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Fertilization of Alfalfa Crop in Order to Develop Sustainable Management Systems

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ABSTRACT

Understanding the complex relationships between soil fertility, crop productivity, and management systems in agriculture would contribute to developing sustainable management systems. The paper analyzed the possibility production systems with reduced fertilization by comparing traditional mineral fertilizer application systems and no-fertilizer systems. The field experiment was carried out in 2017-2019 in central Serbia on eutric cambisol. The experiment with the alfalfa variety K-28 was set up according to a completely randomized block system in 3 replications. The following fertilization variants were applied: A1 (unfertilized - control), A2 (N_{30}:P_{30}:K_{30} kg ha^{-1} in autumn), A3 (N_{30}:P_{30}:K_{30} kg ha^{-1} in autumn and 30 kg ha^{-1} N in spring), A4 (N_{45}:P_{45}:K_{45} kg ha^{-1} in autumn), A5 (N_{45}:P_{45}:K_{45} kg ha^{-1} in autumn and 15 kg ha^{-1} N in spring), A6 (15 kg ha^{-1} N in spring) and A7 (30 kg ha^{-1} N in spring). Variants of application of complex mineral fertilizers in autumn A2, A3, A4, and A5 did not lead to a significantly higher alfalfa forage yield compared to fertilization systems when nitrogen was applied in smaller amounts in spring. Satisfactory alfalfa yields were achieved when nitrogen was applied in the spring in the amount of 15 kg ha^{-1} (A6), especially in conditions of sufficient water supply to the plants. All varieties of fertilization influenced the increase in the proportion of weeds. The use of low rates of nitrogen fertilizers with the application of moderate irrigation can be a good management practice that can reduce environmental pollution without greatly alfalfa forage yield reduction.

Keywords: alfalfa, environment pollution, fertilization method, sustainable agriculture, weeds.

INTRODUCTION

The conservation of the environment issue is highly important nowadays and in future research. In recent years, drastic global warming caused by emissions of greenhouse gases has become a serious environmental concern. Nitrous oxide, methane, and carbon dioxide are the major greenhouse gases contributing to global warming (Wang et al., 2016). Agricultural production is considered a contributor to greenhouse gases emissions and is responsible for approximately 52% and 84% of global methane and nitrous oxide emissions, respectively (Li et al., 2020).

Excessive use of chemical fertilizers has generated several problems in nature such as soil acidification, water eutrophication, algae proliferation, reduction of oxygen in water, ozone depletion, greenhouse effect (Jain, 2019; Ramos-Ulate et al., 2022). Currently, more than half of the nitrogen used for fertilization is lost from agricultural systems causing environmental pollution (Vasileva and Pachev, 2015; Wafa and Farida, 2020). Ammonia volatilization from nitrogen fertilizers applied in agriculture is a global concern that must be reduced (Li et al., 2018). Part of N reaches groundwater in the form of nitrates, and part is lost through surface erosion by water (Wafa and Farida, 2020). It is known that the production of mineral fertilizers, especially nitrogen fertilizers, consumes a huge amount of energy. This process is closely related to CO_2 emissions, whose zero emission has recently been a priority in the world (Rosa and Gabrielli, 2023). The trend in agriculture is to reduce the use of chemicals, including fertilizers, and the adoption of new

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technologies is a necessary habit among farmers (Ramos-Ulate et al., 2022). The development of methods for no pollution of productive soil that provides nutrients for plant growth supports diverse and active soil biotic communities and balances the entire farm ecosystem is one of the core philosophies of sustainable production systems (Li et al., 2018; Wafa and Farida, 2020).

Legume crops contribute to the sustainability of agriculture for many reasons, reduce mineral fertilizers use thus reducing N fertilization and increasing N_2-fixation, renew the soil fertility due to their deep-reaching root, quickly decompose their root organic matter and accumulate humus into the soil (Tomić et al., 2023). Due to its extraordinary production, nutritional value, and desirable agricultural traits, alfalfa (*Medicago sativa* L.) is the most widespread forage legume in many countries around the world (Darapuneni et al., 2020; Gao et al., 2020; McDonald et al., 2021; Baidoo and Shilpakar, 2023). Among other features, alfalfa has a positive impact on soil fertility, biodiversity, soil erosion protection, climate change mitigation, reduction of groundwater nitrate contamination, reduction of fossil fuel consumption, and reduction of greenhouse gas emissions (Ramos-Ulate et al., 2022). Alfalfa is grown on 33 million hectares globally. In Serbia, it is cultivated in approximately 106 340 ha (SYS, 2021).

Forage yield is the most important factor that determines profitability in alfalfa production. Ensuring an adequate level of nutrients through fertilization is a prerequisite for high yields and good forage quality (Bokan et al., 2015). Since alfalfa has significant requirements for mineral nutrients, a high biomass yield is achieved through balanced fertilization. Fertilizing alfalfa should achieve three goals: ensurement of sufficient amounts of nutrients to achieve maximum yield, favorable conditions for good activity of nodule bacteria, and conditions for the longest possible exploitation period of alfalfa crops. P and K mineral fertilizers are traditionally used for fertilizing alfalfa with primary tillage. Alfalfa can take up N from the air through symbiotic fixation by the nodule bacteria *Rhizobium meliloti*. Given that the root system of young plants does not yet carry out symbiotic nitrogen fixation at the time of pre-sowing soil preparation, it is recommended to fertilize with N. Nitrogen fertilization stimulates the growth of weeds, and increases the necessity of applying herbicides (Tomić et al., 2018).

For a long time, there was an effort to intensify the production of alfalfa in such a way as to achieve maximum yields per unit area with the cultivation of highly productive cultivars with maximum application of agrotechnical measures. However, this approach, together with the fact of generally small and irregular application of organic fertilizers on arable land, inevitably leads to accelerated degradation of agroecosystems to worrying levels (Baidoo and Shilpakar, 2023).

Matching fertilizer inputs to the expected crop yield maximizes fertilizer use efficiency, reduces losses, and reduces greenhouse gas emissions (Yu et al., 2021). The aim of the work was to compare reduced alfalfa fertilization systems to traditional systems of applying mineral fertilizers with different amounts of NPK, and a system without the use of mineral fertilizers in order to reduce environmental pollution and develop sustainable management systems in agriculture.

MATERIAL AND METHODS

The field experiment was carried out in the period 2017-2019 in the village of Maleševo near Rekovac, Central Serbia (48°49'41"N, 50°54'47"E, 320 m asl), on eutric cambisol soil type, pH(H_2O) 7.55, having 3.24% organic matter, 1.5% $CaCO_3$, 0.217% N, 7.33 mg P 100 g^{-1} soil, and 23.1 mg K 100 g^{-1} soil. The soil horizon is about 200 cm deep, the arable layer is up to 50 cm deep. The parent substrate is marl, loose, and present in the subsoil horizon. The pre-crop was silage corn, fertilized with a high dose of manure (40 t ha^{-1}). Primary tillage by plowing was carried out in autumn 2017 to a depth of 30 cm. Secondary tillage of the soil was carried out immediately before the sowing of alfalfa. Sowing was done in September 2017, using the K-28 cultivar (Institute for Forage Crops Kruševac) in the amount of 20 kg ha^{-1}.

The experiment was set up according to a completely random block design in 3 replications, with the size of the elementary plot 6 m^2 (4x1.5 m). The following types of fertilization were used: A1 (non-fertilized control), A2 (N_{30}:P_{30}:K_{30} kg ha^{-1} in autumn), A3 (N_{30}:P_{30}:K_{30} kg ha^{-1} in autumn and 30 kg ha^{-1} N in spring), A4 (N_{45}:P_{45}:K_{45}kg ha^{-1} in autumn), A5 (N_{45}:P_{45}:K_{45} kg ha^{-1} in autumn and 15 kg ha^{-1} N in spring) A6 (15 kg ha^{-1} N in spring) and A7 (30 kg ha^{-1} N in spring). Primary autumn fertilization was carried out in autumn 2017 after crop emergence and in autumn 2018 with complex mineral fertilizer $N_{15}P_{15}K_{15}$, and secondary fertilization was carried out in spring, in March 2018 and 2019 with nitrogen fertilizer calcium ammonium nitrate 27% N.

The mean annual air temperature for 2018 and 2019 in the given area was 12.2 and 13.1°C and the average annual precipitation was 606 and 526 mm, respectively. The largest amounts of precipitation were in July 2018 and June 2019 (Table 1).

Table 1. Monthly precipitation distribution (P) and average month's temperature (T) for the experimental period *vs.* 2-year average (2018-2019)

Year \ Month		1	2	3	4	5	6	7	8	9	10	11	12
2018	P (mm)	43.1	69.8	69.0	11.0	57.1	58.9	107.1	64.7	27.9	9.0	46.7	41.6
	T (°C)	2.7	1.6	5.7	15.3	19.0	20.8	21.4	22.2	16.7	12.9	7.2	1.6
2019	P (mm)	63.0	47.0	10.7	49.0	74.6	120.7	27.3	17.6	1.5	12.7	54.8	47.0
	T (°C)	-0.7	3.6	9.0	12.7	14.5	22.5	22.9	24.1	18.5	14.4	11.3	4.4

The crop is mowed in the bud stage, i.e. the formation of flower buds. After mowing, the total amount of forage mass per plot was measured, based on which the forage yield was calculated. Then a 1000 g sample was taken from each plot and the alfalfa was separated from the weeds. The material was dried at 65°C to obtain dry matter content (%). Then, the proportion of alfalfa and weeds in the dry sample was calculated (%). The paper shows the proportion of alfalfa in dry matter expressed in %, and the rest represents the proportion of weeds (the proportion of alfalfa is a more relevant indicator due to the smaller error in statistical data processing). Due to the extreme dry period, only two cuts were made in the first year of exploitation, and three cuts in the second year of production. All cuts were analyzed in the same way.

The results obtained were subjected to a mixed-design analysis of the variance model (year as a random effect, fertilization as fixed effects) by using STATISTICA 8 (StatSoft Inc., 2007). Differences between means were tested through the LSD test.

RESULTS AND DISCUSSION

In all other cuts except for the second cut in the first year of production, forage yield increased significantly with the use of complex NPK fertilizers in autumn and nitrogen fertilizers in spring (Table 2, Figures 1 and 2). That increase was largely dependent on the amount of precipitation during the period of plant growth. Young alfalfa plants are less tolerant to drought conditions due to a poorly developed root system, so the effect of fertilization, especially in the first year of production, was largely dependent on the amount of available water in the soil. The results were confirmed by the research of Gao et al. (2020) and Kamran et al. (2022b) according to which the most promising effects in terms of achieving the optimal alfalfa yield with an adequate nitrogen supply had the amount of precipitation of 550 mm properly distributed during the year. However, Li et al. (2023) indicated that the optimum annual amount of water for alfalfa crops was between 725 and 755 mm (sum of seasonal irrigation and rainfall).

In the first cut in the first year of production (2018) on variants A2, A3, and A4, no significant increase in alfalfa forage yield was recorded compared to the control (Figure 1). Only with the use of $N_{45}P_{45}K_{45}$ in the autumn and 15 kg ha^{-1} N in the spring did the forage yield increased. Both treatments applied in spring (A6 and A7) influenced a significant increase in forage yield compared to the control. The results indicate that the application of nitrogen in the spring had a significantly greater impact on the alfalfa forage yield forage compared to the treatments with compound fertilizers in the autumn and their combination with smaller amounts of nitrogen in the spring. In the second year of production (2019), a significantly higher yield in the first cut compared to all other treatments was recorded in treatments A2 and A4. The results indicate that the use of NPK fertilizers in the autumn, without the application of N in the spring, contributed to the fact that the plants, which were then significantly more developed compared to the first year, were more tolerant to drought, which was manifested in an increased yield. The lower effect of fertilization in 2019 compared to 2018 is a consequence of the lower amount of precipitation during the period of plant growth. In the second cutting in the first year of production (2018), there was no difference between treatments in forage yield (Figure 2).

Table 2. Alfalfa forage yield and dry matter content

		Forage yield (t ha^{-1})			Dry matter content (t ha^{-1})		
		I cut	II cut	III cut	I cut	II cut	III cut
Fertilization (F)	A1	18.069 c	11.931 b	15.778 ab	26.5 a	29.6	29.4
	A2	19.375 bc	12.597 b	16.056 ab	23.7 b	29.3	29.7
	A3	20.069 b	13.375 ab	15.333 ab	23.6 b	29.9	27.9
	A4	20.542 ab	14.278 ab	15.500 ab	23.3 b	30.1	28.9
	A5	22.181 a	15.139 ab	16.556 a	22.5 b	28.8	29.3
	A6	20.514 ab	15.889 a	18.111 a	23.4 b	29.3	28.8
	A7	20.875 ab	16.431 a	13.444 b	23.2 b	29.6	27.9
Year (Y)	2018	22.766 a	10.135 b	-	22.1 b	32.4 a	-
	2019	17.698 b	18.333 a	15.825	25.3 a	26.6 b	28.8
ANOVA	F	**	**	*	**	ns	ns
	Y	**	*	-	**	*	-
	F x Y	**	*	-	ns	ns	-

Values followed by different small letters within columns are significantly different ($P \leq 0.05$) according to the LSD test; *F test significant at $P \leq 0.05$; **F test significant at $P \leq 0.01$.

In the second year of alfalfa production (2019), a significantly higher forage yield in the second cut compared to the control variant was recorded in treatment A5 with the highest amount of fertilizer, as well as in treatments A6 and A7 where 15 and 30 kg ha^{-1} N, respectively were used in spring. The reason for the smaller effect of fertilization on the forage yield in the second cut is the more pronounced lack of precipitation during the growth of plants. In the second year of production, there was a third cut. In the third cut, a significantly higher forage yield was recorded in treatments A5 and A6 compared to treatment A7. Better nutrition of plants with nutrients and water contributes to improved photosynthetic capacity and greater development of leaf mass, which results in greater accumulation of total biomass (Xiao et al., 2015; Giacometti et al., 2021), which was also confirmed in these studies. According to Kamran et al. (2022b), in arid regions, water and nitrogen are the two main limiting factors for sustainable agricultural production systems. Although alfalfa is more drought tolerant than most other forage legumes (Yu et al., 2018), its growth, yield and forage quality are greatly affected by water deficit (Liu et al., 2021). Water deficit impairs N_2 fixation in legumes, leading to N deficiency in plants (Yu et al., 2018), reduction of N acquisition, limitation of mineralization and, N transport from the soil to the rhizosphere (Gao et al., 2020).

Elgharabli and Benes (2021) indicate that symbiotic nitrogen fixation, nodulation activity, and stability may vary during the crop growing season, depending on various environmental factors.

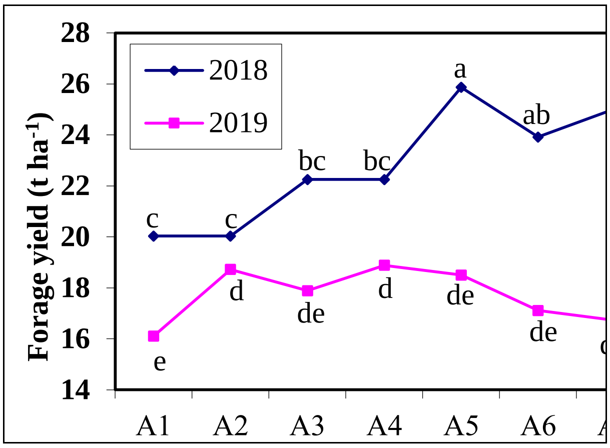

Figure 1. Forage yield of alfalfa in the first cut (fertilization/year interaction)

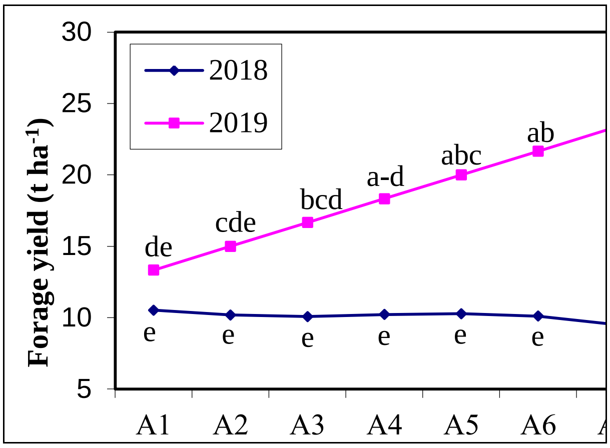

Figure 2. Forage yield of alfalfa in the second cut (fertilization/year interaction)

Higher doses of mineral fertilizers in this experiment did not lead to a linear increase in alfalfa forage yield, especially in the second cut. A lower amount of nitrogen (15 kg ha^{-1}) applied in the fall had a significant effect on the increase in the alfalfa yield forage compared to the control. Li et al. (2018) stated that the reduction in alfalfa forage yield with higher amounts of nitrogen may be related to its inhibitory effects on root growth and development, root nodulation, and nodule configuration, consequently reducing the uptake of water and mineral matter from the soil. According to Zhang et al. (2020), there is a certain threshold for chemical fertilizer absorption by alfalfa. Below this threshold, fertilizers can promote growth and development, while fertilizer that exceeds the maximum absorption negatively affects plant growth and development. Stojiljković et al. (2021) found, after three years of alfalfa fertilization trials, that the highest forage yield was on the 350 kg ha^{-1} $N_8P_{24}K_{16}$ fertilizer variant with the simultaneous application of lime. According to Li et al. (2018), there was no significant influence of the method of nitrogen fertilization on the yield of the third and fourth cuttings of alfalfa, while the influence on root biomass was significant.

Regardless of fertilization, contrary to expectations in the first cut, a significantly higher alfalfa forage yield was recorded in the first year of production (2018) compared to the second year (2019). The reason for this is a more favorable distribution of precipitation. However, in the second cut of 2019, the alfalfa forage yield was 81% higher compared to the second cut of 2018. The reason for this is the better development of the plants in the second year of production and conditions with a sufficient amount of precipitation. Overall, a significantly higher alfalfa forage yield was recorded in the second year of production (51.851 t ha^{-1}) compared to the first year (32.901 t ha^{-1}), which was expected. Jakšić (2014) states that the average alfalfa forage yield in the first cutting was 19.01 t ha^{-1}. Katanski (2017) states that in the first cut, the dry matter yield in the first year of exploitation varied from 6.3 t ha^{-1} to 11.9 t ha^{-1} with the mowing system in the budding stage. Often, the first cut of alfalfa is considered the main determinant of seasonal forage yields, thanks to a longer growth period that results in greater biomass accumulation (Djaman et al., 2020). Li and Su (2017) found that the first cut accounted for 35-50% of the total forage yield. Analyzing the forage yield of different alfalfa cultivars in the dry year of 2012 at different locations in Vojvodina, Katanski (2017) states that it ranged from 17.6 t ha^{-1} to 37.1 t ha^{-1}. In order to examine the dry matter yield of different alfalfa cultivars in the second and third year of production with the applied 6 cuts, Milić et al. (2019) obtained the highest alfalfa dry matter yield of 17.7-18.4 t ha^{-1}. According to Kamran et al. (2022a) forage yield and quality of alfalfa are greatly constrained by a small amount of precipitation, high evaporation, and low soil fertility.

In both years, a significantly higher dry matter content in the forage of the first cut was recorded in the control compared to all fertilized treatments (Table 2). A possible reason for this is the effect of nitrogen on the extension of vegetation in the fertilized treatments, as a result of which the plants in the control treatment were generally in a more mature stage, and if the crop in the first year was not uniform in growth and development. In other cuts in both years, there were no significant differences in dry matter content between treatments. A significantly higher content of dry matter in the forage of the first cut in all treatments was recorded in the second year of production compared to the first, while for the second cut the dry matter content was significantly higher in the first compared to the second year. This may be due to differences in the moment of mowing as well as the amount of precipitation in the period immediately before mowing. Katanski (2017) states that the phenophase of alfalfa mowing significantly affected productivity and almost all cultivars mowed at the beginning of flowering gave a lower dry matter content compared to mowing at later stages. According to Li et al. (2018), high nitrogen rates (225 and 300 kg ha^{-1}) reduced the dry matter content of alfalfa.

Regardless of the year, in general, the fertilized treatments had a significant impact on the increase in crop weediness, as indicated by a significant decrease in the alfalfa proportion in dry matter (Table 3). In the first cut in the first year of production, a significantly higher proportion of alfalfa was recorded in the control compared to the fertilized treatments, while the lowest proportion of alfalfa was recorded in treatment A5 (Figure 3). In the second year of production, a significantly higher alfalfa proportion was recorded in treatments A1, A2, A3, and A4 compared to treatment A5. It can be concluded that the lowest alfalfa proportion, i.e. the highest weediness in the first cut in both years, was recorded in treatment A5, where the highest amount of nitrogen was used for fertilization. Nešić et al. (2007) and Xie et al. (2015) state that nitrogen fertilization of the mixture of alfalfa and grass led to the strengthening of the competitive abilities of grasses in relation to leguminous species, which affected the reduction of the legumes proportion in the total forage yield.

Table 3. Proportion of alfalfa in forage yield

		Alfalfa proportion (%)		
		I cut	II cut	III cut
Fertilization (F)	A1	95.4 a	98.3 ab	99.6 a
	A2	91.5 ab	97.5 b	99.1 ab
	A3	88.8 bc	98.5 a	99.5 a
	A4	88.8 bc	95.7 c	99.6 a
	A5	83.1 c	97.5 b	99.6 a
	A6	87.9 bc	98.0 ab	99.0 ab
	A7	87.8 bc	97.6 b	98.7 b
Year (Y)	2018	80.8 b	96.2 b	-
	2019	97.2 a	99.1 a	99.3
ANOVA	F	*	*	*
	Y	**	**	-
	F x Y	*	*	-

Values followed by different small letters within columns are significantly different (P≤0.05) according to the LSD test; [*]F test significant at P≤0.05; [**]F test significant at P≤0.01.

In the second cut in the first year of production, a significantly lower alfalfa proportion was recorded in treatment A4 compared to all other treatments, while in the second cut in the second year, there were no significant differences between treatments (Figure 4). In the third cut in the second year of production, a significantly lower alfalfa proportion was recorded in treatment A7 compared to treatments A1, A3, A4, and A5 (Table 3). This indicates that fertilizing with phosphorus and potassium in the autumn affected the greater tolerance of plants to the drought that occurred during the growth period of the third cut. Regardless of fertilization, a significantly higher alfalfa proportion was recorded in the second year of production compared to the first, as well as in the second and third cut compared to the first. Krstić (2012) points out that in the year the experiment was established, the proportion of weeds in the alfalfa crop varied from 34.8% to 43.8%.

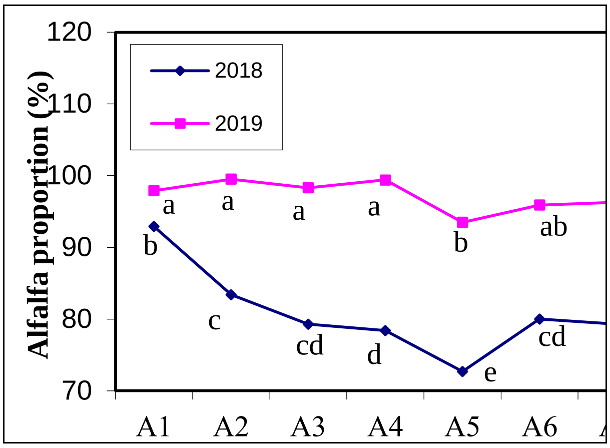

Figure 3. Alfalfa proportion in the first cut (fertilization/year interaction)

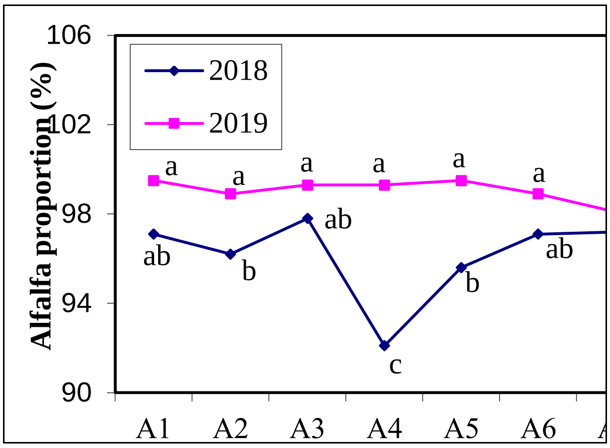

Figure 4. Alfalfa proportion in the second cut (fertilization/year interaction)

Today, are the fact that over 50% of global agricultural land is degraded and that biodiversity and multiple ecosystem functions are threatened (Zhou et al., 2019). Although N fertilizer application can increase forage yield, it also leads to environmental pollution through leaching into groundwater and surface run off (Xie et al., 2015; Ramos-Ulate et al., 2022). Ammonia volatilization from nitrogen fertilizers applied in agricultural systems is a global problem (Li et al., 2018). The author's state that with increasing doses of N application, its cumulative losses in the form of ammonia increased, and greater soil water availability also caused higher ammonia losses but led to higher alfalfa biomass yield. Millar et al. (2018) state that crop fertilization negatively affects the environment, biodiversity, and ecosystem functions. Excessive use and abuse of N fertilizers increased environmental pollution in terms of higher nitrogen oxides emissions (Ning et al., 2022). Methane emission increased with inhibition of methane monooxygenase enzyme activity with increasing soil NH_4^+ content and high osmotic pressure caused by NO_3^- (Kamran et al., 2022a). According to Giacometti et al. (2021) term application of N fertilizers stimulates the mineralization of humus, which leads to a decrease in soil fertility. Nitrogen fertilization stimulates the growth of weeds and increases their competitive abilities in relation to legumes (Tomić et al., 2018), which was also confirmed in this research. This further leads to less persistence and productivity of alfalfa, as well as less nitrogen fixation (Xie et al., 2015) if herbicides are not applied, and the application of herbicides further affects ecosystem degradation.

In this research, the application of different varieties of mineral fertilizers had a different effect on the increase in the alfalfa forage yield. This was expected and similar results are indicated by many authors (Fan et al., 2016; Zhang et al., 2020; McDonald et al., 2021). However, some research results show that there was no positive effect of nitrogen fertilization on alfalfa forage yield due to the nitrogen fixation process (Fan et al., 2011; Xie et al., 2015). The amount of precipitation and the supply of water to the plants had a great influence on the efficiency of the fertilizer treatment. In conditions of a sufficient amount of precipitation, the plants adequately absorbed mineral nutrients and vice versa, which was reflected in the forage yield. According to Darapuneni et al. (2020) and Li et al. (2023) the difference in the time of nitrogen application and the time of irrigation leads to a different effect of fertilization on alfalfa yield. The authors state that a sudden increase in the amount of nitrogen can partially reduce the alfalfa forage yield in the following cut. Therefore, nitrogen application efficiency is higher at low fertilization rates (Chen et al., 2015; Kamran et al., 2022b). High nitrogen content in the soil reduces rhizobium activity (Tomić et al., 2014). According to Wafa and Farida (2020) optimal N management can reduce N leaching below the root zone by 51% and residual ammonia N in the soil by 58%. This reduction can be further improved by 35% with optimal irrigation management. For the production to be more successful, it is recommended to use autochthonous alfalfa cultivars (Zhou et al., 2019), which are more adaptable to the appropriate conditions of the environment.

These studies indicate that good results in alfalfa cultivation with a neutral or even positive effect on the environment can be achieved with lower nitrogen rates with enough water supply. Satisfactory alfalfa yields can be achieved by autumn sowing of alfalfa with the application of the necessary amount of PK fertilizers (calculated based on soil fertility and planned yield) before sowing and the application of 15-30 kg ha^{-1} of nitrogen fertilizers in the spring.

CONCLUSIONS

The efficiency of resource use and its improvement is a key challenge for the development of sustainable management systems in agriculture. There is a search for the development of ecological and at the same time profitable and socially sustainable agroecosystems.

The results suggest that different variants of application of complex mineral fertilizers in autumn (A2, A3, A4, and A5) did not lead to a higher alfalfa forage yield compared to systems where nitrogen was applied in smaller amounts in spring. Satisfactory alfalfa yields were achieved when nitrogen was applied in the spring at the rate of 15 kg ha^{-1} (A6). The amount of 30 kg ha^{-1} nitrogen given in the spring (A7) also did not lead to a significantly higher yield compared to the A6 variant. The effect of nitrogen application was significantly greater in conditions of sufficient soil water supply in the time of intensive crop growth. However, it is realistic to expect that the nitrogen application will lead to a greater occurrence of weeds, the control of which should be aimed at using preventive and mechanical measures. The increase in biomass produced by the use of smaller amounts of fertilizers that are efficiently used by plants affects the increase in the amount of organic matter that is returned to the soil with the biomass of plants, with positive effects on the biological activity of the soil.

It can be concluded that using smaller amounts of nitrogen fertilizers (15-30 kg ha^{-1}) in the spring, with the application of PK fertilizers in the autumn calculated based on soil fertility and planned yield can be a good management practice in semi-arid conditions. Applying such a balanced fertilization system can reduce environmental pollution without greatly reducing alfalfa forage yield.

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