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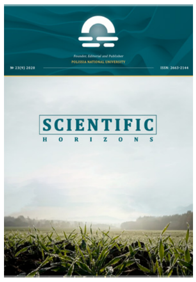

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Agrobiological substantiation of growing Hungarian vetch in mixed crops

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Abstract. The production of high-protein feed stays an integral part of the development of feed production. The purpose of this study was to investigate the biological characteristics of Hungarian vetch when grown in agrophytocenoses using different types of winter cereals. Changes in the chemical composition of dry matter at different microstages of growth and development were studied, and the influence on the yield, nutrient content, and digestibility of plant material was determined depending on the

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stages of growth and development. The study was conducted using field, laboratory, laboratory-field, and statistical methods. It was found that to reach the full flowering phase, the sum of active temperatures should be 754°C, with precipitation of about 100 mm and daylight hours of 973 h. Observations of the growing season indicate the relationship between plants and the environment, which is important to consider when growing Hungarian vetch. Vetch plants reach a height of 100-104 cm in conditions of excessive moisture. The phytocoenotic balance of such mixtures, specifically vetch of the Orlan variety and winter triticale of the Bozhych and Bohodarske varieties, ensures sustainable productivity and nutritional value of plant material. The best harvesting time for high quality vetch is from the beginning to the middle of flowering, which ensures a crude protein content of 17-20% in dry matter. The effectiveness of mixed phytocoenoses has been confirmed by ecological tests of crop combination models in different soil and climatic zones of Ukraine, where yields of 36.2-51.8 t/ha of green mass and 7.1-11.5 t/ha of dry matter were obtained over the years of use. The creation of a mixed crop allows producing high-quality plant material that is superior in energy and protein content to conventional vetch and oat mixtures. It was recommended to create such mixtures by sowing 2.5 mln/ha of cereal and 2.1 mln/ha of leguminous components after applying $N_{45}P_{45}K_{45}$ to form a crop with high digestibility and nutrition. The system of mixed cropping of Hungarian vetch is promising for the production of silage and high-quality haylage in the face of climate change and as a precursor for post-cutting sowing of maize or sorghum crops

Keywords: Hungarian vetch; winter triticale; growth and development; yield; crude protein; feed nutrition

INTRODUCTION

The ongoing transformation of agriculture in the face of climate change requires innovative solutions for efficient and sustainable feed production. One of the most promising areas is the introduction of new annual legumes into winter intercropping systems (Petrychenko *et al.*, 2020). Among them, Hungarian vetch (*Vicia pannonica* Crantz.), a frost-resistant legume species with historical roots in ancient Rome, offers promising opportunities.

Despite its ancient heritage, Hungarian vetch is grown mainly in certain regions such as the Balkans, Turkey, and Central Asia. The appeal of Hungarian vetch is not limited to its winter hardiness. This nitrogen-fixing legume boasts the ability to accumulate significant amounts of organic residues (3-5 t/ha) and nitrogen (up to 70-80 kg/ha) in the soil, meeting a significant part (60-70%) of the crop's own nitrogen needs (Klein *et al.*, 2020). This feature not only reduces the dependence on high doses of mineral nitrogen, contributing to environmentally friendly practices, but also increases soil fertility through enzymatic activity (Fernández Sosa *et al.*, 2021; Vasiljevic *et al.*, 2021). Turkish researchers have aptly identified Hungarian vetch as an organic crop due to its positive impact on soil health (Temel & Torun, 2020).

Apart from its ability to enrich the soil, Hungarian vetch has significant agronomic potential. Its high yield potential combined with an impressive protein content and notable antioxidant activity makes it a valuable addition to livestock diets. The study also highlighted the crucial role of tillage systems, seeding rates, and sowing dates in optimising the productivity of Hungarian vetch. In particular, its unique morphological characteristics allow it to be used as a high-quality feed and green manure (Veklenko *et al.*, 2020; Stein *et al.*, 2023).

In a changing climate, winter crops such as Hungarian vetch is becoming a vital resource for providing high-quality feed during the critical autumn and winter periods. The efficient use of productive moisture during this period offers a sustainable alternative to conventional approaches to feed production. Furthermore, its compatibility with winter cereals such as triticale, rye, and spelt opens the possibility of creating a variety of binary mixtures suitable for hay, haylage, or silage production throughout the year. Recognising the enormous potential of Hungarian vetch for agricultural intensification and biologisation, this study delved into its biological characteristics, focusing on crude protein accumulation during critical growth stages. Moreover, the study investigated the effect of different fertilisation regimes and seeding rates on productivity in combination with different varieties of winter triticale. Through this comprehensive analysis, the study aimed to identify the best strategies for integrating Hungarian vetch into Ukrainian and global agricultural landscapes, ultimately paving the way for sustainable and climate-resilient feed production systems.

LITERATURE REVIEW

The need for high-quality, protein-rich feed is becoming increasingly important in Ukrainian livestock production. Hungarian vetch (*Vicia pannonica* Crantz.) is a promising variant due to its high protein content, drought tolerance, and nitrogen-fixing capacity. This review analysed the existing sources of information on the potential of Hungarian vetch, focusing on its biological characteristics, suitability for mixed cropping, and overall prospects for feed production.

Hungarian vetch is a leguminous annual crop of winter and spring development, known for its rapid growth, cold tolerance, and adaptability to various soil conditions (Bovsunovska, 2018b; Hetman, 2021). The taproot system contributes to the efficient use of water, making it suitable for regions with limited rainfall, such as the Pannonian Basin in Europe, as well as steppe and dry forest-steppe regions of Ukraine (Croccetti *et al.*, 2020). Studies have shown that Hungarian vetch can accumulate more dry matter and crude protein compared to other close legume relatives, such as common vetch (*Vicia sativa* L.) since it effectively uses the reserves of productive moisture in the autumn-winter period (Bengisu, 2019; Gozubuyuk *et al.*, 2020). The presence of beneficial rhizobia bacteria in root nodules enhances nitrogen fixation, enriching the soil for subsequent crops (AVCI, 2021).

Intercropping Hungarian vetch with cereal spiked crops such as winter triticale, wheat, barley, or winter oats has become a sustainable and productive strategy for feed production in the Mediterranean and Balkans (Bozhanska, 2019; Neyestani *et al.*, 2023). Such mixed crops use resources more efficiently than monocultures, contributing to higher biomass and protein yields (Chornolata *et al.*, 2019). The drive for sustainable and high-quality feed production in Ukraine requires a focus on optimising the cultivation of mixed crops. Recent breeding research has explored the potential of combining Hungarian vetch with winter triticale (x *Triticosecale* Wittmack) in mixed crops. The main objective of this study, according to V. Tromsyuk *et al.* (2021), is the selection of the most suitable winter triticale varieties with best parameters of competition, plant habit, leafiness, overall productivity, and nutritional value of the vegetative mass. By carefully selecting triticale varieties that complement the growth characteristics of Hungarian vetch, the researchers hope to achieve a synergistic effect that will lead to higher biomass yields, improved protein content and, ultimately, higher feed quality. The ability to reduce competition within these systems not only increases overall yields, but also potentially minimises the need for external inputs such as fertilisers, thereby promoting environmentally friendly agricultural practices. Several studies in Ukraine have reported considerable increases in dry matter accumulation and crude protein yield when Hungarian vetch was sown with winter triticale, reaching 50 t/ha and 1.2 t/ha, respectively (Bovsunovska, 2018a; Hetman *et al.*, 2019). Furthermore, mixed crops demonstrate better feed quality due to increased digestibility and energy content compared to monoculture of Hungarian vetch (Önal Aşci *et al.*, 2020).

Mixed crops based on Hungarian vetch have a range of advantages for increasing the overall efficiency of feed production. Studies have shown that these systems require less fertiliser due to the nitrogen fixation by vetch, which contributes to environmental sustainability (Skamarokhova *et al.*, 2021). Furthermore, improved soil fertility has a favourable effect on subsequent crops grown in the rotation, further increasing the overall productivity of arable land. Early harvesting of Hungarian vetch allows extending the sowing period of subsequent cash crops, such as maize or sorghum, thereby optimising land use and resource allocation (Senyk, 2020).

Despite its promising potential, the introduction of Hungarian vetch in Ukraine faces certain challenges. The best sowing dates and seeding rates for different regions and soil types require further investigation. Furthermore, breeding programmes aimed at developing varieties with increased resistance to disease and stress will be useful for wider adoption (Semenov *et al.*, 2021; Turfan, 2022). Further research is also needed to improve the economic efficiency of integrating Hungarian vetch into existing farming systems.

Hungarian vetch is a promising legume crop for Ukrainian feed production. Its favourable biological characteristics, combined with its ability to increase mixed crop efficiency and protein content, make it a valuable addition to agricultural landscapes. However, overcoming challenges related to seed availability, cultivation practices, and long-term sustainability is still crucial for successful integration. By addressing these challenges through ongoing research and development, Hungarian vetch can play a significant role in improving the quality and quantity of feed production in Ukraine, ultimately contributing to sustainable livestock feeding systems.

MATERIALS AND METHODS

The research on the productivity of Hungarian vetch was conducted during 2014-2022 at the experimental field of the Department of Field Feed Crops, Hayfields and Pastures of the Institute of Feed and Agriculture of Podillia of the National Academy of Agrarian Sciences of Ukraine. The soil of the experimental plot is grey forest medium loam with a humus content of 2.18% in the topsoil, alkaline hydrolysed nitrogen – 62 mg/kg, mobile phosphorus – 149 mg/kg and exchangeable potassium – 80 mg/kg. The reaction of the soil solution is slightly acidic (salt pH 5.9) with a hydrolytic acidity of 1.14 mg-eq/100 g of soil. The climatic conditions of most years of the study were favourable for the growth and development of grass mixtures of winter triticale with Hungarian vetch. The average temperature in April-May was 11.8-13.3°C. Precipitation during the growing season was unevenly distributed. The most optimum year was 2014 (HTC 1.82) with an average daily temperature of 13.3°C and precipitation of 149 mm. The driest years were 2015 and 2017 (HTC 0.78).

The study was conducted using a two-factor field experiment with six seeding rates (factor A) and three doses of mineral fertilisers (factor B). The experiment repetition was fourfold. The placement of variants was systematic. The plot area – 24.2 m^2, the accounting area – 18 m^2. Legume-cereal mixtures of annual feed crops were used as a precursor. Commonly accepted agricultural techniques were used with basic tillage, application of $P_{30\text{-}45}K_{30\text{-}45}$ for pre-sowing cultivation and nitrogen fertilisers for sowing. The SN-16 seeder was used in combination with a T-25A tractor. The ratio of the components in the mixture was 50%:50%, 75%:75%, 50%:75%, and 75%:50% of the full quantitative seeding rate. The sowing dates depended on weather conditions and were mainly carried out in September and October.

The hydrothermal coefficient (HTC) was calculated as the ratio of the sum of precipitation to the sum of air temperatures reduced by a factor of 10 during certain periods of vegetation. Phenological observations of plant growth and development were carried out with indication of the main stages of development according to the BBCH scale according to H. Bleiholder *et al.* (2001). The height of plants was measured according to the linear method, the botanical composition of the grass stand was studied by weight analysis, and the yield of green mass was determined by weighing the entire crop from the accounting plot and then recalculating it per hectare according to the method of state variety testing (Tkachik *et al.*, 2017). The dry matter content was determined by the thermostat-weight method by drying the samples to a constant weight at 105°C. The chemical composition of the feed was analysed jointly with the Laboratory for Monitoring the Quality, Safety of Feed and Raw Materials of the Institute of Feed and Agriculture of Podillia NAAS of Ukraine (Chornolata *et al.*, 2019), following current standards, namely: sampling was carried out following DSTU ISO 6497:2005 (2008), determination of moisture and other volatile substances – DSTU ISO 6496:2005 (2006), nitrogen and crude protein – DSTU 7169:2010 (2011), crude fat – DSTU ISO 6492:2003 (2005), fibre – DSTU 8844:2019 (2020), crude ash – DSTU ISO 5984:2004 (2006), carbohydrate-lignin complex (sugars, hemicellulose, cellulose) – DSTU 7982:2015 (2017). The results were processed using Statistica 10.0.

Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following the institutional, national, or international guidelines. The study adhered to 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

As part of mixed crops with cereals, Hungarian vetch can form multi-tiered plant communities in combination with other species. Such agrophytocenoses demonstrate higher efficiency of nutrient and solar energy use due to their extensive root system and significant amount of leaf mass. The interaction of legumes and cereals in the phytocoenosis improves nitrogen nutrition of plants, which contributes to higher productivity per unit area. Hungarian vetch, specifically the Orlan variety used in grass mixtures, is of interest to farmers specialising in livestock production. The use of grass mixtures as an intercrop helps to improve soil fertility and soil structure in different soil and climatic zones of Ukraine.

In the context of climate change, the temperature and rainfall in autumn determine the formation of friendly and homogeneous seedlings that appear within 13-15 days. From sowing to the winter cessation of vegetation, the average daily sum of active temperatures was 365°C, and the plants of Hungarian vetch reached the microstage of lateral shoots (BBCH 22-24) at a height of 8-10 cm. After the resumption of spring vegetation, it takes 64-65 days to reach the full flowering stage (BBCH 64-65) for vetch plants, with a sum of active temperatures of 753°C, precipitation of approximately 100 mm, daylight hours of 973 h and a hydrothermal coefficient of 1.32.

A direct indicator of the intensity of the stages of organogenesis in plants is their height, although this parameter depends on the variety. Its variation is also possible under the influence of weather conditions and technological factors. In the early stages of organogenesis, Hungarian vetch plants develop slowly, with a considerable increase in height observed from budding to flowering. At this stage, the height can increase by a factor of 1.5-2.0, which often causes the grass stand to lodge. As the stem of Hungarian vetch plants is thin and juicy, with low resistance to lodging, the presence of a supporting crop, such as winter triticale, is recommended regardless of the maturity group.

During ontogenesis, the reaction of plants to environmental conditions is observed, which is determined by plant growth and the duration of individual phases of development, especially under changed humidity. With increased moisture supply, the duration of the interphase period from vegetation renewal to flowering of Hungarian vetch was 67-69 days, while a decrease in available moisture led to a reduction of this period by 9-10 days. It was found that an intensive increase in plant height occurred with an increase in the average daily temperature in May and the passage of the phases of stem elongation (BBCH 30-39) and budding (BBCH 40-50). The height was adjusted by the level of fertilisation in single-species sowing; on the background of mineral nutrition, it increased by 24-26 cm and in the flowering phase reached 73-79 cm with a total increase of 35-38 cm (Table 1).

***Table 1**. Changes in the height of Hungarian vetch plants by stages of growth and development in agrophytocenoses with winter triticale, cm (M±m)*

Culture, binary mixtures	Seeding rate, %		Fertiliser doses	Phases of growth and development		
	triticale	vetch		branching	budding	flowering
Hungarian vetch	0	100	$N_{30}P_{30}K_{30}$	14±1.14	38±4.14	73±3.12
			$N_{45}P_{45}K_{45}$	15±1.09	41±3.13	79±2.82

Table 1. Continued

Culture, binary mixtures	Seeding rate, %		Fertiliser doses	Phases of growth and development		
	triticale	vetch		branching	budding	flowering
Hungarian vetch + winter triticale	50	50	$N_{30}P_{30}K_{30}$	18±2.31	48±3.13	83±3.21
			$N_{45}P_{45}K_{45}$	18±1.81	51±3.22	86±3.87
Hungarian vetch + winter triticale	75	75	$N_{30}P_{30}K_{30}$	18±2.46	51±3.45	84±3.38
			$N_{45}P_{45}K_{45}$	17±1.90	52±6.03	88±2.98
Hungarian vetch + winter triticale	50	75	$N_{30}P_{30}K_{30}$	16±2.04	45±3.31	81±4.03
			$N_{45}P_{45}K_{45}$	16±2.12	52±5.19	85±3.48
Hungarian vetch + winter triticale	75	50	$N_{30}P_{30}K_{30}$	16±2.38	49±3.84	80±3.53
			$N_{45}P_{45}K_{45}$	16±1.53	51±3.76	87±4.33

Source: *developed by the authors of this study*

However, in grass mixtures on the background of mineral fertilisers, plant growth processes were activated in the created microclimate conditions and mutual stimulation of components. The height of Hungarian vetch from the branching phase increased by 33-36 cm to the budding phase and was within 51-52 cm, while in the flowering phase it reached 86-88 cm. Under single-species sowing, the growth and development of plants was less intense, and the height was 38-41 cm and 73-79 cm, respectively, against the background of $N_{45}P_{45}K_{45}$.

The intensive development of Hungarian vetch plants was noted under conditions of excessive moisture when the plant height was 100-104 cm at a seeding rate of 100% in monoculture. At HTC 1.05, it decreased to 74-77 cm under the influence of a compatible crop – winter triticale. Hence, it can be concluded that the created models of agrophytocenoses require a comprehensive investigation of their adaptability to extreme natural factors (lack of moisture, increased temperature during the growing season, etc.), which can be regulated by elements of cultivation technology (Table 2).

Table 2*. Changes in the height of Hungarian vetch plants in joint crops with winter triticale under different moisture supply, cm (M±m)*

Crops, seeding rate, %	Hydrothermal coefficient	
	1.60	1.05
Hungarian vetch, 100	93±2.36	76±3.63
Hungarian vetch, 50 + winter triticale, 50	96±3.92	75±3.65
Hungarian vetch, 75 + winter triticale, 75	104±2.96	74±3.12
Hungarian vetch, 75 + winter triticale, 50	100±3.78	77±3.53
Hungarian vetch, 50 + winter triticale, 75	102±3.37	77±3.52

Source: *developed by the authors of this study*

The growth of green mass in Hungarian vetch was influenced by the elements of cultivation technology. The best conditions for the formation of leaves were created on the mineral background of $N_{45}P_{45}K_{45}$. At different seeding rates, the leafiness of plants reached 44.85-50.40% and was lower by 1.17-6.72% in single-species sowing under conditions of excessive moisture. When humidity decreases, plants form a smaller leaf surface area, thereby protecting themselves from excessive evaporation and preserving them in the grass stand. In single-species crops, it was 43.47%, while in binary mixtures – 36.14-42.65% (Table 3).

Table 3*. Influence of hydrothermal conditions on the leafiness of Hungarian vetch plants depending on sowing rates and fertilisation, %*

Mixtures	Seeding rate, %	Fertiliser doses	Hydrothermal coefficient		Mean
			1.60	1.05	
Hungarian vetch	100	$N_{30}P_{30}K_{30}$	46.01	38.11	42.08
		$N_{45}P_{45}K_{45}$	51.57	43.47	47.52
Hungarian vetch + winter triticale	50:50	$N_{30}P_{30}K_{30}$	44.96	38.41	41.68
		$N_{45}P_{45}K_{45}$	50.40	40.98	45.68
Hungarian vetch + winter triticale	75:75	$N_{30}P_{30}K_{30}$	42.97	34.81	38.89
		$N_{45}P_{45}K_{45}$	48.17	42.65	45.41

Table 3. Continued

Mixtures	Seeding rate, %	Fertiliser doses	Hydrothermal coefficient		Mean
			1.60	**1.05**	
Hungarian vetch + winter triticale	50:75	$N_{30}P_{30}K_{30}$	40.01	35.88	37.94
		$N_{45}P_{45}K_{45}$	44.85	37.75	41.30
Hungarian vetch + winter triticale	75:50	$N_{30}P_{30}K_{30}$	43.15	35.67	39.41
		$N_{45}P_{45}K_{45}$	48.37	36.14	42.26

Source: *developed by the authors of this study*

The decrease in the sowing rate of the leguminous component in binary mixtures contributed to better leafiness of plants with the introduction of mineral fertilisers in the dose $N_{45}P_{45}K_{45}$. The crops competed with winter triticale for nutrients. There is a tendency for its decrease when sowing with a seeding rate of 50:75% of single-species sowing. To obtain high-protein plant material, it is better to sow Hungarian vetch with winter triticale, which has the same growth and development phases in agrocenoses. In a grass mixture, winter triticale is not only a supporting crop, but also a balancing crop in terms of the sugar-protein ratio.

The tiered placement of plants in the crop provides unequal illumination, which leads to different temperature and water conditions, especially with uneven distribution of precipitation during the growing season. Therefore, by selecting the seeding rates of legumes and cereals, the risks of plant influence on each other can be eliminated, as evidenced by the obtained dry matter yield. Although the performance of the grass mixture models varied, they stayed quite high. The highest yield of dry matter was obtained in the model where crops were sown in the ratio of sowing rates of 75:50% on the background of $N_{45}P_{45}K_{45}$, which was 8.77 t/ha with a content of Hungarian vetch of 2.90 t/ha, or a fraction thereof in the grass mixture was within 33.1%. When changing the ratio of components in the phytocoenosis, the difference in performance was within 0.62-1.10 t/ha, depending on the seeding rate. It was noted that the share of Hungarian vetch in the structure of the dry matter yield decreased to 1.95-2.22 t/ha with the application of mineral fertilisers at $N_{30}P_{30}K_{30}$. Therefore, to form a stable crop of high-protein plant material, it is advisable to apply suspended doses of mineral fertilisers (Table 4).

***Table 4**. Productivity of agrophytocenosis of Hungarian vetch with winter triticale in single-species and combined crops (2014-2016)*

Binary mixtures, seeding rates, % (factor A)	Fertiliser doses (factor B)	Green mass, t/ha	Dry matter, t/ha		Dry matter content, %	
			total	incl. vetch	total	incl. in vetch
Vetch Hungarian vetch, 100	$N_{30}P_{30}K_{30}$	26.5	4.44	4.44	16.76	16.75
	$N_{45}P_{45}K_{45}$	29.6	4.57	4.57	15.44	15.43
Hungarian vetch, 50 + winter triticale, 50	$N_{30}P_{30}K_{30}$	35.9	6.86	1.95	19.54	17.58
	$N_{45}P_{45}K_{45}$	41.7	7.83	2.49	18.85	17.34
Hungarian vetch, 75 + winter triticale, 75	$N_{30}P_{30}K_{30}$	30.4	7.57	2.17	20.10	18.62
	$N_{45}P_{45}K_{45}$	38.1	8.15	2.61	18.86	17.54
Hungarian vetch, 75 + winter triticale, 50	$N_{30}P_{30}K_{30}$	36.7	7.20	2.04	19.20	17.74
	$N_{45}P_{45}K_{45}$	41.8	7.67	2.45	18.98	16.88
Hungarian vetch, 50 + winter triticale, 75	$N_{30}P_{30}K_{30}$	39.6	7.90	2.22	20.06	17.92
	$N_{45}P_{45}K_{45}$	46.2	8.77	2.90	19.02	17.40
$LSD_{0.05}$, t/ha: green mass A-1.50; B-1.06 AB-2.59						
$LSD_{0.05}$, t/ha: dry matter. A-0.35; B-0.25; AB-0.60						

Source: *developed by the authors of this study*

The use of different doses of mineral fertilisers led to a decrease in the accumulation of dry matter in triticale and Hungarian vetch plants over the years of research, offsetting the unfavourable weather conditions of the growing season. The difference in dry matter content between a year with favourable moisture and temperature conditions and a dry year was 2.77%, and in case of uneven distribution – 1.64%, regardless of the level of fertilisation. Therewith, the combination of different sowing rates in agrophytocenosis contributed to an increase in the dry matter content of Hungarian vetch by 0.06-0.20%, compared to the ratio of sowing rates of 50:50% with $N_{45}P_{45}K_{45}$ and 0.16-1.04% with $N_{30}P_{30}K_{30}$. Increasing the dose of mineral fertilisers contributed to a decrease in the content of dry matter in Hungarian vetch by 0.24-1.08%, compared to $N_{30}P_{30}K_{30}$. The highest dry matter yield was 8.77 t/ha with a green mass yield of 46.3 t/ha for a mixture of 50% Hungarian vetch and 75% winter triticale.

The high potential of productivity and quality of Hungarian vetch is confirmed by the study, which involved sampling of green mass from single-species sowing after the same period of 4-6 days at different microstages of crop development to identify the specific features of the production process, the intensity of interphase periods and optimisation of feed quality with the period of harvesting for feed purposes (Fig. 1).

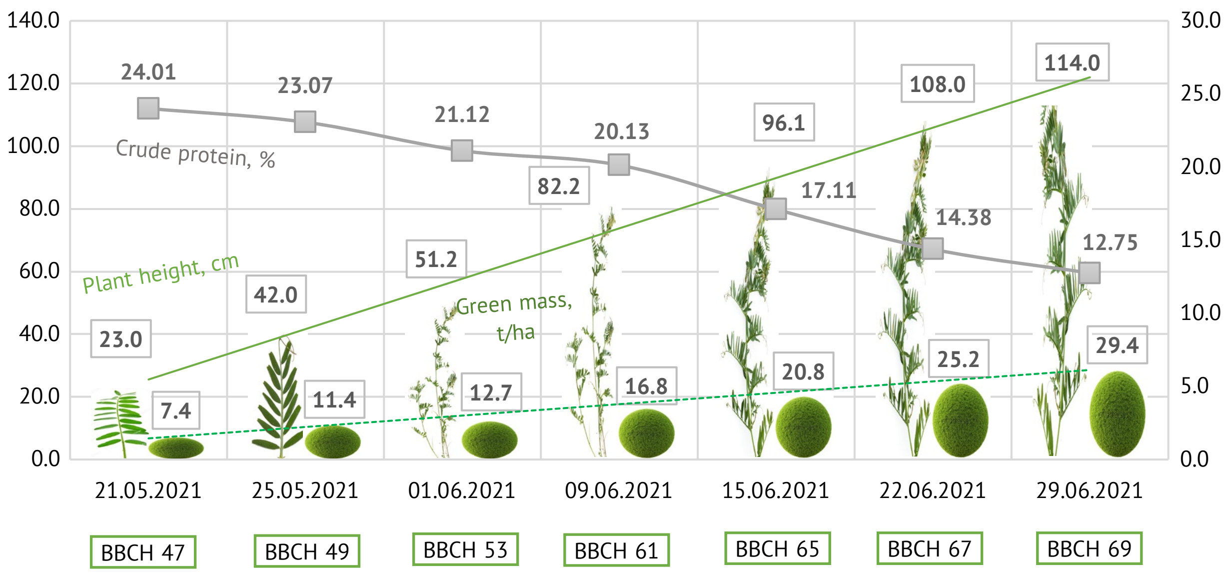

***Figure 1**. Productivity and quality potential of Hungarian vetch in single-species sowing according to BBCH development microstages, 2021*
***Source:** developed by the authors of this study*

It was established that at the initial stage of the generative period of plants – BBCH 47 microstage (budding of 70% of plants), the height of vetch reached 23 cm with a green mass yield of 7.4 t/ha and a crude protein content in dry matter of 24.01%. At the onset of the BBCH 49 microstage (complete budding of plants), a yield of 11.4 t/ha of green mass was formed at a grass height of 42.0 cm and a crude protein content of 23.07%. When the BBCH 53 microstage was reached (the first flower buds appeared), the plant height reached 51.2 cm with a green mass yield of 12.7 t/ha and an even higher crude protein content of 21.12%. With the onset of the flowering phase of Hungarian vetch, the highest intensity of aboveground biomass growth and, at the same time, a sharp loss of its protein nutritional value were observed. Thus, from the completion of the BBCH 61 microstage (the beginning of flowering of 10% of flowers) to BBCH 69 microstage (the end of flowering), which lasted 20 days, the absolute values of plant height and green mass yield increased from 82.2 cm and 16.8 t/ha to 114 cm and 29.4 t/ha, and the content of crude protein in dry matter decreased from 20.13% to 12.75%. Therefore, the best harvesting phase of Hungarian vetch for preparing high-quality feed is the period from the beginning to the middle of flowering (BBCH 61-65), which lasts a week, when their height is 82.2-96.1 cm, green mass yield is 16.8-20.8 t/ha, with a crude protein content in the dry matter of the feed at 17.11-20.13%.

Studies have shown that growing Hungarian vetch in mixed crops with an accompanying cereal component considerably increases the productivity of the feed acreage compared to its single-species sowing. It was found that mixtures of Hungarian vetch with different varieties of winter triticale or Westerwolds ryegrass provided a yield of 37.6-45.0 t/ha of green mass, while only 21.8 t/ha was obtained in pure sowing. The highest yield of green mass was obtained using winter triticale of the Bozhych variety (Fig. 2).

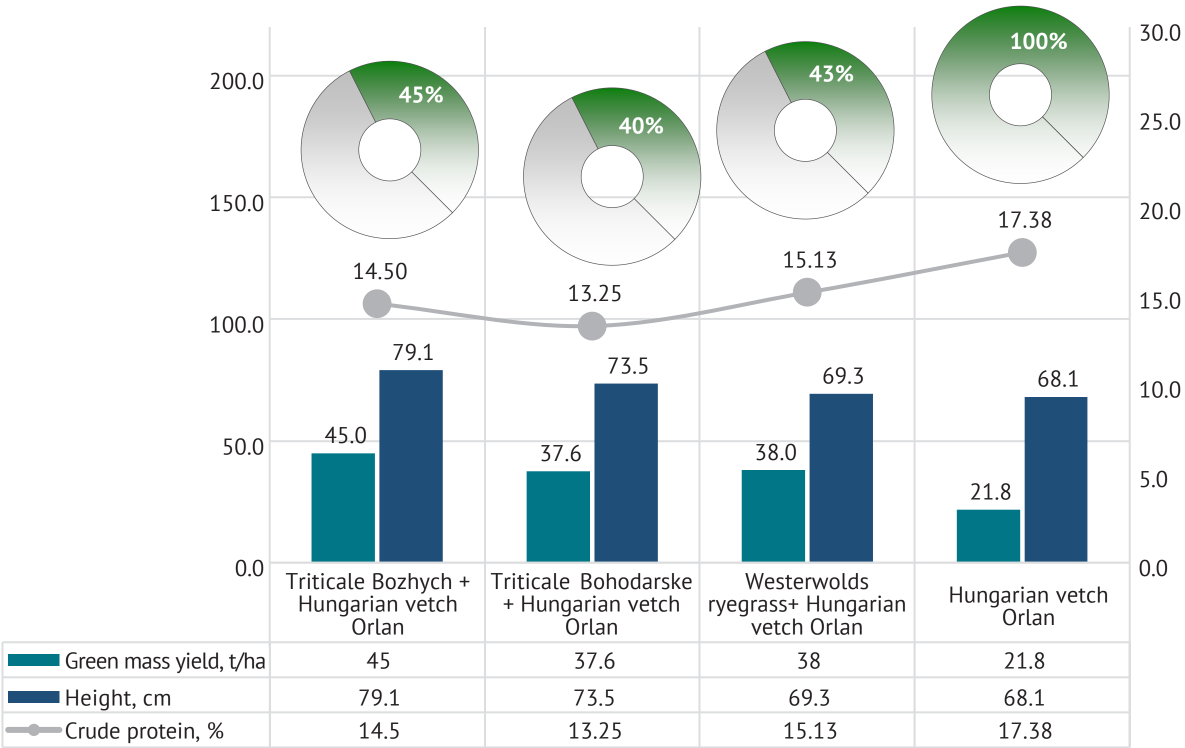

***Figure 2**. Improving the productivity and feed quality of mixed crops with the inclusion of Hungarian vetch in annual winter cereal species, 2021-2022*
***Source:** developed by the authors of this study*

The share of Hungarian vetch in the sowing with triticale was 40-45%, and with ryegrass – 43%. At the time of reaching mowing maturity (27 May), Westerwolds ryegrass was at the BBCH 55 stage (50% of inflorescences were ejected), and winter triticale was at the BBCH 45 stage (swelling of the ear in the axils of the flag leaf), which characterises the different maturity of these components. This resulted in their different coenotic impact on the legume component. At the time of harvesting with Westerwolds ryegrass, the Hungarian vetch was at the BBCH 55 stage of development (flower buds), while with winter triticale, the Hungarian vetch had already begun to flower (BBCH 59). Harvesting winter mixed crops at such stages of plant development allows obtaining a plant mass with a crude protein content in dry matter of 15.13% when sowing Hungarian vetch with Westerwolds ryegrass, 14.50% with winter triticale of Bozhych variety and 13.25% with Bohodarske variety. At this time, a single-species sowing of Hungarian vetch contained 17.38% of crude protein in dry matter.

Ecological testing of Hungarian vetch models with different varieties of winter triticale as the most successful variant of cenotic combination of crops in mixed sowing showed stability of productivity in different soil and climatic zones of Ukraine. On average, over the years of use, 36.2-51.8 t/ha of green mass was obtained with a dry matter yield of 7.1-11.5 t/ha. Such stability in the formation of the productivity of this mixed crop is explained by the successful annual overwintering of the components, the effective use of autumn and winter soil moisture reserves and temperature conditions. Considering that the yield of crude protein from the feed acreage did not decrease below 1.0 t/ha, the phytocoenotic balance of such a mixture was good in terms of the best proportion of the legume component in the grass stand, which contributed to sufficient nutritional value of plant material (Table 5).

***Table 5**. Formation of productivity of a mixture of Hungarian vetch with winter triticale depending on soil and climatic conditions of Ukraine (average for 2016-2020)*

Mixture	Fertiliser	Ratio of seeding rates of components, %	Green mass yield, t/ha	Yield, t/ha	
				dry matter	crude protein
Forest-steppe of the Right Bank (IFAP NAAS)					
Hungarian vetch Orlan + winter triticale Polovetske	$N_{45}P_{45}K_{45}$	75+50	45.6	8.3	1.3
		75+50	42.8	7.6	1.2

Table 5. Continued

Mixture	Fertiliser	Ratio of seeding rates of components, %	Green mass yield, t/ha	Yield, t/ha	
				dry matter	crude protein
Western Forest-Steppe (Ternopil RS IVM)					
Hungarian vetch Orlan + winter triticale Polianske	Seed treatment	75+25	36.8	7.2	1.1
Southern Steppe (IIA NAAS)					
Hungarian vetch Orlan + winter triticale Bohodarske	$N_{60}P_{60}$	75+50	51.8	11.5	1.8
Southern Steppe (Mykolaiv SAES ICSA)					
Hungarian vetch Orlan + winter triticale Polianske	Without fertilisers	75+50	36.2	7.1	1.0

Source: *developed by the authors of this study*

The model of efficiency of the use of bioclimatic resources of central Podillia by mixed sowing of winter triticale of Bohodarske variety with Hungarian vetch of Orlan variety was tested, considering the intensity of the stages of development and growth of the vegetation index in the early spring growing season (Fig. 3)

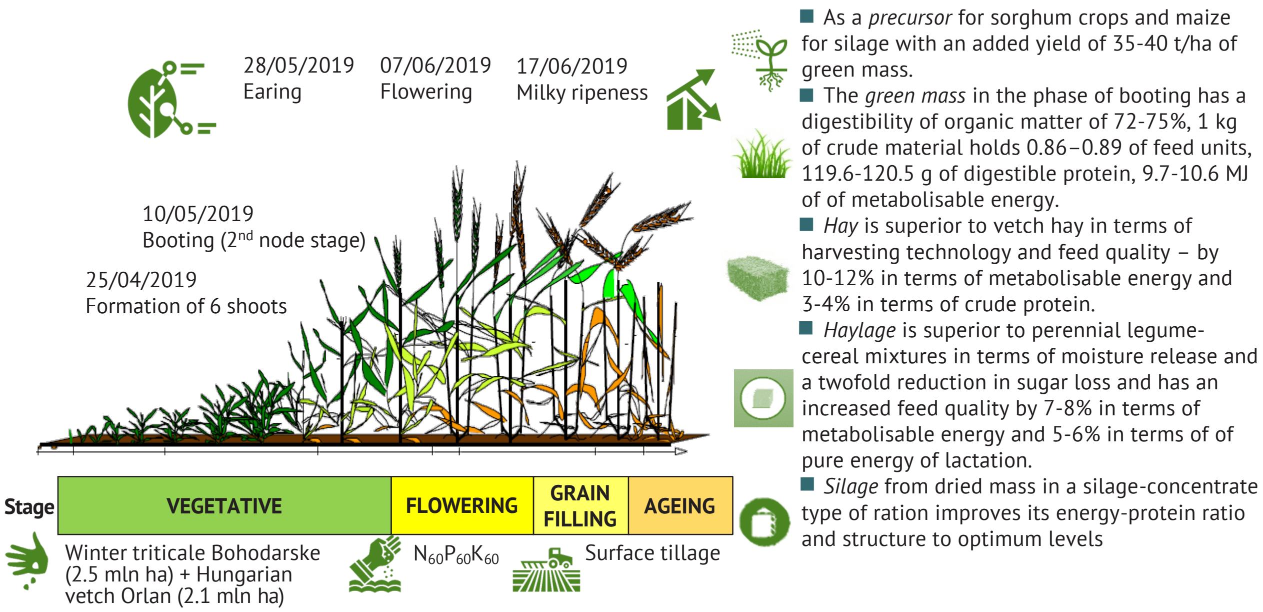

Figure 3*. Demonstration of the effectiveness of photosynthetic activity and feed productivity of a mixture of winter triticale with Hungarian vetch as an intercrop in the early spring growing season, 2019-2020*
Source: *developed by the authors of this study*

It can be noted that the creation of such a mixed crop by sowing 2.5 mln/ha of similar cereal seeds and 2.1 mln/ha of leguminous component after surface tillage and application of mineral fertilisers in a dose of $N_{60}P_{60}K_{60}$ allows forming a crop of green mass at the end of the vegetative stage of plant development (booting of a cereal species) 35-40 t/ha, which is characterised by digestibility of 72-75%, nutritional value of 1 kg of dry matter 0.86-0.89 of feed units with a content of 119.6-120.5 g of digestible protein and 9.7-10.6 MJ of metabolisable energy. Hay harvesting from such a crop is superior in terms of technology and quality to the traditional vetch-oat mixture – by 10-12% in energy content and 3-4% in crude protein. There are also substantial advantages of such a grass stand for the production of early high-quality haylage or silage, as well as a precursor for post-cutting sowing of maize or sorghum crops.

Comprehensive studies of the chemical composition of the mixture of winter triticale with Hungarian vetch at different stages of development show that during the growth and development of its plant components, the content of protein and easily soluble carbohydrates decreases and the content of fibre, i.e., structural carbohydrates, increases. As for crude fat, it tends to decrease, while the content of crude ash increases (Table 6).

***Table 6**. Nutritional value and characteristics of the carbohydrate complex of winter triticale and Hungarian vetch mixture at different stages of development of components*

Developmental stages of the mixture components	Content per 1 kg of dry matter, %					Content per 1 kg of dry matter, g/kg					
	CP	CF	CFi	CA	NFES	EHC	St	Su	HCe	Ce	Li
Triticale tillering and Hungarian vetch stemming	19.52	2.97	17.99	9.86	49.65	322.4	39.5	158.7	118.0	133.2	40.9
Triticale booting and Hungarian vetch budding	17.10	2.32	24.85	7.76	47.96	316.0	33.9	139.5	135.5	148.8	61.0
Triticale heading and Hungarian vetch flowering	16.93	1.43	28.88	11.70	41.06	251.4	31.0	92.0	152.0	161.9	71.2

***Note:** CP – crude protein; CF – crude fat; CFi – crude fibre; CA – crude ash; NFES – nitrogen-free extractive substances; EHC – easily hydrolysed carbohydrates; St – starch; Su – sugar; HCe – hemicellulose; Ce – cellulose; Li – lignin*
***Source:** developed by the author of this study based on research by Chornolata et al. (2019)*

According to the results of the study, the nutritional value of the mixture of winter triticale and Hungarian vetch in the phase of triticale tillering and vetch stemming was 0.87 feed units and 9.29 MJ of metabolisable energy per 1 kg of dry matter, which is the highest. In the phase of triticale booting and vetch budding, these values were 0.84 and 9.11, respectively, while in the phase of triticale earing and vetch flowering – 0.75 and 8.44. Thus, the most optimum time for using the mixture is the phase of cereal booting and legume budding, as the nutritional value stays quite high, and the volume of green mass is almost maximum.

To assess the economic efficiency of feed use, it is important to determine the amount of basic nutrients consumed and absorbed by the animal. This information was obtained during balance experiments on sheep fed a mixture of triticale and Hungarian vetch at different stages of growth and development. It was found that the content of dry matter increased in the phase of triticale booting and vetch budding by 8.7%, and in the phase of triticale earing and vetch flowering – by 11.4% and 2.4%, respectively, compared to the previous phases. Consumption of the mixture in the phase of triticale tillering and vetch stemming was 87%, in the phase of triticale tubing and vetch budding – 57%, and in the phase of triticale earing and vetch flowering – only 34%. In the latter two phases, the proportion of feed residues increases substantially, which leads to a decrease in the intake of nutrients in the animal body.

Based on the data on fed plant mass, feed residues, excreted urine and faeces, the content of the main nutrients in the samples was determined and the digestibility coefficients of dry and organic matter, crude protein, crude fat, crude fibre, and nitrogen-free extractive substances were calculated. It was found that the highest digestibility of all nutrients was observed in the triticale tillering and vetch stemming phases. In the following phases, there was a tendency for a gradual decrease in digestibility, with the greatest decrease in crude fat and fibre digestibility and the least decrease in crude protein digestibility.

The study of the carbohydrate-lignin complex of the samples showed that with the ageing of plants, the content of easily soluble carbohydrates decreases by more than 22% due to a decrease in starch and sugar. At the same time, the content of hemicellulose, cellulose, and lignin in the fraction of structural carbohydrates increases by 1.2-1.8 times, especially in the phase of triticale earing and vetch flowering. Generally, the content of structural carbohydrates increases by more than 30%. Consequently, the digestibility of cellulose and lignin in the animal body decreases dramatically. Thus, as plants age, the proportion of available protein decreases, and the content of hard-to-digest structural carbohydrates increases. Thus, from a livestock perspective, a mixture of winter triticale and Hungarian vetch is a valuable feed and feedstock. It is most appropriate to use it during the cereal booting and legume budding phases, when the nutrient content is still high enough and the depressant effect of fibre is not yet significantly manifested. The experimental data obtained are consistent with the results of studies by other researchers.

In the study by H. Kir (2021a), the yield and quality characteristics of a mixture of Hungarian vetch with triticale were investigated depending on the sowing time. The analysis showed that sowing time had a significant impact on all performance parameters. Specifically, delayed sowing led to a decrease in green feed yield, dry matter yield, and mixture quality. The study highlighted the first week of October as the most optimum sowing date, contributing to high dry matter yields with high quality in the continental climate of Central Anatolia in Turkey.

C. Balabanli *et al.* (2010) found that mixtures of Hungarian vetch with rye, triticale, barley, and wheat produced high hay yields and quality silage. The highest hay yield (9.08 t/ha) and crude protein yield (1.11 t/ha) were obtained from a mixture of Hungarian vetch and rye. The lowest content of NDF and ADF (50.11% and

31.92%, respectively) was observed in the mixture of Hungarian vetch with oats. The conclusion of the study is that all mixtures of Hungarian vetch with cereals can be successfully ensiled and produce high-quality silage without additional preservatives.

A. Uzun *et al.* (2004) studied the effect of four seeding rates (20, 40, 80, and 160 kg/ha) on dry matter, seed, and yield elements of four Hungarian vetch cultivars. According to the data obtained, there were no significant differences between the Hungarian vetch varieties in any of the measured traits, except for the thousand kernel weight. However, seeding rates had a substantial impact on dry matter yield, seed yield, and most yield elements. It was found that high seeding rates resulted in higher dry matter and seed yields compared to low rates in all the years studied.

S. Albayrak *et al.* (2011) investigated the effect of two row spacing (17.5 cm and 35 cm) and four seeding rates (40, 60, 80, and 100 kg/ha) on yield elements of Hungarian vetch under natural moisture conditions in Turkey. It was found that row spacing and seeding rate significantly influenced most traits and yield elements, except for feed quality. The highest dry matter yields were obtained with a row spacing of 17.5 cm and a seeding rate of 80 kg/ha. Among the combinations of sowing methods, the highest seed yield was obtained with a row spacing of 35 cm and a seeding rate of 80 kg/ha.

In the study of the effect of row spacing and seeding rates on the productivity of hairy vetch (*Vicia villosa* Roth), Hungarian vetch (*Vicia pannonica* Crantz) and common vetch (*Vicia sativa* L.) under natural moisture conditions, it was found that wider row spacing significantly increased plant height and lodging index of crops. They also resulted in an increase in the number of branches and beans per plant, seeds per bean, thousand kernel weight, and seed yield. The highest seed productivity among legume species was observed in Hungarian vetch, while the lowest was in hairy vetch. Serbian scientists have found that a wide row spacing (50 cm) increases plant height by 13.6%, the number of branches – by 57%, and the seed yield of Hungarian vetch reaches 1.560 t/ha (Karagić *et al.,* 2011).

The study of yield and feed quality of mixed crops of Hungarian vetch with barley showed a substantial influence of varietal characteristics and the ratio of components in the mixtures in Turkey. The highest content of Hungarian vetch (37.3%), green mass yield (36.3 t/ha), and crude protein content (1.510 t/ha) were obtained from a mixture of 80% Hungarian vetch (Tarm Beyazi-98 variety) and 20% barley. The highest hay yield (10.5 t/ha) was obtained from a mixture of 20% Hungarian vetch (Anadolu Pembesi-2002) and 80% barley. In terms of feed quality among the studied varieties of Hungarian vetch, the Ege Beyazi-79 variety prevailed. Even though the feed yield increased with the share of barley seeds in the mixture, the quality of the feed decreased significantly. The study concluded that the best values in terms of both yield and quality were obtained from a mixture of 80% Hungarian vetch + 20% barley (Kusvuran *et al.*, 2014).

M. Nadeem *et al.* (2010) showed that the addition of cereals to Hungarian vetch crops reduced lodging and improved harvesting. The highest yields of green mass (35.06 t/ha) and dry matter (9.29 t/ha) were recorded in the mixture of oats + Hungarian vetch. Oats provided the highest yields of green mass (31.58 t/ha) and dry matter (7.75 t/ha) in pure crops. It was concluded that the mixture of oats + Hungarian vetch can be recommended for high biomass production under natural moisture conditions in the conditions of Pakistan.

K. Alizadeh and J. Silva (2013) aimed to determine a suitable mixture of annual feed legumes and barley as a winter crop in arid climates. A 1:1 mixture of Hungarian vetch seeds (variety 2670) and other legume species with barley (variety Abidar) was tested in comparison with a monoculture. In provinces with mild winters and more than 400 mm of precipitation, this mixture demonstrated maximum green and dry mass yields, reaching 56 t/ha and 15 t/ha, respectively. The average crude protein content was 17%. Therefore, a mixture of Hungarian vetch and barley can be an effective alternative for farming in cold and semi-cold arid regions.

In a study conducted at Harran University in Turkey in 2017-2018, researcher G. Bengisu (2019) investigated the effect of single-species and mixed sowing of Hungarian vetch and barley on silage quality. When assessing the physical properties of the silage, it was found that the quality of the silage increased with the increase in the proportion of barley in the mixture. In terms of chemical properties of the silage, the lowest ADF and NDF content and the highest protein content were obtained from a silage mixture with a 75%:25% ratio of Hungarian vetch and barley.

In the study by H. Kir (2021b), the highest yields of green feed – 18.3 t/ha, dry matter – 5.7 t/ha, crude protein – 0.76 t/ha, and digestible dry matter – 3.6 t/ha, were achieved with a mixture of 25% Hungarian vetch and 75% oats. However, the highest content of crude protein, total digestible nutrients, and relative feed value was observed in single-species sowing of Hungarian vetch – 18.1%, 65.6%, 163.1, respectively. In a field study conducted in the Black Sea coastal region (Ordu, Turkey), hay yield, quality, and competition of Hungarian vetch with annual ryegrass in mixed crops were studied. It was found that ryegrass was more aggressive in terms of competitiveness in mixtures. The best mixture was 90% Hungarian vetch and 10% annual ryegrass, which provided the highest hay and crude protein yields (4.026 t/ha and 0.732 t/ha, respectively) (Önal Aşci *et al.*, 2020). Thus, the findings obtained are consistent with the data of other researchers on the positive effect of optimising seeding rates, component ratios, sowing, and harvesting dates on the productivity and quality of feed of Hungarian vetch in mixed crops.

CONCLUSIONS

As a result of comprehensive research, it was found that Hungarian vetch is a valuable feed crop that produces a high yield of green mass and seeds due to the intensive growth of the aboveground part. Due to their high productivity and nutritional value, Hungarian vetch can be successfully used as a component of high-performance feed mixtures. It was found that for Hungarian vetch to reach the full flowering phase, 754S°C of the sum of active temperatures, 100 mm of precipitation, and 973 h of daylight hours are required. The duration of the period from vegetation renewal to flowering depends on the moisture supply – with sufficient moisture, it is 67-69 days, with insufficient moisture – 58-59 days. It was proved that in the face of climate change, Hungarian vetch successfully overwinter and form a stable yield due to the efficient use of moisture. This suggests that Hungarian vetch is well-adapted to adverse weather conditions and can be considered a promising feed crop for arid regions.

The advantages of growing Hungarian vetch in mixtures with winter triticale, specifically Bozhych and Bohodarske varieties, were proved – the yield of green mass was 37.6-45.0 t/ha against 21.8 t/ha in pure sowing. Such mixtures are characterised by high performance stability. It was found that the highest yield of dry matter (7.8-8.8 t/ha) and crude protein (1.2-1.3 t/ha) is provided by sowing Hungarian vetch with winter triticale in the ratio of sowing norms of 50:75%. Therefore, it is recommended to create mixtures of Hungarian vetch and winter triticale by sowing 2.5 mln/ha of similar cereal seeds and 2.1 mln/ha of leguminous component on the background of $N_{45}P_{45}K_{45}$ with high quality indicators. The high productivity and stability of the mixture of Hungarian vetch with winter triticale was also proved in different soil and climatic zones of Ukraine.

Consumption and assimilation of the main nutrients by animals when using a mixture of triticale and Hungarian vetch in different growth stages indicates a significant influence of the stage of plant development on their nutritional potential. The results also indicate a decrease in crude protein and easily soluble carbohydrates and an increase in structural carbohydrates as plants age, leading to poorer digestibility. The best harvesting phase of Hungarian vetch for harvesting high-quality feed is the beginning to the middle of flowering (BBCH 61-65), when the content of crude protein in dry matter is 17.11-20.13%.

Further research should be aimed at investigating the possibility of using Hungarian vetch as a component of multispecies grass mixtures, developing varietal agricultural technology and further improving the elements of cultivation technology to maximise its productive potential.

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None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Агробіологічне обґрунтування вирощування горошку паннонського в змішаних посівах

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Анотація. Виробництво високобілкових кормів залишається невід›ємним елементом розвитку кормовиробництва. Основна мета дослідження – вивчення біологічних особливостей горошку паннонського при вирощуванні в агрофітоценозах із застосуванням різних видів злакових озимих культур. Досліджено зміни хімічного складу сухої речовини на різних мікростадіях росту і розвитку, визначено вплив на урожайність, вміст поживних речовин і перетравності рослинної сировини в залежності від фаз росту і розвитку. Дослідження проведено з використанням польових, лабораторних, лабораторно-польових та статистичних методів. Встановлено, що для досягнення фази повного цвітіння, сума активних температур повинна бути 754 °C, із сумою опадів близько 100 мм та тривалістю світлової доби 973 год. Спостереження за вегетаційним періодом вказують на взаємозв'язок між рослинами та довкіллям, врахування якого важливо при вирощуванні горошку паннонського. Рослини горошку досягають висоти 100-104 см в умовах надмірного зволоження. Фітоценотичний баланс таких сумішей, зокрема горошку сорту Орлан та тритикале озимого сортів Божич і Богодарське, забезпечує сталу продуктивність та поживність рослинної сировини. Оптимальною фазою збирання горошку для високоякісного корму визначено період від початку до середини цвітіння, що забезпечує вміст сирого протеїну в сухій речовині 17-20 %. Ефективність змішаних фітоценозів підтверджена екологічними випробуваннями моделей поєднання культур у різних ґрунтово-кліматичних зонах України, де за роками використання було отримано врожаї 36,2-51,8 т/га зеленої маси та 7,1-11,5 т/га сухої речовини. Створення змішаного посіву дозволяє отримати високоякісну рослинну сировину, що переважає за енергетичним вмістом та вмістом протеїну традиційні горошко-вівсяні суміші. Рекомендовано створювати такі сумішки шляхом висіву 2,5 млн/га злакового та 2,1 млн/га бобового компонентів після внесення $N_{45}P_{45}K_{45}$ для формування врожаю з високою перетравністю і поживністю. Система змішаних посівів горошку паннонського є перспективною для виробництва силосу та високоякісного сінажу в умовах зміни клімату та в якості попередника для післяукісних посівів кукурудзи або соргових культур

Ключові слова: горошок паннонський; тритикале озиме; ріст і розвиток; урожайність; сирий протеїн; поживність корму