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THE INFLUENCE OF MINIMAL NPK FERTILISATION ON THE QUANTITY AND QUALITY OF APPLE YIELDS

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ABSTRACT. During an annual cycle, fruit trees go through developmental stages, characterised by a higher demand for some mineral elements, called critical periods, which coincide with the phenophases of bud opening and shoot initiation. Research on mineral nutrition in fruit growing has highlighted that the maximum consumption of nutrients is during the period of shoot growth, fruit development and differentiation of fruit buds. In apple, flowering is influenced more by the time of fertiliser application and the form of nitrogen than by the amount applied, as apple has high requirements for the element phosphorus in the phenophases of intense shoot growth and wood maturation. Fertilisation with NPK increased apple yield for both fertilisation treatments compared to the unfertilised control treatments. After applying 270 $kg \cdot ha^{-1}$ NPK in the first year of the experiment, very significant production increases were obtained, 4.46$t \cdot ha^{-1}$, with a content of 16% dry matter, 13.13°Brix soluble matter and a titratable acidity of 0.465 mg malic acid/100 g.

Keywords: dry weight; soil fertilisation; soluble substance; titratable acidity.

INTRODUCTION

During an annual cycle, fruit trees go through a series of periods, characterised by a higher demand for some mineral elements, called critical periods. These periods coincide with the phenophases of bud opening and shoot initiation. Research in the field of mineral nutrition in fruit growing has highlighted the fact that the maximum consumption of nutrients occurs during the phenophases of shoot growth, fruit development and differentiation of fruit buds (Fallahi, 2010).

Macro-elements and micro-elements present in soils in optimal

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quantities, naturally or administered through fertilisation practices, constitute the foundation for the development of normal plant metabolism. Obtaining production at the expected level, superior in quality and with a minimum energy consumption of the plants are the targets that must be aimed at and that cannot be achieved without ensuring the soil and the plants have corresponding levels of nutritious elements.

Nitrogen is a key element of vegetative growth and is found in structural protoplasmic proteins, the cell nucleus, chlorophyll pigments, the B vitamin complex and enzymes (Rusu *et al.*, 2005). Nitrogen stimulates the total production of dry matter, especially if it is available in June-July, when the dry matter produced is mainly oriented towards the permanent structures of the trees. The differentiation of the fruit buds is influenced by the nitrogen supply status of the trees during the vegetation period in the previous year. In apple, flowering is influenced more by the time of fertiliser application and the form of nitrogen, than by the amount applied (Drake *et al.*, 2002). Following a study on the influence of the form of nitrogen on flowering, a doubling of the number of fruit-bearing buds and an increase in the content of amino acids was observed in the case of root application of ammoniacal nitrogen (Kowalczyk *et al.*, 2022).

Apple has high requirements for the element phosphorus in the phenophase of intense shoot growth and when the wood matures. Research on the influence of phosphorus on the initiation or inhibition of phenophases demonstrated that phosphorus deficiency delayed budding and led to a decrease in the number of vegetative and floral meristems (Neilsen *et al.*, 2008). Potassium is indispensable for plant metabolism, participating in the synthesis of amino acids and proteins. Plants well supplied with potassium use less water, decrease the transpiration coefficient, more intensely assimilate carbon dioxide and regulate the absorption of nitrogen (Nava *et al.*, 2008), with a role in the oxidation of ammonia and, in the case of nitric nutrition, the reduction of nitrates. It increases the resistance of plants to adverse environmental conditions, and it helps to translocate the products of photosynthesis in the reserve organs, a fact that influences the formation of the production and its quality (Dilmaghani *et al.*, 2004).

Foliar fertilisers complement and enhance the nutritional needs of trees, having at the same time a role in the ecological protection of soils in correcting nutritional deficiencies or excesses. The precursors and constituents of proteins which are considered as important for stimulation of cell growth are represented by amino acids (Ilie *et al.*, 2017). Foliar application of amino acids has been reported to improve the growth, yield and quality of apple fruits (Arabloo *et al.*, 2017).

This study aims to highlight the influence of the fertiliser dose in a minimal fertilisation plan on apple yield and quality, Idared variety. For this experiment, the Idared variety was chosen due to its high share in the fruit plantations in Romania, its fruits having a long storage period (7-9 months), and its low culture requirements. There is much information about soil and foliar fertilisation in apple orchards, with many products and varied doses, and it is difficult to choose the best option. However, there is less information regarding this topic on calcareous soil with high pH value (over 8). To more broadly capture the topic addressed, measurements were made on the size of the production, the content of dry mass, the concentration of soluble substances and the titratable acidity of the fruits.

MATERIALS AND METHODS

The experiment was carried out in a ten-year-old apple orchard on the 'Idared' variety in 2019–2020, with planting distances of 4 × 4 m, within the "V. Adamachi" didactic farm of the University of Life Sciences from Iasi. The Idared variety is grafted onto MM-106, a rootstock with a long life and more tolerant than the M9 rootstock under high bicarbonate content of the soil (Sahin *et al.*, 2017). The choice of the experimental doses of NPK was made considering the minimum doses recommended in apple crops in Romania for soil fertilisation and one foliar fertiliser: Pentakeep (16% N, 2.18% P, 2.49% K, 0% Ca, 1.8% Mg, microelements and 5-aminolevulinic acid). In the Iassy orchard ecosystem, apple trees find favorable temperatures for fruiting; the multi-year average temperature for this area is 9.6 ºC. No spring frost damage occurred during the study. The apple's requirements for humidity are high, yielding good results in areas where precipitation exceeds 650-700 mm, distributed evenly throughout the growing season. In the second year of the study, precipitation was much reduced, registering a total of 430.1 mm, of which only 287.2 mm fell during the growing season. Prior setting the experiment, the pH from a soil sample has been measured potentiometric, in aqueous suspension (1:2.5): the pH value is 8.3 for the 21-66cm depth; through Scheibler method, was determined $CaCO_3$ (%) in soil 7.8% (21-66cm) and total nitrogen Nt -0.24% - Kjeldahl method. Available phosphorus P-AL– (37.33 ppm) and available potassium K-AL (134 ppm) in soil have been determined by treating the soil sample with ammonium lactate acetate (AL), pH - 3.7 (Egner-Riehm-Domingo method), precipitation of calcium from the solution with oxalic acid (10%). Phosphorus was quantified by the spectrophotometry method and potassium by the flame-photometry method.

The presence of alkaline earth carbonates at depths of 20 - 40 cm leads to an increase in pH, indicating a considerable change in the pedo-geochemical balance of the soil. This is due to the partial uncovering of the soil and the slight modeling of the slope caused by agricultural practices. The apple grows optimally in conditions with a pH of 5.5-7.5, depending on the northern or southern origin of the varieties.

For the establishment of the experiment, an unfertilised control variant and four variants of fertilisation with different doses of NPK fertiliser and one foliar fertiliser were taken into account: D0 – no fertilisers applied, which was the control, D1 with 180 kg ha^{-1} active ingredient (60 kg N + 60 kg P + 60 kg K), D2 with 270 kg ha^{-1} active ingredient (90 kg N + 90 kg P + 90 kg

K), D3 which was the same as treatment D1 with Pentakeep and D4, which was the same as treatment D2 with Pentakeep.

Fertilisers were applied in autumn when shoot growth was completed but foliage still fully green (phenological growth stage 91 from BBCH scale), and in the spring at the end of bud swelling (phenological growth stage 03 from BBCH scale), by spreading the NPK fertiliser in strips with a width of 40 cm, on one side and on the other of the row of trees followed by its incorporation into the soil. Foliar fertiliser (Pentakeep at 2 L ha^{-1}) was sprayed three times, beginning when the fruit was 5 mm, in diameter and every two weeks thereafter (phenological growth stage 69 -72 from BBCH scale). In this study, pruning, phytosanitary treatments, and recommended agrotechnical works were carried out. The orchard does not have an irrigation system; the water comes exclusively from precipitation. No additional thinning of the buds was performed. During the two experimental years, measurements were made on the production by weighing the fruits of each variant. Yield was estimated by measuring the weight of all the fruits harvested from three trees from each repetition of the fertilization treatment. The average production per tree was calculated and multiplied by the number of trees per hectare. Based on the planting distances, the density is 625 trees ha^{-1}, the production being expressed in tons per hectare.

The analysis of the quality indices was done on 10 apples from each replication of the treatment, harvesting 3-4 fruits from each tree, weighing 200-210 grams per apple, from both sides of the row of apple trees. The analysis of the quality indices was done in two repetitions for each sample/apple analyzed. The dry substance was determined by repeated weighing of the sample with an electronic scale after drying it in the oven at 105°C for four hours and cooling it in a desiccator. The total soluble substance (TSS) was measured in freshly prepared juice. Its content is expressed in Brix and is represented by the simple carbohydrates in the fruit, which are determined in the juice with a handheld refractometer, at 20°C according to STAS 5956-71. Titratable acidity (TA) - (total acidity) is determined by titrating a juice sample with a 0.1 mol/L sodium hydroxide solution in the presence of phenolphthalein until the colour of the solution turns pale pink, to the end point of pH 8.1. The predominant acid in apples is malic acid, which is why it was expressed in g malic acid per 100 g of fresh fruit, by multiplying the volume of solution used for titration with 0.0067. The methodology for determining the quality indices was made according to the standard methods (Beceanu, 2010).

Statistical analysis was performed using analysis of variance (ANOVA) and the least significant difference (LSD) test was used to identify significant differences between means. Each experimental variant was replicated 3 times with five trees per replication.

RESULTS AND DISCUSSION

Production is significantly influenced by the application of complex fertilisers that contain all three primary macro-elements, as each of them contributes on different levels to the improvement of production. Nitrogen is a factor determining the quantity and increase in biomass, while phosphorus determines the increase in production through its influence on flowering. Potassium complements the other two by contributing to the accumulation of reserve substances in the fruit.

Analysing the yields, in the unfertilised control treatment, 24.2 t ha^{-1} of fruits were obtained in the first experimental year, 25.8 t ha^{-1} were obtained for the D1 treatment, and 28.6 t ha^{-1} were obtained for the D2 treatment, resulting in a significant increase in production of 1.67 t ha^{-1} in variant D1 with 180 kg ha^{-1} NPK active ingredient and a very significant production increase of 4.46 t ha^{-1} in D2 with 270 kg ha^{-1} NPK active ingredient. The soil fertilisation with foliar application registered very significant production, with a mean difference of 6.93 t ha^{-1} (*Table 1*).

In the second year of experimentation, the production obtained in the non-fertilised variant D0 was 24.8 t ha^{-1}; however, there were smaller production increases in the fertilised variants compared to the first year. For variant D1, with 180 kg ha^{-1} NPK active ingredient, the increase in production of was statistically insignificant, 0.49 t ha^{-1}, and for variant D2, with 270kg ha^{-1} NPK active ingredient, a distinctly significant increase in production of 1.76 t ha^{-1} fruits was obtained. The D3 and D4 fertilisation variants obtained very significant increases, with mean differences of 2.71 t ha^{-1} and 3.49 t ha^{-1}, respectively (*Table 2*).

Also in this study, three production quality indices were followed, considered representative of a qualitative production: dry substance, soluble substance content and titratable acidity. In the first year of research (*Table 3*), the dry substance content varied between 14.16% (control) and 16.44% (D4). The use of maximum doses of nutrients and the soil fertilisation variants with Pentakeep had a very significant influence on the dry matter content. In the same year, the content in soluble substance recorded a minimum value of 11.87° Brix for the unfertilised control and a maximum value of 13.30° Brix for variant D4. Variant D3 had a mean difference of 0.56, a statistically insignificant value. The titratable acidity recorded values of 0.392 mg/100 g malic acid for the unfertilised variant and a maximum of 0.488 mg/100 g malic acid for the fertilisation variant with 270kg NPK + Pentakeep (D4). Fertilising with 180 kg ha^{-1} NPK had an insignificant influence on acidity.

In the second year of the study (*Table 4*), different values were obtained for quality indices that did not rise to the level of very significant differences. Thus, the maximum content of dry matter was also obtained with the D4 variant, of 18.13%, a statistically significant value. For the soluble substance content, the same variant (D4) had the maximum value of 12.09° Brix, with a very significant statistical difference. With maximum NPK doses of 270 kg ha^{-1} (D2), the acidity of 0.430 mg/100 malic acid that was obtained was like that of variant D3, a statistically significantly different content.

Table 1 – The influence of NPK soil fertilisation on the apple yield in the first year of study

Variant	Yield (t ha⁻¹)	Mean difference (t ha⁻¹)	% increase	Statistical significance	Standard deviation	Coef. of variation %
D0 - Control	24.2	-	100	-	0.94	3.90
D1 - 180kg ha⁻¹ NPK	25.8	1.67	107	*	1.41	5.45
D2 - 270kg ha⁻¹ NPK	28.6	4.46	119	***	0.27	0.96
D3 – D1 + Pentakeep	28.8	4.70	119	***	0.56	1.74
D4 – D2 + Pentakeep	31.1	6.93	129	***	0.57	1.86
	* LSD 5 % - 1.25; ** LSD 1 % - 2.46; *** LSD 0.1 % - 3.72					

LSD - least significant difference

Table 2 – The influence of NPK soil fertilisation on the apple yield in the second year of study

Variant	Yield (t ha⁻¹)	Mean difference (t ha⁻¹)	% increase	Statistical significance	Standard deviation	Coef. of variation %
D0 - Control	24.8	-	100	-	0.77	3.09
D1 – 180 kg ha⁻¹ NPK	25.3	0.49	102	ns	1.60	6.34
D2 – 270 kg ha⁻¹ NPK	26.5	1.76	107	**	1.02	3.85
D3 – D1 + Pentakeep	27.5	2.71	111	***	0.17	0.62
D4 – D2 + Pentakeep	28.2	3.49	114	***	0.67	2.46
	* LSD 5 % - 1.37; ** LSD 1 % - 1.60; *** LSD 0.1 % - 1.88					

ns - not significant

Table 3 – The influence of NPK soil fertilisation on the apple quality in the first year of study

Variant	DW		SSC		TA	
	%	Mean difference	°Brix	Mean difference	(g malic acid/100g)	Mean difference
D0 - Control	14.16	-	11.87	-	0.392	-
D1 – 180 kg ha⁻¹ NPK	14.84	0.68ns	12.58	0.71*	0.420	0.028ns
D2 – 270 kg ha⁻¹ NPK	16.00	1.84***	13.13	1.26***	0.465	0.073***
D3 – D1 + Pentakeep	15.67	1.51***	12.43	0.56ns	0.473	0.081***
D4 – D2 + Pentakeep	16.44	2.28***	13.30	1.43***	0.488	0.096***
	* LSD 5 % - 0.89		*LSD 5 % - 0.57		*LSD 5 % - 0.047	
	** LSD 1 % - 1.08		** LSD 1 % - 0.75		** LSD 1 % - 0.055	
	***LSD 0.1 % - 1.27		***LSD 0.1 % - 0.95		***LSD 0.1 % - 0.062	

DW – dry weight, SSC – soluble solids content, TA - titratable acidity; ns – not significant

Table 4 – The influence of NPK soil fertilisation on the apple quality in the second year of study

Variant	DW		SSC		TA	
	%	Mean difference	°Brix	Mean difference	(g malic acid/100g)	Mean difference
D0 - Control	15.29	-	10.83	-	0.376	-
D1 – 180 kg ha^{-1} NPK	16.73	1.44**	11.35	0.52*	0.398	0.022ns
D2 – 270 kg ha^{-1} NPK	16.90	1.61**	11.51	0.68*	0.430	0.054**
D3 – D1 + Pentakeep	17.32	2.0***	11.45	0.62*	0.426	0.050**
D4 – D2 + Pentakeep	18.13	2.8***	12.09	1.26***	0.448	0.072***
	*LSD 5 % - 0.82		*LSD 5 % - 0.56		*LSD 5 % - 0.043	
	** LSD 1 % - 1.25		** LSD 1 % - 0.74		** LSD 1 % - 0.050	
	***LSD 0.1 % - 1.71		***LSD 0.1 % - 0.94		***LSD 0.1 % - 0.059	

DW – dry weight, SSC – soluble solids content, TA - titratable acidity

The D1 variant had an insignificant influence on acidity, with a similar mean difference compared with the first year of the experiment.

The second year of research, compared to the first year, stands out due to a non-uniformity of values, with different significance values. The maximum doses tended to maximally influence all quality indices, but the difference was very significant for only the D4 variant for the apple quality indices. Our results are within the normal range for the Idared variety, similar to the results obtained by Tomala *et al.* (2020).

The root and leaf absorption of nutrients are processes that take place in the apple under a series of factors: the age of the plantation, the climate and the variety, among other influences, and directly interfere with the adopted fertilisation system. In a study conducted by Mota *et al.* (2022), in five different locations over four years, it was observed that production increases reacted differently to the application of fertilizer doses depending on the location and year of the study. It was noted that the application of 101 kg N+65 kg P+160 kg K led to production increases of 29% compared to the application of 64 kg N+51 kg P+75 kg K (Mota *et al.*, 2022), the same percentage increase in yield was obtained in the current study when 270 kg NPK with Pentakeep was applied. Research on apple trees fertilisation highlighted the positive impact on fruit yield when applying nitrogen in minimal doses - less than 100 kg ha^{-1} (Drake *et al.*, 2002). Increased nitrogen fertilisation (more than 160 kg ha^{-1}) does not help the fruit yield but could negatively affected fruit color, flesh firmness, and TSS content. There are studies that on the influence of the type of fertilizer and doses that affects the yield in apple orchards but the results varied with the cultivar and soil type (Miloševic and Miloševic, 2017; Miloševic *et al.*, 2022). The use of soil fertilisers, in appropriate doses, ratios and assortments solves, on the one hand, the creation and maintenance of a balance of nutrients in the soil easily accessible to the trees and, on the other hand, creates the prerequisites for obtaining high yields without annual fluctuations. Foliar fertilizers do not have a high intake of macroelements compared to what is needed by the crop. Their importance results from their content in microelements, humic acids and biostimulators that improve flowering, fruit growth, ripening and lead to increases in production (Zargar *et al.*, 2019; Ljavić *et al.*, 2023). Complex foliar fertilizers have a positive influence on the content of dry matter in apples, resulting in increases of up to 1% compared to the unfertilized version (Ilie *et al.*, 2017). When applying nitrogen fertilizers in different doses, insignificant increases in soluble dry matter were observed, from 12.2 to 13.9% in the variety Early Spur Rome (Fallahi *et al.*, 2006), similar results as determined in our study.

According to specialized literature, the analysis of titratable acidity in apples highlights a significant variation between apple varieties, as well as within the same variety grown in different pedoclimatic conditions. The titratable acidity is higher, at 0.62-0.66 g malic acid/100g, at low productions, and was not correlated with the application of different doses of nitrogen (Drake *et al.*, 2002). The titratable acidity of apples decreases if their harvesting is delayed, with differences of up to 0.1 g malic acid/100g being insignificant following the statistical analysis (Jan *et al.*, 2012). However, Ilie et al. noted that all the foliar variants exhibited a decrease in the total titratable acidity compared to the control (unfertilised) for the "Golden Delicious" and "Granny Smith" cultivars, with values between 0.65-0.79 g malic acid/100g (2017).

CONCLUSIONS

The application of 180 kg of NPK active substance in combination with foliar spraying of Pentakeep (D3) led to similar increases in production in the first year of the study and even higher increases in the second year under drought conditions, compared to the application of 270 kg of NPK active substance (D4).

Increasing the doses of fertilizers leads to an increase in the quality indices of the fruits.

Considering these results, it is recommended to use lower doses with the application of the soil complete with the application of the foil, reducing possible nitrogen losses and making more efficient the use of elements that at the soil level pass into hard-to-access forms due to the high pH.

The values obtained in the two years of the study reveal a variation of the quality indices from one year to another, which means the involvement of other possible influencing factors that interfered during the experiment.

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