under study, attention is drawn to the issues of quality management of cherry products in the thematic literature, in particular, which concerns the study by Bustamante *et al*. (2021). The paper presents the results of examining the impact of foliar top dressing with potassium before harvesting on the quality of harvested fruits, and the condition of cherry trees grown in plastic shelters in gardens in Southern Chile. It was identified that an intensive potassium regime can improve the quality of fruits of the cherry variety Regina; however, the results vary substantially depending on the season and terrain.

Researchers have developed methods for their post-harvest processing and investigated the content of biologically active components to extend the shelf life and transportation of sweet cherry fruits (Chockchaisawasdee *et al*., 2016).

Changes in the amount of accumulated biologically active substances in the fruits of sweet cherries of the varieties Skeena and Sweetheart by spraying with gibberellic acid (GA_3), abscisic acid (ABA), salicylic acid (SA), and glycine-betaine (GB) were investigated by S. Correia *et al*. (2020). Researchers identified that spraying the trees with GA_3, ABA, SA, and GB increased the anthocyanin content of Skeena sweet cherries. GA_3 and GB caused a decrease in carotenoid content in Skeena and a decrease in ascorbic acid content in Lubka sweet cherries. GA_3 caused the greatest changes by increasing the anthocyanin content (42%), reducing the carotenoid content (19%) and ascorbic acid (53%). *Ascophyllum nodosum* one of the new processing methods, along with GB, causes the opposite effect of GB, increasing carotenoids and ascorbic acid, but reducing the content of phenols.

A large number of studies are devoted to the examination of variations in accumulated biological substances in cherry fruits depending on the variety (Budak, 2017; Antognoni *et al*., 2020). Productivity, namely yields and fruit quality, depending on the density of planting in two varieties of sweet cherries Ziraat 0900 and Cordia on the Gisela 6 graft was investigated by Arsov *et al*. (2020). As a result, it was determined that the highest total yield for these varieties was for planting schemes of 5×3.5 m, and the weight and density of fruits did not vary depending on the planting scheme and met the established standards.

The dependence of the yield and quality of cherry fruits on graft-variety combinations in Ukraine was investigated by O. Kischak (Kishchak, 2013; Kishchak, 2014), and it is noted that the most low-growing trees at the age of six were trees of the Donchanka variety on Gisela 5 (2.6 m), Studenykivs'ka (2.7 m) and VSL-2 (2.8 m), which is 14.7% lower than on Mahalebs'ka sweet cherry, wild sweet cherry; the same varieties (on Studenykivs'ka graft) were also the most precocious and productive, and in the fifth year after planting, the yield reached 13.2 t/ha.

The study of new seven varieties of sweet cherries Cetăţuia, Cătălina, Bucium, Golia, Maria, Ştefan, Tereza in the conditions of the North-East of Romania was conducted by S. Sîrbu and indicates a minor relationship between the number of days from the time of full flowering to the ripening of fruits and their commercial quality and chemical composition (Sîrbu *et al*., 2012).

In Ukraine, breeding work on the creation of new varieties of sweet cherries and, accordingly, the study of productivity indicators depending on varietal characteristics was conducted by M. Turovtsev and V. Turovtseva at Melitopol Research Station of Horticulture named after M.F. Sidorenko of the Institute of Horticulture of National Academy of Agrarian Sciences (Turovtseva & Turovtsev, 2014). Researchers identified new promising varieties of sweet cherries Efektna, Udacha, Avangard, Bigaro Turovtsevoi, Siianets` Turovtsevoi, Modna, Novynka Turovtsevoi, Trudova, Vizytka, Pamyatna, capable of producing an annual harvest of high-quality fruits.

According to an analytical review of literature sources, the study of the quality of fruits of varieties and forms of sweet cherries is conducted simultaneously with many studies related to the cultivation of this crop, the collection and sale of fruits, and subsequent processing. Since sweet cherries as a fruit crop are the hallmark of the region of the Southern Steppe of Ukraine and are of great national economic importance, a comprehensive study of the components of the production process of this crop is an urgent issue.

MATERIALS AND METHODS

The study was conducted during 2008-2019 in horticultural farms of the Melitopol District of the Zaporizhzhia region. To assess quality indicators, cherry fruits of common and promising varieties in Ukraine of three maturation periods were selected: 1st (early) – Sweat Earlies, Merchant, Bigaro Burlat, Rubinova rannia, Valerii Chkalov, Kazka, Zabuta; 2nd (medium) – Kordia, Octaviia, Vynka, Pervistok, Temp, Liubymytsia Turovtseva, Talisman, Dilema, Melitopol'ska chorna, Orion, Chervneva rannia, Dachnytsia, Prostir; 3rd (late) – Karina, Regina, Mirazh, Krupnoplidna, Udivitiel'na, Zodiac, Siurpryz, Kolkhoznitsia, Kosmichna, Prazdnichna, Anons, Temporion, Meotyda.

Determination of the average fruit weight, kernel weight, and kernel-to-pulp ratio in cherry fruits was conducted during the period of economic ripeness. A sample was taken from 100 fruits (in each repetition) from 3-5 typical trees during the period of economic ripeness to determine the weight of one cherry fruit. The experiment is repeated three times. Fruits must be selected in such a way that the sample taken is characteristic in quality for the harvest of this season. All selected fruits were weighed, then the mass of one fruit was determined by dividing the total mass by their number (100 pieces). After weighing the fruit sample, their kernels were removed. The resulting kernels were washed from the pulp. Moisture from the surface of the kernels was removed with filter paper, after which they were weighed and the average mass of one kernel was determined by dividing the total mass by their number (100 pieces) (Serdiuk *et al*., 2020). Sampling and preparation of samples for analysis were conducted in accordance with DSTU ISO 874-2002 (Fresh fruits and..., 2003).

The region of growing is characterised by insufficient moisture in terms of precipitation in general. The climate is Atlantic-continental, arid with high temperatures. The direction of dry winds is North-East. According to the complex of climatic indicators, the region of the study is suitable for growing sweet cherries.

Meteorological data from the Melitopol weather station (46° 49'N, 35° 22'e) for 2008-2019 were used to analyse the impact of weather conditions (Ivanova *et al*., 2020). The average annual air temperature is 9.1-9.9°C. The sum of active temperatures of 10°C and above, from April to October, is over 3,300°C. The average amount of precipitation per year is 475 mm. The hydrothermal coefficient ranges between 0.22...0.77.

The analysis and processing of experimental data was conducted according to V. Mezhenskyi (Mezhenskyi, 2017), using the computer programmes MS Office Excel 2010, the Statistica package.

RESULTS AND DISCUSSION

The results of 12 years of research allow stating that the average weight of the fruit in cherry fruits was at the level of 8.41 grams, the average weight of the kernel was 0.56 grams. In the conducted studies, the average weight of the fruit of early maturing sweet cherries is 7.61 grams, kernels – 0.50 grams (Table 1), that is, it was 10.51% and 12% lower compared to the average varietal value of the investigated indicators.

Table 1. Weight of fruit (grams), kernel (grams), and their ratio (%) in early maturing cherry fruits (2008-2019), $\bar{x} \pm s\bar{x}$, n=5.

Pomological variety	Fruit weight (grams)				Kernel weight (grams)				Ratio of fruit mass to kernel mass, %
	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	
Rubinova rannia	7.32±0.41	5.05	9.07	19.4	0.49±0.01	0.40	0.57	11.5	6.69
Valerii Chkalov	8.35±0.29	6.46	9.43	12.2	0.72±0.02	0.61	0.85	11.9	8.62
Sweat Earlies	7.73±0.23	6.51	9.03	10.6	0.74±0.02	0.58	0.91	12.4	9.57
Merchant	6.25±0.40	4.46	8.34	22.5	0.61±0.03	0.49	0.81	17.5	9.76
Kazka	9.10±0.36	7.17	11.56	14.0	0.60±0.03	0.46	0.89	19.5	6.59
Bigaro Burlat	6.79±0.29	5.38	8.25	14.9	0.63±0.02	0.49	0.80	13.1	9.27
Zabuta	7.73±0.33	6.38	9.60	15.1	0.70±0.03	0.52	0.87	16.7	9.05
Average value	7.61±0.33	5.91	9.32	15.5	0.64±0.02	0.50	0.81	14.6	8.40
HIP_{05}	0.649				0.084				

In the fruits of sweet cherries of medium-ripening and late-ripening varieties, the average fruit weight exceeded the average varietal value by 0.23% and 8.88%, respectively (Table 2, 3). Thus, among the varieties under study, the optimal fruit weight was provided by the fruits of the sweet cherry group of the late ripening period. The average kernel weight in late-ripening fruits was 11.11% higher compared with the average varietal value.

Table 2. Weight of fruit (grams), kernel (grams), and their ratio (%) in cherry fruits of medium-ripening varieties (2008-2019), $\bar{x} \pm s\bar{x}$, n=5.

Pomological variety	Fruit weight (grams)				Kernel weight (grams)				Ratio of fruit mass to kernel mass, %
	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	
Vynka	7.46±0.25	6.34	8.89	11.8	0.62±0.02	0.49	0.72	11.4	8.31
Pervystok	8.13±0.37	6.69	10.98	15.9	0.46±0.02	0.39	0.63	19.7	5.65
Temp	8.90±0.27	7.65	10.55	10.8	0.77±0.02	0.60	0.93	12.6	8.65
Liubymytsia Turovtseva	7.47±0.48	5.11	10.09	22.5	0.53±0.01	0.41	0.62	12.2	7.09
Talisman	8.93±0.51	6.80	11.81	19.8	0.69±0.03	0.52	0.89	16.2	7.72
Dylema	9.91±0.43	7.92	12.01	15.0	0.60±0.02	0.46	0.77	17.0	6.05
Melitopol'ska chorna	9.37±0.38	7.63	11.81	14.2	0.47±0.01	0.40	0.60	11.5	9.05
Cordia	8.54±0.65	5.51	11.75	26.6	0.64±0.02	0.50	0.74	12.6	5.01
Octavia	8.69±0.45	6.01	10.77	18.2	0.52±0.01	0.40	0.61	11.6	6.08
Orion	6.85±0.40	4.61	8.77	20.7	0.39±0.01	0.31	0.50	15.9	5.69
Chervneva rannia	7.48±0.27	5.90	8.68	12.8	0.49±0.02	0.36	0.67	18.7	6.55
Dachnytsia	8.09±0.40	5.71	9.98	17.2	0.50±0.01	0.37	0.61	12.3	6.18

Table 2, Continued

Pomological variety	Fruit weight (grams)				Kernel weight (grams)				Ratio of fruit mass to kernel mass, %
	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	
Prostir	9.34±0.35	7.78	11.67	13.2	0.67±0.03	0.54	0.91	16.1	7.17
Average value	8.39±0.40	6.43	10.59	16.8	0.56±0.02	0.44	0.70	17.3	6.67
HIP_{05}	0.520				0.046				

Table 3. Weight of fruits (grams), kernels (grams), and their ratio (%) in late-maturing cherry fruits (2008-2019), $\bar{x} \pm s\bar{x}$, *n*=5.

Pomological variety	Fruit weight (grams)				Kernel weight (grams)				Ratio of fruit mass to kernel mass, %
	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	Average weight, grams	min weight, gram	max weight, grams	Variation by year, Vy, %	
Krupnoplidna	11.67±0.47	8.73	13.72	14.0	0.51±0.02	0.40	0.61	14.2	4.37
Karina	9.57±0.37	7.55	11.94	13.5	0.66±0.02	0.56	0.79	11.1	6.89
Regina	7.99±0.23	6.71	9.00	10.1	0.74±0.02	0.62	0.88	10.4	9.26
Mirazh	7.73±0.24	6.30	8.81	11.1	0.58±0.01	0.46	0.67	11.5	7.50
Udivitiel’na	12.18±0.51	10.01	14.60	14.7	0.43±0.02	0.30	0.56	20.9	3.53
Zodiak	8.95±0.29	7.23	10.05	11.2	0.56±0.01	0.47	0.64	11.3	6.25
Siurpryz	7.37±0.28	6.00	9.40	13.2	0.57±0.03	0.40	0.79	21.2	7.73
Kolkhoznitsa	8.14±0.37	5.67	9.93	16.0	0.70±0.04	0.40	0.88	21.3	8.59
Kosmichna	9.91±0.41	8.05	12.21	14.6	0.76±0.02	0.56	0.91	13.4	9.44
Prazdnichna	7.27±0.27	5.71	8.76	13.2	0.71±0.02	0.52	0.82	13.5	5.16
Anons	9.84±0.37	7.96	11.77	13.2	0.60±0.02	0.50	0.69	12.4	6.09
Temporion	9.68±0.43	7.44	12.01	15.4	0.75±0.02	0.68	0.89	11.1	7.74
Meotyda	9.78±0.39	7.21	11.72	14.1	0.66±0.02	0.46	0.79	14.9	6.74
Average value	9.23±0.35	7.27	11.07	13.4	0.63±0.03	0.48	0.76	14.4	6.82
HIP_{05}	0.538				0.039				

Among the group of early ripening varieties, the minimum fruit weight was recognised in Merchant fruits (4.46 g) of the 2018 harvest, which is 41.39% lower than the average varietal value. The maximum value of fruit weight at the level of 11.56% was identified in the fruits of the Kazka harvest of 2016 (excess over the average varietal value – 52.03%). The variety of early maturation, which according to the results of the study was characterised by the largest mass of the fruit was Kazka, and the smallest – Merchant at HIP_{05} – 0.649 (Table 1). The minimum average kernel weight was considered for fruits of the Rubinova rannia variety – 0.40 g, harvested in 2008 (37.50% lower than the average varietal value). The maximum kernel mass index was recorded in Sweet Earlies fruits of 0.91 g in 2016 (excess over the average varietal value – 42.18%). The variety of this maturation period, which, according to the results of all years of the study, was characterised by the largest mass of kernels, was Sweat Earlies; the smallest – Rubinova rannia, at HIP_{05} – 0.084. The optimal value of the complex indicator of the kernel-to-pulp ratio, which tends to the minimum values, was determined in the Kazka fruits – 6.59%.

In the groups of medium-ripening and late-ripening varieties, the fruits of the Orion and Kolkhoznitsa varieties harvested in 2012 and 2008 were characterised by the minimum fruit weight of 4.61 g and 5.67 g. The fruit weight was less than the average varietal value by 45.05 and 38.57%, respectively. The largest mass of fruits in varieties of medium and late maturation periods was recorded in Dylema (2010 harvest) and Udivitiel’na

(2011 harvest) with values of 12.01 g and 14.54 g, respectively (excess over the average varietal value – 43.14 and 57.53%, respectively). Among medium-ripening and late-ripening varieties, the maximum average fruit weight was identified in the fruits of the varieties Dylema and Kosmichna (9.91 g). The minimum average kernel weight was determined in the fruits Orion – 0.31 g and Udivitiel'na – 0.30 g, which were harvested in 2008 and 2017, respectively. The indicators were lower than the average value for varieties by 44.64% and 52.38%, respectively. The maximum kernel mass was recorded in fruits of the Temp 0.94 g (in 2011) and Kosmichna varieties 0.91 g (in 2015) (excess over the average varietal value – 67.85% and 44.44%, respectively). Varieties of medium and late maturation periods, which, according to the results of average values of twelve-year studies, were characterised by the largest mass of kernels, were Temp and Kosmichna, and the smallest – Pervistok, Melitopol'ska chorna, Krupnoplidna at HIP_{05} – 0.046 and HIP_{05} – 0.039. The optimal value of the complex indicator of the kernels-to-pulp ratio was determined in the fruits of the Cordia (5.01%), Pervistok (5.65%), Orion (5.69%), Udivitiel'na (3.53%), and Krupnoplidna (4.37%) varieties. Studies by Georgian researchers established that the relative mass of kernels to the mass of fresh fruits ranged from 3.7% to 8.4% (Maglakelidze *et al*., 2017). According to K.M. Bhat, the highest percentage of kernels in the total weight of sweet cherries was recorded at 7.58% in the Makhmali variety (Bhat *et al*., 2018).

From a technological standpoint, varieties, the fruits of which differ not only in the maximum fruit weight, minimum values of kernel mass, and the ratio of kernel mass to fruit but also in the stability of these indicators are of particular value. The presented results indicate the average variability of fruit and kernel weight over the years of research in the group of early-ripening varieties. The greatest influence of abiotic factors on fruit weight and kernel weight was identified in the fruits of this group for Merchant (it has a substantial variability of 22.5%) and Skazka with coefficients of variation – 19.5, respectively. The most stable in terms of indicators under study in the context of early ripening varieties in terms of fruit mass and kernel mass parameters are Sweat Earlies (Vy=10.6%) and Rubinova rannia (Vy=11.5%). The variability of these indicators over the years of research in the fruits of sweet cherries of medium-ripening and late-ripening varieties was average and substantial. Among the medium-ripening varieties, the fruits of the Temp (Vy=11.8%) and Vynka (Vy=11.4%) varieties were the most stable in terms of fruit and kernel weight, respectively, and the most variable were the Kordia (Vy=26.6%) and Pervistok (Vy=19.7%) varieties. In late-maturing varieties, the greatest variability in the content of fruit and kernel weight was recorded in the Kolkhoznitsa (Vy=16.0%) and Udivitiel'na (Vy=20.9%) varieties; the lowest – in Regina (Vy=10.1% and 10.4%).

It was identified that for the formation of fruit mass in all groups of varieties, the dominant influence was exerted by the weather conditions of years of research (factor A) with the part of influence for early-maturing varieties – 39.7%, medium-maturing – 51.5% and late-maturing – 26.1% (Table 4).

Table 4. Results of two-factor analysis of variance in the formation of fruit mass and kernel mass in cherry fruits

Indicator	Fruit weight						Kernel weight					
Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Impact, %	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Impact, %
Group of early ripening cherry varieties												
Factor A (year)	215.7	11	19.61	123.2	1.8	39.7	1.0	11	0.09	34.8	1.8	24.4
Factor B (variety)	194.1	6	32.35	203.3	2.2	35.7	1.5	6	0.26	98.1	2.2	37.5
AB interaction	106.7	66	1.61	10.1	1.4	19.6	1.1	66	0.01	6.4	1.4	27.0
Group of medium-ripening cherry varieties												
Factor A (year)	671.9	11	61.08	598.7	1.8	51.5	1.4	11	0.12	153.2	1.8	16.5
Factor B (variety)	356.5	12	29.71	291.2	1.8	27.3	5.1	12	0.42	513.2	1.8	60.5
AB interaction	236.9	132	1.795	17.5	1.3	18.1	1.6	132	0.01	15.0	1.3	19.5

Table 4, Continued

Indicator	Fruit weight						Kernel weight					
Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Impact, %	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Impact, %
Group of late-ripening cherry varieties												
Factor A (year)	463.7	11	42.16	384.7	1.8	26.1	1.8	11	0.16	275.1	1.8	21.5
Factor B (variety)	1024.4	12	85.37	778.9	1.8	57.8	4.5	12	0.37	626.3	1.8	53.4
AB interaction	248.9	132	1.88	17.2	1.3	14.0	1.9	132	0.01	24.1	1.3	22.6

The part of influence of varietal characteristics (Factor B) on the formation of fruit mass was 35.7%, 27.3%, and 1.8%, respectively. For the formation of kernel mass in all groups of varieties, varietal characteristics (Factor B) had a dominant influence with a part of influence for early-maturing varieties – 37.5%, medium-maturing – 60.5%, and late-maturing – 53.4%. The part of influence of varietal characteristics on the formation of kernel mass was 24.4%, 16.5% and 21.5%, respectively, for the analysed groups.

An important indicator that determines the competitiveness of cherry fruits is the average fruit weight and the kernel-to-pulp ratio (Pérez-Sánchez *et al*., 2010; Maglakelidze *et al*., 2017; Herasko *et al*., 2020). According to many researchers, the average weight of cherry fruits and the kernel-to-pulp ratio are influenced by genetic soil-climatic conditions and characteristics of the variety. Thermal resources of the growing season of crops and varieties and moisture indicators are also important indicators (Diachuk, 2017; Herasko & Todorova, 2020).

The results obtained are consistent with the data of other studies on the formation of the average weight of the fruit and kernel in various pomological varieties of sweet cherries. Thus, the weight of sweet cherries ranged from 5.9 g (Scorpelka) to 9.2 g (Andreiaş) in the conditions of North-Eastern Romania (Corneanu *et al*., 2020). As a result of investigating nine foreign varieties in Georgia, it was identified that all the varieties under study had large fruits except for Moro (Maglakelidze *et al*., 2017). The average weight of sweet cherries ranged from 6.9 g (Moro) to 10.2 g (Celeste), and the kernel weight ranged from 0.2 g (Burlat) to 0.56 g (Celeste).

The study by Bieniek *et al*. (2011) identified that in Lithuania, on average, over three years, the weight of sweet cherries ranged from 3.78 to 6.45 g. Evaluation of nine varieties of sweet cherries based on external signs of fruit quality was conducted in the conditions of the Mediterranean part of Croatia (Radunić *et al*., 2014). It was identified that the fruits of the cherry varieties Isabella and Tugarka had an average weight of more than 7.5 g, and the variety Burlat – less than 5 g. The study by (Iurea *et al*., 2019) in Romania determined that the largest fruit mass was identified in the Elaiaşi (8.9 g) and Croma (9.4 g) varieties. The highest mass index of the cherry fruit (10.0 g) was recorded in the Andreiaş variety by the Romanian researcher M. Corneanu *et al*. (2021). In the conditions of India according to K.M. Bhat *et al*. (2018), the highest kernel mass was identified in cherry fruits of the Regina and Misri varieties at the level of 0.48 g, and the lowest – 0.34 g in the Stella variety. Considering the above, the study of cherry fruits of different varieties according to the selected quality indicators grown in the steppe of Ukraine is relevant.

CONCLUSIONS

The results of twelve-year studies suggest that the average weight of kernels in cherry fruits grown in the conditions of the Southern Steppe zone of Ukraine was at the level of 8.41 grams, the average mass of kernels is about 0.56 grams.

Among the varieties under study, three groups of ripeness, the optimal fruit weight was the fruits of sweet cherries of the late-ripening group (7.27-12.18 g), the average fruit weight exceeded the average varietal value by 8.88%.

The largest fruit mass among early ripening varieties, according to the results of twelve-year studies, was in the Kazka variety (9.10 grams). The lowest mass was identified in the Rubinova rannia variety (7.32 grams). The optimal value of the complex indicator of the kernel-to-pulp ratio was determined in fruits of the Skazka variety – 6.59%.

Among the varieties of the group of medium and late maturation periods, the maximum average fruit weight was recorded in the fruits of the Dylema and Kosmichna varieties (9.91 g). Varieties of two ripening groups, which, according to the results of average values, were characterised by the lowest kernel mass, were Pervistok, Melitopol'ska chorna, and Krupnoplidna. The optimal value of the complex indicator – the kernel-to-pulp ratio is determined in the range of 3.53-5.69% for fruits of the Kordia, Pervistok, Orion, Udivitiel'na, and Krupnoplidna varieties.

The most stable varieties with minimal coefficients of variation in the indicators under study in the context of early ripening varieties in terms of fruit mass and kernel mass were Sweat Earlies (Vy=10.6%) and Rubinova rannia (Vy=11.5%).

Among the group of varieties of medium ripening, the most stable weight of fruits and kernels were identified in the fruits of the Temp (Vy=11.8%) and Vynka (Vy=11.4%) varieties.

In the group of late-ripening varieties, the lowest variability in the content of fruit and kernel weight was recorded in the Regina variety (Vy=10.1% and 10.4%).

It was identified that for the formation of fruit mass in all groups of varieties, the dominant influence was exerted by the weather conditions of years of research with a part of the influence for varieties of the three maturation periods of 26.1-51.5%. For the formation of kernel mass in all groups of varieties, varietal characteristics had a dominant influence with a part of influence within the three groups of varieties of 37.5-60.5%.

REFERENCES

[1] Alrgei, H.O.S., Dabic, D.C., Natic, M.M., Rakonjac, V.S., Milojkovic-Opsenica, D., Tesic, Z.L. & Aksic, M.M.F. (2016). Chemical profile of major taste- and health-related compounds of Oblačinska sour cherry. *Journal of the Science of Food and Agriculture*, 96(4), 1241-1251. doi: 10.1002/jsfa.7212.

[2] Antognoni, F., Potente, G., Mandrioli, R., Angeloni, C., Freschi, M., Malaguti, M., Hrelia, S., Lugli, S., Gennari, F., Muzzi, E., & Tartarini, S. (2020). Fruit quality characterization of new sweet cherry cultivars as a good source of bioactive phenolic compounds with antioxidant and neuroprotective potential. *Antioxidants*, 9(8), article number 677. doi: 10.3390/antiox9080677.

[3] Arsov, T., Kiprijanovski, M., Gjamovski, V., & Saraginovski, N. (2020). Performance of some cherry cultivars growing on different planting distances. *Acta Horticulturae*, 1, 119-124. doi: 10.17660/ActaHortic.2020.1289.17.

[4] Bak, I., Lekli, I., Juhasz, B., Varga, E., Varga, B., Gesztelyi, R., Szendrei, L. & Tosaki, A. (2010). Isolation and analysis of bioactive constituents of sour cherry (*Prunus cerasus*) seed kernel: An emerging functional food. *Journal of Medicinal Food*, 13(4), 905-910. doi: 10.1089/jmf.2009.0188.

[5] Barac, G., Ognjanov, V., Obreht, D., Ljubojevic, M., Bosnjakovic, D., Pejic, I., & Gasic, K. (2014). Genotypic and phenotypic diversity of cherry species collected in Serbia. *Plant Molecular Biology Reporter,* 32, 92-108. doi: 10.1007/s11105-013-0601-4.

[6] Bell, P.G., McHugh, M.P., Stevenson, E., & Howatson, G. (2014). The role of cherries in exercise and health. *Scandinavian Journal of Medicine & Science in Sports,* 24(3), 477-490. doi: 10.1111/sms.12085.

[7] Bhat, K.M., Wani, W.M., Aarifa, J., Kirmani, S.N., Mir, M.A., & Pandith, A.H. (2018). Evaluation of traditional and exotic Sweet Cherry cultivars for horticultural and physico chemical traits under North Western Himalayas. *Journal of Pharmacognosy and Phytochemistry*, 7(1), 1968-1971.

[8] Bieniek, A., Kawecki, Z., Kopytowski, J., & Zielenkiewicz, J. (2011). Yielding and fruit quality of Lithuanian sweet cherry cultivars grown under the climatic and soil conditions of Warmia. *Folia Horticulturae*, 23(2), 101-106. doi: 10.2478/v10245-011-0015-4.

[9] Blando, F., & Oomah, B.D. (2019). Sweet and sour cherries: Origin, distribution, nutritional composition and health benefits. *Trends in Food Science & Technology,* 86, 517-529. doi: 10.1016/j.tifs.2019.02.052.

[10] Bouhadidaa, M., Casas, A.M., Gonzaloa, M.J., Arúsc, P., Morenoa, M.A. & Gogorcenaa, Y. (2009). Molecular characterization and genetic diversity of *Prunus* rootstocks. *Scientia Horticulturae*, 120(2), 237-245. doi: 10.1016/j.scienta.2008.11.015.

[11] Budak, N.H. (2017). Bioactive components of *Prunus avium* L. black gold (red cherry) and *Prunus avium* L. stark gold (white cherry) juices, wines and vinegars. *Journal of Food Science and Technology*, 54, 62-70. doi: 10.1007/s13197-016-2434-2.

[12] Bustamante, M., Muñoz, A., Romero, I., Osorio, P., Mánquez, S., Arriola, R., Reyes-Díaz, M., & Ribera-Fonseca, A. (2021). Impact of potassium pre-harvest applications on fruit quality and condition of sweet cherry (*Prunus avium* L.) cultivated under plastic covers in southern chile orchards. *Plants*, 10(12), article number 2778. doi: 10.3390/plants10122778.

[13] Cao, J., Jiang, Q., Lin, J., Li, X., Sun, C., & Chen, K. (2015). Physical and chemical characteristics of four types of cherries (*Prunus spp.)* grown in China. *Food Chemistry,* 173, 855-863. doi: 10.1016/j.foodchem.2014.10.094.

[14] Chockchaisawasdee, S., Golding, J.B., Vuong, Q.V., Papoutsis, K., Stathopoulos, C.E. (2016). Sweet cherry: Composition, postharvest preservation, processing and trends for its future use. *Trends in Food Science & Technology*, 55, 72-83. doi: 10.1016/j.tifs.2016.07.002.

[15] Corneanu, M., Iurea, E., & Sîrbu, S. (2020). Biological properties and fruit quality of sweet cherry (*Prunus avium* L.) cultivars from Romanian assortment. *Agronomy Research*, 18(4), 2353-2364. doi: 10.15159/AR.20.231.

[16] Corneanu, M., Iurea, E., & Sirbu, S. (2021). Comparison of five new sweet cherry cultivars bred in Romania, with their parental forms. *Journal of Horticultural Research*, 29(1), 1-8. doi: 10.2478/johr-2021-0008.

[17] Correia, S., Aires, A., Queirós, F., Carvalho, R., Schouten, R., Silva, A.P., & Gonçalves, B. (2020). Climate conditions and spray treatments induce shifts in health promoting compounds in cherry (*Prunus avium* L.) fruits. *Scientia Horticulturae*, 263, article number 109147. doi: 10.1016/j.scienta.2019.109147.

[18] Diachuk, O.S. (2017). Cherry varieties (*Cerasus avium* Moench.) of the Institute of Pomology named after L.P. Symyrenko in the Forest Steppe of Ukraine. *Gardening*, 72, 11-16.

[19] Eslami, O., Khorramrouz, F., Ghavami, A., Khaniki, S.H., & Shidfar, F. (2022). Effect of cherry consumption on blood pressure: A systematic review and meta-analysis of randomized controlled trials. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews,* 18(2), article number 102409. doi: 10.1016/j.dsx.2022.102409.

[20] Official website of the Food and Agriculture Organization of the United Nations. (n.d.). Retrieved from https://www.fao.org/home/en.

[21] DSTU ISO 874-2002 "Fresh fruits and vegetables. Sample selection". (2003). Kyiv: State Standard of Ukraine.

[22] Gaudet, M., Villani, F., Cherubini, M., Beritognolo, I., Dalla Ragione, I., Proietti, S., & Mattioni, C. (2019). Genetic diversity and molecular fingerprinting of *Prunus cerasus* var. *austera* from central Italy. *Plant Biosystems – An International Journal Dealing with All Aspects of Plant Biology*, 153(4), 491-497. doi: 10.1080/11263504.2018.1498403.

[23] Gerasko, T.V., & Todorova, L.V. (2020). The effect of inoculation with symbiotic fungi on productivity indicators of cherries under the conditions of treatment with natural herbs and medicinal hyssop. In *Scientific developments of Ukraine and EU in the area of natural sciences* (pp. 102-118). Riga: Publishing House "Baltija Publishing". doi: 10.30525/978-9934-588-73-0/1.7.

[24] Grandi, M., Lugli, S., & Correale, R. (2017). Fruit quality changes in postponed picking of new cherry cultivars. *Acta Horticulturae,* 1*,* 599-602. doi: 10.17660/ActaHortic.2017.1161.95.

[25] Herasko, T.V. (2020). The influence of living mulch on the physiological and biochemical parameters of cherry leaves and fruits according to organic growing technology. *Collection of Scientific Works "Agrobiology",* 1. 20-28.

[26] Iurea, E., Corneanu, M., Militaru, M., & Sîrbu, S. (2019). Assessment of new sweet cherry cultivars released at RSFG Iaşi, Romania. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 47(3), 729-733. doi: 10.15835/nbha47311575.

[27] Ivanova, I., Serdyuk, M., Kryvonos, I., Yeremenko, O., & Tymoshchuk, T. (2020). Formation of flavoring qualities of sweet cherry fruits under the influence of weather factors. *Scientific Horizons*, 4(89), 72-81. doi: 10.33249/2663-2144-2020-89-4-72-81.

[28] Ivanova, I., Serdiuk, M., Malkina, V., Bandura, I., Kovalenko, I., Tymoshchuk, T., Tonkha, O., Tsyz, O., Mushtruk, M., & Omelian, A. (2021). The study of soluble solids content accumulation dynamics under the influence of weather factors in the fruits of cherries. *Potravinarstvo Slovak Journal of Food Sciences*, 15, 350-359. doi: 10.5219/1554.

[29] Ivanova, I., Serdyuk, M., Malkina, V., Tymoshchuk, T., Kotelnytska, A., & Moisiienko, V. (2021). The forecasting of polyphenolic substances in sweet cherry fruits under the impact of weather factors. *Agraarteadus: Journal of Agricultural Science*, 32(2), 239-250. doi: 10.15159/jas.21.27.

[30] Ivanova, I., Serdyuk, M., Malkina, V., Priss, T., Herasko, T., & Tymoshchuk, T. (2021). Investigation into sugars accumulation in sweet cherry fruits under abiotic factors effects. *Agronomy Research*, 19(2), 444-457. doi: 10.15159/ar.21.004.

[31] Ivanova, I., Serdyuk, M., Malkina, V., Tymoshchuk, T., Vorovka, M., Mrynskyi, I., & Adamovych, A. (2022). Studies of the impact of environmental conditions and varietal features of sweet cherry on the accumulation of vitamin C in fruits by using the regression analysis method. *Acta Agriculturae Slovenica*, 118(2), 1-12. doi: 10.14720/aas.2022.118.2.2404.

[32] Keserović, Z., Ognjanov, V., Magazin, N., Dorić, M. (2014). Current situation and perspectives in sour cherry production. *Sour cherry breeding cost action FA1104 Sustainable production of highquality cherries for the European market Novi Sad*, *Serbia*.

[33] Kishchak, O.A. (2014). *Scientific bases of industrial culture of cherries in the Forest-steppe of Ukraine* (Doctoral dissertation, Institute of Horticulture of the National Academy of Agrarian Sciences, Kyiv, Ukraine).

[34] Kishchak, E.A. (2013). Effective types of cherry plantations in Ukraine. *Horticulture and Viticulture*, 6, 10-15.

[35] Maglakelidze, E., Bobokasvili, Z., Kakashvili, V., & Tsigriasvili, L. (2017). Biological and agricultural properties of sweet cherry (*Prunus avium* L.) cultivars in Georgia. *International Journal of Science and Research*, 6(9), 796-803. doi: 10.21275/ART20176036.

[36] Mézes, Z., Szenteleki, K., & Gaál, M. (2017). Simulation model for sour cherry product lines. *Computers and Electronics in Agriculture,* 140, 190-202. doi: 10.1016/j.compag.2017.04.023.

[37] Mezhenskyi, V.M. (2017). *Fundamentals of research in horticulture. Calculations in Microsoft Excel*. Kyiv: LIRA-K Publishing.

[38] Mezhenskyj, V., Kondratenko, T., Mazur, B., Shevchuk, N., Andrusyk, Y., & Kuzminets, O. (2020). Results of *Ribes* breeding at the National University of Life and Environmental Sciences of Ukraine. *Research for Rural Development,* 35, 22-26. doi: 10.22616/rrd.26.2020.003.

[39] Miloševic, T., & Miloševic, N. (2012). Fruit quality attributes of sour cherry cultivars. *International Scholarly Research Notices,* article number 593981. doi: 10.5402/2012/593981.

[40] Mir, M.M., Iqbal, U., & Mir, S.A. (2021). *Production technology of stone fruits*. Singapore: Springer. doi: 10.1007/978-981-15-8920-1.

[41] Pérez-Sánchez, R., Gomez-Sánchez, M.A., & Morales-Corts, R. (2008). Agromorphological characterization of traditional Spanish sweet cherry (*Prunus avium* L.), sour cherry (*Prunus cerasus* L.) and duke cherry (*Prunus* × *gondouinii Rehd*.) cultivars. *Spanish Journal of Agricultural Research,* 6(1), 42-55. doi: 10.5424/sjar/2008061-293.
[42] Radunić, M., Jukić Špika, M., Strikić, J., Ugarković, J., & Čmelik, Z. (2014). Pomological and chemical characteristics of sweet cherry cultivars grown in Dalmatia, Croatia. *Acta Horticulturae*, 1020, 385-388. doi: 10.17660/ActaHortic.2014.1020.54.
[43] Sanderson, V., Bamber, N., & Pelletier, N. (2019). Cradle-to-market life cycle assessment of Okanagan (Canada) cherries: Helicopters, seasonal migrant labour and flying fruit. *Journal of Cleaner Production,* 229, 1283-1293. doi: 10.1016/j.jclepro.2019.04.398.
[44] Serdiuk, M.E., Priss, O.P., Haprindashvili, N.A., & Ivanova, I.Ye. (2020). *Methods of research fruit and berry products*. Melitopol: Liuks.
[45] Shevchuk, L., Grynyk, I., Levchuk, L., Babenko, S., Podpriatov, H., & Kondratenko, P. (2021). Fruit quality indicators of apple (*Malus domestica* Borkh.) cultivars bred in Ukraine. *Journal of Horticultural Research,* 29(2), 95-106. doi: 10.2478/johr-2021-0019.
[46] Shevchuk, L.M., Grynyk, I.V., Levchuk, L.M., Yareshcenko, O.M., Tereshcenko, Y., & Babenko, S.M. (2021). Biochemical contents of highbush blueberry fruits grown in the Western Forest-Steppe of Ukraine. *Agronomy Research,* 19(1), 232-249. doi: 10.15159/ar.21.012.
[47] Sîrbu, S., Niculaua, M., & Chiriţă, O. (2012). Physico-chemical and antioxidant properties of new sweet cherry cultivars from Iaşi, Romania. *Agronomy Research*, 10(1-2), 341-350. Retrieved from https://agronomy.emu.ee/wp-content/uploads/2012/12/p10108.pdf#abstract-2885.
[48] Tolstolik, L.M. (2021). Resistance of cherry varieties to spring frosts in the conditions of the Southern Steppe of Ukraine. In *Innovative agricultural technologies under climate change: Materials III International scientific and practical conference* (pp. 57-58). Retrieved from http://www.tsatu.edu.ua/rosl/wp-content/uploads/sites/20/tolstolik.pdf.
[49] Turovtseva, N.M. & Turovtsev, M.I. (2014). Varieties of sweet cherry selection of the Institute of Irrigated Horticulture named after M.F. Sidorenko NAAS of Ukraine. *Agrobiology*, 1, 96-101.
[50] Ukraine ranks second in the world in cherry production – expert. (2022). Retrieved from https://www.ukrinform.ua/rubric-economy/3063240-ukraina-na-drugomu-misci-v-sviti-z-virobnictva-ceresni-ekspert.html.
[51] Zhang, X., Wang, X., Xing, S., Ma, Y., & Wang, X. (2020). Multi-sensors enabled dynamic. monitoring and quality assessment system (DMQAS) of sweet cherry in express logistics. *Foods,* 9(5), article number 602. doi: 10.3390/foods9050602.

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Динаміка середньої маси плоду та співвідношення кісточки до м'якоті в плодах черешні, що вирощені в умовах півдня степової зони України

Анотація. Популярність черешні серед споживачів обумовлена високими смаковими якостями плодів з привабливим зовнішнім виглядом, а також раннім строком достигання Серед зовнішніх показників якості найбільше значення для споживачів має маса плодів черешні і співвідношення кісточки до м'якоті, що впливає на ринкову вартість. Метою досліджень було вивчення середньої маси плодів та маси кісточки 33 сортів черешні трьох строків достигання як перспективних, так і тих, що поширені в Україні і виділення сортів та сортозразків, що мають наукову та практичну цінність за досліджуваними параметрами. Визначення середньої маси плоду, маси кісточки, співвідношення кісточки до м'якоті у плодах черешні проводили у період споживчої стиглості. Відбір та підготовку проб до аналізів виконували згідно з ДСТУ ISO 874-2002. Середня маса плоду у плодах черешні, вирощених в умовах Півдня Степової зони України, знаходився на рівні 8,41 грам, середня маса кісточки – 0,56 грам. Оптимальну масу плодів мали плоди черешні групи пізнього терміну достигання (7,27-12,18 г.). Найбільш стійкими з мінімальними коефіцієнтами варіації за досліджуваними показниками в розрізі сортів раннього строку достигання за параметрами маси плоду та маси кісточки виявились сорти 'Світ Ерліз' та 'Рубінова Рання'. Серед групи сортів середнього терміну достигання найбільш стабільною масою плодів та кісточки було виділено плоди сортів 'Темп' та 'Винка'. У сортів пізнього терміну достигання найменша варіативність вмісту маси плоду та кісточки зафіксована у сорту 'Регіна'. Встановлено, що домінуючий вплив для формування маси плоду у всіх груп сортів мали погодні умови років досліджень, а для формування маси кісточки у всіх груп сортів – сортові особливості. Результати досліджень будуть корисними при виборі сортів черешні різних строків достигання, що придатні для реалізації плодів і подальшої їх переробки

Ключові слова: стиглість, регресійний аналіз, маса кісточки, варіювання показників

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Formation of castor productivity depending on the width of row spacing and density of standing

Abstract. The selection of plant species, their varieties, or hybrids and the establishment of their productivity is an urgent necessity today due to the shortage of biofuel production at the world level. The purpose of the study was to identify the influence of technological measures (row spacing width and plant density) on the formation of elements of the crop structure of castor varieties. During 2020-2021, a study was conducted in the field to examine the influence of plant density and row spacing on the elements of the crop structure of castor varieties Khortyts'ka 3 and Olesia in the educational and scientific laboratory "Demonstration field of agricultural crops" of the National University of Life and Environmental Sciences of Ukraine. The following methods were used: theoretical (statistical processing) and practical (descriptive, comparative). The following indicators were evaluated: the weight of 1000 seeds, the number of grains on the plant, and the mass of seeds per plant. The yield of castor seeds of the Khortyts'ka 3 variety was 1.27-1.46 t/ha with a maximum standing density of 50 thousand plants/ha and a row spacing of 70 cm. The seed yield of the Olesia variety was 1.34-1.42 t/ha with the allocation of two most productive options – an option with a row spacing of 45 cm and 37.7 thousand plants/ha and an alternative with a row spacing of 70 cm and a density of 50 thousand plants/ha. The seed productivity of one plant can almost double with a decrease in the density of standing from 50 to 25 thousand plants/ha, while simultaneously forming larger seeds. The weight of 1000 seeds of the Khortyts'ka 3 variety ranged from 268 to 283 grams, and the Olesia variety was 294-316 grams. It was identified that the correlation between seed yield and seed productivity indicators is negative or absent at all, and with the density of standing is positive. The results indicate a high compensatory ability of castor oil varieties Khortyts'ka 3 and Olesia in the establishment of productivity elements at a different density of standing and width of row spacing in the conditions of the Right-Bank Forest-Steppe of Ukraine. This allows for conducting further studies on the influence of sowing parameters in a wider range and using the results obtained for growing castor oil in atypical soil and climatic conditions.

Keywords: elements of the crop structure, weight of a thousand seeds, semi-dwarf varieties, seed yield

INTRODUCTION

Alternative sources of crop raw materials – an urgent need today is due to the necessity of improving energy efficiency and diversifying energy supply sources, producing lubricants, preserving and enriching biodiversity and the environment. Due to the shortage of biofuel production at the world level, it became necessary to find crops that could become alternative food crops, which are now widely used for energy purposes. Along with this, there are a number of issues related to climate change and the need to examine the adaptability of crops in this area for growing in atypical soil and climatic conditions. In this regard, there is a revival of interest in the production of castor oil in Ukraine (*Ricinus communis* L.), which belongs to non-food industrial crops. However, there are a number of questions that need to be investigated and relate to identifying the influence of elements of cultivation technology, in particular, the density of plant standing and row spacing on the realisation of the genetic potential of the crop in conditions that are atypical for the growth and development of this crop.

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In the conditions of climate change, the range of crops that were inherent in individual regions changes, which makes it necessary to examine the features of the establishment of productivity of these crops under the influence of technological techniques for growing them in atypical soil and climatic conditions. The examination of the influence and selection of technological processes that increase the productivity of castor varieties will allow growing crops in the conditions of the Right-Bank Forest-Steppe of Ukraine

Castor oil is a non-food oil crop that originates from tropical and subtropical regions and is well adapted to temperate climates. Castor (*Ricinus communis*) can grow up to 10-12 meters in tropical regions and is a perennial, but in temperate latitudes, it is grown as an annual crop with a height of 1-3 m (Salihu *et al.*, 2014). Castor has been cultivated for centuries to produce the oil from its seeds (Ribeiro *et al.*, 2016). Castor seeds contain 40 to 60% fat, which consists of a mixture of triglycerides of various saturated and unsaturated fatty acids, with a substantial predominance of ricinoleic acid, the content of which can reach 89% (Mallah & Sahito, 2020). Despite its wide adaptability, global castor oil production is concentrated in only a few countries, among which India is the undisputed leader, as according to FAO data for 2020, almost 90% of world-produced castor seeds were grown there (Food and Agriculture Organisation..., 2022).

The increase in castor oil production worldwide over the past decade is a clear indication of the wide range of applications of this oil and its derivatives in various industries (Mubofu, 2016). Today, the oil is used in agriculture, food processing, electronics, and for the manufacture of textiles, paper, plastic, rubber, cosmetics, perfumes, medicines, paints, inks, additives, lubricants, and biofuels(Mallah & Sahito, 2020).

The productivity of castor crops in annual cultivation is limited. The yield of castor oil reaches 1.5-2.9 t/ha with repeated fruit harvesting, and record yields (up to 5 t/ha) can be obtained by growing it as a perennial crop (Koutroubas *et al.*, 1999).

Castor oil is characterised by high adaptability to weather and soil conditions. Although it is a long-day plant, for which, increasing the duration of the light season by more than 12 hours contributes to the formation of female flowers, castor oil also grows well in regions with a photoperiod of at least 9 hours and good lighting (Salihu *et al.*, 2014).

In tropical regions, castor oil is grown as a perennial crop, but only annuals are suitable for mechanised harvesting. In the Mediterranean region and moderately warm zones, it is grown as a spring-summer crop, mainly because of its heat-loving nature, especially when sprouting and lowering temperatures in winter. In these regions, castor oil is sown mainly in April, when the soil temperature reaches 16-17°C. Low soil temperature prolongs the process of germination and emergence of seedlings, and frosts below -8°C lead to the death of even the most cold-resistant genotypes in a few hours (Zanetti *et al.*, 2017).

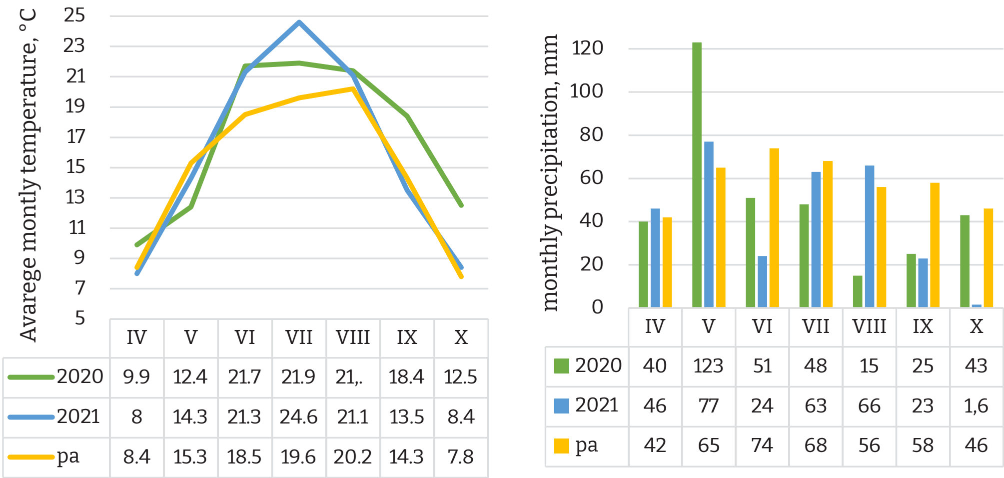
The suitability for industrial cultivation of this crop depends on the main climatic restrictions, i.e. the temperature and duration of daylight hours, regardless of the presence of moisture in the soil and the supply of nutrients that can be provided in the future by the cultivation technology (Patanè *et al.*, 2019).

The purpose of the study – establish the influence of plant density and row spacing on the elements of the crop structure and castor productivity. The goal of the study was to assess the influence of elements of cultivation technology on the yield of the crop under study and to choose the conditions for rational management of agrotechnological processes and measures for stable optimisation of the productivity of alternative oilseeds.

MATERIALS AND METHODS

Field research was conducted in 2020-2021 in the educational-scientific laboratory of the Department of Crop Growing "Demonstration field of agricultural crops" of the National University of Life and Environmental Sciences of Ukraine. According to the complex of weather-climatic conditions, the research area can be attributed to the Forest-Steppe agro-climatic zone.

Weather conditions on the territory of the Forest-Steppe part of the Kyiv region during the research period were characterised by increased average monthly temperatures in summer compared to long-term indicators and substantial deviations in monthly precipitation in certain months (Fig. 1).



	IV	V	VI	VII	VIII	IX	X
2020	9.9	12.4	21.7	21.9	21,.	18.4	12.5
2021	8	14.3	21.3	24.6	21.1	13.5	8.4
pa	8.4	15.3	18.5	19.6	20.2	14.3	7.8

	IV	V	VI	VII	VIII	IX	X
2020	40	123	51	48	15	25	43
2021	46	77	24	63	66	23	1,6
pa	42	65	74	68	56	58	46

Figure 1. Average monthly air temperature (A) and monthly precipitation (B) during the castor growing season (April-October), 2020 and 2021

Note: pa – perennial value

Weather conditions in 2020 were motley, as the air temperature in some months substantially exceeded the perennial value, and in others, it was lower. The average monthly temperature in April of this year exceeded the perennial value by 1.5°C and was 9.9°C, which enabled the beginning of sowing in the third decade of April. The average monthly temperature in May was 2.9°C lower than the perennial value and was 12.4°C, that is, the growing process of castor oil at the initial stage of development slowed down. In the summer months, the air temperature was higher than perennial values because in June the excess was 3.2°C, in July – 2.3°C, and in August – 1.2°C. The air temperature was substantially higher in the autumn months of the growing season, which contributed to the ripening of castor fruits – in September it was 3.9°C warmer, and in October – 4.7°C.

During the period from April to October 2020, 345 mm of precipitation fell, which is 64 mm less than the perennial value for this period of time, but their distribution was heterogeneous – in May, almost twice the normal amount fell, and in subsequent months there was less precipitation. In August and September of this year, 15 and 25 mm of precipitation fell, respectively, which was 27-43% of the norm, that is, in combination with a substantially higher air temperature during this period, there could be a lack of moisture in castor crops.

The air temperature during the growing season of castor in 2021 at the initial stages was close to the perennial value. In April, the average air temperature was 0.4°C below normal and was 8°C, in May it was lower by only 1.0°C (14.3°C), and from June to August substantially exceeded the perennial value. In June 2021, the average monthly air temperature was 21.3°C (+2.8°C to norm), in July – 24.6 (+5°C to the norm), and in August – 21.1°C (+0.9°C to the norm). September was colder than usual, as the air temperature averaged 13.5°C, which is 0.8°C less than theperennial value , and in October it was 0.6°C above the norm – 8.4°C.

The amount of precipitation for April-October 2021 was 300.6 mm, which is 108.4 mm lower than the annual average, and their distribution during the growing season was also heterogeneous. In the spring months, precipitation was close to the perennial value and in June only 24 mm fell, which is 50 mm less than normal. In July and August, the amount of precipitation was close to normal, but at high air temperatures, the humidification regime could substantially differ from the perennial value. The amount of precipitation in September (23 mm) was 35 mm lower than the perennial value, and in October there was almost no effective precipitation (the amount of precipitation for the month was 1.6 mm).

The air temperature and precipitation varied over the years of research, but due to the biological characteristics of castor, these conditions were acceptable and favourable for growing this crop.

The soil of the experimental site is grey forest coarse-dusty light-loamy in granulometric composition. Humus content 2.54±0.18%, easily hydrolysed nitrogen content 72±8 mg, mobile phosphorus 98±25 mg, exchange potassium 70±22 mg per 1 kg of soil; pH_{KOH} 5.8-6.1, the sum of the absorbed bases is 10-15 mg×eq/100 g of soil. Soil density at steady state is 1.1-1.2 g/cm³, the humidity of persistent wilting is 10.2%. The depth of ground water is 2-4 m.

The scheme of plant placement during sowing is developed considering the sowing suitability of castor seeds at the level of 95% (Table 1).

Table 1. Field experiment scheme

Factor A	Factor B	Factor C	Plant placement scheme, cm×cm
Variety	Row spacing width, cm	Standing density, thousands of plants/ha	
A1. Khortyts'ka 3	B1. 45 cm	25.0	45×85
		37.5	45×57
		50.0	45×42
	B2. 70 cm	25.0	70×55
		37.5	70×36
		50.0	70×27
A2. Olesia	B1. 45 cm	25.0	45×85
		37.5	45×57
		50.0	45×42
	B2. 70 cm	25.0	70×55
		37.5	70×36
		50.0	70×27

The predecessor is winter wheat. After harvesting the predecessor, stubble peeling was conducted. Winter ploughing was conducted in the I-II decade of September to a depth of 22-24 cm and fertilisers were applied in the norm $P_{45}K_{45}$ (superphosphate 18%, potassium chloride 60%). According to the physical ripeness of the soil (PV 55-60%), moisture was closed in the spring using a light tooth harrow (BZSL-1,0). On the day of sowing, disking was conducted to the depth of sowing and N_{30} was applied(ammonium nitrate – 33.4%) in pre-sowing cultivation. Seeds were treated with fundazole (benomyl) at a rate of 2.5 kg/t before sowing. Seeds were sown to a depth of 6-8 cm at a soil temperature of 10-12℃ at 10 cm. The date of sowing in 2020 is April 28, in 2021 – May 7. Sowing was conducted manually at a given standing density. Plant protection products were not applied during the growing season. All elements of the cultivation technology, with the exception of the subjects, were the same throughout the experiment.

The repetition rate of the experiment is fourfold. The total area of one plot is 31.5 m^2 (4.2 m × 7.5 m for row spacing of 70 cm; 4.5 m × 7.0 m for row spacing of 45 cm), accounting – 25.2 m^2 (4.2 m × 6.0 m for row spacing of 70 cm; 4.5 m × 5.6 m for row spacing of 45 cm).

Sampling and assessing of samples

In each variant, 10 plants were selected on the side brushes during the full fruit ripeness phase. The results obtained for each of the indicators were tested for normality according to the Shapiro-Wilk criterion (Razali & Wah, 2011). In the case when the variational series did not correspond to the normal distribution, the number of samples was increased.

The seed mass from each plant was determined by collecting all the ripe castor fruits and removing the shells. All ripe seeds from the plant were weighed with an accuracy of 0.1 g, then the average value was determined.

The thousand seeds weight was determined by weighing two samples of 500 seeds each, followed by calculating the arithmetic mean. If the discrepancy between the mass of the samples and the arithmetic mean exceeded 3%, the third sample was taken. It was determined with an accuracy of 0.1 g.

The number of fruits was determined by counting all ripe fruits on the plant that contained at least one ripe seed.

The seed yield was determined by collecting all seeds from the registered plot and converting the value in t/ha to a basic seed humidity of 12%.

Statistical processing of the results was performed using STATISTICA 13.0 software tools and the built-in Microsoft Excel analysis package. A variance analysis was performed, and the Fischer criterion of the smallest substantial difference (HIP_{05}) was used to determine the substantial difference between the options and the influence of factors on performance elements. Fisher's LSD post-hoc analysis module for homogeneous groups was used at a substantiality level of 0.05, and the groups were assigned letters starting with *a* to assess the difference (or similarity) between the variants. The empirical results obtained correspond to the normal distribution (Gaussian distribution).

Regression analysis was performed, linear and polynomial models were developed, and Pearson coefficients of determination and pairwise correlation were determined to establish the dependences of seed mass and plant density. Pearson pair correlation coefficients for pairs of performance elements were set by the Correlation matrix software with the definition of *p*-values for each indicator.

RESULTS AND DISCUSSION

The structure of castor yield is determined by such elements as the density of standing, the mass of seeds per plant, the mass of 1000 seeds, and the number of seeds per plant, which depends on the number of fruits on the main and side brushes.

The results of the analysis of variance (ANOVA) of crop structure indicators are presented in Table 2. The factual standing density was additionally determined to consider the influence of intraspecific competition on the establishment of castor productivity elements.

Table 2. Dispersion analysis of elements of the castor crop structure

Main factors	SWpP		TSW		FpP		SDH		SY	
		Part[1], %		Part[1], %		Part[1], %		Part[1], %		Part[1], %
Variety(V)	*	0.9	**	90.5	**	3.9	ns	0.0	*	15.1
Row spacing width (RS)	ns	0.0	*	0.2	ns	0.0	ns	0.0	ns	0.6
Standing density (SD)	**	98.2	**	8.7	**	95.4	**	99.9	**	52.2
Interactions										
V × RS	ns	0.1	ns	0.0	ns	0.1	ns	0.0	ns	0.6
V × SD	*	0.5	**	0.3	ns	0.2	ns	0.0	**	19.3
RS × SD	*	0.3	*	0.2	*	0.3	ns	0.0	**	11.8
V × RS × SD	ns	0.0	ns	0.1	ns	0.0	*	0.05	ns	0.3

Note: Part[1] – the part of involvement in the establishment of variance due to factors and interactions; * – indicates a substantial difference at the level of $p<0.05$; ** – indicates a substantial difference at the level of $p<0.001$; ns – there is no substantial difference at the level of p = 0.05; SWpP – seed weight per plant; TSW – thousand seeds weight; FpP – fruits per plant; SDH – standing density on harvest; SY – seed yield

The conducted variance analysis of the indicator of standing density on harvest shows that the factor of standing density is dominant (99.9% of the impact), so the decrease or variation in the number of plants in the field is due only to this factor, that is, the influence of other factors is levelled. The results obtained allow for linking the density of standing during germination (and, accordingly, the quantitative seeding rate) with the density of standing at the time of harvesting.

The variety factor was dominant among the main factors in the establishment of the thousand seeds weight, while in the establishment of seed yield, the number and seed weight per plant, its part of involvement in the variation of productivity elements was in the range of 0.9-15.1%, which sometimes (the seed weight per plant) was at the level of statistically unreliable influence (*p*-value was close to 0.05). The width of row spacing, as an independent factor, contributed to an increase in the thousand seeds weight (from 1 to 5 g), where its share of influence was 0.2%, and in other cases, *p*-value exceeded 0.05, that is, this factor in the study did not affect the mass of seeds from the plant, the number of fruits per plant, and yield, but manifested itself in interaction with the density of standing (RS×SD ratio in Table 2), especially in the establishment of seed yield (11.8% of the effect). The standing density factor had a dominant effect on the mass of seeds per plant (98.2%), the number of fruits per plant (95.4%), and the establishment of seed yield caused 52.2% variability. The relationship of factors and their influence on the establishment of individual productivity indicators varied, but in total did not exceed 1-2% (with the exception of yield), and the interaction of all factors at once was statistically unreliable in all elements of the crop structure, except for the standing density on harvest, where its influence was limited to 0.05% variation.

The weight of castor seeds from one plant varied from 28.1 to 54.4 g under the influence of factors of variety and density of standing but did not depend at all on the factor of row spacing width. Notably, the standing density factor caused 98.1% of all variations in seed mass from the plant, while the variety factor caused only 0.9%. About 0.3% of substantial deviations were caused by the interaction "row spacing width*standing density", which was manifested in a substantial difference between the variants of standing density of 37.5 thousand units/ha in the Olesia variety with row spacing of 45 and 70 cm, in favour of the 45 cm variant, where an average of 37.5 g of castor seeds were formed on the plant, and on the 70 cm variant – 35.5 g (Fig. 2).

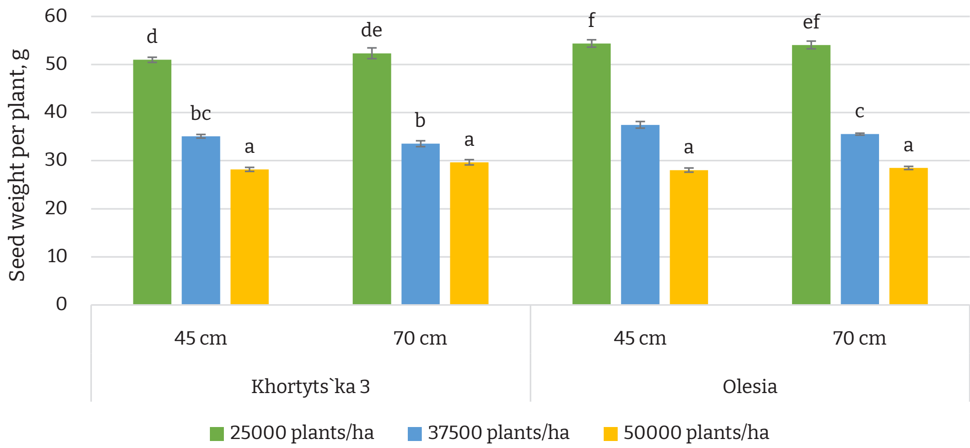


Figure 2. Seed weight (g) per plant

Note: The same letters indicate that there is no substantial difference between the values at the level of p=0.05, columns without letters differ substantially from all other options, columns with different letters also differ substantially qt HIP_{05}

Based on the results of the analysis of variance and subsequent evaluation according to the criterion of HIP_{05} there are six groups of similarities (*a-f*) and one separate variant, which differed in the value of the mass of seeds from the plant and amounted to 37.5 g.

Notably, in the Khortyts'ka 3 variety, there was no statistically substantial difference between variants with the same standing density, but different row spacing widths ($\Delta < HIP_{05}$), therefore, with a standing density of 25 thousand plants/ha, this variety formed an average of 51-52 g of seeds per plant, with a standing density of 37.5 thousand pcs./ha – 34-35 g, and the smallest at a standing density of 50 thousand plants/ha – 28-30 g. The Olesia variety on average formed 54 g of seeds with a standing density of 25 thousand plants/ha, which is 2 g more than in the Khortyts'ka 3 variety on similar variants. With a standing density of 37.5 thousand plants/ha, the Olesia variety formed 37.5 g of seeds with a row spacing width of 45 cm and 2 g less seeds with a width of 70 cm, that is, the difference was substantial because it exceeded HIP_{05}. Therewith, with a standing density of 50 thousand plants/ha, the seed weight per plant was also 28 g, without a difference in the width of row spacing and the Khortyts'ka 3 variety on similar variants.

The formation of castor fruits and seeds is a response of sowing to the availability of life factors, so it is possible to develop empirical models describing the relationship between the mass of seeds from the plant and the density of standing. According to the studies by Cordeiro *et al.* (2019) and Fiorese *et al.* (2016), the regression equation is unique for each variety and may vary depending on the growing conditions. Castor is a very plastic plant, so in addition to the linear model, nonlinear ones, in particular, the polynomial model, can also be used to describe dependencies. The second-degree polynomial relationship describes the relationship between the density of standing and the mass of seeds from a plant substantially more accurately than the linear function, and the coefficient of determination (R^2) in this case, it is close to one (Table 3).

Table 3. Polynomial and linear model of the relationship between seed mass from a plant and standing density (x)

Variety	Row spacing width, cm	Polynomial model ($R^2 = 1$)	Linear model	R^2 for a linear model
Khortyts`ka 3	45 cm	$y=0.0288x^2 - 3.0732x + 109.79$	$y= -0.9111x + 72.256$	0.9505
	70 cm	$y=0.0478x^2 - 4.4935x + 134.79$	$y= -0.9067x + 72.516$	0.8734
Olesia	45 cm	$y=0.024x^2 - 2.8553x + 110.74$	$y= -1.0531x + 79.454$	0.9436
	70 cm	$y=0.0369x^2 - 3.7883x + 125.79$	$y= -1.0233x + 77.734$	0.9367

Note: The variable x is represented as thousands of plants/ha

Therewith, the alternative linear model for each class and row spacing width has a high coefficient of determination (from 0.8734 to 0.9505), that is, the Pearson correlation coefficient (modulo) is in the range of 0.935-0.975, which is a strong relationship close to functional. The available data (standing density options) is not sufficient for the unambiguous selection of the priority model. The polynomial model accurately describes the results obtained and allows identifying the most similar data sets, for example, the equations for varieties

Khortyts'ka 3 and Olesia with row spacing of 45 cm have more in common than the option of 70 cm compared to 45 cm within the variety. The alternative linear model, on the contrary, better describes the varietal features of seed mass formation from a plant depending on the density of plant standing, without considering the width of row spacing (since the coefficient for variable and independent coefficient are similar within the variety). This problem requires corrective studies with an extension of the range of standing densities and a reduction in the step between options. Based on the results obtained by Severino *et al.* (2017), there is generally no association between row spacing and individual productivity of castor plants in the temperate growing zone, whereas, in conditions of unstable humidity, this is important. Therewith, planting crops closer limits the availability of life factors, especially moisture, so induced water stress can cause a decrease in the mass of seeds from the plant, both due to a decrease in the number of fruits per plant and due to a decrease in the mass of 1000 seeds (Alves *et al.*, 2019; Mazurenko *et al.*, 2020).

Mass of 1000 seeds (seed size)

The varieties investigated are characterised by different masses of thousands of seeds. A thousand seeds weight of the Khortyts'ka 3 variety, depending on the seeding rate and row spacing width, varied in the range of 268-283 g, and in the Olesia variety – from 294 to 316 g (Fig. 3).

It was identified that all factors and their individual interactions influenced the establishment of the mass of 1000 seeds, in particular, it was the varietal factor that caused the highest variation – 90.5%, and the density of standing – 8.7%, while the total influence of all other factors was 0.8%.

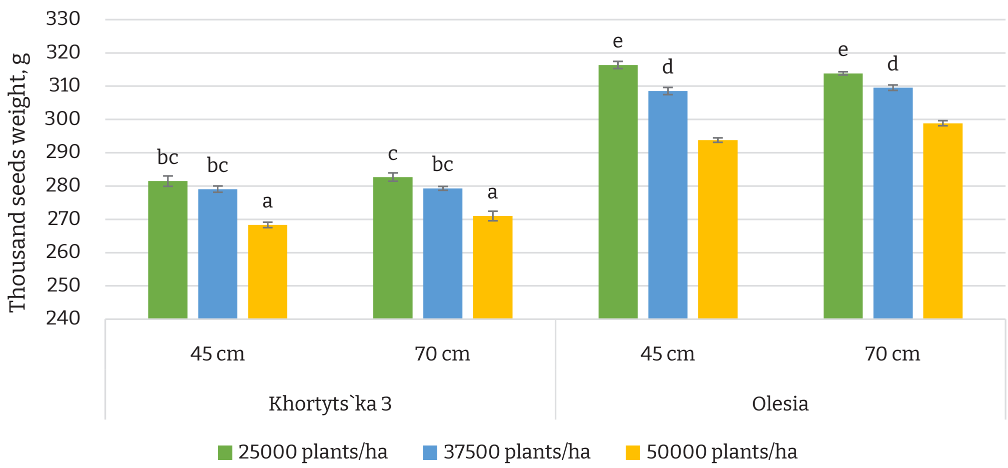


Figure 3. Weight of a thousand castor seeds (g)

Note: The same letters indicate that there is no substantial difference between the values at the level of p=0.05, columns without letters differ substantially from all other options, columns with different letters also differ substantially at HIP_{05}

The mass of 1000 seeds in the Khortyts'ka 3 variety did not statistically differ in variants with a standing density of 25 and 37.5 thousand plants/ha and different standing densities, because it was 279-283 g, that is, the variants belonged to the same similarity group (group *c*). An increase in the density of standing up to 50 thousand plants/ha led to a substantial decrease in the weight of 1000 seeds to 268-271 g – by an average of 4.2%, which allowed distinguishing a block of variants into a group *a*. In the variety Khortyts'ka 3, the difference in the average mass values of 1000 seeds with the same density of standing, but different width of row spacing is within the margin of error of the average, which indicates the inertia of this variety to the spatial placement of plants in relation to the reaction to seed size. Therewith, with a row spacing of 70 cm, the seed 1-3 g larger is formed but this is not a statistically substantial difference.

The Olesia variety had a similar tendency to form a mass index of 1000 seeds, but the influence of standing density was more pronounced. The largest mass of 1000 seeds was formed at a standing density of 25 thousand plants/ha and averaged 316 g with a row spacing of 45 cm and 314 g for 70 cm, however, the difference was statistically insubstantial, so these two options belong to the group *e*. On variants of standing density of 37.5 thousand plants/ha, a substantial decrease in the mass of 1000 seeds was observed, but without a substantial difference between the width of row spacing. On average, the Olesia variety with a standing density of 37.5 thousand plants/ha formed a mass of 1000 seeds at the level of 309-310 g. According to the results of the preliminary analysis of variance, it was identified that 0.2% of the total variance is due to the factor of row spacing width, so only in the Olesia variety with a standing density of 50 thousand plants/ha, there was a difference between variants with different row spacing widths. With a row spacing of 45 cm, castor crops formed seeds with a weight of 1000 seeds at the level of 294 g, and with a row spacing of 70 cm, on average, 5 g heavier – 299 g.

The mass index of 1000 seeds is quite plastic, but the model that describes the dependence of this indicator on the density of standing will vary depending on the variety and growing conditions. Usually, an increase in the density of standing leads to a decrease in the mass of 1000 seeds, that is, the relationship is inversely linear. However, if there is a factor regulating the microclimate in the ground layer (the presence of mulch, cover culture, etc.), then this relationship can be polynomial and until a certain indicator of standing density, the mass of 1000 seeds can grow (Cordeiro *et al.*, 2019; Honchar *et al.*, 2020).

The castor fruit is a three-seeded capsule, so it is more expedient to indicate exactly the number of fruits as an element of the crop structure, and not the number of seeds. The seed inside the fruit develops synchronously, so it is very rare for only one or two seeds to form in the capsules. The number of fruits from one plant has a clear dependence on the density of standing, which causes 95.4% of the variation in this indicator. About 3.9% of the variation in the number of fruits on plants was caused by the variety factor and 0.3% by the interaction of standing density and row spacing width, while other factors and their interactions had a statistically unreliable effect. Confirmation of the results of the analysis of variance is graphically displayed (Fig. 4), where it can be seen that in one variety with the same density of standing and width of row spacing, there is almost no difference in the number of fruits that ripen and form seeds.

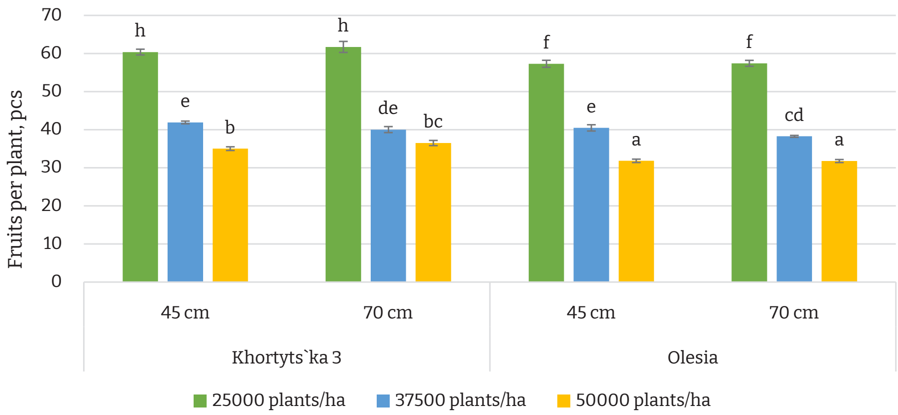


Figure 4. Number of fruits from the castor plant

Note: The same letters indicate that there is no substantial difference between the values at the level of p=0.05, columns without letters differ substantially from all other options, columns with different letters also differ substantially at HIP_{05}

The influence of the variety factor was manifested in an increase in the number of fruits in the Khortyts'ka 3 variety compared to the Olesia variety at the minimum and maximum standing density. The Khortyts'ka 3 variety formed an average of 60-62 capsules with a standing density of 25 thousand plants/ha, and when thickened to 50 thousand plants/ha, it reduced their number to 35-37 pieces. Therewith, about 57 and 32 fruits were formed in the Olesia variety, respectively. This trend continued at a density of 37.5 thousand plants/ha, but due to the high variation in the number of fruits, there was almost no statistically substantial difference between varieties and row spacing.

Larger seeds of the Olesia variety (by weight of a thousand seeds) are formed in a smaller number than in the Khortyts'ka 3 variety, so the previously established seed weight per plant in both varieties is similar with the same parameters of row spacing width and density of standing, the process of forming these indicators is a reflection of the compensatory ability in crop formation, and both varieties vegetated on the verge of realising the genetic potential in the given conditions. Given this fact, the yield formation and its range were substantially narrower than usual for agricultural crops. According to the results received by (Cordeiro *et al.*, 2019), the presence of additional vegetation, even from other ecological niches leads to a substantial decrease in the number of fruits per plant (a decrease of up to 18%), and in the case of intraspecific competition in production crops, the decrease can reach 50%, that is, an increase in the density of standing is levelled by a decrease in individual productivity of the plant.

The yield of castor oil consists of all the considered elements of the crop structure. The variants of standing density investigated in the experiment had a negative correlation with other elements of productivity, but to assess the influence of this factor, the total seed yield should be analysed (Table 4).

Table 4. Castor seed yield in 2020-2021 (average), t/ha

Variety	Spacing width, cm	Standing density of thousands of plants/ha	Yield, t/ha	Similarity groups
Khortyts`ka 3	45 cm	25.0	1.29±0.02	*ab*
		37.5	1.32±0.01	*bcd*
		50.0	1.43±0.02	*fh*
	70 cm	25.0	1.31±0.02	*abc*
		37.5	1.27±0.01	*a*
		50.0	1.46±0.02	*h*
Olesia	45 cm	25.0	1.35±0.01	*cde*
		37.5	1.42±0.02	*fh*
		50.0	1.39±0.02	*ef*
	70 cm	25.0	1.36±0.01	*de*
		37.5	1.34±0.01	*cd*
		50.0	1.42±0.01	*fh*
LSD_{05} = 0,04 t/ha				

Note: The same letters indicate that there is no substantial difference between the values at the level of p=0.05, different letters indicate a substantial difference at HIP_{05}. Similarity groups are marked by the yield from the lowest to the highest *a* – the lowest, *h* – the most productive

During statistical processing of the yield of castor varieties, seven groups of similarity are determined from *a* to *h* – from low-yielding to high-yielding options. The most productive options (group *h*) in the variety Khortyts'ka 3, there were combinations of row spacing width of 70 cm and standing density of 50 thousand plants/ha with a yield of 1.46 t/ha of seeds; and row spacing width of 45 cm with the same standing density, where an average of 1.43 t/ha of seeds was formed. Notably, this variety with a standing density of 25 and 37.5 thousand plants/ha formed substantially fewer seeds for both variants of row spacing. On average, 1.27-1.32 t/ha was formed on these variants, which allowed distinguishing these variants into low-productive groups – *a* and *b*.

In the Olesia variety, two variants were also included in the highly productive group *h* – a combination of row spacing width of 70 cm and standing density of 50 thousand plants/ha with a yield of 1.42 t/ha and a variant with row spacing width of 45 cm and standing density of 37.5 thousand plants/ha with the same yield. Notably, the yield of this variety in the experiment varied less than in the Khortyts'ka 3, because the minimum value was 1.34 t/ha, and the maximum value was 1.42 t/ha. Most of the combinations of the elements of the technology provided an acceptable level of yield and belonged to intermediate groups *d*, *e*, and *f* .

The high yield of variants with a higher density of standing (37.5 and 50 thousand plants/ha) and with a small difference between these variants is a consequence of the adaptation of plants to growing conditions and the establishment of habit depending on the existing life factors. Many researchers confirm the thesis that with certain parameters of standing density, the yield of castor oil transfers into a so-called plateau, that is, further compaction of crops does not lead to an increase or decrease in yield, but this range is unique for each variety and soil and climatic conditions (Cordeiro *et al.*, 2019; Sampaio *et al.*, 2019).

Correlation between elements of castor oil productivity

The data series describing the performance indicators of the two varieties are similar, so they can be used in the same array to determine Pearson correlation coefficients (Table 5).

Table 5. Paired Pearson correlation coefficients between elements of the castor crop structure

	SWpP	TSW	FpP	SD	SY
SWpP	1	0.41*	0.98**	-0,023	-0,001
TSW		1	0.21^{ns}	-0.39*	0.00^{ns}

Table 5, Continued

	SWpP	TSW	FpP	SD	SY
FpP			1	−0.95**	−0.47**
SD				1	0.61**

Note: * – correlation between traits is statistically substantial at the level of 0.05<p>0.01; * * – correlation between traits is statistically substantial at the level of p<0.01; ns – correlation between elements of the crop structure is statistically unreliable at the level of p<0.05; SWpP – seed weight per plant; TSW – thousand seeds weight; FpP – fruits per plant; SD – standing density; SY – seed yield

The relationship between standing density and castor productivity elements is negative, i.e. they decrease with increasing density, but this does not apply to the relationship with yield (r=0.61). Notably, the relationship between standing density and yield has a greater impact compared to other productivity elements, so increasing standing density increases yield, despite the fact that the seed weight per plant and the number of fruits decreases (Angraeni & Purwati, 2022). The yield of castor seeds had a negative correlation with the mass of seeds from the plant and the number of fruits, and there was no correlation with the mass index of a thousand seeds.

CONCLUSIONS

Varieties Khortyts'ka 3 and Olesia have many common features in the establishment of productivity because they are genetically approximate, so the establishment of quantitative indicators of productivity (seed weight per plant, number of fruits) is similar. The developed polynomial and linear models of the dependence of seed mass on standing density indicate similar mechanisms of seed mass establishment from the same plant in the investigated varieties. The main factor influencing the variation in seed mass indicators from the plant, the number of fruits per plant, was the density of standing since the share of this factor in these productivity indicators exceeded 95.4%. Therewith, the influence of standing density on yield was 52.2%, and a substantial share was occupied by interactions of standing density with the varietal factor and standing density, which was not observed in individual productivity elements. In general, varieties were characterised by similar parameters of crop structure elements with the same combinations of standing density and row spacing width, as evidenced by multiple comparisons, but in some variants, the difference was substantial, so certain options were more effective by a set of features. The maximum yield of castor seeds of the Khortyts'ka 3 variety was 1.46 t/ha, and in the Olesia variety – 1.42 t/ha. Notably, the yield variation of the Olesia variety is much smaller, which indicates its adaptability to a wide range of different growing conditions, and the higher productivity of the Khortyts'ka 3 variety indicates the available unused yield potential. Therefore, further research on optimising the parameters of sowing and plant density is promising, given the efficiency and low cost.

A promising area for future research will be the adjustment of crop parameters with the development of practical models for the establishment of productivity indicators and their reduction to the level of a variety to realise the biological potential of productivity in conditions of a limited growing season of castor.

REFERENCES

[1] Alves, A.N., Gheyi, H.R., Junior, J.A.S., da Silva Junior, F.J., Soares, F.A.L., & Uyeda, C.A. (2019). Salinity and nitrogen doses in the production and oil content of castor bean. *Semina Ciencias Agrarias*, 40(6), 2851-2860. doi: 10.5433/1679-0359.2019v40n6Supl2p2851.

[2] Anggraeni, T.D.A., & Purwati, R.D. (2022). Characterization of plant architecture and yield trait of castor (*Ricinus communis* L.) germplasm suitable for mechanical harvesting. *AIP Conference Proceedings*, 2462(1), article number 020025.

[3] Cordeiro, C.F.D.S., Echer, F.R., Pires, L.H., & Creste, J.E. (2019). Productivity of castor bean plants intercropped at different plant densities with *Urochloa ruziziensis*. *Brazilian Journal of Agricultural and Environmental Engineering*, 23, 109-113. doi: 10.1590/1807-1929/agriambi.v23n2p109-113.

[4] Fioreze, S.L., Lara-Fioreze, A.C.D.C., Pivetta, L.G., Rodrigues, J.D., & Zanotto, M.D. (2016). Agronomic characteristics of the castor bean as affected by cultivation method and planting density. *Revista Ciencia Agronomica*, 47, 86-92. doi: 10.5935/1806-6690.20160010.

[5] Food and Agriculture Organization of the United Nations (FAO). Retrieved from http://www.fao.org/faostat/en/-data/QC.

[6] Honchar, L., Mazurenko, B., Sonko, R., Kyrpa-Nesmiian, T., Kovalenko, R., & Kalenska, S. (2020). Biochemical responses of 5 buckwheat (*Fagopirum esculentum* Moench.) cultivars to seed treatment by *Azospirillum brasilense*. *Agronomy Research*, 18(S3), 1680-1688. doi: 10.15159/AR.20.080.

[7] Koutroubas, S.D., Papakosta, D.K., & Doitsinis, A. (1999). Adaptation and yielding ability of castor plant (*Ricinus communis* L.) genotypes in a Mediterranean climate. *European Journal of Agronomy*, 11(3-4), 227-237. doi: 10.1016/S1161-0301(99)00034-9.

[8] Mallah, T.A, & Sahito A.R. (2020). Optimization of castor and neem biodiesel blends and development of empirical models to predicts its characteristics. *Fuel*, 262, article number 116341. doi: 10.1016/j.fuel.2019.116341.

[9] Mazurenko, B., Novytska, N., & Honchar, L. (2020). Response of spring and facultative triticale on microbial preparation (*Azospirillum brasilense* and *Bacillus polymyxa*) by different nitrogen nutrition. *Journal of Central European Agriculture*, 21(4), 763-774. doi: 10.5513/JCEA01/21.4.2914.
[10] Mubofu, E.B. (2016). Castor oil as a potential renewable resource for the production of functional materials. *Sustainable Chemical Processes*, 4(1), 1-12. doi: 10.1186/s40508-016-0055-8.
[11] Patanè, C., Cosentino, S.L., Corinzia, S.A., Testa, G., Sortino, O., & Scordia, D. (2019). Photothermal zoning of castor (*Ricinus communis* L.) growing season in the semi-arid Mediterranean area. *Industrial Crops and Products*, 142, article number 111837. doi: 10.1016/j.indcrop.2019.111837.
[12] Razali, N.M., & Wah, Y.B. (2011). Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests. *Journal of Statistical Modeling and Analytics*, 2(1), 21-33.
[13] Ribeiro, P.R., de Castro, R.D., & Fernandez, L.G. (2016). Chemical constituents of the oilseed crop Ricinus communis and their pharmacological activities: A review. *Industrial Crops and Products*, 91, 358-376. doi: 10.1016/j.indcrop.2016.07.010.
[14] Salihu, B.Z., Gana, A.K., & Apuyor, B.O. (2014). Castor oil plant (*Ricinus communis* L.): botany, ecology and uses. *International Journal of Science and Research,* 3(5), 1333-1341.
[15] Sampaio, O.M., Silva, S.D.O., Donato, S.L.R., Silva, S.A., & Silva, M.D.S.D. (2019). Optimum experimental plot size in the castor bean. *Revista Ciencia Agronomica*, 50, 276-281. doi: 10.5935/1806-6690.20190032.
[16] Severino, L.S., Auld, D.L., Vale, L.S., & Marques, L.F. (2017). Plant density does not influence every castor plant equally. *Industrial Crops and Products*, 107, 588-594. doi: 10.1016/j.indcrop.2017.05.061.
[17] Zanetti, F., Chieco, C., Alexopoulou, E., Vecchi, A., Bertazza, G., & Monti, A. (2017). Comparison of new castor (*Ricinus communis* L.) genotypes in the mediterranean area and possible valorization of residual biomass for insect rearing. *Industrial Crops and Products*, 107, 581-587. doi: 10.1016/j.indcrop.2017.04.055.

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Формування продуктивності рицини залежно від ширини міжрядь та густоти стояння

Анотація. Підбір видів рослин, їх сортів чи гібридів та формування їх продуктивності є гострою необхідністю сьогодення у зв'язку з дефіцитом виробництва біопалива на світовому рівні. Мета роботи полягала у виявленні впливу технологічних заходів (ширина міжряддя та густота стояння рослин) на формування елементів структури врожаю сортів рицини. Впродовж 2020-2021 рр. у польових умовах проводили дослідження з вивчення впливу густоти стояння рослин та ширини міжряддя на елементи структури врожаю рицини сортів Хортицька 3 та Олеся в навчально-науковій лабораторії «Демонстраційне поле сільськогосподарських культур» НУБіП України. Використовували такі методи: теоретичні (статистична обробка) та практичні (описові, порівняльні). Проводили оцінку наступних показників: маса 1000 насінин, кількість плодів на рослині, маса насіння з рослини. Урожай насіння рицини сорту Хортицька 3 становив 1,27-1,46 т/га з максимумом при густоті стояння 50 тисяч рослин/га і ширині міжряддя 70 см. Урожайність насіння сорту Олеся становила 1,34-1,42 т/га з виділенням двох найпродуктивніших варіантів – опція з шириною міжрядь 45 і 37,7 тисяч рослин/га та альтернативна з шириною міжрядь 70 см і густотою 50 тисяч рослин/га. Насіннєва продуктивність однієї рослини може зростати майже вдвічі при зниженні густоти стояння з 50 до 25 тисяч рослин/га, з одночасним формуванням крупнішого насіння. Маса 1000 насінин сорту Хортицька 3 становила від 268 до 283 грам, а сорту Олеся становила 294-316 г. Встановлено, що кореляція між урожайністю насіння та показниками насіннєвої продуктивності є негативною, або взагалі відсутньою, а з густотою стояння позитивною. Результати досліджень вказують на високу компенсаційну здатність рицини сортів Хортицька 3 та Олеся при формуванні елементів продуктивності за різної густоти стояння та ширини міжрядь в умовах Правобережного Лісостепу України. Це дозволяє проводити подальші дослідження з вивчення впливу параметрів сівби у більш широкому діапазоні та використовувати отримані результати за вирощування рицини у нетипових для неї ґрунтово-кліматичних умовах

Ключові слова: елементи структури врожаю, маса тисячі насінин, напівкарликові сорти, урожайність насіння

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Influence of hydrothermal factors on feed and seed productivity of alfalfa in the conditions of the Right-Bank Forest-Steppe

Abstract. The relevance of the study is due to the need to examine the influence of hydrothermal resources of the region on the formation of the crop of leaf-stem mass and alfalfa seeds, which is important in the conditions of modern climate changes. In this regard, the purpose of the study is to identify the influence of precipitation and temperature conditions on the growth and development of plants of varieties and hybrids by harvest cycles and years of use of the herbage. In the course of the study, the following methods were used: field (conducting phenological observations and accounting), laboratory (structural analysis of the grass stand), mathematical-statistical (objective assessment of the obtained experimental data). It was identified that the amount of precipitation from the beginning of the period of the relative rest to the onset of active temperatures above 10°C had the greatest impact on the formation of the 1st harvest; the amount of precipitation after the establishment of active temperatures above 10°C and before accounting for the yield of leaf-stem mass moderately affected the formation of the 2nd harvest and strongly – the 3rd; the amount of precipitation of the previous harvest – the 2nd-4th harvest (the strongest – the 4th); the sum of active temperatures above 10°C – the 1st and 3rd harvests; indicators of hydrothermal coefficient – the 2nd-3rd; duration of the growing season with active temperatures above 10°C – the 1st and 3rd harvests. Seed yield, in contrast to feed productivity, largely depended on the amount of precipitation before the flowering phase and in general during the growing season of alfalfa. It is established that the yield of dry matter and seed yield are influenced by: the sum of active temperatures, the amount of precipitation per harvest or vegetation of plants, and the genetic characteristics of the hybrids and varieties under study. It was identified that the hydrothermal conditions of the year have different effects on the level of plant productivity – excessive and sufficient moisture increases feed productivity and reduces seed yield. The data obtained are of practical value for predicting the yield of green mass of alfalfa each subsequent harvest of the herbage, depending on the amount of precipitation during the growing season of the previous one, and for developing programmes for creating synthetic varieties with increased yield of leaf-stem mass and seeds

Keywords: hybrid, hydrothermal coefficient, harvest cycle, dry matter yield, seed yield, correlation

INTRODUCTION

Alfalfa is one of the most productive and widespread forage crops in the world. The value is not limited only to its feed benefits, it is also important in the biologisation of Agriculture. Alfalfa (*Madisago sativa* L.) is one of the oldest agricultural plants in the world, which, in pure crops and as part of grass mixtures, provides a high yield of green mass with a high content of digestible protein and in the process of symbiotic nitrogen fixation enriches the soil with biological nitrogen, which in the conditions of an energy crisis is important for increasing soil fertility (Bugayov & Zadorozhnay, 2012).

There is an increase in the interest of researchers in the use of this culture in medicine and the food industry, which indicates its versatility and the prospect of further research (Apostol *et al*., 2017; Rafinska *et al*., 2017; Yakhlef *et al*. 2020). Due to its plasticity in terms of

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longevity and resistance, alfalfa is the most suitable crop for biotic and abiotic factors. However, according to its biological characteristics, alfalfa plants grow well and develop at a pH of 6.5-7.5. A decrease in the reaction of the soil solution to pH 5.1-5.5 negatively affects the enzymatic apparatus of cells, which leads to inhibition and suspension of synthesis processes in plants, disruption of hydrocarbon and protein metabolism. Alfalfa is one of the crops that responds best to soil liming (Hetman *et al.*, 2017). According to the agrochemical certification of arable land in Ukraine, the area of acidified soils is 3.7-4.4 million hectares. In particular, in the zone of Forest-Steppe and Polesia, such soils occupy 25-37%. Alfalfa crop losses on acidic soils reach 20-40% (Baliuk *et al.*, 2010; Melnyk, 2010). This is especially true for seed formation under such conditions (Buhaiov & Horenskyi, 2021). Therefore, increasing seed productivity will continue to be one of the main areas of breeding this crop.

It is known that most studies on alfalfa breeding are aimed at creating varieties adapted to abiotic and biotic factors of the growing area (Tyshchenko & Tyshchenko, 2014), improving or developing certain agrotechnical techniques aimed at increasing feed and seed productivity (fertilisation, sowing dates and norms, plant protection, etc.) (Hetman *et al.*, 2017; Noskova, 2015). However, researchers do not always consider the hydrothermal resources of the research site. It is established that the amount of precipitation and the sum of active temperatures of a particular year substantially differ from the average annual values, especially recently, in the conditions of climate change, and this accordingly affects the productivity of the crop (Petrychenko *et al.*, 2020).

Alfalfa (*Medicago sativa* L.) among other perennial legumes, is the most common forage crop in all soil and climatic zones of Ukraine. It provides the production of high-quality protein feed and promotes the biological reproduction of soil fertility (Petrychenko *et al.*, 2018). A substantial amount of studies has been conducted to improve the agricultural technology of alfalfa cultivation for feed and seed purposes under various agroclimatic conditions in Ukraine. Optimal terms and methods of sowing, seeding rates, and application of mineral fertilisers were identified (Demydas *et al.*, 2010; Petrychenko *et al.*, 2020). Considerable attention is paid to the development of ways to increase the proportion of symbiotic nitrogen fixed by alfalfa plants in symbiosis with nodule bacteria (Holoborodko, 2021; Tyshchenko *et al.*, 2018). A positive effect of growth stimulators and microfertilisers on the formation of leaf-stem mass and seeds of alfalfa varieties was identified (Vlasenko *et al.*, 2003; Vozhehova *et al.*, 2021; Tyshchenko *et al.*, 2020). A number of researchers have considered the ecological and genetic foundations of adaptive crop production (Zaporizhchenko *et al.*, 2018; Ivashchenko & Rudyk-Ivashchenko, 2011; Karta, 2006). Creating favourable conditions for the growth and development of alfalfa plants involves a scientifically based approach to adapting them to natural and climatic conditions, considering genetic, biological, and hydrothermal factors (Hetman *et al.*, 2017; Noskova, 2015; Lili *et al.*, 2019). Despite the substantial success of Ukrainian breeding, it is relevant to create alfalfa varieties with a combination of high seed and feed productivity and adaptability (Buhainov & Gorenskyi, 2021; Tyshchenko & Tyshchenko, 2014). A number of researchers have identified that aluminium ions at the physiological, biochemical, and molecular levels have both stimulating and toxic effects on the growth of alfalfa plants (Buhaiov *et al.*, 2014; Khu *et al.*, 2012).

The formation of seed productivity is influenced by a number of factors: increased soil acidity, insufficient supply of nutrients, lack of a sufficient number of pollinating insects, hydrothermal conditions, abortivity of flowers and beans (Rudska, 2016; Bolaños-Aguilara *et al.*, 2002; Katepa-Mupondwa *et al.*, 1996).

The purpose of the study – identification of the influence of hydrothermal conditions of the year on the processes of growth, development, and formation of the yield of leaf-stem mass of alfalfa, depending on the harvest and years of use.

MATERIALS AND METHODS

The study was conducted in 2013-2020 at the Institute of Feed Research and Agriculture of Podillya of the National Academy of Agrarian Sciences of Ukraine, located in the Right-Bank Forest-Steppe of Ukraine, Vinnytsia district, Vinnytsia region. Vinnytsia district is located in the central zone of the Vinnytsia region, which is characterised by a moderately warm and humid climate typical of the Central Forest-Steppe. The hydrothermal coefficient (HTC) is 1.7-1.8. Precipitation during the year is 534-540 mm. Of this amount, about 70% is during the warm period of the year. The soil cover of the fields where the studies were conducted is represented by grey forest medium-loamy soils with a pH of salt extract from 5.0 to 5.5 and a hydrolytic acidity of 26-28 mg.-eq/1 kg of soil. Humus content is 1.5-1.8%; easily hydrolysed nitrogen – 34-54 mg.-eq/1 kg of soil; mobile phosphorus 100-120, and exchange potassium 120-140 mg.-eq/1 kg of soil. The degree of soil saturation with bases is 85.7%. Samples of alfalfa (Syniukha (UJ0700134), Regina (UJ0700031), Yaroslavna (UJ0700225) (Ukraine); Vika (Denmark); Mega (UJ0700365), Grilys (Uj0700772) (Sweden), Zhidrune (UJ0700699, Lithuania), and 37 hybrid populations, created with their involvement, were used as research materials of the third and fifth generation. Its predecessor is winter triticale. Mineral fertilisers were applied for sowing in a dose of $N_{30}P_{60}K_{30}$ kg/ha. In autumn, every year the herbage of the second and subsequent years of use was supplemented at a dose of $P_{60}K_{30}$ kg/ha. Seed herbage was additionally supplemented annually with foliar boric and molybdenum preparations, and if necessary, insecticide treatment was conducted in the budding and seed formation phase.

Laying of breeding nurseries was conducted by the summer coverless method of sowing (10-15 June): continuously (15 cm) – to assess feed productivity, and wide-row (45 cm) – seed with the corresponding seeding rate of 8 and 3.5 million tonnes germinating seeds/1 ha. The area of the registered plot is 3 m² in the F_3 nursery and 10 m² – in F_5. Sowing with a Maple 1.5 selection seeder, the depth of seed embedding is 1.5-2 cm. Evaluation of the yield of green mass and seeds was conducted on alfalfa stands of the first, second, third, and fourth years of use. Field studies and phenological observations were conducted in accordance with methodological recommendations (Andriushchenko *et al*., 2010). The data from four harvests were used at the onset of the budding phase to account for feed productivity – the beginning of flowering, seed – from the grass stand of the first harvest. In the future, the average dry matter yield along the harvests was used for calculations. Accounting of the seed harvest was conducted by a Sampo 130 small-sized harvester.

For a brief description of hydrothermal conditions, the period 2013-2020 is given, which is characterised by a heterogeneous distribution of precipitation and temperature regime in comparison with the perennial average values (Table 1).

Table 1. Hydrothermal parameters

Parameter	2013	2014	2015	2016	2017	2018	2019	2020	Perennial average
Average air temperature, °C	16.0	17.6	18.8	17.0	17.9	17.7	16.7	18.1	16.5
Sum of precipitation, mm	418.5	385.8	160.7	213.9	266.0	370.3	364.4	302.0	409.0
Sum of active temperatures >10°C ,	2937.9	2164.8	2877.7	3114.9	2743.2	3250.4	2562.6	2767.3	2521.0
HTC[1]	1.42	1.78	0.56	0.69	0.97	1.14	1.42	1.09	1.62

Notes: [1]HTC (hydrothermal coefficient)

The Selyaninov hydrothermal coefficient was calculated (Polovyi *et al*., 2012), according to which 2015 corresponds to the conditions of severe drought, 2016, 2017 – mild drought, 2013, 2018, 2019, 2020 – sufficiently humid conditions, and 2014 – excessive moisture to improve the perception of such conditions. In general, in comparison with the perennial average values, a substantial decrease in precipitation and an increase in the sum of active temperatures is observed, which had an ambiguous effect on the level of feed and seed productivity.

Statistical processing of data was performed using Agrostat, IBM SPSS Statistics, and Microsoft Excel software.

RESULTS AND DISCUSSION

During the research period of 2013-2020, it was identified that hydrothermal factors were characterised by a heterogeneous distribution of precipitation and temperatures. An analysis of the level of dry matter yield along the harvests was conducted to objectively assess their impact.

Thus, from the time of relative dormancy of plants to the establishment of average daily temperatures of above 10°C (approximately from November to the beginning of April ±10-15 days), the amount of precipitation ranged from 177 mm in 2013 to 313 mm in 2017, or on average for years of research – about 230 mm. The amount of precipitation received after the onset of average daily temperatures of above 10°C and before the time of the first harvest also varied substantially over the years and ranged from 15 mm (2018) to 136 mm (2019). It is noted that the sum of active temperatures above 10°C varied greatly (Table 2).

Table 2. Dry matter yield in hybrid alfalfa populations (F_3 and F_5) and hydrothermal indicators of 2013-2020 (1st and 2nd harvests)

Years	1st harvest					2nd harvest			
	Total precipitation (rest state – onset of t_{fact}>10°C), mm	Precipitation amount (t_{fact}>10°C – accounting), mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m	Sum of precipitation, mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m
2013	176.9	60	859.2	0.70	4.81±1.12	107	722	1.48	2.51±0.41
2014	193.2	57	392.5	1.45	3.13±1.25	152	759.4	2.0	2.93±1.06
2015	224	39	406.1	0.96	3.20±1.1	28.3	629.5	0.45	1.81±0.86

Table 2, Continued

Years	1st harvest					2nd harvest			
	Total precipitation (rest state – onset of t_{fact}>10°C), mm	Precipitation amount (t_{fact}>10°C – accounting), mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m	Sum of precipitation, mm	Sum of active temperatures (t_{fact}>10), °C	HTC	Dry matter yield, t/ha M±m
2016	237	68	559.4	1.22	3.21±1.46	63	681.7	0.92	2.99±1.32
2017	313	51	558.6	0.91	7.00±0.87	24	656.1	0.37	2.40±0.42
2018	258	15	562.4	0.27	4.77±0.6	100.5	785.8	1.28	2.67±0.39
2019	231.4	136	407	3.34	4.59±0.56	74	639.6	1.16	3.29±0.48
2020	201	79.5	312	2.54	3.8±0.44	127.5	688	1.85	2.99±0.48
Average	229.31	63.19	507.1	1.42	4.31±1.44	84.54	695.26	1.19	2.70±0.46

In terms of the yield of dry matter in the first harvest, 2017 should be highlighted – 7 t/ha. Evidently, this is due to substantial precipitation during the period of relative dormancy of plants, which allowed forming sufficiently high reserves of productive moisture in the soil, and, despite a weak drought in the spring (HTC – 0.91), plants were able to fully realise their genetically determined yield level. Therewith, the dry matter yield in other years was in the range of 3.13-4.81 t/ha. It is necessary to highlight 2013, when this indicator was 4.8 t/ha, 2018 – 4.77, and 2019 – 4.57 t/ha with HTC of 0.7, 0.27, and 3.34, respectively.

In 2013 and 2019, a fairly high level of precipitation in winter also substantially affected the formation of the leaf-stem mass. In 2018, the dry matter yield was most strongly affected by precipitation during the relative rest period, since after setting active temperatures of above 10°C , rather harsh conditions developed (HTC – 0.27, precipitation – 15 mm). Alfalfa plants needed from 26 to 53 days with active temperatures of above 10°C to form a crop in the first harvest. In the second harvest, precipitation also varied substantially over the years – from 152 mm in 2014 to 24 mm in 2017. Thus, according to the HTC indicator (0.37), 2017 corresponded to the conditions of a very strong drought, 2015 (0.45) – a strong drought, 2016 (0.92) – a weak drought, 2013 (1.48), 2018 (1.28), 2019 (1.16) – sufficiently humid conditions, and 2014 (2.0) and 2020 (1.85) – excessive moisture.

The dry matter yield was in the range of 1.81-3.29 t/ha. Therewith, an increase in the value of this feature was observed depending on the increase in precipitation. The sum of active temperatures increased and ranged from 629.5 to 785.8°C , and the number of days before harvest, on the contrary, decreased to 31-43. Hydrothermal conditions can be considered more unfavourable for the formation of yield on harvests 3 and 4 (Table 3).

Table 3. Dry matter yield in hybrid alfalfa populations (F_3 and F_5) and hydrothermal indicators of 2013-2021 (3rd and 4th harvests)

Years	3rd harvest				4th harvest			
	Sum of precipitation, mm	Sum of active temperatures (t fact>10), °C	HTC	Dry matter collection, t/ha M±m	Amount of precipitation (before accounting), mm	Sum of active temperatures (t fact>10), °C	HTC	Dry matter yield, t/ha M±m
2013	46.2	827.4	0.56	2.79±0.7	174.7	739.5	2.36	0.94±0.2
2014	54	756.9	0.71	1.90±0.75	102	905	1.13	0.89±0.25
2015	22	801.8	0.27	1.49±0.69	41	1313	0.31	1.21±0.55
2016	44	602	0.73	1.89±0.83	35	974.4	0.36	1.09±0.48
2017	61	736	0.83	1.64±0.34	64	760.3	0.84	0.51±0.11
2018	187	791.3	2.36	3.31±0.38	58.8	887.4	0.66	2.37±0.3
2019	68	783	0.87	2.00±0.40	9.3	836.9	0.11	0.60±0.17
2020	49	721	0.68	1.60±0.35	36.4	953.5	0.38	1.00±0.17
Average	66.4	752.43	0.88	2.08±0.65	65.15	921.25	0.77	1.08±0.57

Thus, the amount of precipitation before the 3rd harvest was in the range of 22-68 mm (with the exception of 2018 – 187 mm), on the 4th – 9.3-64 mm (with the exception of 2013 – 174.7 and 2014 – 102 mm). The sum of active temperatures, in comparison with the first and second harvests, increased and amounted to 752.4°C in the 3rd harvest and 921.2°C in the 4th, and the number of days for crop formation was 28-42 in the 3rd and 42-74 days in the 4th. The HTC values, respectively, except for some exceptions, were less than 1 and linked to various drought variants, which had a corresponding effect on the level of dry matter yield, which in the 3rd harvest was 1.49-3.31 t/ha and in the 4th – 0.51-2.37 t/ha. In total, for four harvests, the yield of dry matter of alfalfa in hybrid nurseries was: 2013 – 11.05 t/ha; 2014 – 8.85; 2015 – 7.71; 2016 – 9.18; 2017 – 11.55; 2018 – 13.12; 2019 – 10.48; 2020 – 9.39 t/ha, or on average – 10.17 t/ha.

For a more complete perception of the dependence of the level of feed productivity on hydrothermal factors and the duration of the growing season, correlation coefficients between these features are calculated (Table 4).

Table 4. Dependence of dry matter yield on harvests on hydrothermal factors and the duration of the growing season

Harvest	Amount of precipitation, mm (autumn-winter before the onset of active temperatures of above 10°C, potential moisture reserves)	Amount of precipitation, mm (after the onset of active temperatures above 10°C before accounting)	Amount of precipitation, mm (previous harvest)	Sum of active temperatures above 10°C	HTC	Number of days before harvest with (t fact>10), °C
1	0.69[1]	-0.05	–	0.39[1]	-0.17	0.63[1]
2	-0.16	0.52[1]	0.66[1]	0.20	0.58[1]	0.17
3	-0.09	0.78[1]	0.33[1]	0.39[1]	0.75[1]	0.46[1]
4	–	-0.06	0.78[1]	0.24	-0.10	0.03

Notes: [1] – the correlation is substantial at 0.05

According to the obtained calculations, the manifestation of dependencies was identified, characterised by a strong relationship between the amount of precipitation from the beginning of the relative rest period and the sum of active temperatures above 10°C – 0.69. It is noted that winter precipitation did not affect the subsequent harvests. Therewith, the amount of precipitation after the establishment of active temperatures above 10°C and before harvest ripeness moderately affected the formation of the 2nd harvest (0.52) and strongly – the 3rd (0.78), while no effect was identified on the 4th. This is due to the fact that with a decrease in the length of daylight at a relatively high average daily temperature, the duration of the inter-harvest period and the average daily linear growth icrease (Hetman *et al.*, 2018; Lili *et al.*, 2019).

Notably, the productivity of alfalfa plants largely depends on the intensity of shoot formation, which is influenced by various factors, in particular, soil and meteorological conditions (Georgieva & Nikolova, 2015). The regrowth of alfalfa after harvesting in different harvests has its own characteristic features. It is known that in the first harvest, shoots are formed from the crown of the root of plants, and in the second, third and fourth – 54-78% of shoots are formed due to the axillary buds of the plant stem and only 22.1-46.2% – from the buds of the root crown. Stems formed from the buds of the root crown are characterised by a larger mass compared to shoots formed from the stem axillary buds (Hetman *et al.*, 2018; Petrychenko *et al.*, 2021;).

Thus, the feed productivity of alfalfa is affected not only by precipitation during the growing season of plants of a particular harvest but also by the previous one, since plants lay buds to restore shoots throughout almost the entire growing season. The identified dependencies were confirmed by the corresponding correlation coefficients: in the 2nd harvest – 0.66, in the 3rd – 0.33, and, especially, in the 4th – 0.78. The sum of active temperatures above 10°C was characterised by an average effect on the level of feed productivity in the 1st and 3rd harvests.

According to the level of the HTC indicator, the average correlation coefficient was identified in the 2nd harvest – 0.58, and a strong one in the 3rd – 0.75. Since the HTC indicator includes precipitation and temperature, it is quite evident that the available soil moisture in this case has a stronger impact. Between the duration of the growing season of plants and the sum of active temperatures above 10°C and the yield of dry matter, an average relationship was identified only in the first and third harvests – a correlation coefficient of 0.63 and 0.46, respectively.

Notably, in the first year of life, the root system of alfalfa is not yet sufficiently developed and cannot fully provide plants with the necessary nutrients and moisture, this is also influenced by the genetic characteristics of varieties and hybrid populations (Karta, 2006; Georgieva & Nikolova, 2015) (Fig. 1).

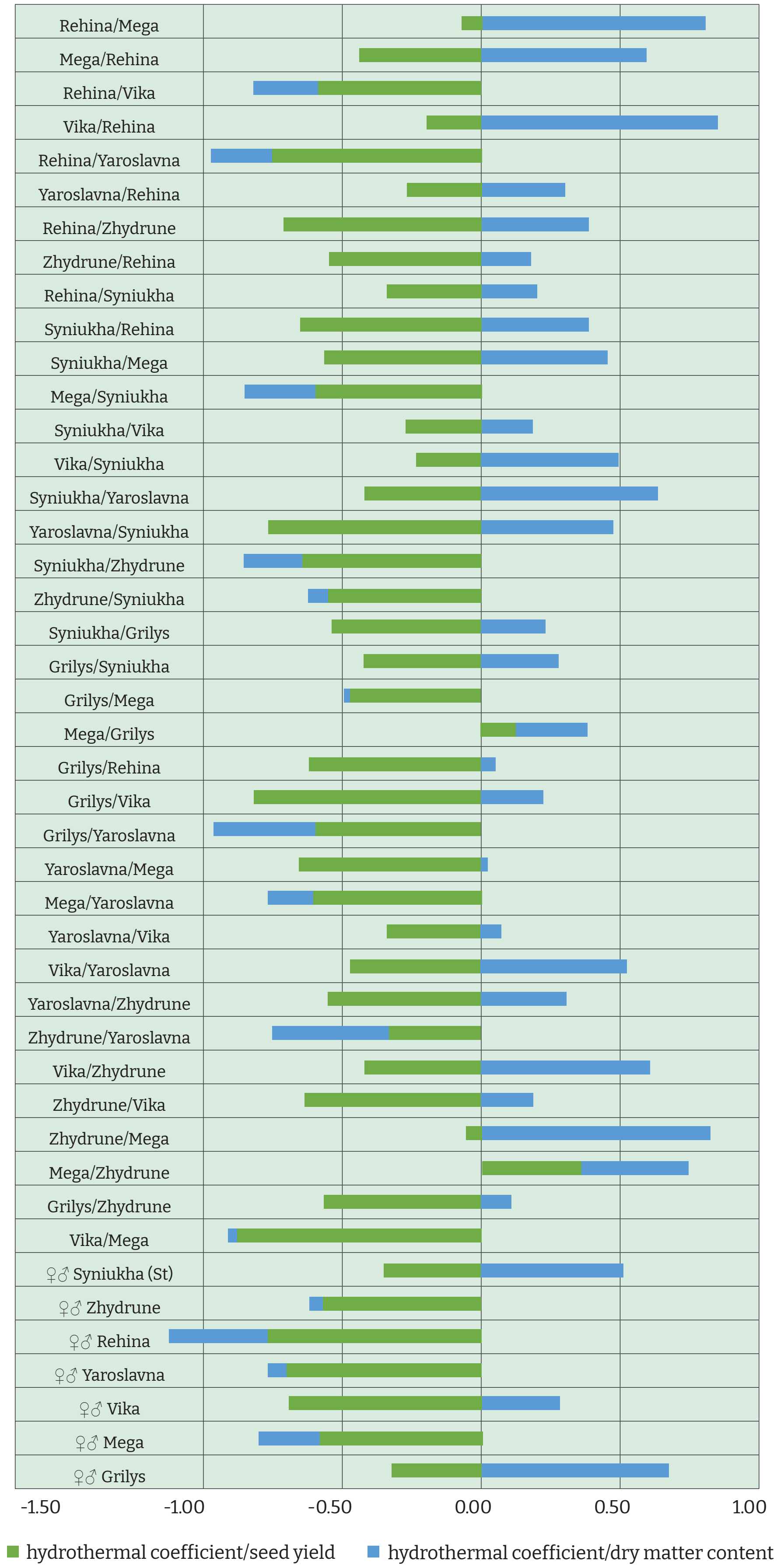

Figure 1. Dependence of the influence of hydrothermal factors on the feed and seed productivity of varieties and hybrids (F_{3-5}) alfalfa seed populations

It was identified that varieties and hybrid populations reacted differently to hydrothermal conditions, among which, as already noted, moisture has the greatest impact. In general, in most cases, a positive reaction was recorded for the dry matter yield. The strongest effect was identified in the samples of Yaroslavna (correlation coefficient was 0.85), Syniukha/Mega (0.82), Grilys (0.8), Regina/Mega (0.68), Yaroslavna/Zhidrune (0.64), Syniukha/Vika (0.61), Mega (0.59). Potentially, these samples can form a fairly high feed productivity on irrigated land. Some populations of alfalfa, on the contrary, reduced the accumulation of vegetative mass with an increase in available moisture, among which the following should be highlighted: Regina/Yaroslavna (-0.46), Vika/Syniukha (-0.43), and Grilys/Syniukha (-0.36).

As for seed productivity, with an increase in the amount of moisture, almost all samples showed a negative effect on the level of the correlation coefficient – from -0.06 to -0.87. Only two hybrid populations showed a positive effect of HTC indicators on the level of seed and feed productivity: Syniukha/Regina (0.36; 0.38) and Grilys/Regina (0.13; 0.25). It was identified that hybrids and varieties decreased the level of seed productivity with fodder growth: Syniukha/Mega (-0.06 and 0.82), Grilys (-0.08 and 0.8), Yaroslavna (-0.2 and 0.85), Zhidrune/Yaroslavna (-0.23 and 0.5), Vika/Zhidrune (-0.28 and 0.18). That is, an inversely proportional relationship was identified, which is important for the development of breeding programmes for creating synthetic alfalfa varieties with increased feed and seed productivity.

In contrast to feed productivity, the formation of the seed crop, in addition to the negative impact of high soil acidity, is influenced by a number of other factors: insufficient supply of nutrients (both macro- and microelements), lack of a sufficient number of pollinating insects, abortivity of flowers and beans, and appropriate hydrothermal conditions (Buhaiov & Horenskyi, 2021; Rudska, 2016; Buhaiov *et al*., 2018).

It is known that the potential of seed productivity of alfalfa in the Forest-Steppe is only partially realised. This is due to the low level of pollination of flowers (usually 40-60%) and a small number of seeds in the bean (3-4 pcs.), which largely depends on hydrothermal and soil conditions (Bolaños-Aguilara *et al*., 2002; Katepa-Mupondwa *et al*., 1996). A brief description of hydrothermal conditions is given in Table 5.

Table 5. Seed yield in hybrid populations (F_3 and F_5) alfalfa sowing and hydrothermal indicators 2013-2020

Years	Precipitation, mm (30 days before flowering)	Precipitation, mm (30 days during flowering)	Total precipitation (30 days before and during flowering) mm	HTC	Precipitation amount (t fact>10°C), mm	Sum of active temperatures (t fact>10), °C	Seed yield, t/ha M±m
2013	62	152	214	1.18	278.2	2365.5	0.352±0.15
2014	135	53	188	1.56	263	1689.3	0.167±0.07
2015	34.3	35	69.3	0.49	89.3	1809.8	0.525±0.15
2016	54	52	106	0.73	186	2557.8	0.231±0.11
2017	15	20	35	0.59	125	2108.2	0.319±0.12
2018	14	186.5	200.5	1.21	302.5	2504.4	0.229±0.08
2019	144	88	232	1.37	278	2032.4	0.093±0.06
2020	136	68	204	1.07	292.4	2724.4	0.211±0.08
Average	74.29	81.81	156.10	1.03	226.80	2223.98	0.258±0.141

Since alfalfa is a cross-pollinated entomophilic crop, and its wild pollinating insects arrange nesting sites mainly in the soil, precipitation during 30 days before and during the flowering of plants (May-June) is considered for analysis, in addition to the factors used in assessing feed productivity. It is this period that is critical for the reproduction of pollinators, thus, accordingly, it directly affects the level of seed yield.

The calculated HTC indicators during the growing season of alfalfa show that in 2015 there was a severe drought; in 2016 and 2017 – average; in 2013, 2018, 2019, and 2020 – there were quite wet conditions, and in 2014 – excessive moisture. The amount of precipitation was 89.3-302.5 mm, of which 57-83% fell in the period of 30 days before and during the flowering of plants. With the exception of 2017, when only 28% of the specified amount, or 35 mm, fell during this period. The sum of active temperatures over the years was 1689.3-2724.4°C.

It was identified that seed yield depended to a greater extent on the amount of precipitation (Table 6).

Table 6. Relationship of alfalfa seed yield with hydrothermal conditions

Parameter	Indicator value
Precipitation 30 days before flowering	-0.64[1]
Average daily temperatures 30 days before flowering	0.19
Precipitation during flowering (30 days)	-0.17
Average daily temperatures during flowering (30 days)	-0.17
Amount of precipitation 30 days before and during flowering	-0.48[1]
Amount of precipitation during the growing season	-0.7[1]
Sum of active temperatures	-0.19
HTC of the reporting year	-0.73[1]
HTC of the previous year	-0.27

Notes: [1] – the correlation is substantial at 0.05

Thus, in 2015, with a precipitation level of 89.3 mm, a seed yield of 0.525 t/ha was obtained, and in 2017 (125 mm) – 0.319 t/ha. In 2013, a sufficient level of yield was also obtained (0.352 t/ha) with very substantial precipitation – 278.2 mm. In such years, the duration of precipitation and the sum of active temperatures during this period are essential.

Other authors (Petrychenko *et al*., 2021; Demydas *et al*., 2010; Tyshchenko & Tyshchenko, 2014) analysed the influence of these factors in general for the entire growing season of alfalfa plants. Moreover, one or more varieties were used as the object of research. According to the results, the dependence of the formation of the leaf-stem mass of 44 varieties and hybrids of alfalfa on the amount of precipitation and temperature was established. The relationship between dry matter yield and seed yield was identified. Most studies, as a rule, are conducted separately for these indicators and, accordingly, their dependencies are not analysed (Tyshchenko *et al*., 2020; Petrychenko *et al*., 2021).

According to the study by Tishchenko (2012), in years with favourable weather conditions, the yield of alfalfa seeds was in the range of 0.67-1.17 t/ha, with unfavourable conditions – 0.17-0.36 t/ha. It was also possible to identify hybrid populations that responded less to the deterioration of environmental conditions and responded well to their improvement and were characterised by high nitrogen-fixing activity. Harvesting the grass stand in the early stages (the beginning of budding) does not allow plants to deposit enough plastic substances in the root crown for regrowth in the next harvest, which leads to a decrease in the density of the grass stand and yield. The flowering phase is crucial for the most intense and sufficient supply of starch and other plastic substances in the root crown.

Zhang (2005) believes that transgenic alfalfa plants can be used in breeding this crop to increase resistance to drought conditions, because due to the increased waxy coating of the leaf cuticle, transpiration decreases, water is better retained in the plant, and therefore slow wilting occurs after watering is stopped and faster and better recovery after watering is resumed. Alfalfa regrowth begins early in spring with buds located on the root crown. The intensity of spring and post-harvest regrowth of alfalfa species and varieties depends on their genotype, nutrient reserves in the plant root crown, soil moisture, and meteorological conditions, and is closely related to plant height.

Tucak *et al.* (2008) consider plant height to be one of the important indirect indicators of feed mass yield. They observed a high association of alfalfa plant height with the yield of green mass and dry matter (g=0.85; 0.87). It was identified that the height of the alfalfa grass stand (the phase of the beginning of flowering) decreases from harvest to harvest, so in the first harvest it was 67-81 cm, in the second – 54-63 cm, in the third – 38-61 cm. Along the harvests, the height of plants largely depended on meteorological conditions and was, as a rule, maximum in the first harvest, reaching 70.6-76.4 cm, and minimum (20.6-31.5 cm) – in the third harvest. Sometimes, in the first year of life, the height of alfalfa plants was lower than in subsequent years, and it naturally increases from the first year of life to the third. The author explains this by saying that in the first year of life, the alfalfa root system is not yet sufficiently developed and cannot provide plants with the necessary nutrients, and the genetic characteristics of populations are also important.

Based on the results of the study, the relationship between dry matter and seed yields with indicators of hydrothermal conditions was established. Thus, the conducted studies indicate the specific features of the influence of precipitation and temperature on the formation of leaf-stem mass in separate harvest cycles.

CONCLUSIONS

Based on the results of the assessment (2013-2020), the influence of hydrothermal indicators of the growing zone on the feed and seed productivity of alfalfa for different years of use of the herbage was established. It is identified that the formation of maximum indicators of dry matter yield in a particular harvest and seed yield is influenced by both the hydrothermal resources of the region and the biological characteristics of varieties and hybrids. This is confirmed by the corresponding correlation coefficients. Thus, the amount of precipitation from the beginning of the relative rest period to the onset of active temperatures above 10°C had the greatest impact on the formation of the leaf-stem mass of the 1st harvest; the amount of precipitation during the time after the establishment of active temperatures above 10°C and before accounting for the leaf-stem mass moderately affected the formation of the 2nd harvest and strongly – the 3rd; the amount of precipitation during the previous harvest – the 2nd-4th harvests (the strongest – the 4th); the sum of active temperatures above 10°C – the 1st and 3rd harvests; the HTC indicator – the 2nd and 3rd; duration of the growing season with active temperatures above 10°C – the 1st and 3rd harvests.

In contrast to feed productivity, seed yield largely depended on the amount of precipitation before the flowering phase and in general during the growing season of alfalfa. Accordingly, the lower the value of the HTC indicator, the more likely it is to get a high seed yield from the first harvest. Thus, the complexity of breeding alfalfa is confirmed, when the opposite conditions of the year accordingly affect plant productivity – excessive and sufficient moisture increases the level of feed productivity, while seed productivity decreases. Arid and insufficiently humid conditions, on the contrary, contributed to the formation of seeds, while reducing the yield of leaf-stem mass.

The identified features of the formation of leaf-stem mass and seeds of varieties and hybrids depending on the hydrothermal parameters of the growing area encourage further research on this subject. In particular, identifying the relationship between the yield of dry matter and the yield of seeds from the grass stand of the second harvest, since this technological agricultural approach is widely used in practice.

REFERENCES

[1] Andryushchenko, A.V., Kryvytskyi, K.M., & Veselovska, O.B. (2010). *Methodology for varietal examination of alfalfa (Medicago sativa L. M., M. x varia Martyn) for distinction, homogeneity and stability*. Kyiv.

[2] Balyuk, S.A., Medvedev, V.V., & Tarariko, O.G. (2010). *National report on the state of soil fertility in Ukraine*. Kyiv. Retrieved from http://www.iogu.gov.ua/wp-content/uploads/2013/07/stan_gruntiv.pdf.

[3] Buhaiov, V.D., & Gorenskyi, V.M. (2021). Peculiarities of expression of traits of feed and seed productivity of alfalfa collection accessions under high soil acidity. *Plant Genetic Resources,* 29, 61-69. doi: 10.36814/pgr.2021.29.06.

[4] Bugayov, V.D., & Zadorozhnay, I.S. (2012). Form the history of alfalfa research in Ukraine. *Feeds and Feed Production*, 72, 175-183. Retrieved from https://fri-journal.com/index.php/journal/article/view/819.

[5] Bugayov, V.D., Mamalyha, V.S., & Gorenskyi, V.M. (2014). Evaluation and creation of starting material for alfalfa breeding in conditions of increased soil acidity. *Factors of Experimental Evolution of Organisms*, 15, 153-155.

[6] Vlasenko, M.Yu., Kononenko, O.I., & Zhuk, T.M. (2003). New growth stimulants on alfalfa seed crops. *Herald of Agrarian Science of the Black Sea Region,* 3(23), 207-209.

[7] Vozhegova, R.A., Tyshchenko, A.V., Tyshchenko, O.D., Pilarska, O., & Ghalchenko, N. (2021). Yield and sowing qualities of seeds of alfalfa varieties depending on growing conditions. *Herald of Agrarian Science,* 8(821), 55-63. doi: 10.31073/agrovisnyk202108-07.

[8] Hetman, N.Ya., Veklenko, Yu.A., & Tkachuk, R.O. (2017). Formation of ecologically resistant agrophytocenoses of Lucerne depending on the growing conditions. *Feeds and Feed Production,* 84, 70-74. Retrieved from https://fri-journal.com/index.php/journal/article/view/177.

[9] Hetman, N., Demidas, G., & Kvitko, M. (2018). Formation of morphometric indicators by different ecotypes of alfalfa in conditions of the Right Bank Forest Steppe of Ukraine. *Agronomie* şi *agroecologie,* 52(1), 173-177.

[10] Holoborodko, S.P., Dymov, O.M., Iutynska, G.O., & Tytova, L.V. (2021). Influence of the use of complementary strains of nodule and phosphate-mobilizing bacteria on alfalfa seed productivity. *Agrarian Innovations*, 7, 21-30. doi: 10.32848/agrar.innov.2021.7.4.

[11] Demidas, G.I., Ivanovska, R.T., & Kovalenko, V.P. (2010). Indicators of organogenesis and productivity of alfalfa depending on the time of sowing and cover crop. *Feed and Feed Production*, 66, 183-188.

[12] Zaporozhenko, V.Yu., Shepel, A.V., & Tkachuk, A.V. (2018). Creation of neural networks of alfalfa productivity in the steppe zone of Ukraine. *Agrology*, 2(1), 47-50. doi: 10.32819/2617-6106.2018.140.17.

[13] Ivashchenko, O.O., & Rudnyk-Ivashchenko, O.I. (2011). Directions of adaptation of agricultural production to climate change. *Herald of Agrarian Science,* 8, 10-12.

[14] Melnyk, A.F. (2010). Soil acidification as a problem of agriculture. *Proposition*, 9, 80-81.

[15] Noskova, O.Yu. (2015). Agroecological features of growing alfalfa in conditions of the steppe zone. *Agroecological Journal*, 2, 74-78.

[16] Petrychenko, V.F., Hetman, N.Ya., & Tsyganskyi, V.I. (2018). Lucerne as stabilizing factor for intensification of feed processing industry. *Herald of Agrarian Science,* 10(787), 18-26. doi: 10.31073/agrovisnyk201810-03.

[17] Petrychenko, V.F., Korniychuk, O.V., & Veklenko, Yu.A. (2018). Sustainable development of pasture feed production in conditions of climate change. *Herald of Agrarian Science*, 6, 25-32. doi: 10.31073/agrovisnyk201806-04.
[18] Petrychenko, V.F., Hetman, N.Ya., & Veklenko, Yu.A. (2020). Substantiation of alfalfa productivity at long-term use of grass stands in conditions of climate change. *Herald of Agrarian Science,* 3(804), 20-26. doi: 10.31073/agrovisnyk202003-03.
[19] Poliovyi, A.M., Bozhko, L.Yu., & Volvach, O.V. (2012). *Basics of Agrometeorology.* Odesa: TES.
[20] Rudska, N.O. (2016). Formation of the species composition of pollinators and their influence on the seed productivity of alfalfa plants in the Right bank Forest steppe of Ukraine. *Interdepartmental Thematic Scientific Collection of Plant Protection and Quarantine,* 62, 206-215. doi: 10.36495/1606-9773.2016.62.206-215.
[21] Tyshchenko, A.V., Tyshchenko, O.D., & Pilyarska, O.O. (2020). Effect of bacterial preparations on seed productivity, root system and nitrogen fixation during cultivation of alfalfa varieties under irrigation conditions. *Irrigated Agriculture,* 74, 155-163. doi: 10.32848/0135-2369.2020.74.28.
[22] Tyshchenko, O.D., Borovyk, V.O., & Tyshchenko, A.V. (2012). Gene pool of perennial species of alfalfa of the subgenus *Falcago* (Rchb.) Grossh., characteristics of the main features. *Plant Genetic Resources,* 10, 67-74.
[23] Tyshchenko, O.D., & Tyshchenko, A.V. (2014). Alfalfa breeding directions for irrigation conditions. *Irrigated Agriculture,* 62, 93-95.
[24] Tyshchenko, O.D., Tyshchenko, A.V., & Kuts, H.M. (2018). Characterization of alfalfa starting material for productivity selection. *Bulletin of the Lviv National Agrarian University: Agronomy,* 22(1), 33-39.
[25] Apostol, L., Iorga, S., Mosoiu, C., Racovita, R.D., & Niculae, M. (2017). Alfalfa concentrate – A rich source of nutrients for use in food products. *Agriculture & Food,* 5, 66-73.
[26] Bolaños-Aguilara, E.D., Huyghe, C., & Ecallea, C. (2002). Effect of cultivar and environment on seed yield in alfalfa. *Crop Science,* 42(1), 45-50. doi: 10.2135/cropsci2002.4500.
[27] Buhaiov, V., Horenskyy, V., & Liatukiene, A. (2018). The response of *Medicago sativa* to aluminium toxicity under laboratory and field conditions. *Zemdirbyste-Agriculture,* 105(2), 141-148. doi: 10.13080/z-a.2018.105.018.
[28] Georgieva, N., & Nikolova, I. (2015). Stem formation at alfalfa varieties and correlative dependences with some main parameters. *Journal of Central European Agriculture*, 16(2), 89-98. doi: 10.5513/JCEA01/16.2.1593.
[29] Kalsa, K.K. (2006). Seed yield performance of alfalfa (*Medicago sativa* L.) varieties under rain environment: A vital prospect for domestic production of alfalfa seed. In *14th Annual Conference of Ethiopian Society of Animal Production* (pp. 11-17). Addis Ababa.
[30] Katepa-Mupondwa, F.M, Barnes, D.K., & Smith, J.R. (1996). Influence of parent and temperature during pollination on alfalfa seed weight and number of seeds per pod. *Canadian Journal of Plant Science,* 76(2), 259-262. doi: 10.4141/cjps96-046.
[31] Khu, D.M., Reeno, R., Brummer, E.C., & Monteros, M.J. (2012). Screening methods for aluminum tolerance in alfalfa. *Crop Science*, 52(1), 161-167. doi: 10.2135/cropsci2011.05.0256.
[32] Nan, L., Nie, Z., Zollinger, R., & Guo, Q. (2019). Evaluation of morphological and production characteristics and nutritive value of 47 lucerne cultivars/lines in temperate Australia. *Plant Production Science*, 22(4), 490-500. doi: 10.1080/1343943X.2019.1608835.
[33] Petrychenko, V., Kovtun, K., Korniychuk, O., Veklenko, Y., & Babich-Poberezhna, A. (2021). Nutritional value and productivity of alfalfa by the phases of growth and development of plants in the conditions of the right-bank Forest-steppe of Ukraine. *Polish Journal of Science*, 38(1), 3-7.
[34] Rafińska, K., Pomastowski, P., Wrona, O., Górecki, R., & Buszewski, B. (2017). *Medicago sativa* as a source of secondary metabolites for agriculture and pharmaceutical industry. *Phytochemistry Letters*, 20, 520-539. doi: 10.1016/j.phytol.2016.12.006.
[35] Tucak, M., Popovic, S., Grljusic, S., Cupic, T., Kozumplik, V., & Simic, B. (2008). Variability and relationships of important alfalfa germplasm agronomic traits. *Periodicum Biologorum*, 110(4), 311-315.
[36] Yakhlef, M., Giangrieco, I., Ciardiello, M.A., Fiume, I., Mari, A., Souiki, L., & Pocsfalvi, G. (2020). Potential allergenicity of *Medicago sativa* investigated by a combined IgE-binding inhibition, proteomics and *in silico* approach. *Journal of the Science of Food and Agriculture*, 101(3), 1182-1192. doi: 10.1002/jsfa.10730.
[37] Zhang, J-Y., Broeckling, C.D., Blancaflor, E.B., Sledge, M.K., Sumner, L.W., & Wang, Z.-Y. (2005). Overexpression of *WXP1*, a putative *Medicago truncatula* AP2 domain-containing transcription factor gene, increases cuticular wax accumulation and enhances drought tolerance in transgenic alfalfa (*Medicago sativa*). *The Plant Journal,* 42(5), 689-707. doi: 10.1111/j.1365-313X.2005.02405.x.

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Вплив гідротермічних факторів на кормову та насіннєву продуктивність люцерни посівної в умовах Лісостепу Правобережного

Анотація. Актуальність дослідження зумовлена необхідністю вивчення впливу гідротермічних ресурсів регіону на формування врожаю листостеблової маси та насіння люцерни посівної, що є важливим за умов сучасних змін клімату. У зв'язку з цим дана стаття спрямована на виявлення впливу опадів і температурного режиму на ріст і розвиток рослин сортів і гібридів за циклами скошування та роками використання травостою. В процесі дослідження використано методи: польовий (проведення фенологічних спостережень та обліків), лабораторний (структурний аналіз травостою), математично-статистичний (об'єктивна оцінка одержаних експериментальних даних). З'ясовано, що кількість опадів від початку періоду відносного спокою до настання активних температур вище 10 °C мала найбільший вплив на формування 1-го укосу; сума опадів після встановлення активних температур вище 10 °C і до обліку урожаю листостеблової маси помірно впливала на формування 2-го укосу та сильно – на 3-й; сума опадів попереднього укосу – на 2-4-й укіс (найсильніше – на 4-й); сума активних температур вище 10 °C – на 1-й та 3-й укоси; показники гідротермічного коефіцієнту – на 2-3-й; тривалість вегетаційного періоду з активними температурами вище 10 °C – на 1-й і 3-й укоси. Урожайність насіння, на відміну від кормової продуктивності, значною мірою залежала від суми опадів перед фазою цвітіння та в цілому під час вегетації люцерни посівної. Встановлено, що на вихід сухої речовини та урожайність насіння мають вплив: сума активних температур, кількість опадів за укіс чи вегетацію рослин та генетичні особливості досліджуваних гібридів і сортів. Виявлено, що гідротермічні умови року по-різному впливають на рівень продуктивності рослин – надлишкове і достатнє зволоження підвищує кормову продуктивність та зменшує урожайність насіння. Практичну цінність одержані дані становлять для прогнозування врожаю зеленої маси люцерни посівної кожного наступного укосу травостою залежно від суми опадів впродовж вегетації попереднього, а також для розробки програм створення сортів-синтетиків з підвищеними показниками урожайності листостеблової маси та насіння

Ключові слова: гібрид, гідротермічний коефіцієнт, цикл скошування, вихід сухої речовини, урожайність насіння, кореляція

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Yield and energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems

Abstract. Over the past 15-20 years, Ukrainian agricultural production has shifted to growing more profitable, highly marketable, and drought-resistant crops, in particular, chickpeas and sunflower. Therewith, the technology of growing these crops is energy-consuming, especially in irrigation conditions. Therefore, it is relevant to examine the influence of microirrigation system designs on the energy parameters of chickpea and sunflower cultivation. The purpose of the study is to perform an energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems and the method of water supply. Research methods: short-term field experiments, analytical and statistical methods for processing experimental data. The scheme of experiments provided for laying irrigation pipelines in the horizontal and vertical planes, and implementing a pulse water supply mode (standard). Control is an option without irrigation. It is established that the method of laying pipelines (designs of microirrigation systems) substantially affects the productivity of crops. Higher yields were recorded at shorter distances between irrigation pipelines (0.7 and 1.0 m), regardless of the depth of laying. It is proved that the highest level of yield of chickpeas (4.28 t/ha) and sunflower (4.50 t/ha) was obtained by implementing a pulse water supply mode, but this increase was within the error of the experiment. The introduction of underground drip irrigation is more appropriate for the cultivation of chickpeas and sunflower according to the criterion of total energy costs for the technology. The analysis of energy efficiency by the value of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of chickpea and sunflower cultivation in both ground and ground drip irrigation (EEC=2.03-2.23 and 2.32-2.50, respectively). The most effective method was to grow these crops under a pulse water supply regime: the EEC was 2.44 for growing chickpeas and 2.61 for growing sunflower. The research materials are of practical value for farmers in managing energy consumption in chickpea and sunflower microirrigation technologies.

Keywords: drip irrigation, underground drip irrigation, pulse drip irrigation, irrigation pipelines, energy efficiency coefficient

INTRODUCTION

Climatic transformations and the high genetic potential of crop productivity led to an increase in actual irrigation standards in the Steppe zone to 4500-6000 m^3/ha, which is 2-2.5 times higher than the design parameters of irrigation systems (Shatkovsky & Zhuravlov, 2021). This practically makes it impossible to increase the irrigation area on a large scale, because the existing pumping equipment is used at maximum capacity. This problem is also relevant for the Forest-Steppe zone of Ukraine, where, in the absence of large state irrigation systems, access to potential irrigation sources is practically nonexistent. In addition, farmers use irrigation water extremely inefficiently – from 60 to 90% are losses on infiltration and physical evaporation from the surface of soil and plants. That is, only 10 to 40% of the volume of water intake for irrigation is received exclusively for the needs of plants – transpiration (Shatkovsky & Zhuravlov, 2021)

In this context, the "Irrigation and drainage strategy in Ukraine" (2019) defines that the development of irrigation should be based solely on a new, water- and energy-saving concept. It is known that microirrigation methods correspond to this as much as possible: drip

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irrigation with ground and underground placement of irrigation pipelines and pulse drip irrigation. The essence of the latter is the most synchronous compensation of moisture consumption by the plant for transpiration (Romashko *et al*., 2020, Shatkovskyi & Zhuravlov, 2021). However, the introduction of these irrigation methods requires substantial energy and material costs. Therefore, in a market economy, the energy analysis of the introduction of the latest agricultural technologies is important since it gives grounds to justify various options for growing agricultural crops from the standpoint of their energy saving. Thus, it was relevant to research the justification and energy assessment of agricultural technologies for growing chickpeas and sunflower, depending on the design of microirrigation methods.

The energy efficiency of agricultural technologies for growing both chickpeas and sunflower has been thoroughly investigated both in Ukraine and by foreign researchers. However, the analysed complex of papers concerned the influence on the energy parameters of such factors as fertiliser systems (Kyrychenko *et al*., 2014; Parlikokoshko & Burykina, 2021; Mazur *et al*., 2022), seed treatment (Mordovaniuk, 2020; Lohosha *et al*., 2020), growth regulators (Elhami *et al*., 2016; Unakıtan & Aydın, 2018), seeding schemes and dates (Krainiak, 2008; Oguz & Ogur, 2018; Pinkovsky & Tanchyk, 2019), plant protection products (Malysh *et al*., 2013; Korobko, 2019), tillage (Koocheki *et al*., 2011; Nabavi-Pelesaraei, 2012; Vozhehova *et al*., 2021,) etc. Therewith, under irrigation conditions, experiments were conducted only on sunflower culture. In particular, according to long-term data from the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences (Vozkhehova *et al*., 2021), higher energy efficiency was achieved when applying deep basic tillage with rotating topsoil. Researchers of the Institute of Agriculture of the National Academy of Agricultural Sciences (Kyrychenko *et al*., 2014), proved that the highest increase in gross energy – 30901 MJ/ha, was achieved when applying mineral fertilisers with doses of $N_{50}P_{30}K_{30}$ for cultivation and $N_{10}P_{10}K_{10}$ when sowing in rows. A comparison of energy efficiency and economic analysis of sunflower cultivation in Turkey was conducted based on a passive experiment – the survey method (Gökhan & Başak, 2018). Energy efficiency, energy productivity, specific energy, and net energy for sunflower cultivation were calculated as 3.77, 0.15 kg/MJ, 6.63 MJ/kg, and 28111 MJ/ha, respectively. In addition, Turkish researchers (Oguz & Ogur, 2018) calculated the energy value, productivity, and energy efficiency of resources used for growing sunflower seeds. It was identified that the energy efficiency (EEC) was 4.94, and the specific energy value was 5.06 MJ/kg.

Thus, a study on the influence of microirrigation system designs on the energy parameters of chickpea and sunflower cultivation in the southern region of Ukraine has not been conducted.

The purpose of the study was to perform an energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems and the method of water supply.

MATERIALS AND METHODS

Field research within the framework of the state enterprise experimental establishment Brylivske of Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences (Privitne village, Vinogradivska rural community of the Kherson district of the Kherson region, Dry Steppe subzone, 46°40´N. 33°12´E) during 2020-2022. The energy parameters were calculated depending on the following irrigation system designs: drip irrigation (DI) with ground-based irrigation pipeline laying (IP), underground drip irrigation (UDI) with IP laying to a depth of 30 cm. In addition, the design parameter was the distance between IP: for growing chickpeas 1.0 and 1.4 m, sunflower – 0.7 and 1.4 m. The reference option was underground drip irrigation with a pulse water supply mode (PUDI), and the conditional control was the option with natural moisture supply – without irrigation. The study was conducted according to generally accepted methods: placement of land plots – systematic, repetition – fourfold, the area of accounting plots – 32 m^2 (Ushkarenko *et al*., 2014, Romashchenko *et al*., 2014), sunflower hybrid of confectionery area of use – Ukrains'kyi F1, chickpea variety – Budzhak.

The soil of the experimental plot is liver-coloured light loamy, the density of the layer composition is 0-50 cm – 1.47 g/cm^3, the content of humus – 1.44%, alkaline hydrolysed nitrogen (Kornfield determination method) (DSTU 7863:2015, 2016) – 7.0 mg/100 g of soil, mobile compounds of phosphorus and potassium in the soil according to the Chirikov method (DSTU 4115:2002, 2003) – 32.3 mg/100 g and 9.3 mg/100 g of soil, respectively.

The amount of productive precipitation during the growing season of sunflower and chickpeas was different over the years of research. Thus, in 2020, only 68 mm fell, which is 35.5% of the climatic norm, during 2021 – 393.8 mm or 205.5%, which is also an abnormal phenomenon for the conditions of the Dry Steppe, and in 2022 – 167.6 mm, or 87.5% of the climatic norm. The level of pre-irrigation humidity in experiments is 80% of the lowest moisture capacity of 0-50 cm of the soil layer. Instrumental complexes were used to set irrigation dates: the Drill and Drop Sentek moisture meter probe and the iMetos soil moisture station with Echo Probe EC-5 sensors (Shatkovsky & Zhuravlov, 2016). Statistical analysis of the research results was performed using variance, correlation, and regression methods using the Statistica 6.0 programme.

Energy efficiency was calculated according to the method of energy assessment of crop cultivation technologies (Zasukha & Ponomarenko, 1998). The energy efficiency coefficient was determined by the formula (Medvedovsky & Ivanenko, 1988, Zasukha & Ponomarenko, 1998) without considering by-products:

$$K = \frac{Q_H}{Q_B} \quad (1)$$

where Q_A – energy accumulated by the economically valuable part of the crop, MJ/ha; Q_S – total energy spent on production, MJ/ha.

When calculating the energy accumulated by the economically valuable part of the crop, reference data on the energy value of dry organic matter were used: the calculations took the energy content in one kilogram of chickpeas – 36 MJ/kg and sunflower – 19.3 MJ/kg (Zasukha & Ponomarenko, 1998; Demchak *et al.*, 2015). Calculated specific energy consumption (Demchak *et al.*, 2015) for irrigation from the well amounted to 10.52 MJ/m^3. This considers the specific costs of electricity, the energy intensity of the drip and underground drip irrigation, and water systems.

RESULTS

The maximum yield of chickpea grain in the experiment (at the standard humidity of 14%) was obtained in the variant with the placement of irrigation pipelines at a distance of 1 m – 4.00-4.17 t/ha (Figure 1). The yield for placing IP at a distance of 1.4 m was substantially lower – 3.69-3.76 t/ha (0.31–0.41 t/ha) (HIP$_{0.5}$=0.285 t/ha).

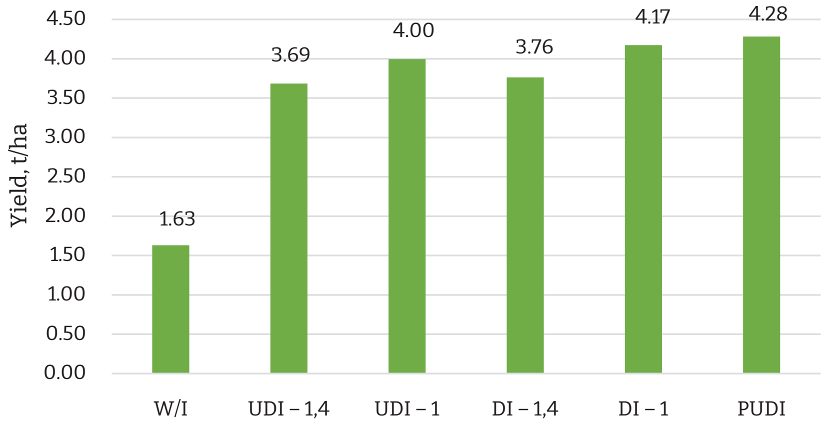

Figure 1. Chickpea yield depending on the schemes of laying irrigation pipelines of drip irrigation (HIP_{AB}=0.285 t/ha)

The average yield indicator for underground drip irrigation (3.85 t/ha) practically corresponded to the variant with the ground placement of IP (3.97 t/ha), and the excess of the latter (DI) of 0.12 t/ha was within the margin of error of the field experiment. Considering the average amount of productive precipitation during the three years of research (it was higher than the climatic norm), productivity at the control (without irrigation) was at the level of 1.63 t/ha, which also confirms the characteristic feature of chickpea crops as drought resistance. The yield of dry chickpea beans in the experiment (pulse water supply mode) was 4.28 t/ha. Thus, the established level of productivity growth was also within the margin of error of the field experiment (compared to the drip irrigation option), and substantially higher than the underground drip irrigation option.

In a parallel experiment, the highest yield of sunflower grain was obtained in the variant with the placement of irrigation pipelines at a distance of 0.7 m – 4.41 t/ha for drip irrigation and 4.09 t/ha for underground drip irrigation (Figure 2).

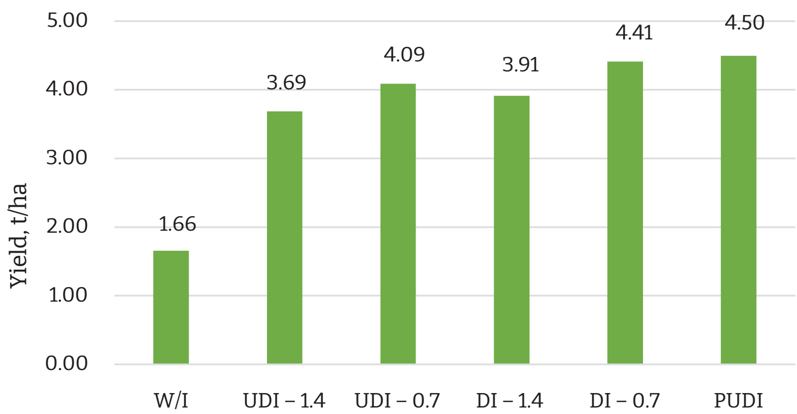

Figure 2. Sunflower yield depending on the schemes of laying irrigation pipelines of drip irrigation (HIP_{AB}=0.352 t/ha)

The seed yield for placing irrigation pipelines at a distance of 1.4 m was substantially lower – from 3.69 t/ha (DI) to 3.91 t/ha (UDI).

The average yield for underground drip irrigation (3.89 t/ha) was slightly lower compared to the option with ground-based irrigation pipelines (4.16 t/ha), but the excess of 0.27 t/ha was within the margin of error of the field experiment.

Considering the relatively sufficient availability of productive precipitation during the growing season of the years of the study (2020-2022), the yield of seeds under control (without irrigation) was at the level of 1.66 t/ha, which is almost 2.5 times lower compared to the irrigated conditions for growing sunflower.

The yield of sunflower seeds in the search experiment (pulse mode of water supply with the underground laying of pipelines) was a maximum of 4.50 t/ha. Thus, this increase (+0.09-0.41 t/ha compared to UDI) in seed yield was also within the margin of error of the field experiment.

Based on the productivity data of crops (main products), calculations of the energy assessment of the parameters of agricultural technologies for growing chickpeas and sunflower for various designs of microirrigation systems were conducted (Table 1).

Table 1. Energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems

Factor A	Factor B	Energy accumulated on harvest, GJ/ha	Energy consumption for cultivation, GJ/ha	Energy efficiency ratio EEC
CHICKPEA				
DI	IP at a distance of 1.0 m	177.84	79.6	2.23
	IP at a distance of 1,4 m	157.68	77.6	2.03
UDI (-30 cm)	IP at a distance of 1.0 m	167.40	78.3	2.14
	IP at a distance of 1.4 m	155.52	76.5	2.03
Pulse UDI (standard, IP at a distance of 1.0 m)		181.80	74.4	2.44
Without irrigation (control)		72.80	38.8	1.88
SUNFLOWER				
DI	IP at a distance of 0,7 m	106.15	42.5	2.50
	IP at a distance of 1,4 m	94.18	39.0	2.41
UDI (-30 cm)	IP at a distance of 0.7 m	98.62	41.4	2.38
	IP at a distance of 1.4 m	88.78	38.3	2.32
Pulse UDI (standard, IP at a distance of 0.7 m)		107.50	41.2	2.61
Without irrigation (control)		41.88	21.0	1.99

Analysis of the table data shows that the introduction of microirrigation increased the energy intensity of chickpea cultivation technologies by almost 2 times – up to 74.4-79.6 GJ/ha, respectively. Without irrigation (control), energy costs for chickpea production were within 38.8 GJ/ha. The basic analysis of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of chickpea cultivation in both ground and underground irrigation conditions (EEC=2.03-2.23) and an average level of energy efficiency of the option without irrigation (EEC=1.88). The most effective cultivation of chickpeas was underground drip irrigation with a pulse water supply mode (standard), where the energy efficiency coefficient was 2.44.

The introduction of microirrigation has also increased the energy intensity of agricultural technologies for growing sunflower almost twice – up to 38.0-42.5 GJ/ha, respectively. Without irrigation (control), energy costs for growing sunflower hybrids were within 21.0 GJ/ha. The analysis of the value of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of growing sunflower hybrids in both underground and ground irrigation conditions (EEC=2.32-2.50) and the average level of energy efficiency of the control option without irrigation (EEC=1.99). The most effective method was the cultivation of sunflower hybrids with underground drip irrigation with a pulse water supply mode (standard version), where an energy efficiency coefficient of 2.61 was obtained.

The results of this study are original for the soil and climatic conditions of the Dry Steppe subzone of Ukraine. For the first time, an energy assessment of chickpea and sunflower cultivation using various designs of microirrigation systems was performed and their reliable impact on crop productivity was proved.

DISCUSSION

The results obtained on the productivity of chickpeas under various water supply conditions confirm the results of Indian researchers (Rao et al., 2019), although, they were obtained using mulching. However, researchers from the Central Queensland University and the Queensland Department of Agriculture and Fisheries (Bhattarai *et al*., 2010) identified that chickpea yields in areas irrigated by aerial underground drip irrigation (oxygenation) were 27% higher than in drip irrigation with ground-based IP. The same researchers (Bhattarai *et al*., 2008) proved that underground drip irrigation increases the efficiency of irrigation water use (IWUE) by minimising evaporation losses and maximising the use of seasonal precipitation by the soil profile. Similar parameters for increasing the yield of chickpea grain by drip irrigation (by 2.3-2.5 times) were obtained in the experiments of Indian researchers (Rai & Singh, 2019). Researchers of the Brazilian Agricultural Research Corporation have investigated the water demand and productivity of various chickpea varieties on irrigation in a more comprehensive manner (Silva *et al*., 2021). In particular, they substantiate the coefficients of the culture by plant development phases (0.38-1.0) and water requirement parameters (4.1-5.6 mm/day). Lower yield parameters were obtained in the experiments of Serbian researchers (Stepanović *et al*., 2019) subject to irrigation of chickpeas by sprinkling – 2.82-3.12 t/ha.

The results obtained confirm the experimental data of Spanish researchers (Soriano et al., 2004), where the productivity of early hybrids was 3.0 t/ha, and late hybrids – 2.4 t/ha. The effectiveness of drip irrigation of sunflower seeds for placing irrigation pipelines on the soil surface has also been proven by other researchers (Sesen et al., 2011, Kadasiddappa et al., 2017), however, in these studies, the method of irrigation by sprinkling was used as a control. In particular, in the study by Turkish researchers (Sezen *et al*., 2011), drip irrigation productivity was 1.7 times higher and amounted to 3.82 t/ha, and in the one by Indian researchers (Kadasiddappa *et al*., 2017) – 1.5 times and amounted to 3.36 t/ha.

In general, the highest productivity of sunflower grain was obtained by researchers from Lebanon (Karam *et al*., 2007), who investigated the response of plants to insufficient and optimal irrigation. The average annual yield under optimal irrigation was 5.36 t/ha, which is 25.4% more than under scarce irrigation. In the context of Pakistan (Qureshi, A. et al., 2015), drip irrigation provided a 26% increase in sunflower grain yield (up to 3.24 t/ha), 56% savings in irrigation water, and the efficiency of water use was 3.2 times higher than drip irrigation. The influence of various irrigation systems and row spacing on growth processes and yield of sunflower hybrids was investigated by W. Simões *et al*., (2020). The highest yield (3.96 t/ha) of the Helio 251 hybrid was obtained with drip irrigation systems and row spacing of 0.55 m, the Helio 360 hybrid achieved the highest yield (3.25 t/ha) with microirrigation and row spacing of 0.55 m and 0.45 m. On sprinkling, the Helio 360 hybrid had the highest yield with a row spacing of 0.45 m (3.02 t/ha).

CONCLUSIONS

Based on the results of experimental studies, it is proved that the designs of microirrigation systems, namely, the method of laying irrigation pipelines, substantially affect the yield and energy parameters of chickpea and sunflower cultivation technology. Primarily, the effectiveness of drip irrigation of these crops in the conditions of the steppe of dry Ukraine is generally confirmed. In addition, it was identified that the introduction of underground drip irrigation is more appropriate for these crops from the standpoint of energy efficiency, which is explained by their relative biological drought resistance. The pilot version with the underground installation of irrigation pipelines and pulse water supply mode provided the highest level of the yield of these crops – 4.28 t/ha of chickpea grain and 4.50 t/ha of sunflower grain.

The introduction of microirrigation technologies increased the energy consumption of agricultural technologies for growing chickpeas and sunflower almost twice – up to 74.4-79.6 GJ/ha and 38.0-42.5 GJ/ha, respectively. The analysis of energy efficiency by the value of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of chickpea and sunflower cultivation both in the conditions of ground and underground laying of drip irrigation pipelines (EEC=2.03-2.23 and 2.32-2.50 for chickpeas and sunflower, respectively). The most effective cultivation of these crops was under the pulse water supply mode, when the calculated energy efficiency coefficient amounted to 2.44 for growing chickpeas and 2.61 for growing sunflower.

The issue of introducing various microirrigation technologies for growing chickpeas and sunflowers requires further research. In particular, the environmental aspects of the impact of fertigation and irrigation water of different soil quality are currently unresolved.

REFERENCES

[1] Bhattarai, S.P., Midmore, D.J. & Pendergast, L. (2008). Yield, water-use efficiencies and root distribution of soybean, chickpea and pumpkin under different subsurface drip irrigation depths and oxygation treatments in vertisols. *Irrigation Science*, 26, 439-450. https://doi.org/10.1007/s00271-008-0112-5

[2] Bhattarai, S. P., Midmore, D. J., & Su, N. (2010). Sustainable Irrigation to Balance Supply of Soil Water, Oxygen, Nutrients and Agro-Chemicals. *Sustainable Agriculture Reviews*, 5, 253-286. https://doi.org/10.1007/978-90-481-9513-8_9

[3] Demchak, I.M., Mytchenok, O.O., Kysliachenko, M.F. & Shatkovskyi, A.P. (2015). Methodical provisions and standards of productivity and consumption of electricity and fuel for irrigation of agricultural crops. Kyiv: SRI «Ukrahroprompoduktyvnist».
[4] Elhami, B., Akram, A., & Khanali, M. (2016). Optimization of energy consumption and environmental impacts of chickpea production using data envelopment analysis (DEA) and multi objective genetic algorithm (MOGA) approaches. *Information Processing in Agriculture*, 3(3), 190-205. https://doi.org/10.1016/j.inpa.2016.07.002.
[5] Gökhan, U. & Başak, A. (2018). A comparison of energy use efficiency and economic analysis of wheat and sunflower production in Turkey: A case study in Thrace Region. *Energy*, 149, 279-285. https://doi.org/10.1016/j.energy.2018.02.033.
[6] Kadasiddappa, M., Rao, K., Reddy, V., Ramulu, M. & Narender R. (2017). Effect of irrigation (drip/surface) on sunflower growth, seed and oil yield, nutrient uptake and water use efficiency – A review. *Agricultural Reviews*, 38(02), 152-158. https://doi.org/10.18805/ag.v38i02.7947.
[7] Karam, F., Lahoud, R., Masaad, R., Kabalan, R., Breidi, J., Chalita, C. & Rouphael, Y. (2007). Evapotranspiration, seed yield and water use efficiency of drip irrigated sunflower under full and deficit irrigation conditions. *Agricultural Water Management*, 90(3), 213-223. https://doi.org/10.1016/j.agwat.2007.03.009.
[8] Krainiak, O.K. (2008). Economic and bioenergetic analysis of technologies for growing legumes. *Innovative Economy*, 2, 109-113.
[9] Koocheki, A., Ghorbani, R., Mondani, F., Alizade, Y. & Moradi, R. (2011). Pulses Production Systems in Term of Energy Use Efficiency and Economical Analysis in Iran. *International Journal of Energy Economics and Policy*, 1(4), 95-106.
[10] Korobko, O.O. (2019). *Biological substantiation of the use of herbicide, plant growth regulator and microbial preparation in chickpea crops in the conditions of the Right Bank Forest Steppe of Ukraine* (Doctoral thesis, Uman National University of Horticulture, Uman, Ukraine).
[11] Kyrychenko, V.V., Tymchuk, V.M. & Sviatchenko, S.I. (2014). Energy assessment of sunflower production. *Scientific and technical bulletin of the Institute of Oil Crops of the NAAS*, 21, 154-171. Retrieved from http://bulletin.imk.zp.ua/pdf/2014/21/Kirichenko_21.pdf
[12] Lohosha, O.V., Khalep, Yu.M. & Vorobei, Yu.O. (2020). Economic and bioenergetic efficiency of chickpea bacterial strain Mesorhizobium ciceri ND-64. *Agricultural Microbiology*, 31, 64-71. https://doi.org/10.35868/1997-3004.31.64-71
[13] Malysh, M.N., Havrysh, V.I. & Perebijnis, V.I. (2013). Analysis of the energy efficiency of sunflower production in southern Ukraine. *Herald of Agrarian Science of the Black Sea Region*, 1, 18-25.
[14] Mazur, V.A., Didur, I.M., Pantsyreva, H.V. & Mordvaniuk, M.O. (2022). Energy efficiency of technological methods of growing chickpeas in conditions of climate change. *Agriculture and Forestry,* 25, 5-13. https://doi.org/10.37128/2707-5826-2022-2.
[15] Medvedovskyi, O.K. & Ivanenko, P.I. (1988). *Energy analysis of intensive technologies in agricultural production*. Kyiv: Urozhai.
[16] Mordvaniuk, M.O. (2020). *The formation of chickpea grain productivity and its quality indicators depending on the technological methods of cultivation in the conditions of the Right Bank Forest Steppe* (Doctoral thesis, Vinnytsia National Agrarian University, Vinnytsia, Ukraine).
[17] Nabavi-Pelesaraei, A. (2012) Assessment technical efficiency of energy consumption in chickpea production under dry farming system in Kangavar county of Iran. *Seed*, 14(17), 41-22.
[18] Oguz, C. & Yener Ogur, A. (2018). Energy Productivity and Efficiency in Sunflower Production. *JAST*, 24(4), 767-777.
[19] Parlikoshko, M. & Burykina, S. (2021). Effectiveness of chickpea cultivation technologies depending on mineral and organo-mineral fertilizers in the conditions of the southern Steppe of Ukraine. *Young Scientist*, 5(93), 20-26. https://doi.org/10.32839/2304-5809/2021-5-93-4.
[20] Pinkovskyi, H.V. & Tanchyk, S.P. (2019). Economic and energy efficiency of improved elements of sunflower cultivation technology in the Right Bank Steppe of Ukraine. *Bulletin of the Poltava State Agrarian Academy*, 2, 39-44. https:/10.31210/visnyk2019.02.04
[21] Qureshi, A., Gadehi, M., Mahessar, A., Memon, N., Soomro, A. & Memon, A. (2015). Effect of Drip and Furrow Irrigation Systems on Sunflower Yield and Water Use Efficiency in Dry Area of Pakistan. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 15 (10), 1947-1952. https:/10.5829/idosi.aejaes.2015.15.10.12795.
[22] Rao, K., Aherwar, P., Gangwar, S. & Yadav, D. (2019). Effect of Mulching on Chickpea under Low Head Drip Irrigation System. *Legume Research*, 44, 1233-1239. https:/10.18805/LR-4184.
[23] Rai, P. & Singh, V. (2019). Effects of drip irrigation and fertigation on yield of garden pea and chickpea. *HortFlora Research Spectrum*. 8 (3/4), 86-89.19. Rao, K., Aherwar, P., Gangwar, S. & Yadav, D. (2019). Effect of Mulching on Chickpea under Low Head Drip Irrigation System. *Legume Research*, 44, 1233-1239. https:/10.18805/LR-4184

[24] Resolution of the Cabinet of Ministers of Ukraine No. 688 «Irrigation and drainage strategy in Ukraine until 2030». (2019, August). Retrieved from https://zakon.rada.gov.ua/laws/ show/688-2019-%D1%80.

[25] Romashchenko, M., Shatkovskyi, A., Vasiuta, V., Zhuravlov, O., Usatyi, S., Usata, L., & Ovchatov, I. (2020). State and prospects of microirrigation' application in the context of climate change. *Land Reclamation and Water Management*, 2(112), 31-38. https://doi.org/10.31073/mivg202001-262.

[26] Romashchenko, M.I. (Ed.). (2014). *Methodological recommendations for conducting research on drip irrigation*. Kyiv: DIA.

[27] Sezen, S.M., Sezen, S., Yazar, A., Yazar, A., Kapur, B., Kapur, B. & Tekin, S. (2011). Comparison of drip and sprinkler irrigation strategies on sunflower seed and oil yield and quality under Mediterranean climatic conditions. *Agricultural Water Management,* 98, 1153-1161. https:/10.1016/j.agwat.2011.02.005.

[28] Shatkovskyi, A.P.& Zhuravlov, O.V. (2016). Management of drip irrigation based on the use of Internet weather stations. *Scientific reports of NULES of Ukraine*. 2(59). Retrieved from http://journals.nubip.edu.ua/index.php/Dopovidi/article/view/6489/6373

[29] Shatkovskyi, A.P. & Zhuravlov, O.V. (2021). *Scientific bases of technologies of drip irrigation of agricultural crops*. Odesa: Helvetyka.

[30] Silva, K., Morato, D., Mesquita, M., Elias, H., Marcos, W., Battisti, R. & Flores, R. (2021). Water requirement and crop coefcient of three chickpea cultivars for the edaphoclimatic conditions of the Brazilian savannah biome. *Irrigation Science*. 39, 607-616. https://doi.org/10.1007/s00271-021-00737-z.

[31] Simões, W., Silva, J., Oliveira, A., Neto, A., Drumond, M., Lima, J. & Nascimento, B. (2020). Sunflower cultivation under different irrigation systems and planting spacings in the sub-middle region of São Francisco Valley. *Semina: Ciências Agrárias*. 41(2), 2899-2910

[32] National standard of Ukraine 7863:2015. "Soil quality. Determination of easily hydrolyzable nitrogen by the Kornfield method". Kyiv.

[33] National standard of Ukraine 4115:2002. "Soils. Determination of mobile compounds of phosphorus and potassium according to the modified Chirikov method". Kyiv.

[34] Soriano, M.A., Orgaz, F., Villalobos, F.J & Fereres, E. (2004). Efficiency of water use of early plantings of sunflower. *European Journal of Agronomy*, 21(2), 465-476.

[35] Stepanović, S., Arsenijevic, N. & Ugljic, Z. (2019). *Yield and Water Use of Field Peas and Chickpeas Under Irrigation*. Retrieved from https://cropwatch.unl.edu/2019/yield-water-use-irrigated-field-peas-chickpeas.

[36] Ushkarenko, V.O. (Ed.). (2014). *Methodology of field experiment (irrigated agriculture)*. Kherson: Hrin D.S.

[37] Vozhehova, R.A., Mytrofanov, O.A. & Maliarchuk, M.P. (2021). Effectiveness of modern sunflower growing technologies under different conditions of moisture and methods and depth of the main tillage in the south of Ukraine. *Equipment and Technologies of the Agricultural and Industrial Complex,* 1, 19-21.

[38] Zasukha, T.V. & Ponomarenko, M.M. (1998). *Bioenergetic assessment of technologies for growing fodder and forage crops: methodical recommendations*. Kyiv: International Financial Agency.

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Урожайність та енергетична оцінка вирощування нуту і соняшнику залежно від конструкцій систем мікрозрошення

Анотація. За останні 15-20 років сільськогосподарське виробництво України переорієнтувалось на вирощування більш рентабельних, високоліквідних, а також посухостійких культур, зокрема – нуту і соняшнику. Одночасно, технології вирощування цих культур є енерговитратним, особливо – в умовах зрошення. Тому актуальним є дослідження щодо впливу конструкцій систем мікрозрошення на енергетичні параметри вирощування нуту і соняшнику. Мета наукової роботи – виконати енергетичну оцінку вирощування нуту і соняшнику залежно від конструкцій систем мікрозрошення та способу водоподачі. Методи дослідження: короткотермінові польові досліди, аналітичні і статистичні методи обробки експериментальних даних. Схема дослідів передбачала укладання поливних трубопроводів у горизонтальній та вертикальній площині, а також реалізацію імпульсного режиму водоподачі (еталон). Контроль – варіант без зрошення. Встановлено, що спосіб укладання трубопроводів (конструкції систем мікрозрошення) достовірно впливає на продуктивність культур. Вищу врожайність зафіксовано за менших відстаней між поливними трубопроводами (0,7 та 1,0 м) незалежно від глибини укладання. Доведено, що вищий рівень врожайності нуту (4,28 т/га) і соняшнику (4,50 т/га) отримано за реалізації імпульсного режиму водоподачі, проте таке збільшення було у межах похибки досліду. Впровадження підґрунтового краплинного зрошення є більш доцільним за вирощування нуту і соняшнику за критерієм сумарних енергетичних витрат на технологію. Аналіз енергоефективності за величиною коефіцієнта енергетичної ефективності (Кее), свідчить про високий рівень енергоефективності вирощування нуту і соняшнику як в умовах наземного, так і підґрунтового краплинного зрошення (Кее = 2,03-2,23 та 2,32-2,50 відповідно). Найбільш ефективним було вирощування цих культур за імпульсного режиму водоподачі: Кее дорівнював 2,44 за вирощування нуту та 2,61 за вирощування соняшнику. Матеріали дослідження становлять практичну цінність для фермерів у питанні управління енерговитратами у технологіях мікрозрошення нуту і соняшнику

Ключові слова: краплинне зрошення, підґрунтове краплинне зрошення, імпульсне краплинне зрошення, поливні трубопроводи, коефіцієнт енергетичної ефективності

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