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FACTORS OF INCREASING ALFALFA YIELD CAPACITY UNDER CONDITIONS OF THE FOREST-STEPPE

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ABSTRACT. It was found that southern ecotype alfalfa (*Medicago sativa*) of variety 'Angelica' adapted to the soil and climatic conditions of the Forest-Steppe and was not inferior in yielding capacity to variety 'Rosana' which provided maximum indices in the phase of the beginning of budding at sowing rates of 6.0 million pcs ha^{-1} and ordinary row sowing method with row spacing 12.5 cm. It was discovered that with the increase of alfalfa sowing rate from 4.0 to 8.0 million ha^{-1} the dry matter content of varieties increased by 0.11–0.20% for sowing with row spacing of 25.0 cm. compared to row spacing of 12.5 cm. (22.62–22.83%). The average crude protein content in variety 'Rosana' was 20.68–21.37 and 'Angelica' 20.67–21.07%. Narrowing of row spacing contributed to an increase in crude protein content by 0.55–0.58%. The highest content NDF and ADF were observed in the second year of alfalfa grass life, respectively 30.72–34.91 and 23.02–24.60%. During the third year of alfalfa grass usage, the indices decreased to 27.09–33.03 and 19.53–24.18%, respectively. Thus, during three years of life at different geographical origins, alfalfa in the phase of budding provided a stable dry matter output of 27.45–27.81 and crude protein output of 5.86–5.87 t ha^{-1} for sowing with row spacing of 12.5 cm. and sowing rate of 6.0 million pcs ha^{-1}.

Introduction

One of the priority development directions for the agro-industrial complex of Ukraine is the provision of husbandry with high-protein fodders at unstable moisture supply and high-temperature regime (Kvitko *et al.*, 2014; Petrychenko, Hetman, 2017). Therefore, the creation of long-term agro-phytocenoses requires innovative approaches, especially in the selection of alfalfa varieties, which, with the maximum realization of genetic potential can form stable yields under extreme hydrothermal conditions. Today, alfalfa (*Medicago sativa L.*) due to its biological characteristics is the most drought-resistant crop (Holoborodko, Pohinaiko, 2018) and an unsurpassed component of agro-phytocenoses of cheap plant protein for the preparation of various fodder types (Petrychenko *et al.*, 2020).

In fodder production intensification for the production of high-quality fodder primarily is used new generation alfalfa varieties (Syniuha) which can produce on soils of high acidity (Hetman, Tsyhansky, 2014) resistant to salt stress ('Nadezhda') (Tyshchenko *et al.*, 2013) and have high nitrogen-fixing ability ('Angelica', 'Zoriana', 'Veselka' and others) (Vozhegova, Tyshchenko, 2017).

The method of sowing alfalfa with row spacing of 15 cm and sowing rate of 8–10 million ha^{-1} for uncovered growing provides an increase in crude protein output by 27.4–36.0 and 30.4% – 12 million ha^{-1} compared to cover sowing under spring barley for grain has been scientifically substantiated (Petrychenko, Kvitko, 2010).

Scientists from around the world have established the dependence of crop production processes on the width of row spacing and soil-climatic conditions of growing. Thus, in the United States on sub-sandy soils of 'Sesil' the yield of alfalfa green mass increased with the narrow-row sowing method compared to the broad-row sowing method (Madhav *et al.*, 2020^{a}; Karbivska *et al.*, 2020; Tonkha *et al.*, 2021) and crude protein content remained unchanged with increasing row spacing (Stringer *et al.*, 1996). On clay soils in Bandeirantes, Pararana state (Brazil), no significant influence of row spacing (15, 20, 30, 40 cm) on plant height and alfalfa dry matter output was observed (Bellettini *et al.*, 1997; Karbivska *et al.*, 2019; Karpenko *et al.*, 2019), and under conditions of southern Serbia (Geren *et al.*, 2003) with the increase of row spacing were improved water balance and the number of generative organs (Madhav *et al.*, 2020[b]).

Based on literature analysis was not established a unanimous opinion concerning the width of alfalfa row spacing when growing for green fodder. Under conditions of climate change, this issue has become the subject and object of in-depth study of the life cycle of alfalfa new varieties in the Forest-Steppe of Ukraine.

The research aims to study alfalfa (*Medicago sativa* L.) yielding capacity depending on variety, seeding rates and row spacing.

Materials and methods

The field study was conducted during 2017–2019 in the experimental field of the department of field fodder crops, hayfields and pastures at the Institute of fodders and agriculture of Podillia NAAS of Ukraine.

The soil of the experimental field is grey forest, medium loamy by mechanical composition. The arable layer of soil (0–30 cm) contained 2.06% of humus (according to Tiurin), alkaline hydrolyzed nitrogen – 7.7 mg per 100 g of soil (according to Cornfield), movable phosphorus and metabolic potassium, respectively 14.2 and 8.0 mg per 100 g of soil (according to Chirikov), $pH_{sal.}$ – 5.9. Soil analysis was conducted in the Vinnytsia branch of SE Derzhgruntohorona at the Institute of soil protection of Ukraine.

The weather conditions in May-September 2017 were arid. The air temperature was 18.2 °C and the hydrothermal coefficient 0.68. In 2018–2019, air temperature during this period fell to 16.7–17.8 °C and the hydrothermal coefficient (HTC) increased by 1.21–1.25 (Fig. 1).

The technology of alfalfa growing was generally accepted for the Forest-Steppe of Ukraine. Predecessor – spring rye for grain. In the experiment was sown alfalfa varieties 'Rosana' (Forest-Steppe) and 'Angelica' (southern Steppe) which are included in the State Register of Plant Varieties Suitable for Growing in Ukraine. Superphosphate and potassium-magnesium were used as mineral fertilizers and lime was added according to hydrolytic acidity. Sowing was carried out in the third decade of April 2017 by the uncovered method. Alfalfa was sown by row method with row spacing of 12.5 and 25.0 cm at sowing rates of 4, 6, 8 million pcs ha^{-1} of similar seeds.

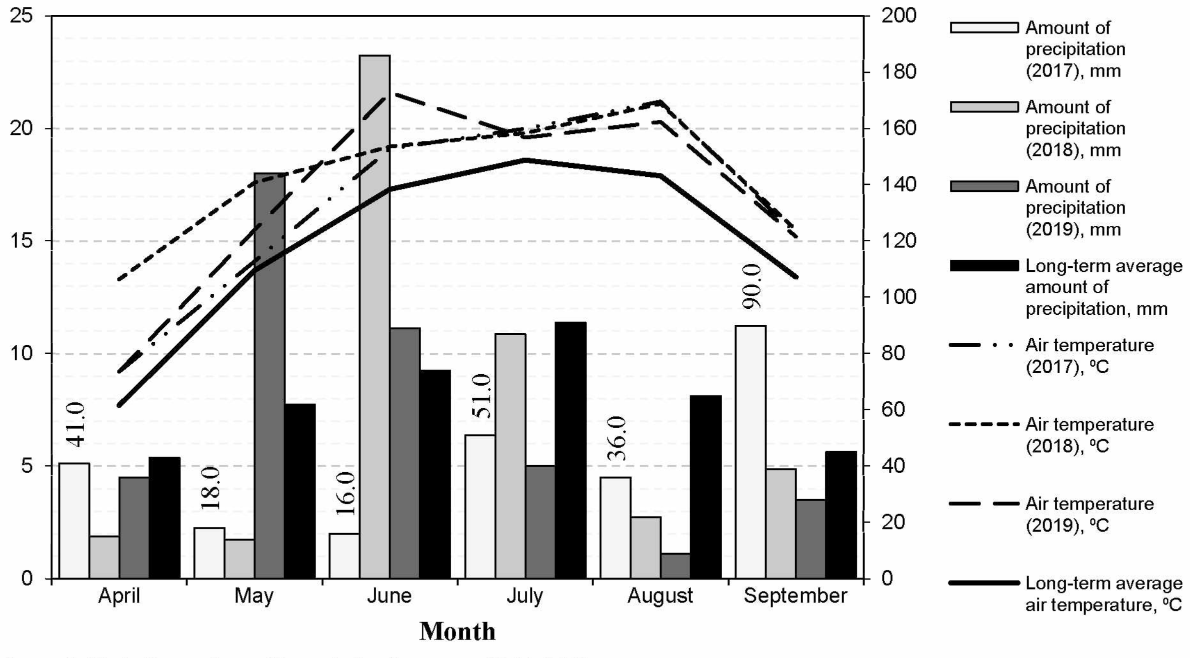

Figure 1. Hydrothermal conditions during the years 2017–2019

In the year of sowing, alfalfa was sprayed with herbicide Bazagran (a.m. bentazol, 3.0 l ha^{-1}) + Achiba (a.m. Hizalofol-P-ethyl, 50 g l^{-1}, Bayer) in a norm of 2.0 l ha^{-1} at alfalfa plant height of 12–14 cm. During the 2nd and 3rd years of life, alfalfa grasses were mowed at the beginning of the budding phase.

The research was carried out by the method of field experiments. The chemical composition of alfalfa dry matter was determined in a certified laboratory of the Institute of fodders and agriculture of Podillia NAAS.

Statistical and correlation-regression analysis of research results was conducted on a personal computer using modern packages of applied programs for mathematical processing MS Excel, Statistica 6.0 and appropriate methods for conducting field experiments (Dospekhov, 1985; Ushkarenko *et al.*, 2009).

Resuts and discussion

With the uncovered method of cultivation, alfalfa crops were infested with weeds, which took the largest share of crops in terms of botanical composition. The cropped grass was mainly represented by such weed species as *Raphanus raphanistrum, Chenopodium album, Thlaspi arvense, Setaria pumila* and others, which germinated at low average daily air temperature and inhibited the growth processes of the main crop. After spraying alfalfa crops in the year of sowing weeding decreased by 85–90%. Due to arid conditions of May and June, as well as uneven distribution of precipitation in July and August, alfalfa plants formed a bush and reached the stemming phase. Already in the first decade of September, it was in the phase of budding-beginning of flowering with a plant height of 29–33 cm, yield capacity of 8.39–8.88 and 2.17–2.26 t ha^{-1} of green mass and dry matter respectively.

During the second and the next years of life, to obtain high-quality plant material (green mass, hay) mowing of alfalfa grass was carried out at the beginning of the budding phase as harvesting in the flowering phase although provides a higher yield of green mass, but of low quality. It is worth noting that regrowth and formation of subsequent hay harvest depended on the timing of mowing and weather conditions.

After the restoration of vegetation in the second year of life alfalfa reached the beginning of the budding phase in 40 days. The grass was formed mainly due to the usage of productive moisture of the autumn-winter period but not from precipitations of April-May (29 mm). In the third year of life, the phase of budding began 5 days later after the restoration of vegetation in spring. It is explained by excessive moisture in May (144 mm, long-term norm of 63 mm). Therefore, there was a reduction in the time of green mass formation to 30–40 days, compared to 2018 – 37–42 days.

Optimization of row spacing from 25.0 to 12.5 cm. provided the highest yield capacity of alfalfa green mass. The studied varieties differed slightly in terms of green mass yield and realization of biological potential. The southern variety of alfalfa 'Angelica' adapted to the conditions of forest-steppe cultivation and in the third year of life provided the largest yield of green mass of 66.15 t ha^{-1} with sowing rates of 8.0 million ha^{-1} and row spacing of 12.5 cm. Variety 'Rosana' distinguished by the stability of green mass yield formation at the level of 58.33 t ha^{-1} (2018) and 61.13 t ha^{-1} (2019). With row spacing of 25.0 cm, the green mass yield was 53.66–56.05 t ha^{-1} for variety 'Rosana' and 51.10–60.20 t ha^{-1} for variety 'Angelica'.

The distribution of biomass between hay harvests differed over the years and amounted to 21.7–27.2% of total yield. The largest percentage difference was observed between the third and the fourth hay harvests – 5.5% and the smallest between the first – the third 1.3–2.3% in the second year of life. Opposite conditions were created for the formation of alfalfa green mass for the third year of life where the percentage of the first hay harvest was the highest – 31.6 and 14.7% for the fourth hay harvest.

The influence of factor "precipitation" increased the duration of the stalking phase in 2019, and therefore the beginning of plant budding was observed after 45 days. High yields of green mass in the first hay harvest were obtained by increasing the height of plants by 7.7–8.1 cm. compared to 2018 which was 69.2–71.9 ± 3.5 cm. Hence, we can state that alfalfa can form stable yields of green mass in compliance with mowing dates.

It is established that there is a strong positive correlation R = 0.731–0.742 between green mass yield formation and hydrothermal conditions. Correlation between obtained data are described by the following multiple regression equations:

$$y = 20.2316 + 0.0299\ x_1 - 0.5143\ x_2;\ R = 0.731 \quad (1)$$

where: y – green mass yield, t ha^{-1}; x_1 – precipitation, mm, x_2 – average daily air temperature, °C.

$$y = 14.7522 + 0.0205\ x_1 - 0.2222\ x_2;\ R = 0.742 \quad (2)$$

where: y – green mass yield, t ha^{-1}; x_1 – precipitation, mm, x_2 – length of daylight, hours. min.

In characterizing the nutritional value of alfalfa fodder, the dry matter content plays an important role, the indices of which were determined by hydrothermal conditions, seeding rates and row spacing. Obtained data are confirmed by scientists from different countries. When passing the stages of organogenesis, the dry matter content in plants increases and proportion of leaves decreases (Aksoy, Nursoy, 2010; Ayhan *et al.*, 2004) and the percentage of fibre increases compared to early stages of growth and development (Chatepa, 2012; Geren *et al.*, 2003; Homolka *et al.*, 2008; Yu *et al.*, 2003; Karpenko *et al.*, 2020).

During crop vegetation with the increase of daylight duration (14:23–16:19) and optimal hydrothermal conditions, dry matter content in alfalfa green mass increased from the first to the second hay harvests from 23.72–23.76 to 26.74–26.91% respectively. And with reduction of daylight duration and temperature lowering, in the third hay harvest dry matter decreased to 21.34–21.44 % and in the fourth – to 21.77–22.01%.

Under conditions of excessive moisture, dry matter content in the green mass of the first hay harvest of alfalfa was the lowest 18.52–19.27%, in the second hay harvest it gradually increased to 20.28–20.58%. With air temperature rising and uneven distribution of precipitation in the third hay harvest, the indices were already 21.62–22.06% and the largest ones were received in the fourth hay harvest – 27.32–27.52%.

It can be concluded that dry matter content was determined by hydrothermal conditions and the factors studied. With the increase of seeding rate from 4.0 to 8.0 million ha^{-1}, it decreased from 23.02 to 22.52% and increased with increasing row spacing from 22.62–22.83 to 22.82–22.94%, regardless of variety. Alfalfa variety 'Rosana' dominated in dry matter content by 0.16% (22.88%) over 'Angelica' variety – 22.72%.

It was found that twice the narrowing of row spacing contributed to dry matter yield increase by 0.63–2.04 t ha^{-1} at alfalfa seeding rates of 6.0–8.0 million ha^{-1}. At the same time, yielding capacity indices, regardless of variety, distinguished by stability, which for 'Rosana' variety amounted to 12.65–12.97 t ha^{-1}, and in sum for three years – 27.45 t ha^{-1} (Table 1).

Table 1. Accumulation of dry matter in the green mass of alfalfa (*Medicago sativa* L.) depending on sowing rates and row spacing, t ha^{-1}

Row spacing, cm (factor C)	Seeding rate, million ha (factor B)	Variety 'Rosana' (factor A)				Variety 'Angelica'			
		Vegetation years			Sum for 3 years	Vegetation years			Sum for 3 years
		2017	2018	2019		2017	2018	2019	
12.5	4.0	1.96	12.05	12.21	26.22	1.81	11.50	13.12	26.43
	6.0	1.83	12.65	12.97	27.45	1.58	12.42	13.81	27.81
	8.0	2.26	12.06	12.89	27.21	2.17	11.64	13.79	27.60
25.0	4.0	1.62	12.44	12.59	26.65	1.17	11.84	13.18	26.19
	6.0	1.68	12.49	12.65	26.82	1.27	11.72	13.14	26.13
	8.0	1.21	12.46	11.72	25.39	1.00	11.90	12.66	25.56
LSD_{05}	2017: A – 0.04; B – 0.05; C – 0.07; 2018: A – 0.11; B – 0.10; C – 0.12; 2019 A – 0.09; B – 0.09; C – 0.11.								

Southern ecotype of alfalfa 'Angelica' provided maximum dry matter output of 13.81 t ha^{-1} at the third year of life at a seeding rate of 6.0 million $^{-1}$ha and row spacing of 12.5 cm or was 6.5% higher than 'Rosana' and 11.2% compared to the second year of life. During three years of grass usage, the output of dry matter was 27.81 t ha^{-1} and there was a tendency to reduction of dry matter output in other variants.

It is known that fodder quality is one of the yielding capacity indices of cattle where alfalfa is the main component in the diet of animals in the form of green mass, hay or haylage.

Content of crude protein, neutral and acid-detergent fibre was determined in the dry matter of alfalfa green mass collected at the beginning of the budding phase. With the reduction of daylight length (period of the 3–4th hay harvest formation) was established regularity of increase in crude protein content from 21.11 to 23.47%. In the first and second hay harvests, there was a decrease in the percentage of crude protein 19.79–20.31 and 17.83–20.14% respectively, which is explained by increased dry matter content in the green mass. Regardless of the width of row spacing, the content of crude protein in variety 'Rosana' increased by 0.38–0.53 and in variety 'Angelica' by 0.63–0.79% – (Fig. 2, 3).

The southern ecotype of alfalfa variety Anzhelika provided the highest indicators during the third year of vegetation (13.81 t ha^{-1}) under the seeding rates of 6.0 million seeds ha^{-1} and row spacing of 12.5 cm. Over three years of mowing the dry matter yield were 27.81 t ha^{-1}. Under other seeding rates and changes in-row the spacing, there was observed a tendency towards the decrease in the dry matter yield.

Agricultural and ecological conditions and the elements of cultivation technology influenced the crude protein content, neutral- and acid-detergent fibre content over the years of vegetation of alfalfa of different dormancy classes. During the second year of vegetation with a reduction in the daylight duration and optimal moisture supply of plants at the time of formation of the third and fourth harvests, the crude protein content was the highest, which was 22.10–23.47 and 21.11–22.40%, respectively. In the first and second harvests, the percentage of crude protein in the dry matter of alfalfa decreased significantly and amounted to 20.18–20.25 and 18.08–18.32% (Fig. 2).

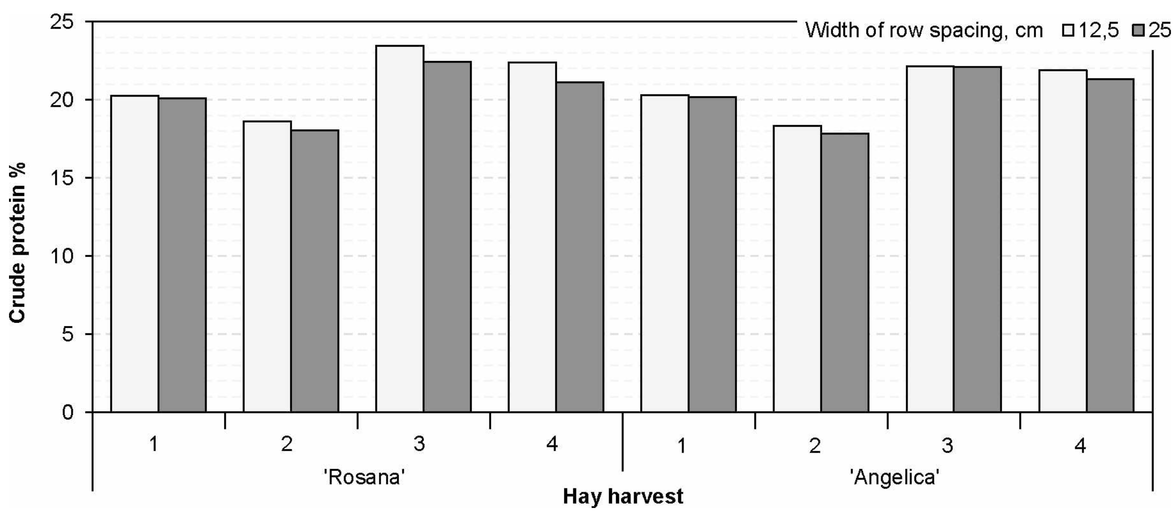

Figure 2. The content of crude protein in alfalfa dry matter of varieties 'Rosana' and 'Angelica' depending on hay harvest and row spacing width for the second year of life, %

In our opinion, due to dense grass formation of the crop, evaporation of moisture decreased with narrowing of row spacing, and conditions for nitrogen transformation in plants improved. Therefore, the content of crude protein in alfalfa of varieties 'Rosana' and 'Angelica' differed little between them and averaged 20.68–21.37 and 20.67–21.07% respectively. In particular, narrowing of row spacing increased crude protein content by 0.55–0.58% and the factor "variety" provided a difference between ecotypes of 0.15% in favour of the 'Rosana' variety.

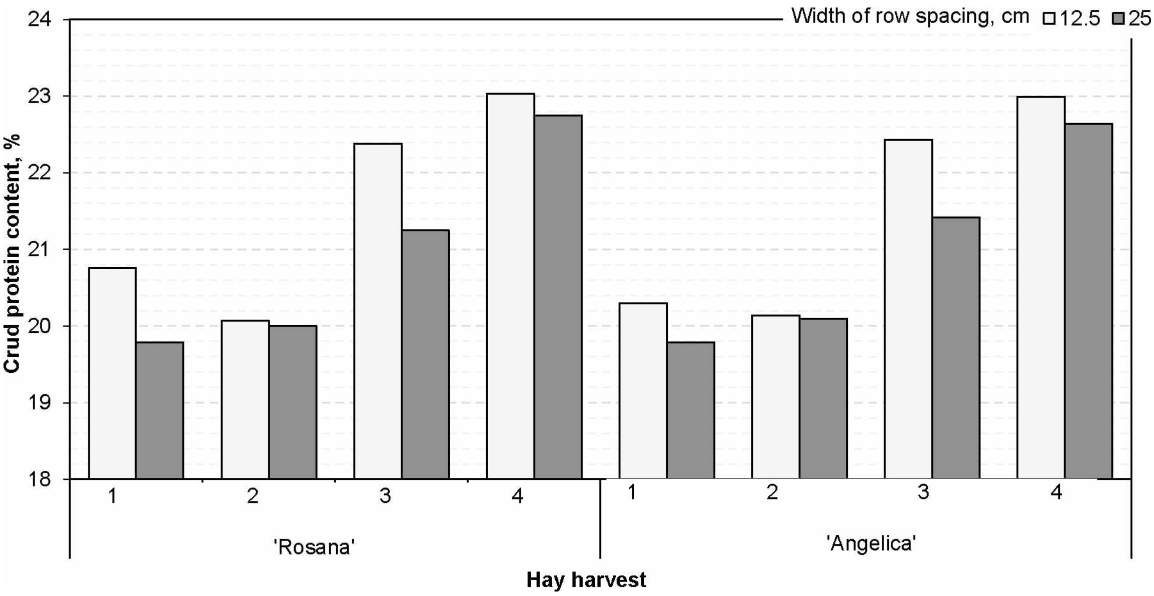

Figure 3. The content of crude protein in alfalfa dry matter of varieties 'Rosana' and 'Angelica' depending on hay harvest and row spacing width for the third year of life, %

The highest output of crude protein (5.86–5.87 t ha^{-1}) the varieties provided at sowing rates of 6.0 million ha^{-1} and sowing with row spacing of 12.5 cm. For three-year usage of alfalfa grass at the beginning of budding phase with an increase in sowing rate from 6.0 to 8.0 million ha^{-1} and twice increase of row spacing width was registered the tendency to reduction of crude protein output in both varieties from 5.40–5.55 to 5.37–5.39 t ha^{-1} (Fig. 4).

According to the practice and research of scientists in the system of evaluation of fodder carbohydrate nutrition in the diets of ruminants, it is advisable to control the content of neutral-detergent fibre (NDF) and acid detergent fibre (ADF). The level of NDF in fodder is related to dry matter consumption and ADF is related to digestibility. The authors believe that for highly productive cows (40 kg day^{-1} of milk) it is recommended to optimize rations with a content of NDF not more than 32%, and for cows with lower-yielding capacity (20 kg day^{-1} of milk), so as not to minimize fodder consumption – not higher than 44% (Ruban *et al.*, 2018).

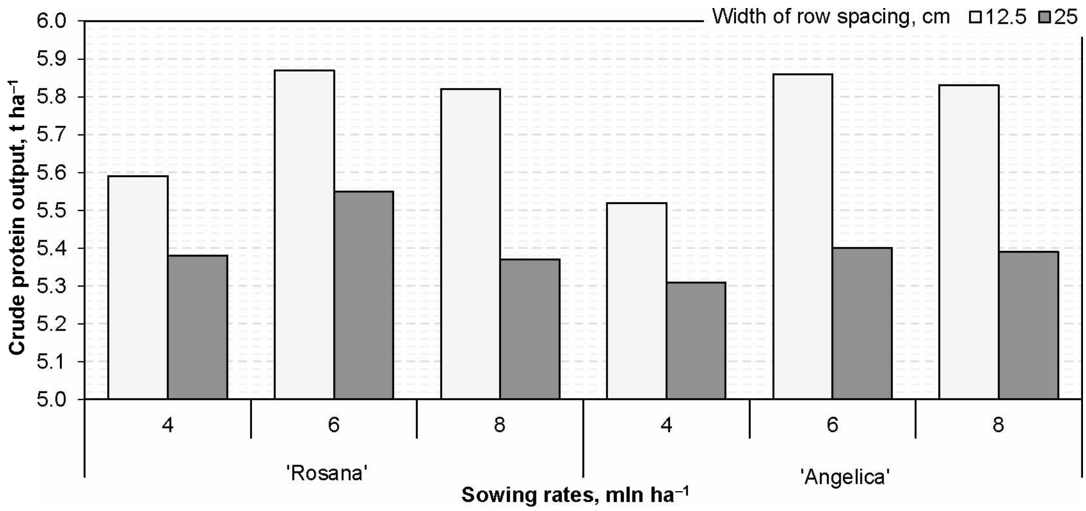

Figure 4. The output of alfalfa crude protein for varieties 'Rosana' and 'Angelica', depending on sowing rates and row spacing width for three years of life, t ha^{-1}

Scientists from province Gansu (Nan *et al.*, 2019) and Huang-Huai-Hai, Shandong Province (China) (Lü *et al.*, 2019) found a tendency to decrease the content of neutral and acid-detergent fibre when increasing seeding rate and narrowing row spacing from 40 to 15 cm. They received the highest content of raw protein 20.06% at a sowing rate of alfalfa 16 kg ha^{-1}.

According to data of scientists (Nan *et al.*, 2019), the lowest content of neutral detergent fibre (31.74%) and acid detergent fibre (25.64%) was at alfalfa seeding rates of 24 kg ha^{-1} with row spacing of 10 and 15 cm, others proved the dependence of indices on phases of alfalfa growth and development (Mysenko *et al.*, 2019).

Our data are confirmed by the results of foreign and domestic scientists and for variety 'Rosana' they are within limits from 29.11 to 33.97% NDF and 22.21–24.64% ADF, depending on the sequence of mowing. Alfalfa variety 'Angelica', from the first to the fourth hay harvest, provided indices at the level of 29.01–31.47% of NDF and 21.32–23.01% of ADF. The highest percentage of NDF and ADF was observed on alfalfa grass of the second year of life and was within limits of 30.72–34.91 and 23.02–24.60% respectively. For the third year of alfalfa grass usage, the content of NDF and ADF in dry matter decreased to 27.09–33.03 and 19.53–24.18% respectively (Fig. 5).

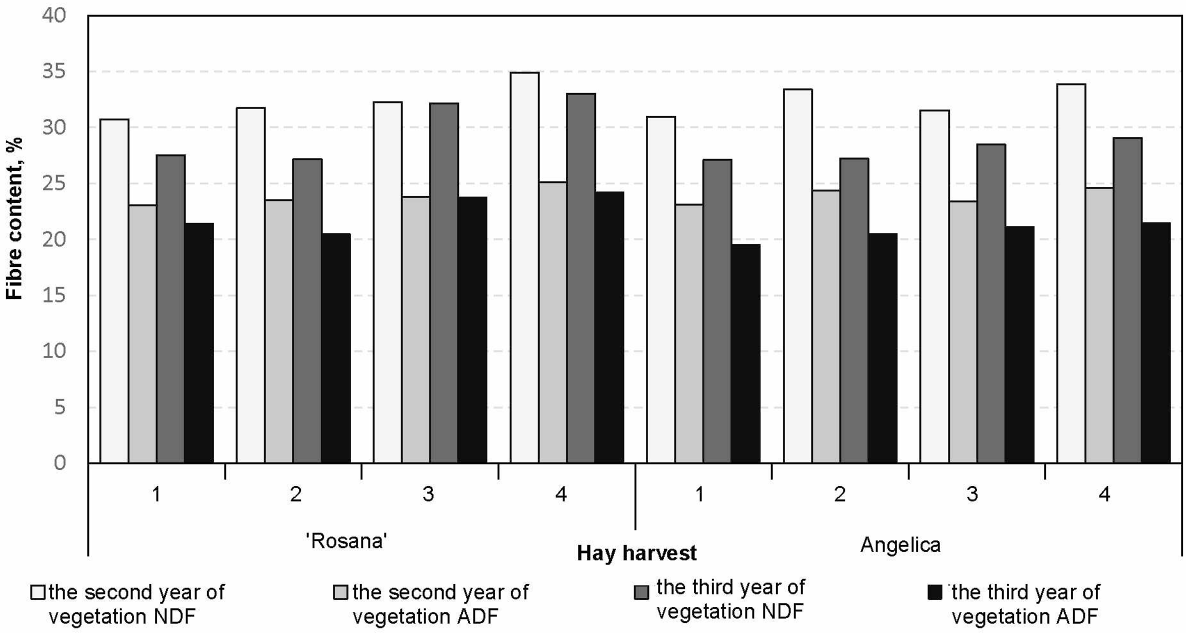

Figure 5. Content of neutral and acid detergent fibre in dry matter of alfalfa green mass depending on variety and hay harvest, %

Conclusion

Alfalfa (*Medicago sativa* L.) of southern ecotype, variety 'Angelica' adapted to the soil and climatic conditions of the Forest-Steppe and was not inferior to variety 'Rosana' in terms of yielding capacity. The content of alfalfa crude protein in the phase beginning of budding averaged in varieties 'Angelica' and 'Rosana' 21.07–21.37% for sowing with row spacing of 12.5 cm and 20.67–20.68% – 25.0 cm. Narrowing of row spacing contributed to the increase of crude protein content by 0.55–0.58%. The content of neutral and acid-detergent fibre during two years of life averaged 31.18 and 23.15% in variety 'Rosana' and 30.19 and 22.26% in variety 'Angelica' at a sowing rate of 6.0 million pcs ha^{-1} and sowing with row spacing of 12.5 cm. In terms of fodder yielding capacity, alfalfa varieties 'Angelica' and 'Rosana' were equivalent and provided dry matter output of 27.45–27.81 and crude protein output of 5.86–5.87 t ha^{-1}.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

MK – study conception and design, drafting of the manuscript;
GD – an author of the idea, guided the research;
AB – analysis and interpretation of data and is the corresponding author;
NG, LB – acquisition of data, drafting of the manuscript;
VM – performed the literature data analysis and discussion of the results;
SS, VO – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

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