FORAGE YIELD AND NUTRITIONAL VALUE OF ALFALFA IN RELATION TO CUTTING HEIGHT, STAGE OF MATURITY AND CLIMATIC CHANGES

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Abstract. In the central Serbian region, a three-year study without irrigation examined the influence of cutting height (6, 10, and 15 cm), maturity stage, and agroecological conditions on the yield and nutritional value of alfalfa. Variable agroecological conditions caused a yield difference of 10.32 t ha^{-1}, from an average of 37.77 t ha^{-1} in the first year to 48.09 t ha^{-1} in the second year, across all tested mowers. The yield decreased with the increase in cutting height and increased with the progress of the maturity stage. With the increase in cutting height, the crude protein (CP) content increased, while the crude fiber (CF) content decreased. At a cutting height of 15 cm, the crude protein (CP) content was significantly ($p \leq 0.05$) higher than at a cutting height of 6 cm. A cutting height of 15 cm had a significantly ($p \leq 0.05$) lower crude fiber (CF) content of alfalfa compared to cutting heights of 6 and 10 cm. The crude protein (CP) content was significantly ($p \leq 0.05$) higher during the budding phase compared to the full bloom phase. The strongest negative correlation ($p \leq 0.001$) was observed between crude protein (CP) and crude fiber (CF) content (r=-0.957 to r=-0.944) and between yield and crude protein content (r=-0.896 to r=-0.878). There are no statistically significant differences ($p \geq 0.05$) in the content of calcium (Ca), phosphorus (P) and potassium (K), but a trend of increase or decrease has been determined.
Keywords: *mower, alfalfa cutting, crude protein, crude fiber, agroecological conditions*

Introduction

The high crude protein content (18-25%) and lower crude fiber content (25-28%) in the early stages of maturity make alfalfa one of the highest-quality forage crop. Forage with a high crude protein content also possesses significant energy value (Zhang et al., 2018). Lauzon et al. (2019) state that temperature affects the nutritional value of animal feed. Due to adverse climatic changes characterized by rising temperatures and increased atmospheric CO_2 emissions, Thivierge et al. (2016) predict a decrease in alfalfa yield and nutritional value. Under global warming, drought, and adverse climatic changes, the need for alfalfa irrigation increases (Alemayehu et al., 2020). Therefore, developing a strategy to expand forage cultivation areas is essential (Tan and Yolcu, 2021). Mowing operation significantly affects the yield and nutritional value of alfalfa (Jin et al., 2021; Kim et al., 2021). Testa et al. (2011) state that mowing green mass in dry land conditions showed a significant decrease in yield (about 30%). Stanisavljević et al. (2021) state that the proper selection of the appropriate type of mower significantly affects the efficiency of alfalfa

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hay preparation. Rotary mowers with an optimal operating speed of up to 15 km h^{-1} are the most common in use (Karimi et al., 2021). The mowing time has a significant impact on the yield of green mass (Abdushaeva, 2020) and the quality of forage (Bumb et al., 2016). Cutting height, phenological stage of maturity and climatic conditions have the main influence on forage quality (Gashaw, 2015; Wood et al., 2019; Sayar et al., 2022) and significantly influence the composition of alfalfa nutrients and mineral elements (Sezmis and Gursoy, 2020; Chang et al., 2022). With the progression of the maturity stage from the budding stage to the full bloom stage, statistically significant differences were found for all the examined traits (Sayar et al., 2022). The content of crude protein and crude ash decreases with the progression of the maturity stage to the full bloom stage. At the same time, the crude fiber content increases significantly (Palmonari et al., 2014; Min, 2016; Tlahig et al., 2021; Tiruneh et al., 2022; Bélanger et al., 2023), due to the reduction in the number of leaves and the increase in the proportion of the stem in the mass (Stavarache et al., 2015; Atis et al., 2019). Cutting height significantly affects alfalfa yield and quality. Uncertainties still exist about the optimal mowing height and its interaction with harvest time and agroecological conditions (Jungers et al., 2020). Mowing at a low height (5-10 cm) achieves high yields (up to the full bloom stage), but the nutritional value of the forage is low because the crude protein content decreases significantly (Atis et al., 2019; Kim et al., 2021; Basbag et al., 2023; Bélanger al., 2023). At lower cutting heights, an increased content of crude ash (Digman et al., 2013), a source of mineral matter, is observed. Mowing alfalfa at a higher cutting height (15-20 cm) leads to a significant decrease in yield and an increase in the nutritional value of the forage (Kim et al., 2021; Chang et al., 2022). The content and concentration of calcium (Ca), phosphorus (P) and potassium (K) affect the nutritional value of alfalfa. Calcium is the primary mineral in the nutrition of dairy cows. Phosphorus with calcium has primary importance for skeletal structure, while potassium plays a key role in muscle function and nerve transmission. Their deficiency reduces the nutritional value of animal feed (Albu et al., 2012). The content of Ca increases with the progress of the maturity stage, while the content of P and K decreases (Bumb et al., 2016; Karayilanli and Ayhan, 2016; Basbag et al., 2023).

Examining the influence of cutting height, maturity stage, and climatic conditions on the yield and nutritional value of alfalfa, Sezmis and Gursoy (2020), Kim et al. (2021), report an optimal cutting height of 10 cm when mowing alfalfa. Considering the correlation between yield and nutritional value of alfalfa, Lauzon et al. (2019), Tlahig et al. (2021), Chang et al. (2022), Sayar et al. (2022), and Tiruneh et al. (2022) recommend mowing alfalfa at the beginning of flowering (10% bloom) as the most suitable time. Mowing at the beginning of flowering in the ago-ecological conditions of Southeast Europe significantly increases the nutritional value of alfalfa (Katanski et al., 2020). The study aims to determine the optimal cutting height and maturity stage, which gives a high yield and nutritional value of alfalfa, under the agroecological conditions of the research. The results obtained will help producers in organizing production.

Materials and methods

To examine the influence of cutting height, phenological stage of maturity and agroecological conditions on the nutritional value of alfalfa, three-year research was conducted in central Serbia in the Kruševac region (43^{o} 34' 30"N; 21^{o} 30' 55"E) where alfalfa is cultivated in specific extensive dryland conditions without organized irrigation

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during the entire growing season. It is a region with a tradition of using alfalfa in cow nutrition. Alfalfa of the Banat VS variety was mowed in a three-cuts growing system. The variety is drought tolerant, and under irrigation conditions achieves a high yield of green mass of 80-100 t ha^{-1}. In extensive cultivation conditions (without irrigation), the yield is 45-60 t ha^{-1}. Tests were carried out at theoretical cutting heights of 6, 10 and 15 cm during three phenological phases of alfalfa maturity: budding phase, early bloom phase (10% bloom) and full bloom phase. The alfalfa was in its third (2019), fourth (2020) and fifth (2021) years of cultivation. Mowing was done with three types of mowers: self-propelled oscillatory mower-conditioner Hesston 8400 (Type A) with a working width of 4,270 mm, rotary mower Pöttinger cat 185 (Type B) with two drums and a working width of 1,850 mm, and rotary mower JF Stoll SB 200 (Type C) with five discs, a working width of 2000 mm. The rotary mowers were aggregated with the IMR Rakovica tractor with an installed power of 48 kW. Self-propelled oscillatory mower-conditioner Hesston 8400 (Type A) outperforms rotary mowers (Type B and Type C) because it has a crushing device (two rollers) that crushes and splits the stems. The drying speed of the stem (high fiber content) and leaf (high protein content) is uniform and the nutritional value of alfalfa is preserved. Using the random block system (each sample was divided into three parts, which represented a repetition), the average yield of green mass was determined for all three cutting heights (6, 10 and 15 cm) during the tested maturity stages. The collected green mass of alfalfa was measured from an area of one square meter diagonally across the plot in the swath width and converted to an area of one hectare (Al-Gaadi, 2018). The samples were measured using an electronic analytical balance Mettler Toledo JS1603C. The operating speed of the tested mowers was determined by the chronometric method using a digital chronometer TFA Dostmann Triple Time KSL-Digitaler 3-fach Timer (Al-Gaadi, 2018). The movement time of the machines on a 100 m road was measured. The working speed and cutting height were determined in four tests with three repetitions each for cutting heights of 6, 10 and 15 cm in all maturity stages. The average for each trial was determined based on the obtained parameters. Using the random sample method (each sample was divided into four parts, which represented a repetition), the content of crude protein (CP), crude fiber (CF), crude ash (Cash), calcium (Ca), phosphorus (P) and potassium (K) was determined using appropriate laboratory methods. The crude protein content was determined according to the Kjeldahl method (Thiex et al., 2009), by decomposing organic matter with concentrated sulfuric acid (H_2SO4) in the presence of catalysts (K_2SO_4 and $CuSO_4$) that accelerate the reaction. The obtained values are multiplied by the coefficient 6.25. The crude fiber content was determined by the method of treating samples with solutions of sulfuric acid (H_2SO4) and sodium hydroxide (NaOH) of standard concentration (Thiex et al., 2009). The crude ash content was determined by the method (Thiex et al., 2012) of burning the samples at a temperature of 600 º for 2 hours. After that, the sample is cooled and weighed immediately. The content of calcium and phosphorus was determined by standard spectrometric methods (Albu et al., 2012), with detection limits of 10 mg/kg for Ca and 50 g/kg for P. To measure the potassium concentration, the samples were finely dried in an oven set to 70 °C, and then wet digested (Mertens, 2005). The obtained experimental data were processed using the software package (R Core Team, 2018). The analysis of variance (ANOVA F-test) was applied to determine the influence of the factors and Tukey's multiple range test and Pearson's correlation coefficient were used to test the effects of treatment using Minitab Inc. Version 16.1.0. State College, PA, USA (https://www.minitab.com/en-us/).

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Climatic data of the experimental area

In the Balkan region, alfalfa is mostly grown under non-irrigated conditions. The amount of distribution of precipitation and monthly temperatures is similar in Bulgaria (Vasileva and Kostov, 2015), while in Greece the ratio of precipitation and temperature at the time of first mowing is even more unfavorable (Karamanos et al., 2009). Due to climate change, the length of warm periods is increasing in Hungary. A study by Szabo et al. (2023) predicts record-high temperatures in the coming period. As our research was carried out in agroecological conditions without irrigation, temperatures and precipitation had a decisive influence on the yield and nutritional value of alfalfa. Average monthly values of temperature and amount of precipitation for the area where the research was carried out, compared to the multi-year average, are shown in *Table 1*.

Table 1. *Mean monthly air temperatures (ºC) and monthly amount of rainfall (mm)*

Year	**2019**		**2020**		**2021**		**1989-2018**	
Month	**Tmean (ºC)**	**Rainfall (mm)**	**Tmean (ºC)**	**Rainfall (mm)**	**Tmean (ºC)**	**Rainfall (mm)**	**Tmean (ºC)**	**Rainfall (mm)**
March	9.2	24.1	7.7	92.3	5.2	85.7	7.1	52.3
April	13.0	59.2	11.8	41.6	9.6	59.7	12.8	60.5
May	14.9	73.5	15.9	103.1	16.9	57.2	16.5	67.7
June	22.6	67.5	19.7	130.8	21.6	33.7	19.9	68.5
July	22.7	47.1	21.6	187.5	24.6	124.8	22.4	59.8
August	23.1	83.1	22.0	74.3	22.4	20.0	21.3	47.2
September	18.5	4.8	18.8	15.4	17.5	39.5	17.1	52.0
Mean/total	**17.71**	**359.3**	**16.78**	**645.0**	**16.83**	**420.6**	**16.73**	**408.00**

The average value of the air temperature was the highest in the first year of the study (17.71 ºC) which was the warmest in relation to the multi-year average shown, and the lowest in the second year (16.78 ºC). The amount of precipitation during the research had a direct impact on the yield of alfalfa. Significant deviations in the amount of precipitation during the research years and about multi-year average values were recorded. The minimum rainfall of 359.3 mm was recorded in the first year. At that time, the minimum alfalfa yields were achieved with all types of mowers in all phenological stages of maturity, for the tested cutting heights. The maximum amount of precipitation of 645.0 mm was in the second year. Compared to the first year, it had a significant impact on the increase in alfalfa yields.

Results and discussion

By applying the ANOVA-F test for four-factor analysis, the A factor showed a significant ($p \leq 0.05$) influence on the yields of green mass. Factor B had a significant ($p \leq 0.05$ or $p \leq 0.01$) influence on yields of green mass (YGM), crude protein (SP), crude fiber (CF), and crude ash (Cash). Factor C had a significant ($p \leq 0.01$ or $p \leq 0.001$) effect on yields of green mass (YGM), crude protein (SP), crude fiber (CF), and crude ash (Cash). The D factor had a significant effect ($p \leq 0.05$ or $p \leq 0.001$) on the yields of green mass (YGM), crude protein (SP), crude fiber (CF), and crude ash (Cash) (*Table 1*). For other influences and all interactions, the tested factors did not have a significant effect ($p \geq 0.05$) on the tested properties (*Table 2*).

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Table 2. *ANOVA by Type of mower (A), Hcut (B), Stage of maturity (C), Yield (D), with regard to: yields of green mass (YGM), crude protein (SP), crude fiber (CF), crude ash (Cash), calcium (Ca), phosphorus (P) and potassium (K)*

Source-Faktor	d.f	YGM	SP	CF	Cash	Ca	P	K
A	2	*	ns	ns	ns	ns	ns	ns
B	2	**	*	*	*	ns	ns	ns
C	2	**	***	***	**	ns	ns	ns
D	2	***	*	*	*	ns	ns	ns
Interactions								
AxB	4	ns	ns	ns	ns	ns	ns	ns
AxC	4	ns	ns	ns	ns	ns	ns	ns
AxD	4	ns	ns	ns	ns	ns	ns	ns
BxC	4	ns	ns	ns	ns	ns	ns	ns
BxD	4	ns	ns	ns	ns	ns	ns	ns
CxD	4	ns	ns	ns	ns	ns	ns	ns

d.f. – degrees of freedom; F test, statistical significance levels: *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$, ns – not significant $p \geq 0.05$

Unfavorable agroecological conditions (primarily in the first year of testing), which were reflected in a small amount of precipitation, influenced a significant decrease in yield in all types of mowers in all stages of maturity, at cutting heights of 6, 10 and 15 cm (*Table 3*). The maximum yield of alfalfa was achieved in the second year of the study. With the increase in cutting height, the yield decreased. At the same time, with the progression of the alfalfa phenological maturity stage, the yield increased. The maximum yields of alfalfa green mass were achieved by: mower B in the second year (2020) of the test at a cutting height of 6 cm (51.36 t ha^{-1} during the beginning of flowering phase (10% bloom) and 52.38 t ha^{-1} during the full bloom phase (100% bloom)), and mower C of 51.73 t ha^{-1} in the second year (2020) of the test at a cut height of 6 cm during the full bloom phase (100 % bloom). Minimum yield values of 32.83 t ha^{-1}, at a theoretical cutting height of 15 cm, were achieved by mower A in the first year (2019) of the test during the budding phase. The yield height in the phenological phase of full bloom was significantly higher ($p \leq 0.05$) than the yield height during the budding phase. There was no significant variation in yield between the phenological phase of full bloom and the phase of the beginning of flowering (10 % bloom) in all types of tested mowers during the test. The achieved results of alfalfa yield in our research are comparable to the results of studies (Stavarache et al., 2015; Atis et al., 2019; Kim et al., 2021) which state that the total alfalfa yield is higher when mowing is carried out in the full bloom phase with a low cutting height (5 to 10 cm).

The results of our tests prove that the cutting height and the phenological stage of maturity significantly influence the nutritional value of alfalfa. With an increase in the cutting height, an increase in the crude protein content is observed. At a cutting height of 15 cm, the crude protein (CP) content was significantly ($p \leq 0.05$) higher than at a cutting height of 6 cm in all three types of tested mowers (*Table 4*). The influence of the phenological stage of maturity was reflected in the fact that the crude protein (CP) content was significantly ($p \leq 0.05$) higher during the budding phase compared to the full bloom phase. The maximum crude protein contents were achieved in the second year (2020) of the research: mower A during the budding phase (22.54% at a cutting height of 15 cm, and 21.71% at a cutting height of 10 cm), mower C (21.89% at a cutting height of 15 cm

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during the budding phase) and mower B (21.77% at a cutting height of 15 cm during the budding phase). The minimum content of 14.06% was achieved by mower B at a cutting height of 6 cm in the first year (2019) during the full bloom phase. The low concentration of crude protein (CP) is a consequence of the influence of unfavorable climatic conditions (low precipitation). The results obtained are consistent with those reported by Xu et al. (2021).

Table 3. *Average yields of green mass of alfalfa (t ha^{-1}) depending on cutting height (Hcut) and phenological stage of maturity*

Type of mower	**Hcut** (cm)	**Stage of maturity**	**Yield** (t ha^{-1})		
			Year 1	**Year 2**	**Year 3**
A	**6**	**budding**	36.78^{bC}	47.25^{bA}	39.63^{bB}
		10% bloom	39.13^{aC}	49.50^{aA}	41.53^{abB}
		full bloom	40.25^{aC}	50.83^{aA}	42.60^{aB}
	10	**budding**	34.70 ^{cC}	44.55^{cA}	37.48^{cB}
		10% bloom	37.03^{bC}	46.83^{bA}	39.60^{bB}
		full bloom	38.30^{aC}	48.05^{aA}	40.75^{aB}
	15	**budding**	32.83^{bB}	42.28^{bA}	35.55^{bB}
		10% bloom	35.10^{aB}	44.43^{aA}	37.38^{aB}
		full bloom	36.15^{aB}	45.86^{aA}	38.40^{aB}
B	**6**	**budding**	38.73^{bC}	49.15^{bA}	41.45^{bB}
		10% bloom	40.83^{abC}	51.35^{abA}	43.28^{aB}
		100% bloom	41.75^{aC}	52.38^{aA}	43.95^{aB}
	10	**budding**	36.88^{cC}	47.28^{bA}	39.73^{bB}
		10% bloom	38.90^{bC}	49.35^{aA}	41.58^{abB}
		full bloom	40.05^{aC}	50.40^{aA}	42.68^{aB}
	15	**budding**	35.08^{bC}	45.10^{cA}	37.88^{bB}
		10% bloom	36.95^{abC}	47.60^{bA}	39.98^{aB}
		full bloom	37.88^{aC}	48.78^{aA}	40.80^{aB}
C	**6**	**budding**	38.18^{bB}	48.55^{bA}	40.63^{bB}
		10% bloom	40.13^{aB}	50.83^{aA}	42.50^{aB}
		full bloom	41.03^{aB}	51.73^{aA}	43.48^{aB}
	10	**budding**	36.50^{cC}	46.60^{cA}	39.00^{cB}
		10% bloom	38.35^{bC}	48.93^{bA}	40.85^{bB}
		full bloom	39.68^{aC}	50.28^{aA}	41.80^{aB}
	15	**budding**	34.60^{bC}	44.73^{bA}	37.15^{bB}
		10% bloom	36.60^{aC}	47.08^{aA}	39.25^{aB}
		full bloom	37.45^{aC}	48.73^{aA}	40.00^{aB}

Type A - self-propelled oscillatory mower-conditioner; Type B - rotary mower with drums; Type C - rotary mower with discs; Tukey's multiple range test: $p \leq 0.05$, small letters a, b, c for the column, capital letters A, B, C for the row

In contrast to the crude protein content, the cutting height of 15 cm had a significantly ($p \leq 0.05$) lower crude fiber (CF) content of alfalfa compared to cutting heights of 6 and 10 cm. Crude fiber content during the budding phase was significantly ($p \leq 0.05$) lower compared to the full bloom phase. The minimum crude fiber content of 23.06% was recorded with mower A at a cut height of 15 cm during the budding phase in the second year (2020). The maximum value of crude fiber content of 35.07% was achieved by

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mower B at a cutting height of 6 cm during the full bloom phase in the first year (2019) of the test. There were no significant ($p \leq 0.05$) variations in the crude ash (Cash) content under the influence of cutting height, phenological stage of maturity and climatic conditions during the study. The crude ash content is higher in the initial stages of maturity, and then decreases in the full bloom stage, which is also reported in the studies of Karayilanli and Ayhan (2016), Tlahig et al. (2021), and Tiruneh et al. (2022). The results of this study are consistent with the findings of Kim et al. (2021), that increasing the cutting height increases the crude protein content while decreasing the crude fiber and crude ash content. As with the results (Testa et al., 2011; Gashaw, 2015; Karayilanli and Ayhan, 2016; Tlahig et al., 2021; Xu et al., 2021; Chang et al., 2022; Horvat et al., 2022; Sayar et al., 2022; Bélanger et al., 2023) which prove that with the progression of the maturity stage, the crude protein content decreases, while the crude fiber content increases, which affects the nutritional value of alfalfa. Applying Tukey's multiple range test for the influence of cutting height, stage of maturity and year on the content of calcium (Ca), phosphorus (P) and potassium (K), no statistically significant difference ($p \geq 0.05$) was found, but a trend of increase or decrease was determined (*Table 5*).

Table 4. *Effect of cutting height and stage of maturity of tested mowers (type A, B, C) on the chemical composition of alfalfa*

	Hight (cm)	Stage of maturity	CP %			CF %			Cash %		
			Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
A	6	budding	18.03^{aA}	19.42^{aA}	18.39^{aA}	28.83^{cA}	26.58^{cB}	28.34^{cA}	8.26^{aA}	8.62^{aA}	8.44^{aA}
		10% bloom	16.35^{bB}	18.61^{bA}	16.71^{bB}	30.62^{bA}	28.65^{bB}	30.41^{bA}	8.08^{aA}	8.20^{aA}	8.17^{aA}
		full bloom	14.28^{cB}	16.73^{cA}	14.88^{cB}	34.18^{aA}	31.41^{aB}	33.62^{aA}	7.85^{aA}	8.11^{aA}	8.04^{aA}
	10	budding	18.65^{bB}	21.71^{bA}	19.35^{bB}	26.63^{cA}	24.92^{cB}	26.28^{cA}	7.90^{aA}	8.10^{aA}	8.03^{aA}
		10% bloom	17.91^{bB}	20.52^{bA}	18.23^{bB}	29.47^{bA}	27.26^{bB}	29.36^{bA}	7.75^{aA}	7.96^{aA}	7.77^{aA}
		full bloom	15.45^{aB}	18.50^{aA}	16.45^{aB}	33.25^{aA}	30.65^{aB}	32.78^{aA}	7.33^{bA}	7.61^{aA}	7.54^{aA}
	15	budding	19.88^{bB}	22.54^{aA}	20.60^{bB}	25.96^{cA}	23.06^{cB}	25.12^{cA}	7.53^{aA}	7.65^{aA}	7.60^{aA}
		10% bloom	18.69^{bB}	21.65^{aA}	19.31^{bB}	28.98^{bA}	26.21^{bB}	28.23^{bA}	7.28^{aA}	7.40^{aA}	7.33^{aA}
		full bloom	16.98^{bB}	18.66^{aA}	17.52^{bB}	31.48^{aA}	29.87^{aB}	31.18^{aA}	7.10^{aA}	7.26^{aA}	7.17^{aA}
B	6	budding	17.74^{aB}	19.08^{aA}	18.02^{aB}	29.46^{cA}	27.43^{cB}	28.62^{cA}	8.12^{aA}	8.43^{aA}	8.25^{aA}
		10% bloom	16.16^{bB}	18.25^{bA}	16.48^{bB}	31.77^{bA}	29.34^{bB}	31.11^{bA}	7.90^{aA}	8.16^{aA}	8.03^{aA}
		full bloom	14.06^{cB}	16.20^{cA}	14.22^{cB}	35.07^{aA}	32.68^{aB}	34.10^{aA}	7.39^{aA}	7.91^{aA}	7.72^{aA}
	10	budding	18.30^{aB}	21.05^{aA}	18.82^{aB}	27.94^{cA}	26.23^{cB}	27.24^{cA}	7.75^{aA}	7.83^{aA}	7.79^{aA}
		10% bloom	17.62^{bB}	20.18^{bA}	17.86^{bB}	30.96^{bA}	28.10^{bB}	30.57^{bA}	7.54^{aA}	7.65^{aA}	7.60^{aA}
		full bloom	15.18^{cB}	17.85^{cA}	15.79^{cB}	33.62^{aA}	31.56^{aB}	33.26^{aA}	7.15^{aA}	7.38^{aA}	7.24^{aA}
	15	budding	19.57^{aC}	21.77^{aA}	20.06^{aB}	26.65^{cA}	24.75^{cB}	25.63^{cAB}	7.26^{aA}	7.36^{aA}	7.31^{aA}
		10% bloom	18.41^{bC}	20.82^{bA}	18.74^{bB}	29.83^{bA}	27.44^{bB}	29.43^{bA}	7.13^{aA}	7.20^{aA}	7.16^{aA}
		full bloom	16.59^{cC}	18.08^{cA}	16.97^{cB}	32.33^{aA}	30.72^{aB}	31.87^{aA}	6.95^{aA}	7.07^{aA}	7.00^{aA}
C	6	budding	17.87^{aB}	19.17^{aA}	18.08^{aB}	29.31^{cA}	27.16^{cB}	28.53^{cA}	8.10^{aA}	8.57^{aA}	8.34^{aA}
		10% bloom	16.23^{bB}	18.33^{bA}	16.54^{bB}	31.54^{bA}	29.05^{bB}	31.03^{bA}	7.94^{aA}	8.22^{aA}	8.16^{aA}
		full bloom	14.15^{cB}	16.27^{cA}	14.34^{cB}	34.91^{aA}	32.60^{aB}	33.92^{aA}	7.46^{aA}	8.04^{aA}	7.85^{aA}
	10	budding	18.39^{aB}	21.16^{aA}	18.97^{aB}	27.89^{cA}	26.12^{cB}	27.17^{cA}	7.82^{aA}	7.97^{aA}	7.90^{aA}
		10% bloom	17.70^{bB}	20.26^{bA}	17.95^{bB}	30.83^{bA}	28.01^{bB}	30.33^{bA}	7.68^{aA}	7.71^{aA}	7.78^{aA}
		full bloom	15.26^{cB}	17.95^{cA}	15.64^{cB}	33.56^{aA}	31.53^{aB}	33.48^{aA}	7.23^{aA}	7.44^{aA}	7.49^{aA}
	15	budding	19.63^{aB}	21.89^{aA}	20.19^{aAB}	26.47^{cA}	24.69^{cB}	25.54^{cAB}	7.31^{aA}	7.42^{aA}	7.38^{aA}
		10% bloom	18.47^{bB}	20.78^{bA}	18.85^{bB}	29.77^{bA}	27.32^{bB}	29.31^{bA}	7.20^{aA}	7.21^{aA}	7.15^{aA}
		full bloom	16.66^{cB}	18.15^{cA}	17.04^{cB}	32.28^{aA}	30.61^{aB}	31.65^{aA}	7.02^{aA}	7.13^{aA}	7.04^{aA}

Type A - self-propelled oscillatory mower-conditioner; Type B - rotary mower with drums; Type C - rotary mower with discs; CP – crude protein; CF – crude fiber; CAsh – crude ash; Tukey's multiple range test: $p \leq 0.05$, small letters a, b, c for the column, capital letters A, B, C for the row

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Table 5. *Effect of cutting height and stage of maturity of tested mowers (type A, B, C) on the mineral composition of alfalfa*

	Height (cm)	Stage of maturity	Ca %			P %			K %		
			Year			Year			Year		
			1	2	3	1	2	3	1	2	3
A	6	budding	1.20	1.27	1.23	0.27	0.32	0.29	2.42	2.57	2.47
		10% bloom	1.22	1.29	1.24	0.25	0.31	0.26	2.37	2.51	2.42
		full bloom	1.28	1.37	1.31	0.23	0.27	0.24	1.76	2.03	1.85
	10	budding	1.23	1.30	1.24	0.29	0.34	0.30	2.47	2.63	2.51
		10% bloom	1.24	1.32	1.24	0.28	0.32	0.29	2.45	2.60	2.47
		full bloom	1.31	1.39	1.33	0.26	0.29	0.27	1.83	2.11	1.92
	15	budding	1.25	1.33	1.27	0.30	0.38	0.31	2.52	2.69	2.60
		10% bloom	1.25	1.34	1.28	0.28	0.37	0.29	2.51	2.67	2.58
		full bloom	1.35	1.46	1.37	0.25	0.32	0.26	1.98	2.19	2.04
B	6	budding	1.18	1.25	1.21	0.25	0.31	0.27	2.39	2.54	2.45
		10% bloom	1.19	1.27	1.23	0.24	0.29	0.26	2.32	2.48	2.41
		full bloom	1.25	1.36	1.29	0.21	0.25	0.22	1.71	1.85	1.79
	10	budding	1.20	1.27	1.22	0.28	0.33	0.28	2.41	2.60	2.49
		10% bloom	1.21	1.26	1.23	0.26	0.31	0.27	2.38	2.57	2.44
		full bloom	1.28	1.37	1.31	0.24	0.28	0.25	1.77	2.05	1.87
	15	budding	1.23	1.31	1.24	0.28	0.35	0.30	2.47	2.65	2.55
		10% bloom	1.25	1.31	1.26	0.27	0.33	0.28	2.43	2.64	2.51
		full bloom	1.34	1.43	1.36	0.23	0.30	0.25	1.92	2.16	1.93
C	6	budding	1.19	1.26	1.22	0.26	0.32	0.28	2.40	2.55	2.44
		10% bloom	1.21	1.27	1.23	0.24	0.30	0.26	2.34	2.51	2.42
		full bloom	1.26	1.36	1.30	0.22	0.26	0.23	1.73	1.94	1.80
	10	budding	1.21	1.29	1.23	0.28	0.33	0.29	2.45	2.62	2.50
		10% bloom	1.21	1.30	1.24	0.27	0.32	0.27	2.43	2.58	2.46
		full bloom	1.30	1.37	1.32	0.25	0.29	0.26	1.82	2.08	1.90
	15	budding	1.24	1.32	1.25	0.29	0.37	0.30	2.52	2.68	2.57
		10% bloom	1.25	1.32	1.26	0.28	0.36	0.29	2.45	2.65	2.53
		full bloom	1.33	1.42	1.35	0.24	0.31	0.25	1.94	2.11	1.99

Type A - self-propelled oscillatory mower-conditioner; Type B - rotary mower with drums; Type C - rotary mower with discs; Ca – calcium; P – phosphorus; K – potassium

Minerals (Ca, P, K) play an important role in evaluating the nutritional value of alfalfa. The results of our tests are compatible with the results of Bumb et al. (2016) and Basbag et al. (2023), who state that calcium content increases with advancing alfalfa maturity stage. The maximum concentration of calcium (Ca) of 1.46% was achieved in the second year of the test (2020), using mower A at a cutting height of 15 cm during the full bloom phase. The content of phosphorus (P) and potassium (K) decreases with the progression of the phenological stage of maturity (Bumb et al., 2016; Engin and Mut, 2018; Basbag et al., 2023). Phosphorus (P) content ranged from a maximum of 0.38% in the second (2020) year of testing, achieved by mower A at a cutting height of 15 cm during the budding phase, to a minimum of 0.21% in the first (2019) year of testing, achieved with mower B at a cutting height of 6 cm in the full bloom phase. We note a drop in the value of potassium (K) from a maximum of 2.69% (mower A in the second year of testing at a cutting height of 15 cm, in the budding phase) to a minimum of 1.71% (mower B in the first year of testing at a cutting height of 6 cm, in the full bloom phase). Basbaga et al.

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(2023), state that the potassium content decreases due to the high consumption of this element for plant growth in the late phenological stages.

During the three-year study period that followed the different agroecological conditions, the correlation dependence between the examined traits did not differ in whether it was positive or negative (*Table 6*).

Table 6. *Correlation coefficients (r) of the investigated parameters in a three year (n=27)*

Year	Parameter	CP	CF	Cash	Ca	P	K
I	**Yield ($kg\ h^{-1}$)**	**-0.884*****	**0.848*****	**0.147^{ns}**	**0.020^{ns}**	**-0.871*****	**-0.636*****
	CP %	-	-0.957***	-0.067^{ns}	-0.361^{ns}	0.902***	0.895***
	CF %		-	-0.248^{ns}	0.460*	-0.900***	-0.873***
	Cash			-	-0.775***	-0.101^{ns}	-0.886***
	Ca %				-	-0.316^{ns}	-0.674***
	P %					-	0.807***
	K %						-
II	**Yield ($kg\ h^{-1}$)**	**-0.878*****	**0.841*****	**0.269^{ns}**	**0.019^{ns}**	**-0.909*****	**-0.652*****
	CP %	-	-0.944***	-0.184^{ns}	-0.390*	0.935***	0.882***
	CF %		-	-0.085^{ns}	0.537**	-0.902***	-0.918***
	Cash			-	-0.644***	-0.255^{ns}	-0.718***
	Ca %				-	-0.246^{ns}	-0.691***
	P %					-	0.831***
	K %						-
III	**Yield ($kg\ h^{-1}$)**	**-0.896*****	**0.830*****	**0.280^{ns}**	**0.087^{ns}**	**-0.855*****	**-0.609*****
	CP %	-	-0.952***	-0.125^{ns}	-0.125^{ns}	0.899***	0.858***
	CF %		-	-0.098^{ns}	0.585**	-0.913***	-0.872***
	Cash			-	-0.641***	-0.219^{ns}	-0.781***
	Ca %				-	-0.486*	-0.781***
	P %					-	0.846***
	K %						-

* $p \le 0.05$, **$p \le 0.01$, ***$p \le 0.001$, ns not signifcant ($p \ge 0.05$); CP – crude protein; CF - crude fiber; CAsh - crude ash; Ca - calcium; P – phosphorus; K – potassium

Regarding the significance of the dependence between calcium (Ca) and phosphorus (P) content, a significant* ($p \le 0.05$) dependence was found in the third year, while in the first and second years there, was no significant dependence ($p \le 0.05$). A significant* ($p \le 0.05$) dependence was found between the content of crude fiber (CF) and calcium (Ca) in the first year and a higher** ($p \le 0.01$) dependence in the second and third years. During our research, the positive and highest ($p \le 0.001$) correlation dependence was achieved: Between the crude protein content (CP) and the phosphorus content (P) from r=0.935 in the second year to r=0.899 in the third year; Between crude protein content (CP) and potassium content (K) from r=0.895 in the first year to r=0.858 in the third year; Between the achieved yield and the content of crude fiber (CF) from r=0.848 in the first year to r=0.830 in the third year; And between the phosphorus (P) and potassium (K) content from r=0.846 in the third year to r=0.807 in the first year.

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On the other hand, the negative and highest ($p \leq 0.001$) correlation dependence was achieved: Between the content of crude proteins (CP) and crude fiber (CF) from r=-0.957 in the first year to r=-0.944 in the second year, which is generally the highest dependence. The achieved negative results of the correlation dependence ($p \leq 0.001$) between the content of crude proteins and crude fiber in our studies are consistent with the results of the study by Heuze et al. (2013). The negative correlation dependence of the highest rank existed: Between the realized yield and the crude protein (CP) content from r=-0.896 in the third year to r=-0.878 in the second year; Between the realized yield and the phosphorus (P) content, from r=-0.909 in the second year to r=-0.855 in the third year; Between the realized yield and the potassium (K) content from r=-0.652 in the second year to r=-0.609 in the third year; Between crude fiber content (CF) and phosphorus content (P) from r=-0.913 in the third year to r=-0.900 in the first year; Between crude fiber content (CF) and potassium content (K) from r=-0.918 in the second year to r=-0.872 in the third year; Between crude ash content (Cash) and calcium content (Ca) from r=-0.775 in the first year to r=-0.641 in the third year; Between crude ash content (Cash) and potassium content (K) from r=-0.886 in the first year to r=-0.718 in the second year; Between calcium content (Ca) and potassium content (K) from r=-0.781 in the third year to r=-0.674 in the first year.

During the three-year test period, no correlation dependence was found between the content of crude ash (Cash) and the achieved yield, crude ash (Cash) and the content of crude proteins (by the study of Tuğrul et al., 2023), and between the content of crude ash (Cash) and the content of crude fiber (CF).

Conclusion

Unfavorable agroecological conditions (long dry period) had a significant impact on the yield and nutritional value of alfalfa at theoretical cutting heights (6, 10 and 15 cm), during the tested phenological maturity stages of all types of mowers. A negative and the highest ($p \leq 0.001$) correlation dependence was found between the content of crude protein (CP) and crude fiber (CF), from r=-0.957 in the first year to r=-0.944 in the second year, and between the realized yield and the crude protein (CP) content from r=-0.896 in the third year to r=-0.878 in the second year. There were no statistically significant differences ($p \geq 0.05$) in the content of calcium (Ca), phosphorus (P) and potassium (K), but an increasing or decreasing trend was found. Due to unfavorable climatic conditions that threaten agricultural production in the region of Southeastern Europe and the results of our research, it is recommended that alfalfa mowing in dry land conditions during a longer dry vegetation period should be done at a cutting height of 10 cm during the alfalfa budding phase. This is justified by the fact that the crude protein (CP) content was significantly ($p \leq 0.05$) higher during the budding phase compared to the early bloom (10% bloom) and full bloom phases. The recommended cutting height of 10 cm is a compromise solution regarding the height of the yield and the nutritional value of alfalfa, bearing in mind that with an increase in the cutting height, a decrease in yield is observed.

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