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THE INFLUENCE OF NITROGEN FERTILIZATION ON GROWTH, YIELD AND FRUIT SIZE OF 'JONAGORED' APPLE TREES

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Abstract. Guidelines in European Union for N management in orchards aim to limit fertilizer applications under threshold limits, in order to reduce N losses to the environment, but at the same time to attain optimum tree growth, high yield and good fruit quality. The experiment was carried out at the Wilanów Research Farm, situated in the postglacial valley of the Vistula River, on a fertile silty loam alluvial soil. The soil of the field assigned for the experiment was at the depth of 0–20 cm, slightly acid (pH_{KCl} = 6.0), showed high available Mg (16.6 mg%) and P (6.6 mg%) contents, medium available K (19.6 mg%) and a low K/Mg ratio (1.2). Considering a low ratio of K to the other kations as well as occasionally appearing K deficiency symptoms in the neighbouring orchard, before tree planting potassium salts were applied at the rate of 200 kg K_2O ha^{-1}. Throughout all the years of studies potassium, magnesium and phosphorus fertilizers as well as liming soil were not applied. 'Jonagored' apple trees on M.9 rootstock were planted in spring 2000, spaced 3.5 × 1.5 m. From spring 2000, five fertiliser treatments were applied: (1) N-0 (check); (2) N-50 (50 kg N ha^{-1}), over the whole orchard area in early spring); (3) N-100 (100 kg N ha^{-1}, over the whole area, in early spring); (4) N-$100_{delayed}$ (100 kg N ha^{-1}, in early spring, starting from the fourth year after planting 2004); (5) N-100_{sward} (100 kg N ha^{-1}, in early spring, starting from the fourth year after planting, in sward alleyways only). Nitrogen was applied as ammonium nitrate, before the start of vegetative growth. After 10 years, the higher dose, i.e. 100 kg N ha^{-1} applied from the first year after planting resulted in the smallest trunk cross-sectional area (TCSA), during when the same dose starting from the fourth year after planting resulted in the highest TCSA. N fertilization did not significance effect on growth of the trees as compared with not fertilized control. The first yield was harvested in the 3rd year after planting (2002), but in any year neither dose or mode of N fertilisation had any significant effect of yield. The cumulative yield for the years 2002–2009 and fruit size did not depend on N fertilization either. No significant response to nitrogen fertilization was noted on cropping efficiency coefficient for eight years of bearing in relation to the final trunk cross-sectional area.

Key words: apple, nitrogen, cultivar, trunk cross-sectional area, cumulative yield, mean fruit mass, cropping efficiency coefficient

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INTRODUCTION

Nitrogen fertilization plays an important role in the production of apple tree orchard and is a major means of controlling their growth and fruiting [Noe et al. 1995, Tagliavini et al. 1996]. Guidelines in European Union for N management in orchards aim to limit fertilizer applications under threshold limits, in order to reduce N losses to the environment, but at the same time maintenance of a high yield and good fruit quality. In sustainable fruit production it is recommended adapting rates of N fertilizers adequate to tree demands, taking into account natural soil resources and adopting highly efficient technology of nutrient supply [Tagliavini and Millard 2005].

Elaboration of the proper N fertilisation recommendations is very difficult because the effectiveness of fertilization often do not take into account the response in yield and fruit quality. Additionally, the specific character of perennial plants causes that effects of N supplying can be observed after many years [Pacholak 2008]. Most of scientific experiments confirmed, that under conditions of proper soil management, apple trees rarely responded to nitrogen fertilisation [Deckers et al. 2001, Widmer et al. 2006, Wrona 2009]. Excessive N supply has been often decreased yield, had negative effect on fruit blush and results in a high level of soluble N in the soil solution [Pacholak 1986, Rupp 1995, Wrona 2004, Thalheimera and Paoli 2006, Unuk et. al. 2008].

The main objective of this study was to elaborate a rational method of nitrogen fertilization in apple orchard, which would allow to minimise the use of N fertilizers and at the same time to attain optimum tree growth, high yield and good fruit quality.

MATERIAL AND METHODS

The experiment was carried out at the Wilanów Research Farm, situated in the post-glacial valley of the Vistula River, on a fertile silty loam alluvial soil. The soil of the field assigned for the experiment was at the depth of 0–20 cm, slightly acid (pH_{KCl} = 6.0), showed high available Mg (16.6 mg%) and P (6.6 mg%) contents, medium available K (19.6 mg%) and a low K/Mg ratio (1.2). Considering a low ratio of K to the other cations as well as occasionally appearing K deficiency symptoms in the neighbouring orchard, before tree planting in autumn 1999 potassium salts were applied at the rate of 200 kg K_2O ha^{-1}. Throughout all the years of studies potassium, magnesium and phosphorus fertilizers as well as liming soil were not applied.

'Jonagored' apple trees on M.9 rootstock were planted in spring 2000, spaced 3.5 × 1.5 m. Alleyways were maintained under sward, while 1 m herbicide strips were maintained along tree rows. From spring 2000, five fertiliser treatments were applied: (1) N-0 (control-unfertilized); (2) N-50 (50 kg N ha^{-1}), over the whole orchard area in early spring); (3) N-100 (100 kg N ha^{-1}, over the whole area, in early spring); (4) N-$100_{delayed}$ (100 kg N ha^{-1}, in early spring, starting from the fourth year after planting 2004); (5) N-100_{sward} (100 kg N ha^{-1}, in early spring, starting from the fourth year after planting, in sward alleyways only). Nitrogen was applied as ammonium nitrate, before the start of vegetative growth. The experiments were set up in a randomized block design, with 5 replications. Tree training, protection against diseases and pests were carried out according to the recommendations for commercial orchards.

Tree growth was estimated by trunk cross-sectional area (TCSA) after ten years (spring 2010), as well as its increase within ten years (spring 2000 – spring 2010), based on diameter measurements at 30 cm above the ground. The yield was assessed each year on the basis of yield per tree and as cumulative yield for eight years (2002–2009). Mean fruit mass was also determined. The cropping efficiency coefficient (CEC) was calculated as a ratio of cumulative yield for 8 years (2002–2009) to the final TCSA (spring 2010).

All data were elaborated by analysis of variance. Significance of differences between treatment means was estimated using the Newman-Keuls test at p = 0.05.

RESULTS

Trunk cross-sectional area (TCSA), used as a measure of the overall tree growth and final tree size was affected by dose or mode of N fertilisation (tab. 1). After 10 years, the higher dose, i.e. 100 kg N ha^{-1} applied from the first year after planting resulted in

Table 1. Trunk cross-sectional area (TCSA), increase of trunk cross-sectional area within ten years of the study and cropping efficiency coefficient (CEC) depending on fertilizer treatments

Tabela 1. Pole powierzchni przekroju pnia (PPPP), przyrost pola powierzchni przekroju pnia (PPPPP) po dziesięciu latach badań i wskaźnik intensywności owocowania w zależności od nawożenia azotem

Treatment Nawożenie	TCSA – PPPP spring – wiosna 2000 cm^2	TCSA – PPPP spring – wiosna 2010 cm^2	Increase of TCSA – PPPPP spring 2000–2010 cm^2	CEC – WIO kg cm^{-2}
N-0	1,41 a*	55.24 ab	53.83 ab	3.38 a
N-50	1,43 a	52.78 ab	51.35 ab	3.64 a
N-100	1,37 a	48.99 a	47.62 a	3.89 a
N-100$_{delayed, od 4 roku}$	1,42 a	56.43 b	55.01 b	3.39 a
N-100$_{sward, murawa}$	1,41 a	51.08 ab	49.67 ab	3.66 a

N-0 – check– kontrola, bez nawożenia azotem

N-50 – 50 kg N ha^{-1}, over the whole orchard area in early spring (from 2000) – 50 kg N ha^{-1} jednorazowo wiosną, na całą powierzchnię (od 2000 roku)

N-100 – 100 kg N ha^{-1}, over the whole area, in early spring (from 2000) – 100 kg N ha^{-1} jednorazowo wiosną, na całą powierzchnię (od 2000 roku)

N-100$_{delayed, od 4 roku}$ – 100 kg N ha^{-1}, in early spring, starting from the fourth year after planting (2004) – 100 kg N ha^{-1} jednorazowo wiosną od czwartego roku po posadzeniu (2004) na całą powierzchnię

N-100$_{sward, murawa}$ – 100 kg N ha^{-1}, in early spring, starting from the fourth year after planting (2004), in sward alleyways only – 100 kg N ha^{-1} jednorazowo wiosną, tylko w obrębie murawy, od czwartego roku po posadzeniu (2004)

* means followed by the same letter in columns are not significantly different at α = 0.05 – średnie oznaczone tą samą literą w kolumnach nie różnią się istotnie przy α = 0,05

the smallest TCSA, during when the same dose starting from the fourth year after plant ing resulted in the highest TCSA. N fertilization did not significance effect on growth of the trees as compared with not fertilized control. In this case, growth of trees without fertilization expressed as trunk cross-sectional area was vigorous and similar to growth of trees when 100 kg N ha^{-1} used from the fourth year after planting. The same applies to the increase of trunk cross-sectional area within ten years of the study (spring 2000––2010), where fertilization did not exert any significant effect to growth of trees in comparison to unfertilized check (tab. 1).

The first yield was harvested in the 3rd year after planting (2002), but in any year neither dose or mode of N fertilisation had any significant effect of increasing the yield (tab. 2). During the following eight years independently of fertilization, yield per tree systematically increased in successive years, where in 2009 exceed 30 kg. Fruit size was different in respective years, bat did not depend on N fertilization either (tab. 3). No significant differences in mean fruit weight due to treatments were found. Fruit size was apparently a function mainly of weather conditions in particular seasons than N fertilization.

Table 2. Yield of trees as affected by different fertilizer treatments, kg tree^{-1}
Tabela 2. Plonowanie drzew w zależności od kombinacji nawożenia, kg drzewo^{-1}

Treatment Nawożenie	2002	2003	2004	2005	2006	2007	2008	2009	∑2002–2009
N-0	9.1	13.3	26.0	22.5	27.2	25.1	27.4	35.7	186.3
N-50	9.3	14.2	29.1	20.6	22.8	28.7	33.7	32.7	191.1
N-100	7.8	13.2	26.6	20.7	28.7	25.7	30.9	36.2	189.8
$N\text{-}100_{\text{delayed, od 4 roku}}$	9.4	15.5	26.8	21.8	26.6	25.7	27.6	37.9	191.3
$N\text{-}100_{\text{sward, murawa}}$	7.8	12.6	25.5	22.5	26.7	25.9	30.0	34.6	185.6

Explanation – see table 1 – Objaśnienia – patrz tabela 1
* means in columns are not significantly different at α = 0.05 – średnie w kolumnach nie różnią się istotnie przy α = 0,05

Table 3. Mean fruit mass depending on fertilizer treatments, g
Tabela 3. Masa owocu w zależności od kombinacji nawożenia, g

Treatment Nawożenie	2002	2003	2004	2005	2006	2007	2008	2009	Average with 8 years Średnia z 8 lat
N-0	350	231	273	197	239	241	291	262	261
N-50	316	242	252	210	237	237	269	249	251
N-100	299	241	275	217	237	242	274	258	255
$N\text{-}100_{\text{delayed, od 4 roku}}$	334	262	283	221	246	242	285	253	266
$N\text{-}100_{\text{sward, murawa}}$	325	249	265	195	244	244	291	252	257

Explanation – see table 1 – Objaśnienia – patrz tabela 1
* means in columns are not significantly different at α = 0.05 – średnie w kolumnach nie różnią się istotnie przy α = 0,05

Fertilization had no significant effect on the cumulative yield for the years 2002–2009 and average fruit size (tab. 2, 3). Thus, it must be pointed out that highest total yield and average mean fruit mass for the years 2002–2009 was obtained from the highest trees in combination where used 100 kg N ha^{-1} starting from the fourth year after planting.

No significant response to nitrogen fertilization was noted on cropping efficiency coefficient (CEC) for eight years of bearing in relation to the final trunk cross-sectional area; however, the higher dose, i.e. 100 kg N per ha applied from the first year after planting, resulted in the highest CEC and nil fertilization resulted in the lowest CEC (tab. 1).

DISCUSSION

Analysis relating to growth of trees and yielding indicated that under conditions of proper soil management N fertilization did not exert significant effect on this features. As shown by our study, the strongest vigor of trees was in combination where used 100 kg N ha^{-1} starting from the fourth year after planting but not significant differences in comparison with unfertilized treatment was noted. Lack of reaction to N fertilization is a line with most of the previous studies [Yogaratnam and Greenham 1982, Papp 1997, Ernani and Dias 1999, Neilsen et al. 1999, Rogachev 2007, Pacholak 2008, Wrona 2009]. The present authors explain the absence of such reaction by a low requirement of apple trees for nitrogen than other plants and a good soil preparation before orchard establishment. Maintaining soil in a weed-free state by means of herbicides undoubtedly favours abundant N availability. It has been also demonstrated by Wrona and Sadowski [1999] that herbicide strips were additionally enriched by organic matter with grass mown in alleyways. Thus, the roots under herbicide strips grow under luxurious conditions of nutrient supply.

According to Wrona and Sadowski [1999] and Scudellari et al. [1993] yearly applications of nitrogen might tremendously increase the N fertility of some soils and tree N reserves, and that interrupting the N supply even for long periods might not result in tree growth and yield reduction. Additionally, fruit trees are capable to store N during the winter for remobilization in the spring. On the other hand N used by leaves, shoots, flowers and buds remain in the orchard and only with harvested fruit is carried away. In this situation the apple trees find good conditions for nitrogen supply, particularly when the soil is rich in organic matter. That was probably the reason nil response of apple trees to N fertilisation in our experiment.

Fertilisation restricted to the sward alleyways only, seems useless, as both under herbicide and sword treatment abundant amounts of available nitrogen are evolved which may fully satisfy demand for nitrogen, particularly when the soil is rich in organic matter, what it confirmed by Raese et al. [2007].

CONCLUSIONS

1. The growth of trees was affected by dose or mode of N fertilisation. After 10 years, the higher dose, i.e. 100 kg N ha^{-1} applied from the first year after planting resulted the smaller tree size, during when the same dose starting from the fourth year after planting resulted the larger tree size. N fertilization did not significance effect on growth of the trees as compared with not fertilized control.

2. Nitrogen fertilization for 10 years had not effect on yield in successive years, cumulative yield for the years 2002–2009 and cropping efficiency coefficient.

3. No effect on tree growth and productivity due to N fertilization was a consequence of good soil preparation before orchard establishment, maintaining herbicide strips along tree rows and increase of available N content at the soil during the vegetative period.

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WPŁYW ZRÓŻNICOWANEGO NAWOŻENIA AZOTEM NA WZROST, PLONOWANIE I WIELKOŚĆ OWOCÓW ODMIANY JONAGORED

Streszczenie. Jednym z bardziej dyskusyjnych zagadnień w nawożeniu roślin sadowniczych pozostaje nawożenie azotowe, a przede wszystkim jego rola we wzroście i plonowaniu drzew owocowych, zwłaszcza jabłoni. Celem badań było opracowanie racjonalnej metody nawożenia azotem, pozwalającej na minimalizację zużycia nawozów, przy osiągnięciu optymalnego wzrostu drzew, obfitego plonowania oraz optymalnej wielkości owoców. Doświadczenie przeprowadzono w latach 2000–2009 na jabłoniach odmiany 'Jonagored' na podkładce M.9, rosnących na glebie typu mada wykazującej skład pyłu ilastego w rozstawie 3,5 × 1,5 m. Gleba pola przeznaczonego pod doświadczenie wykazywała na głębokości 0–20 cm odczyn lekko kwaśny (6,0), odznaczała się wysoką zawartością przyswajalnego Mg (16,6 mg%) i P (6,6 mg%), średnią zawartością przyswajalnego K (19,6 mg%) i niskim stosunkiem K/Mg (1,2). Biorąc pod uwagę niekorzystny stosunek K w glebie do innych kationów, zastosowano pod orkę sól potasową w dawce 200 kg K_2O/ha. Przez wszystkie lata trwania doświadczenia nie stosowano wapnowania gleby, a także nawożenia potasem, magnezem i fosforem. W doświadczeniu porównywano następujące obiekty nawożenia azotem: 1. N-0 (bez azotu, kontrola); 2. N-50 (50 kg N ha^{-1} jednorazowo wiosną od 2000 r. na całą powierzchnię); 3. N-100 (100 kg N ha^{-1} jednorazowo wiosną od 2000 r. na całą powierzchnię); 4. N-$100_{od\ 4\ roku}$ (100 kg N ha^{-1} jednorazowo wiosną od 4. roku po posadzeniu (2004) na całą powierzchnię); 5. N-100_{murawa} (100 kg N ha^{-1} wiosną, od czwartego roku po posadzeniu (2004), tylko w obrębie murawy). Jako nawóz azotowy stosowano saletrę amonową na powierzchnię gleby. Korony prowadzono w formie wrzecionowej; wysokość pnia wynosiła 60–70 cm. Wzdłuż rzędów drzew utrzymywano wąski ugór herbicydowy (1 m szerokości), natomiast w międzyrzędziach była murawa, często koszona. Wzrost drzew mierzony polem przekroju poprzecznego pnia po 10 latach prowadzenia doświadczenia był uzależniony od dawki i sposobu nawożenia azotem. Najsłabiej rosły drzewa, gdy stosowano dawkę 100 kg N ha^{-1} jednorazowo wiosną na całej powierzchni, a najsilniej, gdy stosowano również dawkę 100 kg N ha^{-1}, ale dopiero od 4. roku po posadzeniu. Nie stwierdzono jednak istotnej różnicy pomiędzy kombinacjami nawożonymi a kombinacją nienawożoną azotem. Podobną sytuacje zanotowano w przyroście pola przekroju poprzecznego pnia za okres 10 lat badań (wiosna 2000 – wiosna 2010). Zarówno plonowanie drzew w poszczególnych latach, jak i suma plonów za lata 2002–2009 oraz wielkość owoców nie zależała w sposób istotny ani od dawki, ani od sposobu nawożenia azotem. Zarówno dawka, jak i sposób nawożenia azotem nie miały wpływu na wskaźnik intensywności owocowania wyrażony stosunkiem sumy plonów do końcowego pola powierzchni przekroju poprzecznego pnia.

Słowa kluczowe: jabłoń, azot, odmiana, pole powierzchni przekroju pnia, suma plonu, średnia masa owocu, wskaźnik intensywności owocowania

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