
PhD THESIS

Research concerning the effect of the foliar fertilization on production and soil fertility evolution in alfalfa technology in Transylvanian area

SUMMARY OF Ph.D. THESIS

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CONTENTS

INTRODUCTION	III
LITERATURE REVIEW	
1. Alfalfa culture	III
2. The fertilization of the cultures	III
PERSONAL CONTRIBUTION	
3. Research objectives	III
4. Particularities of the natural environment where took place the experimentation	III
5. Material and method	IV
6. Results and discussions	IV
7. Conclusions and recommendations	VIII
SELECTIVE REFERENCES	X

INTRODUCTION

Alfalfa (*Medicago sativa* L.) is one of the most important forage plants, which is widely cultivated throughout the world. For its high protein content, rich nutritional value and high biomass yield, it is known as the "King of Fodder" and is grown on approximately 32.2 million hectares worldwide (ET AL., 2020).

1. Alfalfa culture

Lucerne (*Medicago sativa* L.) is a perennial legume with a history of cultivation dating back over 2000 years. Because of its high value as animal feed, especially if kept as hay, farmers frequently harvest alfalfa in autumn. Mowing can be an important factor affecting alfalfa cultivation. Research is available showing that mowing frequency has multiple effects on alfalfa both when grown as a single species and in mixtures, as well as on dry matter distribution and productivity (BORDEA AND PĂCURAR, 2022a; LIU ET AL., 2017 ; VENTRONI ET AL., 2010).

2. The fertilization of the cultures

As is well known, from an agrochemical point of view, fertilizers are considered to be those organic and mineral substances, which are either compound or simple, which can be obtained either by chemical synthesis, but can also be of natural origin, which are applied to the soil, to the soil surface and/or to the plant, in liquid or solid form. Fertilizers are administered to (BORDEA AND PĂCURAR, 2022b): improve the growth and/or development regime of crop plants, facilitate the decomposition processes of organic residues on the soil, increase the activity intensity of microbiological organisms, increase soil fertility.

3. Research objectives

The PhD thesis is focused specific objectives formulated to determine the effect of differentiated fertilization on alfalfa production in a three-factor experiment (variety x fertilization x year), namely: quantitative and qualitative study of yields, comparative study of the quantity and quality of alfalfa yields and the interrelationship between yield and crude protein content, and the study of nitrogen use efficiency.

4. Particularities of the natural environment where took place the experimentation

The PhD thesis experiments were conducted on a private farm in the village of Mihăiești, Sânpaul commune, Cluj county. The experimental field was located in the natural environment of Mihăiești village, Sânpaul commune, Cluj county, on an area of 2500 m² - 46°54'12"N, 23°25'7"E (www.google.com).

5. Material and method

Two Romanian alfalfa varieties, approved and produced by the National Institute for Agricultural Research and Development Fundulea, namely the varieties Mădălina and Sandra, were used in this study. Soil fertilization was carried out with conventional fertilizer N₂₇:P_{13.5} Superphosphate (30%P₂O₅) and foliar fertilization with conventional Nutri-Leaf and unconventional Algorbor. The experiments were executed according to a trifactorial randomized block design in 2018 and 2019 on a 3000 m² plotted area (250 m² each plot), corresponding to 12 experimental variants, with experiments executed in six replications. Statistical methods were used to process the raw data. For this purpose, STATISTICA v.8.0 for Windows was used.

6. Results and discussions

Alfalfa yields recorded under different fertilization conditions. The average dry matter yields of the variety Mădălina obtained when foliar fertilization with the conventional product associated with soil fertilization with different doses of mineral fertilizer was chosen, ranged from 14.93 t dry matter/ha (corresponding to soil fertilization with N₅₀P₃₀) to 18, 08% (corresponding to soil fertilisation with N₁₀₀P₉₀), and in the case of the use of the unconventional product associated with soil fertilisation with different doses of complex mineral fertiliser, they range from 14.29 t dry matter/ha (soil fertilised with N₅₀P₃₀) to 17.63 t dry matter/ corresponding to soil fertilized with N₁₀₀P₉₀ (Table 1). In the Sandra variety, the average dry matter yields when foliar fertilization with conventional product was chosen, the highest yield value corresponds to soil fertilization with N₁₀₀P₉₀ and is equal to 17.38 t dry matter/ha, while when unconventional foliar fertilization was chosen, alfalfa yields are in the range of 13.80 t dry matter/ha (soil fertilized with N₅₀P₃₀) and 17.08 t dry matter/ha, corresponding to soil fertilized with N₁₀₀P₉₀ (Table 2).

Qualitative study of alfalfa production recorded under different fertilization conditions. Over the whole experimental period 2018 - 2019, in the unfertilized alfalfa variety Mădălina, considered as a control, a crude protein content equal to 18.01% is reported. In the experimental variants, the highest crude protein content is equal to 19.57% and corresponds to the alfalfa fertilized according to the variants combined with N₁₀₀P₉₀ complex fertilizer in soil and foliar with conventional product and foliar with unconventional product, respectively, and the lowest content is equal to 18.82% and corresponds to the simple foliar fertilization variant with unconventional product. Crude cellulose is in the range 15.95% (simple foliar fertilization variant with conventional product) - 16.86% (simple soil fertilization variant with complex fertilizer N₅₀P₃₀), crude fat is in the range 3.24% (combined soil fertilization variant with complex fertilizer N₁₀₀P₉₀ and foliar with conventional product) and 16.86% (simple foliar fertilization variant with unconventional product), the non-conventional product and the combined variant of fertilising the soil with N₅₀P₃₀ complex fertiliser and foliar with the non-conventional product) - 3.32% (non-fertilised control variant), and crude ash between the limits 8.13% for the combined

variant of fertilising the soil with N₅₀P₃₀ complex fertiliser and foliar with the conventional product and 8.85% for the combined variant of fertilising the soil with N₇₀P₆₀ complex fertiliser and foliar with the non-conventional product.

Table 1

The basic statistics for alfalfa production, Mădălina variety, when combined fertilization is performed with complex mineral fertilizer, and foliar conventional, in 2018 - 2019 (t/ha DM)

Varianta/Variant	N	X	Minimum	Maximum	s	CV
1	12	13,07 ^d	11,60	15,20	1,08	8,24
2	12	14,93 ^d	13,50	17,30	1,13	7,56
3	12	16,54 ^{db}	13,30	19,60	1,64	9,93
4	12	18,08 ^{ddb}	14,30	19,60	1,54	8,52
5	12	14,29 ^b	12,70	16,50	1,10	7,70
6	12	16,07 ^{dc}	13,90	18,20	1,32	8,19
7	12	17,63 ^{db}	14,20	19,50	1,69	9,59

1 – control unfertilized; 2 – fertilization with N₅₀P₃₀ and conventional foliar; 3 – fertilization with N₇₀P₆₀ and conventional foliar; 4 – fertilization with N₁₀₀P₉₀ and conventional foliar; 5 – fertilization with N₅₀P₃₀ and unconventional foliar; 6 – fertilization with N₇₀P₆₀ and unconventional foliar; 7 fertilization with N₁₀₀P₉₀ and unconventional foliar; X – arithmetic mean (t/ha SU/DM); s – standard deviation (t/ha SU/DM); CV – the variation coefficient (%); b – p < 0.05; d – p < 0.001.

Table 2

The basic statistics for alfalfa production, Sandra variety, when combined fertilization is performed with complex mineral fertilizer, and foliar conventional, in 2018 - 2019 (t/ha DM)

Varianta/Variant	N	X	Minimum	Maximum	s	CV
1	12	12,24 ^d	11,20	13,50	0,75	6,15
2	12	14,18 ^{db}	12,00	17,00	1,23	8,70
3	12	15,28 ^{db}	12,40	17,00	1,19	7,79
4	12	17,38 ^d	15,30	18,90	1,04	6,01
5	12	13,80 ^d	11,90	15,20	0,81	5,89
6	12	14,87 ^{db}	12,00	17,00	1,36	9,15
7	12	17,08 ^d	15,00	19,00	1,04	6,11

1 – control unfertilized; 2 – fertilization with N₅₀P₃₀ and conventional foliar; 3 – fertilization with N₇₀P₆₀ and conventional foliar; 4 – fertilization with N₁₀₀P₉₀ and conventional foliar; 5 – fertilization with N₅₀P₃₀ and unconventional foliar; 6 – fertilization with N₇₀P₆₀ and unconventional foliar; 7 fertilization with N₁₀₀P₉₀ and unconventional foliar; X – arithmetic mean (t/ha SU/DM); s – standard deviation (t/ha SU/DM); CV – the variation coefficient (%); b – p < 0.05; d – p < 0.001.

The highest content of non-nitrogenous extractive substances is equal to 53.27% and is observed in the non-fertilized control variant, and the lowest, equal to 52.24% in the combined experimental variant of soil fertilization with N₁₀₀P₉₀ complex fertilizer and foliar fertilization with unconventional product.

In the Sandra variety, over the whole experimental period 2018 - 2019, the average crude protein content is equal to 17.95% in the control variant. Regarding the experimental variants, it is observed that the maximum value of crude protein equal to

19.27% corresponds to alfalfa fertilized according to the combined variant of soil fertilization with N₁₀₀P₉₀ complex fertilizer and foliar with conventional product, and the minimum value equal to 19.18 corresponds to the experimental variants for which simple, foliar fertilization with conventional product and combined soil fertilization with N₇₀P₅₀ complex fertilizer and foliar with unconventional product are administered. Crude cellulose has values within the range 16.28% (combined soil fertilization variant with N₁₀₀P₉₀ complex fertilizer and foliar fertilization with unconventional product) - 17.08% (control variant), crude fat is contained within the range 2.92% (simple foliar fertilization variant with unconventional product) - 3, 13% (combined soil fertilization variant with N₁₀₀P₉₀ complex fertilizer and foliar with conventional product), and crude ash between the limits 8.17% for the combined soil fertilization variant with N₇₀P₆₀ complex fertilizer and foliar with unconventional product and 8.43% for the unfertilized control variant. The study of the content of non-nitrogenous extractive substances leads to the observation that the highest value is equal to 53.47% and corresponds to the unfertilized control variant, and the lowest is equal to 52.73% for the combined experimental variant of soil fertilization with N₁₀₀P₉₀ complex fertilizer and foliar with conventional product.

Study of the interrelationship between alfalfa yield and quality under different fertilization conditions. In the variety Mădălina, a weak negative correlation, mean ($R = -0.356$), between alfalfa yield and crude protein content was observed in the unfertilized control variety, which means that an increase in yield is accompanied by a decrease in crude protein, the latter being 13.30% representative. In the case of the experimental variants in which the soil was fertilized and in which the crop was foliar fertilized, different evolutions are observed, but all characterized by high variability. Negative correlations are obtained for the fertilization of the soil with different doses of nitrogen and phosphorus, N₅₀P₃₀, N₇₀P₆₀ and N₁₀₀P₉₀, which are weak in the case of fertilization with the doses of N₅₀P₃₀ ($R = -0.297$) N₇₀P₆₀ and ($R = -0.187$) and weak to medium ($R = -0.354$), respectively, for the fertilization of the soil with the dose of N₁₀₀P₉₀. In all these cases the decrease in crude protein with increasing yield is a process with low representativeness, 8.80% for the variant where the soil is fertilized with N₅₀P₃₀, 3.50% for the variant where the soil is fertilized with N₇₀P₆₀ and 12.50% for the variant where the soil is fertilized with N₁₀₀P₉₀. In the Sandra variety, for the non-fertilised control variety, a weak negative correlation ($R = 0.266$) between alfalfa yield and crude protein content is observed, which means that an increase in yield is also accompanied by an increase in crude protein, which is representative for 7%. In the case of the experimental variants where soil and foliar fertilization of the crop was applied, different evolutions are observed. A very weak positive correlation ($R = -0.049$) with very low representativeness is obtained for N₅₀P₃₀ soil fertilisation. For soil fertilization with N₇₀P₆₀ a medium positive correlation is observed ($R = 0.518$), with a representativity of 26.5%. For soil fertilisation with N₁₀₀P₉₀ a weak negative correlation ($R = -0.395$) is observed, with a representativity equal to 15.60%.

Study of nitrogen use efficiency in alfalfa cultivation under different fertilization conditions. In order to quantify the nitrogen use efficiency under different conditions of soil fertilization with complex, foliar and combined fertilizer (soil and

foliar fertilization), four indices (partial productivity factor, partial nutrient balance, agronomic efficiency and nitrogen uptake efficiency) were calculated. In both alfalfa varieties studied in 2018-2019, Mădălina and Sandra, both in the case of simple soil and foliar fertilization and combined soil and foliar fertilization with different nitrogen rates, it is found that, similar to our results obtained in the case of calculating the nitrogen use efficiency (NUE) and nitrogen use efficiency response (NRE) indices, the values of all indices studied in the case of using the nitrogen use efficiency estimation methodology proposed by AUGARTEN ET AL. (2019), i.e. PFP, GNP, AE and EU, show the same evolution (Tables 3 and 4).

Table 3

The indices of nitrogen use efficiency in Mădălina variety, 2018 -2019

Fertilization	PFP	PNB (%)	AE	UE (%)
Control	35,51	8,04	-	-
N ₅₀ P ₃₀	28,62	6,18	6,48	26,00
N ₇₀ P ₆₀	22,61	4,43	4,13	20,00
N ₁₀₀ P ₉₀	17,37	3,12	3,25	16,00
Conventional product	80,05	15,55	16,55	75,00
Unconventional product	38,53	8,17	3,01	27,00
Conventional product + N ₅₀ P ₃₀	29,86	4,43	6,20	28,00
Conventional product + N ₇₀ P ₆₀	23,62	3,47	4,46	22,86
Conventional product + N ₁₀₀ P ₉₀	18,08	2,61	3,13	17,00
Unconventional product + N ₅₀ P ₃₀	28,58	4,28	6,11	26,00
Unconventional product + N ₇₀ P ₆₀	22,95	3,39	4,39	17,71
Unconventional product + N ₁₀₀ P ₉₀	17,63	2,13	3,02	15,00

PFP - partial factor productivity; PNB - partial nutrient balance; AE - agronomic efficiency; UE - uptake efficiency.

Table 4

The indices of nitrogen use efficiency in Sandra variety, 2018 -2019

Fertilization	PFP	PNB	AE	UE
Control	33,26	7,80	-	-
N ₅₀ P ₃₀	27,14	6,14	4,54	40,00
N ₇₀ P ₆₀	21,08	4,40	3,60	30,00
N ₁₀₀ P ₉₀	16,78	3,08	2,66	21,00
Conventional product	37,17	15,40	15,45	105,00
Unconventional product	26,98	8,30	3,91	51,63
Conventional product + N ₅₀ P ₃₀	28,36	6,14	5,14	28,57
Conventional product + N ₇₀ P ₆₀	21,82	4,40	4,34	23,33
Conventional product + N ₁₀₀ P ₉₀	17,38	3,09	3,88	18,33
Unconventional product + N ₅₀ P ₃₀	27,60	6,23	4,84	57,07
Unconventional product + N ₇₀ P ₆₀	21,24	4,37	3,75	54,35
Unconventional product + N ₁₀₀ P ₉₀	17,08	3,04	3,12	50,27

PFP - partial factor productivity; PNB - partial nutrient balance; AE - agronomic efficiency; UE - uptake efficiency.

Thus, maximum values are obtained for foliar fertilization with the

conventional product and a progressive decrease with increasing nitrogen dose applied to the soil, in the case of simple soil fertilization with complex fertilizer and combined soil and foliar fertilization (Tables 3 and 4).

The partial productivity factor (PPF) values reported for most of the experimental variants for both alfalfa varieties studied, Maidlina and Sandra, fall for both the classification system developed for cereals and the classification system developed for silage into the category of low nitrogen use efficiency in cereals and silage. There is one exception, for the variety Mădălina, for the experimental variety foliar-fertilised with the conventional product, which falls into the low to medium nitrogen use efficiency category.

7. Conclusions and recommendations

For both the alfalfa varieties Mădălina and Sandra, statistically significant differences between the mean yields of the different fertilisation variants are obtained at different significance levels, from 5% to 0.1%. The degrees of dispersion of the individual yield values show a normal distribution and the values of the coefficients of variation, well below the 30% threshold, reflect the homogeneity of the yields and the representativeness of the means.

Over the whole experimental period, for the alfalfa variety Mădălina, values of the raw chemical composition were obtained for each of its components within the ranges: 19.57% PB (fertilization with N₁₀₀P₉₀ complex fertilizer in soil and foliar conventional and unconventional) - 18.82% PB (foliar fertilization with organic product); 3.29% GB (soil fertilization with N₇₀P₆₀ and N₁₀₀P₉₀ complex fertilizer) - 3.23% GB (combined fertilization with N₁₀₀P₉₀ soil and foliar with unconventional product); 16.86% B (fertilization with N₅₀P₃₀ soil) - 16.17% B (combined fertilization with N₇₀P₆₀ soil and foliar with unconventional product); 8.85% Cen B (combined fertilization with N₇₀P₆₀ complex fertilizer on soil and foliar with unconventional product) - 8.13% Cen B (combined fertilization with N₅₀P₃₀ complex fertilizer on soil and foliar with conventional product); 53.04% (foliar fertilization with conventional product) - 52.25% SEN (combined fertilization with N₁₀₀P₉₀ complex fertilizer on soil and foliar with unconventional product). In the alfalfa variety Sandra, the following values were obtained: 19.27% PB (fertilization with N₁₀₀P₉₀ soil and foliar with conventional product) - 19.17% PB (foliar fertilization with unconventional product); 3.13% GB (fertilization with N₁₀₀P₉₀ soil and foliar with conventional product) - 2.92% GB (foliar fertilization with unconventional product); 16.53% B (N₁₀₀P₉₀ soil and foliar fertilisation with conventional product) - 16.28% B (N₁₀₀P₉₀ soil and foliar fertilisation with unconventional product); 8.34% Cen B (fertilization with N₁₀₀P₉₀ soil and foliar with conventional product) - 8.17% Cen B (fertilization with N₅₀P₃₀ complex fertilizer soil and foliar with unconventional product); 53.38% (foliar fertilization with unconventional product) - 52.73% SEN (combined fertilization with N₁₀₀P₉₀ soil and foliar with conventional product).

With regard to the study of qualitative parameters of alfalfa production, in the varieties Mădălina and Sandra depending on the fertilization variant, during the whole

experimental period 2018 - 2019, a number of peculiarities are observed. For simple fertilization, no statistically assured differences are observed at the 5% significance threshold between the qualitative parameters studied, but with the exception of the content of non-nitrogenous extractive substances, in the variety Mădălina, higher values of the contents of: crude protein, crude fat, crude cellulose and crude ash are observed. For the combined fertilization of the soil with different doses of complex and foliar fertilizer with conventional and unconventional products, similar results are observed, the differences between the two studied alfalfa varieties in terms of the analyzed qualitative parameters are not statistically assured at the 5% significance threshold.

The representativities of the correlations established between the yield of alfalfa, variety Mădălina and its crude protein content differ greatly, ranging from 0.03% (for the experimental variant in which the soil is fertilized with complex fertilizer N50P30 and foliar with the conventional product) to 64.80% (for the experimental variant in which the soil is fertilized with complex fertilizer N70P60 and foliar with the unconventional product). Between the yield of alfalfa, variety Sandra, and its crude protein content, the correlation representativities established differed widely, ranging from 0.02% (for the experimental variant where combined soil fertilization with N70P60 complex fertilizer and conventional product is carried out) to 39.10% (for the experimental variant where foliar fertilization with conventional product is carried out).

The use of the methodology proposed by AUGARTEN ET AL. (2019) to quantify the degree of nitrogen utilization under different conditions of soil fertilization with complex, foliar and combined fertilizer (soil fertilization and foliar fertilization) using four indices (partial productivity factor - PFP, partial nutrient balance - PBN, agronomic efficiency - AG and nitrogen uptake efficiency EU) leads to the conclusion that, similar to our results obtained in the case of NUE and NRE calculation, the values of all indices show similar trends. Maximum values are obtained for foliar fertilization with the conventional product both in the variety Mădălina (PFP = 80.50; GNP = 15.50%; AE = 16.55; EU = 75%) and in the variety Sandra (PFP = 37.17; GNP = 15.40%; AE = 15.45; EU = 105%) and a progressive decrease with increasing nitrogen dose to the soil, in case of simple soil fertilization with complex fertilizer and combined soil and foliar fertilization. Based on the results obtained, we recommend that in order to obtain high yields in native alfalfa varieties close to variety standards, soil fertilization with NPK complex fertilizer (or NP where there is an excessive supply of K in the soil, as in the present study) using high doses of nitrogen and phosphorus (N₁₀₀P₉₀), combined with foliar fertilisation with both conventional foliar fertiliser rich in mu- and micro-nutrients (including nitrogen) and unconventional foliar fertiliser not containing nitrogen, based on natural compounds.

The originality of the PhD thesis is represented, in our opinion, by the following aspects: ▶the study of the effectiveness of combined variants of soil fertilization with foliar fertilization and comparison of the results obtained with simple variants of fertilization with complex and foliar fertilizer, both in terms of productivity

and quality of alfalfa crops; ►the comparative study, between two native varieties of alfalfa, of the intensity of the interaction between alfalfa productivity and crop quality in terms of crude protein content; comparative study of the efficiency of nitrogen use, in two native varieties of alfalfa. **The innovative contributions** of the PhD thesis we consider to be the following: ►the experimental protocol and the methodology of interpretation of raw data using statistical-mathematical methods used made it possible to assess alfalfa yield; ► the introduction into the study of methodologies for calculating nitrogen use efficiency indices, which are not limited to the commonly used ones, namely the nitrogen use efficiency index (NUE) and the nitrogen use efficiency response index (NRE), but also to a recent approach using a more complex methodology including four indices.

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