

# SCIENTIFIC HORIZONS

Journal homepage: <https://sciencehorizon.com.ua>

*Scientific Horizons*, 27(7), 45-52



UDC 633.84:633.3:57.063.8

DOI: 10.48077/scihor7.2024.45

## ***Sinapis alba* L. as an important green manure and fodder crop in the Carpathian region of Ukraine**

**Igor Voloshchuk\***

Doctor of Agricultural Sciences, Senior Researcher  
Institute of Agriculture of Carpathian Region of the National Academy of Agrarian Science of Ukraine  
81115, 5 Hrushevskiyi Str., Obroshyne Village, Ukraine  
<https://orcid.org/0000-0002-2944-8656>

**Oleh Stasiv**

Doctor of Agricultural Sciences, Associate Professor, Corresponding Member  
of the National Academy of Agrarian Science of Ukraine  
Institute of Agriculture of Carpathian Region of the National Academy of Agrarian Science of Ukraine  
81115, 5 Hrushevskiyi Str., Obroshyne Village, Ukraine  
<https://orcid.org/0000-0003-3737-739X>

**Oleksandra Voloshchuk**

Doctor of Agricultural Sciences, Professor  
Institute of Agriculture of Carpathian Region of the National Academy of Agrarian Science of Ukraine  
81115, 5 Hrushevskiyi Str., Obroshyne Village, Ukraine  
<https://orcid.org/0000-0002-2509-9452>

**Valentyna Hlyva**

PhD in Agricultural Sciences, Senior Researcher  
Institute of Agriculture of Carpathian Region of the National Academy of Agrarian Science of Ukraine  
81115, 5 Hrushevskiyi Str., Obroshyne Village, Ukraine  
<https://orcid.org/0000-0002-9033-6549>

**Maria Voloshchuk**

Graduate Student  
Institute of Agriculture of Carpathian Region of the National Academy of Agrarian Science of Ukraine  
81115, 5 Hrushevskiyi Str., Obroshyne Village, Ukraine  
<https://orcid.org/0000-0001-5740-272X>

### **Article's History:**

Received: 05.02.2024

Revised: 02.06.2024

Accepted: 24.06.2024

**Abstract.** White mustard is an important green manure and fodder crop in the Carpathian region. The purpose of this study was to determine the indicators of fodder productivity and chemical composition of fodder of white mustard varieties recommended for cultivation in the studied soil and climatic zone. The methodological framework of this study was formed by general scientific and special

### **Suggested Citation:**

Voloshchuk, I., Stasiv, O., Voloshchuk, O., Hlyva, V., & Voloshchuk, M. (2024). *Sinapis alba* L. as an important green manure and fodder crop in the Carpathian region of Ukraine. *Scientific Horizons*, 27(7), 45-52. doi: 10.48077/scihor7.2024.45.



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\*Corresponding author

research methods. The findings presented in the study for 2021-2023 highlight the dynamics of accumulation of vegetative mass and dry matter of white mustard in different major growth stages and development phases (BBCH) and the chemical composition of the feed. Studies have shown that the climate changes observed in recent years with increased temperature and sufficient rainfall meet the biological requirements of crop cultivation, while the created high-performance varieties meet the requirements of agricultural production of both seeds and green mass. It was found that per 1 ha the varieties Ariadna and Bila Pryntsesa leave about 9.9-10.1 t/ha of root residues in the soil and form a high yield of green mass (37.1-37.8 t/ha), which can be used for green fertiliser in the sixth stage of growth (flowering) of the BBCH 65 phase (full flowering: 50% of flowers on the main raceme are open, old petals have fallen off). Although the chemical composition of the biomass is somewhat inferior to conventional fodder crops, the crop under study can provide a balanced fodder in combination with high-protein crops. In the main sixth stage (flowering), the developmental phase BBCH 65, the value of the varieties was 4.081-4.158 t/ha of feed units and 5.194-5.292 t/ha of digestible protein. The findings of this study can be used by agricultural enterprises and farms for both green manure and fodder, which will increase soil fertility and improve animal nutrition

**Keywords:** white mustard; variety; green mass; fodder unit; digestible protein; quality

## INTRODUCTION

The search for alternative types of green manure crops that can compete with conventional ones has led to an increase in the share of white mustard in the structure of sown areas. The solution to the problem of green manuring crops is closely related to the biological characteristics of the varieties introduced into agricultural production and their ability to form a large vegetative mass in the soil and climatic conditions of cultivation. According to S.S. Dhaliwal *et al.* (2021) and T.V. Melnichuk *et al.* (2023), the production volumes of niche oilseeds can be achieved by increasing the yield and sowing qualities of the grown seeds.

The phytomeliorative properties of white mustard are high, as it leaves about 5.5-6.0 t/ha of air-dry mass of root and stubble residues. The value of the crop is also in the fact that, with the decrease in soil organic matter content observed in recent years by almost 4-5 times, it can replenish it with labile forms of nutrients. The deeply penetrating roots of the crop (up to 2.5 m) convert hard-to-reach phosphates into easily assimilated forms of phosphorus. It builds up a large biomass in a short time and before flowering, which occurs in 60-75 days depending on the variety, forms a good cover layer that suppresses weeds, prevents erosion processes, promotes the active action of microorganisms, reduces the damage to subsequent crops by diseases and the spread of pests (Tsitsyura *et al.*, 2022).

Due to the essential oil and other biologically active compounds secreted by the plant, mustard effectively inhibits root rot, scab, phytophthora rot and fusariosis, blackleg and rhizoctonia pathogens. A.V. Melnyk *et al.* (2019a; 2019b) argue that among all types of mustard, white mustard is the most versatile for growing in the face of climate change. This crop should be introduced into the crop rotation to reduce the risk compared to conventional crops, which in a brief time allows enriching the soil with many easily accessible nutrients and increasing its overall soil fertility. The

green mass of mustard in the amount of 15.0-20.0 t/ha ploughed into the soil is equivalent in terms of nutrients to the use of 20 t/ha of manure.

Mustard has a great phytosanitary role as a green manure crop in neutralising soil fatigue, incompatibility in the crop rotation system to increase the gap for placement in a monoculture. According to L.V. Hubenko and O.Ya. Liubchych (2020), when ploughed into the soil, green manure biomass decomposes easily and evenly, filling it with nutrients. The use of green manure crops, specifically white mustard as a green manure, provides a sufficient amount of organic matter and enriches available forms of phosphorus and nitrogen, especially soils poor in natural fertility, increases the water resistance of structural particles, increases capillary humidity, resulting in improved water regime and reduced acidity (Sivak & Kostyukevich, 2021).

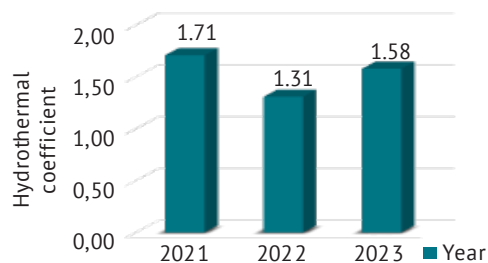
White mustard can be grown both pure and mixed with other crops for green fodder. This crop does not require high costs for post-harvest sowing, due to the lower seeding rate and shallow and simplified cultivation, according to P. Jia *et al.* (2021a; 2021b), and S. Butenko *et al.* (2022). According to I.J. Irin *et al.* (2020), mustard produces high yields of green mass – 25-30 t/ha, which corresponds to 20 t/ha of organic fertiliser. With the application of 1 t of dry weight, the soil is replenished with 15-25 kg of nitrogen, 5 kg of phosphorus and up to 80 kg of potassium. And 100 kg of white mustard green mass contains 12 feed units and about 1.5 kg of digestible protein (Butenko & PeiPei, 2022).

The technology of white mustard cultivation will be of interest to many countries around the world. Based on the study conducted by A. Sarkar *et al.* (2021), chemical fertiliser doses (RDF) and foliar application of DAP (2.0% concentration), or urea (2%), or sulphur (0.5%) were found to improve plant growth and development and yield of hybrid mustard and improve nutrient status of the Ganges alluvial soil of West Bengal.

Considering the somewhat low degree of systematic scientific research on white mustard cultivation, which is controversial and mostly focused on the seed productivity of the crop by individual elements of technology, publications on fodder productivity are few and far between. The purpose of this study was to determine the dynamics of green mass growth by growth stage and plant development phase (BBCH) and nutritional value of fodder of Ariadna and Bila Pryntsesa varieties recommended for cultivation in the studied soil and climatic zone.

## MATERIALS AND METHODS

The study was conducted in 2021-2023 at the Department of Seed Production and Seed Science of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences (49°47'07" N, 23°52'07" E, 314 m above sea level). The grey forest, surface-ashy, light loamy soil of the experimental plots was characterised by the weighted average agrochemical parameters: low humus content (according to Tyurin) – 2.3% and the amount of absorbed bases – 13.7 mg-eq per 100 g of soil, soil pH – 5.4 – slightly acidic. The soil has a low content of easily hydrolysed nitrogen (according to Kornfield) – 89.6 mg/kg of soil and exchangeable potassium (according to Kirsanov) – 68.0 mg/kg of soil, and an average content of mobile phosphorus – 69.5 mg/kg of soil. In 2021, the hydrothermal coefficient (HTC) was excessive at 1.71, and optimal in 2022 at 1.31 and in 2023 at 1.58 (Fig. 1).



**Figure 1.** Humidity level (2021-2023)

**Source:** compiled by the authors

The agricultural technique of white mustard cultivation was generally accepted for the growing area and included: the predecessor – maize, sowing date – the third decade of April, conventional row sowing method (15.0 cm) with a seeding rate of 1.5 million germinating seeds/ha and a planting depth of 2-4 cm. The pesticides used were Modesto, 48% FC (insecticidal and fungicidal action, 12.5 l/t), roundup, 48% AS (2-3 weeks before ploughing), butyzan, 40% SC (1.75-2.50 l/ha) and calypso, 48% SC (0.25-0.40 l/ha).

The object of research included varieties: Ariadna (Carpathian State Agricultural Research Station of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine) and Bila Pryntsesa (National Research Centre "Institute of

Agriculture of the National Academy of Agrarian Sciences of Ukraine"). The study was conducted using the following methods: methodology for the examination of white mustard (*Sinapis alba* L.) varieties for distinctiveness, uniformity and stability (Methodology..., 2023); green mass yield was determined by the method of accounting plots; chemical composition – using the SupNir 2700 infrared analyser. Quality indicators – by infrared spectroscopy; statistical analysis of the results – according to the method of V.O. Ushkarenko et al. The results were calculated using Microsoft Excel. The study followed the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

## RESULTS AND DISCUSSION

The intensive development of the vegetative mass of white mustard during the years of research was ensured by a prominent level of mineral nutrition  $N_{110}P_{90}K_{100}$  and a sufficient amount of precipitation during the germination-flowering period (HTC) (Fig. 2).



**Figure 2.** Sowing of white mustard on the Institute's experimental plots (2023)

**Note:** a) BBCH 65, b) BBCH 75

According to the dynamics of green mass accumulation in the main growth stage 1 (leaf development), phase BBCH 18 (8 leaves unfolded), the average for the years was 31.1 t/ha for Ariadna and 31.2 t/ha for Bila Pryntsesa. By stage 5 (inflorescence), phase BBCH 50 (flower buds covered with leaves), the growth by varieties was 3.7 t/ha and 4.5 t/ha, respectively, while in the 6<sup>th</sup> stage of growth (flowering), phase BBCH 65 (full flowering: 50% of flowers on the main raceme are open, old petals have fallen off) – 6.0 t/ha and 6.6 t/ha (Table 1).

The high yields of green mass and dry matter in 2021 and 2023 were caused by moisture supply, with excessive HTC of 1.71 and 1.58, which had a positive impact on plant growth intensity from the early stages of organogenesis. At the 6<sup>th</sup> stage of growth (flowering), BBCH 65, the average yield of Ariadna was 37.1 t/ha, Bila Pryntsesa – 37.8 t/ha, and no significant differences between varieties were observed ( $NIR_{0.05} = 1.0-1.5$  t/ha).

**Table 1.** Dynamics of green mass accumulation of white mustard varieties (2021-2023), t/ha

Growth stage, developmental phase (BBCH)	Variety, year									
	Ariadna					Bila Pryntsesa				
	2021	2022	2023	mean	± to control	2021	2022	2023	mean	± to control
1, BBCH 18	32.5	29.3	31.6	31.1	–	32.7	30.8	32.4	32.0	–
5, BBCH 50	36.7	32.6	35.1	34.8	3.7	37.2	34.9	35.1	35.7	3.7
6, BBCH 65	38.2	35.8	37.4	37.1	6.0	39.5	36.2	37.6	37.8	5.8
LSD <sub>0.05</sub>	1.5	1.1	1.3			1.3	1.0	1.2		

Source: compiled by the authors

At growth stage 1, developmental phase BBCH 18 (development of leaf rosette), the average dry matter yield of white mustard varieties was 3.89-3.90 t/ha and increased by stage 5 (inflorescence), BBCH 50 (flower

buds covered with leaves) by 0.46-0.57 t/ha. The highest increases were observed in stage 6 of growth (flowering), the BBCH development phase, respectively, by 0.79-0.83 t/ha (Table 2).

**Table 2.** Dry matter content of white mustard varieties by growth stages and phases of development (2021-2023), t/ha

Growth stage, developmental phase (BBCH)	Variety, year									
	Ariadna					Bila Pryntsesa				
	2021	2022	2023	mean	± to control	2021	2022	2023	mean	± to control
1, BBCH 18	4.01	3.67	3.95	3.89	–	4.09	3.85	4.05	3.90	–
5, BBCH 50	4.59	4.08	4.39	4.35	0.46	4.65	4.37	4.39	4.47	0.57
6, BBCH 65	4.78	4.48	4.68	4.68	0.79	4.94	4.53	4.70	4.73	0.83
LSD <sub>0.05</sub>	0.15	0.25	0.20			0.13	0.21	0.18		

Source: compiled by the authors

The chemical composition of the aboveground vegetative biomass shows a low level of crude protein – 3.6% (Ariadna variety) – 3.7% (Bila Pryntsesa) and sugar,

respectively, 0.6% and 0.5% (Table 3). The fat content averaged 1.2%, fibre – 12.1%, nitrogen-free extractables – 14.7%, ash – 3.5%, and water – 64.5%.

**Table 3.** Chemical composition of aboveground vegetative biomass of white mustard in the 6<sup>th</sup> stage of growth (flowering), developmental phase BBCH 65 (2021-2023), %

Indicator	Cultivar		Mean
	Ariadna	Bila Pryntsesa	
Crude protein	3.6	3.7	3.7
Sugar	0.6	0.5	0.6
Fat	1.2	1.2	1.2
Fibre	12.1	12.0	12.1
REM	14.5	14.8	14.7
Ash	3.4	3.5	3.5
Water	64.6	64.3	64.5

Source: compiled by the authors

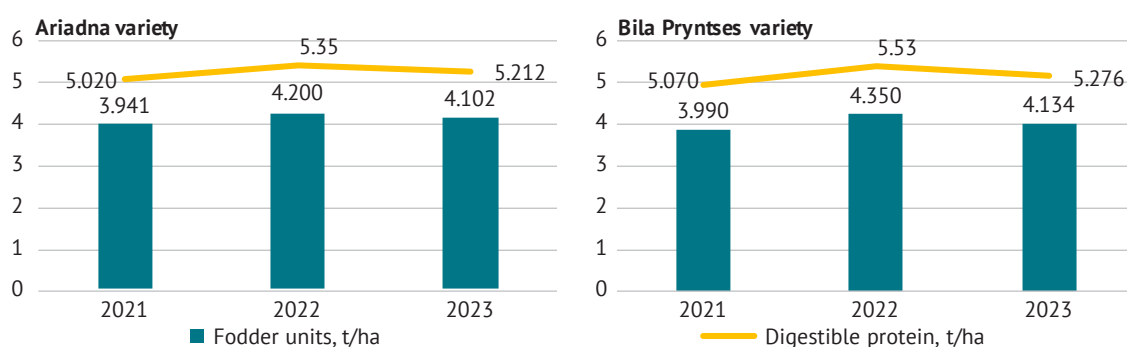
In the phase of full flowering, the weight of a white mustard plant of the Ariadna variety was 21.0 g, including 16.6 g of aerial parts and 4.5 g of roots, and 21.2 g of the Bila Pryntsesa variety, respectively, including 17.0 g and 4.2 g (Table 4). The mass of root residues

was 9.9-10.1 t/ha, and the vegetative part of plants was 37.1-37.8 t/ha. With a green mass content of 0.11 units/kg and 0.14 g/kg of digestible protein, white mustard provided 4.081-4.158 t/ha of feed units and 5.194-5.292 t/ha of digestible protein (Fig. 3).

**Table 4.** Structure of white mustard plants in the 6<sup>th</sup> stage of growth (flowering), developmental phase BBCH 65 (2021-2023)

Indicator	Variety, year							
	Ariadna				Bila Pryntsesa			
	2021	2022	2023	mean	2021	2022	2023	mean
Plant weight, g	19.3	22.4	21.3	21.0	19.7	22.6	21.3	21.2
incl. roots	4.3	4.7	4.4	4.5	4.1	4.5	4.0	4.2
incl. vegetative part	15.0	17.7	17.1	16.6	15.6	18.1	17.3	17.0
Weight of root residues in the soil, t/ha	9.4	10.9	10.0	10.1	9.5	10.4	9.8	9.9
Weight of the aboveground part of plants, t/ha	35.8	38.2	37.4	37.1	36.2	39.5	37.6	37.8

Source: compiled by the authors



**Figure 3.** Indicators of fodder value of white mustard varieties (2021-2023)

Source: compiled by the authors

Considering the current trends in farming, mustard should take a prominent place in Ukrainian agricultural production due to its set of economically valuable attributes. It is a cheap and effective means of fertilising the soil as a green manure crop. Seeds (almost 100% of use) are used in many industries. The by-product is mustard meal, which, after degreasing and grinding, is converted into mustard powder, a product that is valued in the domestic and foreign markets. The oil is used in the food, confectionery, canning, margarine, soap, perfume, and paint industries. The natural antiseptic properties caused by the specific chemical composition and presence of essential oil allow using it in medicine due to its high content of biologically active substances necessary for our body (vitamins (A, D, E, K), fatty acids, phytosterols, chlorophyll, phytoncides, etc.) Linoleic and linolenic essential fatty acids improve the functioning of the cardiovascular system, normalise fat metabolism, maintain hormonal balance, help strengthen the immune system, and neutralise the harmful effects of toxins. Ukraine has all the prerequisites for growing this crop: fertile land, favourable climatic conditions and a rich scientific base, which makes it possible to successfully compete with the European market (Sluchak *et al.*, 2021).

Different types of mustard are the subject of a series of studies in many countries around the world. For instance, T.V. Melnichuk *et al.* (2023) argued that mustard has a high genetic potential for seed productivity,

which can be realised by optimising elements of cultivation technology. A balanced nutrition system that combines pre-sowing mineral fertilisation with foliar application of water-soluble fertilisers has a major impact on the formation of productivity elements and biological yield. The combination of  $N_{45}P_{45}K_{45}$  and two feedings in BBCH microphases 21-23 and 50-53 with a mixture of urea and complex fertiliser Quantum provides the largest number of seeds on a plant and their weight. O.G. Zhuikov and T.A. Khodos (2021) argue that after mustard as a precursor, grain yields increase by 10-15% without additional costs, which contributes to an increase in crop rotation productivity and efficiency in general. B. Utomo (2022) found a positive effect of NPK on the nutrition of green mustard (*Brassica juncea* L.) plants in studies conducted at the Faculty of Agriculture, Mayjen Sungkono University Mojokerto, Indonesia. The study of the effectiveness of different rates of NPK fertiliser application on the growth and yield of this crop revealed changes in plant length, number of leaves and green mass at the highest rate of 350 kg/ha.

Investigating the effectiveness of mustard cultivation under tillage systems, L.V. Hubenko and O.Ya. Liubchych (2020) established that the highest structure indicators and yield of 2.06 t/ha of this crop were obtained with shelf cultivation and the rate of mineral fertiliser application –  $N_{60}P_{60}K_{60}$ , while the organic-mineral fertilisation system reduced plant height by 7% and the number and weight of seeds per plant by 5% and 12%.

The productivity of mustard (*Brassica juncea* L. Czern & Coss) cultivar Pusa Vijay was studied at the Crop Production Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Mirut (UK) on a drained sandy loamy soil with low organic carbon and available nitrogen, medium available phosphorus, potassium, sulphur, and zinc, and moderately alkaline pH. The application of 100% NPK&S + nano Zn spray resulted in maximum yield and oil content (Verma *et al.*, 2022).

In general, all researchers note the significance of investigating a series of elements of white mustard cultivation technology: specifically, varietal assortment, plant nutrition system, protection against diseases and pests, etc., which are narrow and insufficiently covered in scientific publications and require an extended and comprehensive study.

### CONCLUSIONS

The sod-podzolic soils of the Carpathian region of Ukraine are poor in nutrients with a humus content of 0.5-2.5% in the topsoil. The reaction of the soil solution makes them acidic, which is one of the significant drawbacks to obtaining high crop yields. Increased acidity has a negative impact on all soil processes: it inhibits the development of soil microflora and nitrogen-fixing bacteria, increases the harmfulness of mobile aluminium, and delays root growth, resulting in lower yields. As a green manure crop, white mustard has a direct impact on increasing the humus content of the soil and allows it to replenish its upper layers with fresh organic matter. Considering the specialisation of the Carpathian region as a livestock area, it is also a significant fodder crop that is well eaten by various species of animals.

Climatic conditions with sufficient moisture supply and high average daily temperature in spring and summer, cause the phenological phases of white mustard to

pass more intensively and meet the biological requirements of growing the crop, while the latest developments in domestic breeding allow fulfilling the biological potential of varieties for both seeds and green mass.

It was found that the varieties of white mustard: Ariadna and Bila Pryntsesa leave about 9.9-10.1 t/ha of root residues in the soil and form a high yield of green mass – 37.1-37.8 t/ha, which can be used for green fertiliser at the 6<sup>th</sup> stage of growth (flowering) of the BBCH 65 phase (full flowering: 50% of the flowers on the main raceme are open, old petals have fallen off). White mustard is somewhat inferior to conventional fodder crops in terms of its biomass chemical composition, but when mixed with high-protein crops, it can provide balanced animal feed.

In the 6<sup>th</sup> stage of growth (flowering), the phase of development of BBCH 65 varieties of white mustard provided 4.081-4.158 t/ha of feed units and 5.194-5.292 t/ha of digestible protein. Considering the inclusion in the State Register of Plant Varieties Suitable for Distribution in Ukraine of varieties that provide higher productivity of green mass and seeds and are more environmentally plastic, it is advisable to increase the area under white mustard in different soil and climatic zones of Ukraine. Increasing seed production will help to increase the share of this crop in the structure of sown areas. Therefore, further research should focus on the introduction of new varieties of the originator institutions located in the service area of farms and the study of effective methods of their cultivation.

### ACKNOWLEDGEMENTS

None.

### CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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## **Sinapis alba L. важлива сидеральна та кормова культура в умовах Карпатського регіону України**

### **Ігор Волощук**

Доктор сільськогосподарських наук, старший науковий співробітник  
Інститут сільського господарства Карпатського регіону  
Національної академії аграрних наук України  
81115, вул. Грушевського, 5, с. Оброшине, Україна  
<https://orcid.org/0000-0002-2944-8656>

### **Олег Стасів**

Доктор сільськогосподарських наук, доцент, член-кореспондент  
Національної академії аграрних наук України  
Інститут сільського господарства Карпатського регіону  
Національної академії аграрних наук України  
81115, вул. Грушевського, 5, с. Оброшине, Україна  
<https://orcid.org/0000-0003-3737-739X>

### **Олександра Волощук**

Доктор сільськогосподарських наук, професор  
Інститут сільського господарства Карпатського регіону  
Національної академії аграрних наук України  
81115, вул. Грушевського, 5, с. Оброшине, Україна  
<https://orcid.org/0000-0002-2509-9452>

### **Валентина Глива**

Кандидат сільськогосподарських наук, старший науковий співробітник  
Інститут сільського господарства Карпатського регіону  
Національної академії аграрних наук України  
81115, вул. Грушевського, 5, с. Оброшине, Україна  
<https://orcid.org/0000-0002-9033-6549>

### **Марія Волощук**

Аспірант  
Інститут сільського господарства Карпатського регіону  
Національної академії аграрних наук України  
81115, вул. Грушевського, 5, с. Оброшине, Україна  
<https://orcid.org/0000-0001-5740-272X>

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**Анотація.** Гірчиця біла важлива сидеральна і кормова культура в Карпатському регіоні. Мета досліджень полягала у визначенні показників кормової продуктивності та хімічного складу корму сортів гірчиці білої, рекомендованих для вирощування в досліджуваній ґрунтово-кліматичній зоні. Методологічну основу становили загальнонаукові та спеціальні методи досліджень. Подані в статті результати досліджень за 2021-2023 рр. висвітлюють питання динаміки накопичення вегетативної маси й сухої речовини гірчиці білої в різні основні стадія росту та фази розвитку (ВВСН) та хімічного складу корму. Дослідженнями встановлено, що зміни клімату, які спостерігаємо в останні роки з підвищеним температурним режимом і достатньою кількістю опадів відповідають біологічним вимогам вирощування культури, а створені високопродуктивні сорти забезпечують вимоги сільськогосподарського виробництва як насіння, так і зеленої маси. Встановлено, що на 1 га сорти Аріадна і Біла Принцеса залишають в ґрунті біля 9,9-10,1 т/га корневих решток та формують високу врожайність зеленої маси (37,1-37,8 т/га), яка може бути використана на зелене добриво в шостій стадії росту (цвітіння) фази ВВСН 65 (повне цвітіння: 50 % квіток на головній китиці відкрито, старі пелюстки опали). Хоча за хімічним складом біомаси, досліджувана культура, дещо поступається традиційним кормовим та в суміші з високобілковими може забезпечувати збалансований корм. У основній шостій стадії (цвітіння), фазі розвитку ВВСН 65 цінність сортів складала 4,081-4,158 т/га кормових одиниць і 5,194-5,292 т/га перетравного протеїну. Результати досліджень можуть бути використані сільськогосподарськими підприємствами та фермерськими господарствами як на сидерати, так і на корми, що дозволить підвищити родючість ґрунтів та покращити систему живлення тварин

**Ключові слова:** гірчиця біла; сорт; зелена маса; кормова одиниця; перетравний протеїн; якість

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