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ORIGINAL PAPER

CONTENT OF MINERALS IN SOIL, APPLE TREE LEAVES AND FRUITS DEPENDING ON NITROGEN FERTILIZATION*

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Abstract

Nitrogen, as one of the most important elements in the life of a plant, has a significant impact on the growth and bearing of apple trees. The natural amount of nitrogen in soil is essential in the process of fertilization with this component. The experiment was established in 2000 at an experimental orchard of the Department of Pomology, Warsaw University of Life Science in Wilanów, on apple trees of the cultivar Jonagored. The aim of the study was to evaluate the needs for apple orchard fertilization with nitrogen that would minimize the use of nitrogen fertilizers while maintaining an optimal content of available nutrients in the soil, leaves and fruits of apple trees. There were four different treatments with nitrogen: N-0 (no nitrogen); N-50 (50 kg N ha^{-1} over the whole growing area in early spring); N-100 (100 kg N ha^{-1} over the whole growing area in early spring); and N-100_{sward} (100 kg N ha^{-1} in early spring only in sward alleyways). The studies were conducted in 2010 and 2013 (content of selected minerals in the soil) and from 2010 to 2012 (nutrient content in leaves and fruits). Application of nitrogen did not affect soil pH, content of available potassium, phosphorus and magnesium or the ratio K/Mg in the soil. In the analyzed period, there were no differences in the content of N, K, Mg, P and Ca in the fruits. Nitrogen fertilization caused an increase in the content of N in leaves when compared to the unfertilized combination. The opposite situation was observed in the case of phosphorus in leaves.

Keywords: apple tree, nitrogen, fertilization, mineral content, soil.

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INTRODUCTION

Nitrogen is one of the most important elements in the life of plants, hence its significant impact on the growth and bearing of apple trees. The need for fertilization with this component depends undoubtedly on the natural amount of nitrogen in soil. The dependence of the nutrition of fruit trees with nitrogen on the soil content of this component in various forms has not been well investigated yet (Stefanelli et al. 2010). Views on the dose, timing and fertilization methods are often divergent. Most experiments concerning nitrogen fertilization of orchards on fertile soil show lack of effectiveness of this treatment (Ernani, Dias 1999, Wrona 2004, 2011). The positive response of trees to nitrogen fertilization is observed only within moderate doses of nitrogen (Stefanelli et al. 2010). The use of high doses of nitrogen causes unfavorable changes in the chemical properties of the soil and creates the risk of contamination of groundwater by nitrates. Our current state of knowledge on the changes occurring in soil due to nitrogen fertilization is still insufficient (Thalheimer, Paoli 2006, Unuk et al. 2008, Stefanelli et al. 2010). From the environmental point of view, it is very important to reduce the risk of contamination of the environment and thus to minimize the fertilizer component, taking into account the natural soil fertility (Tagliavini, Millard 2005, Dong et al. 2005, Raese et al. 2007). Doses of nitrogen currently used in Polish apple orchards range from 60 to 100 kg N ha^{-1}. Contrary to this practice, long-term studies conducted both in the country and abroad confirm that nitrogen fertilization can be reduced to 50-70 kg N ha^{-1} in order to obtain high-quality crops. The use of nitrogen doses above this limit may result in stronger growth of trees and dilution of some nutrients in the plant (Cmelik et al. 2006, Fallahi et al. 2006, Tahir et al. 2008). The aim of the study was to evaluate the fertilization needs of an apple orchard with nitrogen that would allow to minimize the use of nitrogen fertilizers, while maintaining the optimum content of available nutrients in the soil, leaves and fruits of apple trees.

MATERIAL AND METHODS

The experiment was conducted in 2010-2013, at the Experimental Station in Wilanów, owned by the Department of Pomology. It was set up on fertile silty loam alluvial soil rich in humus, with the texture of medium silty loam or silt loam, containing > 35% of floatable elements. The apple cultivar Jonagored was planted in spring 2000 on M.9 and spaced at distances of 3.5 x 1.5 m. The fertilization of trees started within the second year after planting (2001) and was done annually. In the experiment, the following combinations of nitrogen fertilization were compared: N-0 (control without fertilization); N-50 (50 kg N ha^{-1} over the total area); N-100 (100 kg N ha^{-1} over the total area); N-100_{sward} (100 kg N ha^{-1} only in sward alleyways). Ammonium nitrate was used as fertilizer in the spring, approximately two weeks before the expected blooming of the trees. Moreover, 200 kg K_2O ha^{-1} in the form of potassium nitrate was applied every year. Before the start of the experiment (spring 2010) and after its termination (spring 2013), soil samples were collected for the determination of phosphorus and potassium levels, using the Egner-Riehm method. The magnesium level was investigated by the Schatschabel method. Additionally, the soil pH in KCl to a depth of 90 cm, divided into 30 cm layers was investigated. The assimilable ratio of potassium to magnesium was calculated. Samples were collected separately from herbicide fallow and from under the sward. In 2010-2012, after the top shoots' growth, 100 leaves per plot were taken for analysis in order to determine the total nitrogen content with the Kjeldahl method. Additionally, after combustion in a muffle furnace at 550°C, the potassium, phosphorus, magnesium and calcium content was investigated by ICP-AES emission spectrometry. These methods have also been used to evaluate the total content of nitrogen, potassium, phosphorus, magnesium and calcium in ripe fruits harvested. The results were submitted to one-way analysis of variance in a dependent split-block system, separately for each year. The experimental plot contained 6 trees, and fertilizer plots were distributed randomly within 5 repetitions (blocks). The means were placed into homogeneous groups according to the Newman-Keuls test at a significance level $\alpha = 0.05$.

RESULTS AND DISCUSSION

Regardless of the layer of soil and sampling, the fertilization did not influence the content of potassium, phosphorus and magnesium in the soil (Tables 1, 2, 3). The content of assimilable potassium in the soil in the two years of the study differed depending on the soil layer. It was noted that the potassium content decreased with the soil depth (Table 1). In 2010, the potassium content in the 0-30 cm soil horizon was moderate relative to the norm, but ranged from low and average in the the layers of 30-60 cm and 60-90 cm deep (Table 1). On the contrary, there was an increase in the soil potassium content in 2013 compared to 2010, and its content in all layers of soil varied between medium and high (Table 1). In both years of the research, higher potassium concentration was observed in soil samples taken from the 0-30 cm layer of soil under herbicide fallow (Table 1). Ross et al. (1985) claim that maintaining herbicide strips and sward in orchards together with mineral fertilization significantly affects the changes of physical and chemical properties of the soil, which in turn determines the nutritional status of trees and their productivity. Ystaas and Frøynes (1993) argue that the lack of plants in herbicide fallow favors cations leaching from the soil, whereas sward absorbing microelements prevents nutrients leaching. Nutrients absorbed by the sward after its mowing and mineralization return to soil (WRONA 2004). HAYNES and GOH (1980) found that the soil under herbicide fallow had a lower content of magnesium and potassium than in the soil under the sward.

Table 1

The content of available potassium in the soil (mg kg^{-1})

Year	Layer (cm)	Sampling site	Variants of nitrogen fertilization			
			N-0	N-50	N-100	N-100_{sward}
2010	0-30	sward	112.9*a*	110.0*a*	86.0*a*	95.4*a*
		herbicide fallow	152.3*a*	149.9*a*	151.3*a*	138.0*a*
	30-60	sward	51.4*a*	47.6*a*	42.7*a*	59.0*a*
		herbicide fallow	51.0*a*	69.4*a*	57.1*a*	62.5*a*
	60-90	sward	46.1*a*	55.9*a*	43.6*a*	50.9*a*
		herbicide fallow	45.2*a*	38.8*a*	41.2*a*	45.1*a*
2013	0-30	sward	142.2*a*	114.5*a*	123.8*a*	100.3*a*
		herbicide fallow	196.7*a*	145.6*a*	176.8*a*	151.4*a*
	30-60	sward	88.3*a*	71.8*a*	78.3*a*	66.7*a*
		herbicide fallow	88.4*a*	74.9*a*	96.9*a*	84.6*a*
	60-90	sward	80.4*a*	71.1*a*	82.1*a*	82.3*a*
		herbicide fallow	87.9*a*	83.9*a*	94.9*a*	70.3*a*

Values marked in each row with identical letters are not significantly different at $\alpha = 0.05$.

In the experiment, a decrease in the phosphorus content with the depth of sampling was observed (Table 2). In both years, the content of assimilable phosphorus in the soil layer of 0-30 cm varied between medium and low, but was low in the 30-60 cm and 60-90 cm horizons (Table 2).

The content of assimilable magnesium in the soil was high in 2010 and 2013. Amounts of magnesium decreased with the depth of soil samples (Table 3). HAYNES (1981) reported that high nitrogen fertilization affects the accumulation of certain nutrients and consequently the nutritional status of the trees.

Nitrogen fertilization did not significantly affect the soil pH, which varied between years and between variants of soil maintenance depending in the orchard (Table 4). HAYNES and GOH (1980) reported a significant difference in the pH of the soil in herbicide fallow and sward. Soil under the herbicide fallow showed significantly lower pH. TAN and KELTJENS (1990) claim that high nitrogen fertilization reduces pH of the soil and therefore affects the accumulation of certain nutrients and consequently the nutritional status of the trees.

The use of nitrogen fertilizers did not affect the ratio of potassium to magnesium, which in both years of the research was proper (Table 5), as verified in SADOWSKI et al. (1990).

Table 2

The content of assimilable phosphorus in soil (mg kg^{-1})

Year	Layer (cm)	Sampling site	Variants of nitrogen fertilization			
			N-0	N-50	N-100	N-100$_{sward}$
2010	0-30	sward	31.4*a*	14.6*a*	17.2*a*	18.3*a*
		herbicide fallow	31.2*a*	24.6*a*	26.5*a*	27.8*a*
	30-60	sward	12.0*a*	7.3*a*	7.6*a*	7.3*a*
		herbicide fallow	8.2*a*	19.9*a*	9.3*a*	8.9*a*
	60-90	sward	6.5*a*	6.5*a*	7.4*a*	7.1*a*
		herbicide fallow	7.3*a*	6.7*a*	8.0*a*	7.9*a*
2013	0-30	sward	27.3*a*	12.7*a*	28.3*a*	14.2*a*
		herbicide fallow	33.5*a*	20.3*a*	21.3*a*	23.2*a*
	30-60	sward	12.1*a*	8.9*a*	8.6*a*	8.0*a*
		herbicide fallow	9.8*a*	9.4*a*	15.0*a*	10.7*a*
	60-90	sward	9.9*a*	7.9*a*	10.0*a*	13.8*a*
		herbicide fallow	10.2*a*	10.4*a*	10.5*a*	9.1*a*

Key: cf. Table 1

Table 3

Content of assimilable magnesium in soil (mg kg^{-1})

Year	Layer (cm)	Sampling site	Variants of nitrogen fertilization			
			N-0	N-50	N-100	N-100$_{sward}$
2010	0-30	sward	162.7*a*	164.6*a*	158.8*a*	153.6*a*
		herbicide fallow	146.5*a*	148.5*a*	132.8*a*	143.4*a*
	30-60	sward	117.5*a*	144.7*a*	150.8*a*	155.8*a*
		herbicide fallow	115.9*a*	159.9*a*	135.5*a*	146.1*a*
	60-90	sward	101.4*a*	119.5*a*	118.2*a*	137.7*a*
		herbicide fallow	89.1*a*	117.4*a*	94.2*a*	114.8*a*
2013	0-30	sward	171.4*a*	151.8*a*	147.2*a*	138.3*a*
		herbicide fallow	154.4*a*	134.1*a*	136.2*a*	124.5*a*
	30-60	sward	132.0*a*	133.8*a*	142.9*a*	132.4*a*
		herbicide fallow	139.2*a*	148.0*a*	155.6*a*	128.5*a*
	60-90	sward	119.2*a*	91.3*a*	105.7*a*	111.4*a*
		herbicide fallow	124.3*a*	119.4*a*	122.0*a*	120.0*a*

Key: cf. Table 1

Significantly lower total nitrogen content in leaves of the trees not fertilized with N in relation to the other treatments with N fertilization was observed in all the years of the research (Table 6). In addition, no significant

Table 4

Soil factor (pH KCl)

Year	Layer (cm)	Sampling site	Variants of nitrogen fertilization			
			N-0	N-50	N-100	N-100$_{sward}$
2010	0-30	sward	6.25*a*	5.39*a*	5.41*a*	5.31*a*
		herbicide fallow	5.58*a*	4.98*a*	4.66*a*	5.20*a*
	30-60	sward	7.93*a*	6.61*a*	6.54*a*	6.26*a*
		herbicide fallow	7.01*a*	6.44*a*	6.36*a*	6.46*a*
	60-90	sward	6.67*a*	6.88*a*	6.85*a*	6.86*a*
		herbicide fallow	7.48*a*	6.22*a*	6.70*a*	6.67*a*
2013	0-30	sward	5.13*a*	5.27*a*	5.90*a*	5.13*a*
		herbicide fallow	5.33*a*	5.03*a*	4.53*a*	5.03*a*
	30-60	sward	6.90*a*	6.43*a*	6.20*a*	6.13*a*
		herbicide fallow	6.43*a*	6.13*a*	5.97*a*	5.67*a*
	60-90	sward	7.10*a*	6.87*a*	6.53*a*	6.57*a*
		herbicide fallow	6.93*a*	6.63*a*	6.00*a*	6.30*a*

Key: cf. Table 1

Table 5

The ratio of assimilable potassium to magnesium in the soil; average for all layers and herbicide fallow and sward

Year	Variants of nitrogen fertilization			
	N-0	N-50	N-100	N-100$_{sward}$
2010	0.60*a*	0.61*a*	0.53*a*	0.53*a*
2013	0.84*a*	0.79*a*	0.85*a*	0.76*a*

Key: cf. Table 1

Table 6

Content of nitrogen in leaves (g kg^{-1})

Year	Variants of nitrogen fertilization			
	N-0	N-50	N-100	N-100$_{sward}$
2010	19.10*a*	21.10*b*	21.50*b*	21.13*b*
2011	19.20*a*	23.23*b*	23.70*b*	22.83*b*
2012	18.16*a*	22.30*b*	22.60*b*	22.13*b*

Key: cf. Table 1

differences were found between different variants of nitrogen fertilization. Similar results were obtained in the research of RUPP and HÜBNER (1995), WRONA and SADOWSKI (1997), as well as WRONA (2004). They observed an increase of the nitrogen content in leaves after an application of nitrogen fertilization, although only up to a certain level. Very high doses of nitrogen did not result in a further increase of its content in leaves. COMAI et al. (1995) confirmed the lack of influence of a dose and method of nitrogen fertilization on the N content in leaves of apple trees.

In the second and third year of the research (2011 and 2012), a decrease in the potassium content after the application of nitrogen fertilizer was observed. Within the first year (2010), differences in the potassium content from the unfertilized treatment were observed only when using 50 kg N ha^{-1} (Table 7). Similar results, confirming a decrease in the potassium content in leaves of apple trees after nitrogen application, were obtained by FALLAHI and KRISHNA MOHAN (2000). Researchers like SOTIROPOULOS et al. (2005) underline that the effect of nitrogen on the content of other nutrients in leaves is mainly correlated with the intensity of vegetative growth, which may cause the so-called growth dilution.

Table 7

Content of potassium in leaves (g kg^{-1})

Year	Variants of nitrogen fertilization			
	N-0	N-50	N-100	$N\text{-}100_{sward}$
2010	15.36*b*	12.26*a*	13.10*ab*	13.40*ab*
2011	15.60*b*	10.63*a*	12.40*a*	11.40*a*
2012	15.50*b*	11.50*a*	12.76*a*	12.43*a*

Key: cf. in Table 1

In 2011 and 2012, a significant increase in the magnesium content in the leaves of apple trees fertilized with nitrogen was observed when compared to the unfertilized combination. Within the first year, no such relationship was observed, although the Mg content in the leaves of apple trees unfertilized with nitrogen was slightly lower than in the other variants (Table 8). Similar results were noted by FALLAHI and KRISHNA MOHAN (2000) in a study on the cultivar Scarlet Gala. On the other hand, FALLAHI et al. (2001) observed similar effects of nitrogen fertilization on cv. Fuji, albeit at higher nitrogen doses. RUPP and HÜBNER (1995) claim that even minimal nitrogen doses cause an increase of the Mg content in leaves of the apple trees.

Table 8

Content of magnesium in leaves (g kg^{-1})

Year	Variants of nitrogen fertilization			
	N-0	N-50	N-100	$N\text{-}100_{sward}$
2010	19.33*a*	27.00*ab*	24.12*ab*	24.23*ab*
2011	24.66*a*	29.67*b*	29.33*b*	30.66*b*
2012	22.00*a*	28.66*b*	27.00*b*	27.66*b*

Key: cf. Table 1

On the basis of the experiment, it was demonstrated that the nitrogen fertilization caused a significant decrease in the P content in leaves of apple trees fertilized with nitrogen compared to the ones unfertilized with this element (Table 9). On the other hand, individual doses of nitrogen did not affect significantly the content of P in the leaves. Fallahi and Krishna Mohan (2000) showed that nitrogen fertilization of apple trees contributed to a decrease in the P level in apple tree leaves. Rupp and Hübner (1995) indicated that doses from 0 to 100 kg N ha^{-1} decreased the P content in leaves of the apple cultivar Golden Delicious.

Table 9

Content of phosphorus in leaves (g kg^{-1})

Year	Variants of nitrogen fertilization			
	N-0	N-50	N-100	N-100$_{sward}$
2010	2.90*b*	1.63*a*	1.53*a*	1.70*a*
2011	3.00*b*	1.76*a*	1.36*a*	1.70*a*
2012	2.96*b*	1.73*a*	1.60*a*	1.73*a*

Key: cf. Table 1

The Ca content in leaves of apple trees was not affected by the nitrogen fertilizers (Table 10). These results are consistent with the observations reported by Rupp and Hübner (1995). On the other hand, Fallahi et al. (2001) demonstrated different results, proving that nitrogen fertilization increased the Ca content in leaves of apple trees.

Table 10

Content of calcium in leaves (g kg^{-1})

Year	Variants of nitrogen fertilization			
	N-0	N-50	N-100	N-100$_{sward}$
2010	21.40*a*	21.36*a*	21.40*a*	21.23*a*
2011	21.83*a*	21.50*a*	21.30*a*	21.50*a*
2012	21.70*a*	21.40*a*	21.46*a*	21.50*a*

Key: cf. Table 1

In the first year of the study (2010), no significant impact of nitrogen fertilization on the content of N, K, Mg, P and Ca in fruits was observed (Table 11). No effect of nitrogen fertilization with respect to K, Mg, P and Ca level was observed within the second year of the research (2011), although the highest N content was observed in fruits harvested from the trees fertilized with doses of 50 and 100 kg N ha^{-1} applied to the entire surface of the soil (Table 11). In the third year of the research (2012), it was noticed that an application of nitrogen fertilizers resulted only in an increase of the N content in the fruits compared to the control, whereas no significant effect of nitrogen fertilizer on the content of other nutrients was observed.

Table 11

Content of mineral elements in fruits (g kg^{-1})

Year	Mineral elements	Variants of nitrogen fertilization			
		N-0	N-50	N-100	N-100_{sward}
2010	N	2.73*a*	3.30*a*	3.33*a*	2.84*a*
	K	7.80*a*	6.86*a*	7.10*a*	6.70*a*
	Mg	0.33*a*	0.30*a*	0.36*a*	0.30*a*
	P	1.03*a*	0.93*a*	0.96*a*	0.96*a*
	Ca	0.46*a*	0.36*a*	0.40*a*	0.30*a*
2011	N	2.14*a*	3.20*b*	3.38*b*	2.85*ab*
	K	7.46*a*	7.50*a*	6.90*a*	7.13*a*
	Mg	0.33*a*	0.33*a*	0.30*a*	0.33*a*
	P	0.83*a*	0.83*a*	0.80*a*	0.83*a*
	Ca	0.33*a*	0.33*a*	0.33*a*	0.33*a*
2012	N	2.46*a*	3.26*b*	3.36*b*	3.20*b*
	K	7.33*a*	7.20*a*	7.03*a*	6.93*a*
	Mg	0.33*a*	0.30*a*	0.33*a*	0.30*a*
	P	1.00*a*	0.93*a*	0.86*a*	0.90*a*
	Ca	0.40*a*	0.30*a*	0.33*a*	0.33*a*

Key: cf. Table 1

CONCLUSIONS

1. Nitrogen fertilization caused a significant increase in the N content in apple tree leaves compared to the unfertilized treatment, although the dosage and method of fertilization with N did not affect this parameter.

2. Nitrogen fertilization resulted in a decrease in the phosphorus content in apple tree leaves.

3. The content of Ca in leaves of apple trees was not affected by the use of nitrogen fertilizers.

4. The use of nitrogen fertilizers had no effect on the content of N, K, Mg, P and Ca in apple fruits.

5. Nitrogen fertilization had no effect on soil pH, content of assimilable potassium, phosphorus and magnesium or the ratio of K to Mg in the soil.

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