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INFLUENCE OF FERTIGATION WITH NITROGEN AND A COMPLETE FERTILIZER ON GROWTH AND YIELDING OF 'GALA' APPLE TREES

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A B S T R A C T

Modern methods of orchard cultivation require more effective ways of irrigation and fertilization. An advantage of fertigation is the possibility of regulating the doses and frequency of water and nutrient applications according to plant requirements influenced by plant age, growth cycle and weather conditions. An experiment was performed to evaluate the effectiveness of fertigation using only a nitrogen fertilizer and a complete nutrient fertilizer compared with the traditionally used surface application of such fertilizers in an apple orchard. The experiment was conducted over seven years (1993-1999) on apple trees cv. 'Gala' grafted on rootstock M.9 in the Experimental Orchard located in Dąbrowice (central Poland). Two types of fertilizers were used: I – containing only nitrogen, and II – a complete nutrient fertilizer containing all macronutrients. Both types of fertilizers were applied to trees either via a drip irrigation system or by the traditional method of broadcasting.

The results of the experiment showed that, in general, fertigation increased the growth and yielding of apple trees. The type of fertilizer used had a significant effect on only the growth of the trees. Initially, in the first two years after planting, stronger growth was shown by the trees fertilized with nitrogen only. However, in the subsequent years, stronger tree growth was found on plots fertilized with the complete fertilizer, irrespective of the fertilizer application method. The final result of this was that at the end of the experiment the trunk cross-sectional areas of the trees fertilized with the complete fertilizer were significantly larger in comparison with those fertilized with nitrogen only.

Key words: drip irrigation, fertigation, apple 'Gala'

INTRODUCTION

In Polish climatic conditions, frequent spells of drought become a limiting factor in the development of modern fruit production. Intensive methods of orchard cultivation require more effective ways of irrigation and fertigation. According to Bravdo (1993), the high effectiveness of fertigation results from the possibility of applying optimal concentrations of fertilizing solutions and a higher root density in the wetted soil volume. Kenworthy (1979) says that applying fertigation allows to reduce nitrogen doses by half. Bravdo and Proebsting (1993) suggest that with fertigation it is easier to control growth than yielding. A high level and constant availability of nitrogen, especially in spring, strongly influence the growth of trees, which has a negative effect on the fruit crop.

The aim of the experiment was to evaluate the effectiveness of fertigation with nitrogen and a complete fertilizer in an apple orchard in Polish conditions.

MATERIAL AND METHODS

The experiment was carried out at the Experimental Station at Dąbrowice in central Poland, which belongs to the Research Institute of Pomology and Floriculture. In the spring of 1993, apple trees of the cultivar 'Gala' grafted on the M.9 dwarfing rootstock were planted 3.5 x 1.25 m apart (2286 trees per hectare). The orchard was planted on a light sandy loam soil. In 1992, in the field where black currant bushes had been grown, 3 t of lime and 180 kg of K_2O as potassium chloride were applied after deep ploughing. Chemical analyses showed that the soil was slightly acidic and the levels of phosphorus, magnesium and potassium were high (Tab. 1). The proportion between the potassium and magnesium in the analyzed soil was correct. The evaluation of the fertility of the soil was based on the limiting values worked out by Sadowski et al. (1990).

Two kinds of fertilizer were used: one containing only nitrogen – ammonium nitrate (30 g nitrogen per tree), while the other was a complete fertilizer containing all macronutrients – (30 g nitrogen, 4 g phosphorus, 37 g potassium, 6 g magnesium and 4 g calcium per tree). In the first year, one third of the above rates was applied, and in the second year, two thirds were applied. All nutrients were applied by means of a drip irrigation system or conventionally by spreading (broadcasting) on the soil surface.

Table 1. Levels of available phosphorus, potassium and magnesium in the soil before the start of the experiment (mean values)

Depth [cm]	$pH_{(KCl)}$	mg/100 g of soil			Ratio Mg:K
		P	K	Mg	
0-20	4.7	7.0	14.9	5.9	2.53
21-40	4.7	6.0	14.5	5.7	2.54

Weeds in the tree rows were controlled with herbicides, and the grassy inter-rows were mowed. The trees were trained as spindles. The experimental orchard was irrigated with Raam pressure compensation drip-lines at a discharge rate of 2.3 l h^{-1}. The distance between the drippers was 0.7 m. Well water was used for irrigation and fertigation (pH 7.4, Ec 0.35 mS cm^{-1}, 85 mg dm^{-3} Ca and 14 mg dm^{-3} Mg). The water was supplied at a rate sufficient to maintain a soil water potential between 0 and -0.02 MPa at a depth of 20 cm, which was controlled by tensiometers. Fertigation depended on weather conditions and was conducted from May to July at least once a week. The experiment was carried out in a split block design with four replicates of seven trees per experimental plot. The data were elaborated using an analysis of variance, followed by Duncan's multiple range t-test or Student's t-test.

RESULTS AND DISCUSSION

Weather conditions

Average monthly temperatures, and especially rainfall, varied from one year to another (Fig. 1). The initial period of cultivation (1993-1995) was dry due to insufficient rainfall. The springs in the subsequent years offered a lot of rainfall, which influenced the growing conditions in the summer. The situation was significant in the year 1997, which had heavy rains in May through July while the second half of the summer was dry.

Tree growth

The growth of trees was evaluated by measuring the length of 1-year-old branches in the first two years of cultivation and by taking measurements of the trunk cross-section area (TCSA) at the height of 30 cm above the soil every year. Both the kind of fertilizer applied and the method of its application had a significant effect on the growth of trees (Tab. 2). The strongest growth of 1-year-old branches was observed in the trees fertigated with ammonium nitrate. The values of TCSA in the consecutive years are shown in Figure 2. The differences in tree growth vigour, which depended on the combinations used, were observed as early as the first years after planting. The fertigated trees grew more vigorously than the trees fed with broadcast fertilizers. TCSA was also positively affected by the type of fertilizer used.

Analysis of the data shows that the trees grew more vigorously when fertigated with ammonium nitrate at the beginning of cultivation, whereas fertigation with a complete (NPK) fertilizer resulted in stronger growth in the subsequent years. These findings suggest that the initial supply of phosphorus, potassium and magnesium in the soil was sufficient for tree growth, but in the long run the trees required additional feeding with a complete NPK fertilizer. The importance of fertigation and its influence on better apple tree growth has been confirmed by many authors (Hipps, 1992; Dencker and Hansen, 1994; Widmer and Krebs, 1999; Neilsen et al., 2000).

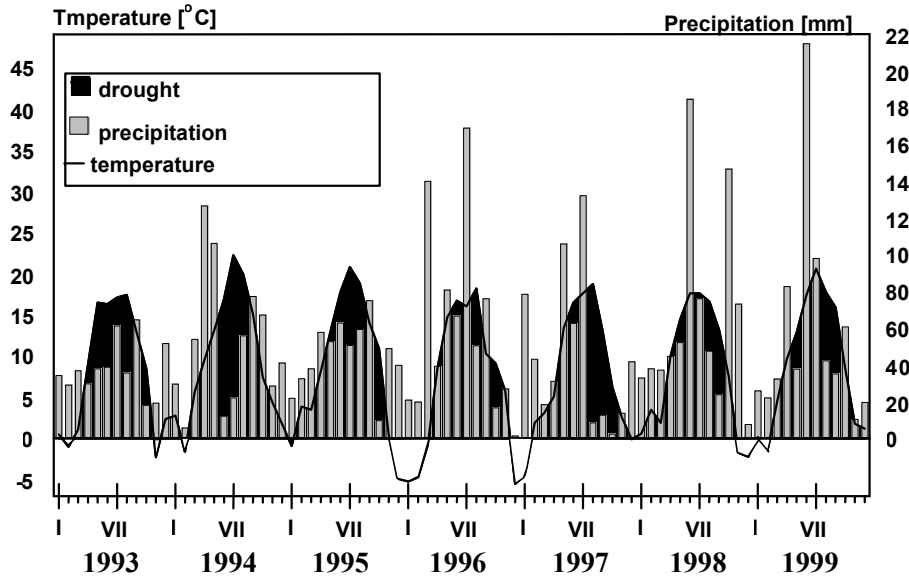

Figure 1. Climatic graph – Skierniewice, 1993-1999

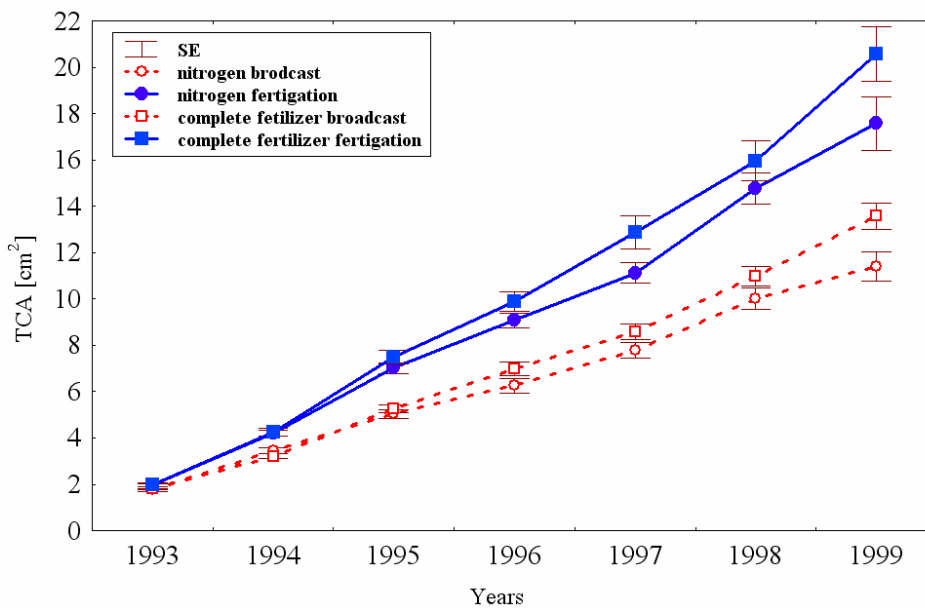

Figure 2. Trunk cross-section area of 'Gala' apple trees in 1993-1999

Table 2. Total length of annual shoots [cm/tree] of cv. 'Gala'. Evaluation of the main effects and interaction

Treatment	Year	
	1993	1994
Nitrogen – broadcast	184.0 b*	495.8 ab
Nitrogen – fertigation	236.4 c	790.9 c
Complete fertilizer – broadcast	149.1 a	432.5 a
Complete fertilizer – fertigation	174.3 b	564.0 b

*Means in columns marked with the same letters do not differ significantly at 5 % (Duncan's t-test)

Yielding

The full potential of yielding was obtained in the third year after planting. In order to eliminate the aspect of alternate bearing, the analysis of yielding involved the results of consecutive two-year periods and the total yield. The kind of fertilizer applied did not affect the total yield, but in the years 1996 and 1997 higher yields were obtained from the trees fertilized with the complete fertilizer (Tab. 3). The method of fertilization had a statistically significant influence on the yielding of apple trees. The trees supplied with the broadcast fertilizer produced larger crops in the initial period of cultivation, but later yields (in the next two periods of evaluation) and the total yield were higher when fertigation was applied. The lowest total yield was obtained from the trees fertigated with ammonium nitrate. In central Poland, the positive effects obtained for cv. 'Gala' as a consequence of fertigation are confirmed by the findings of a number of authors: (Bootsma, 1989; Boesveld, 1991; Kodde et al., 1992; Scholtens et al., 1990; Robinson and Stiles, 1993; Buban and Lakatos, 1998). However, there are also publications reporting a very weak influence of fertigation on apple crops (Tromp and Bolding, 1988; Zydlik and Pacholak, 1999), or complete lack of it (Beushlein, 1994; Widmer and Krebs, 1999). The authors explain that the lack of positive effects of fertigation on yielding is caused by the different environmental conditions compared with the Dutch and Canadian sites, where the results obtained were positive (Alway, 1993). Stiles and Robinson (1997), carrying out experiments on fertigation of apple trees at an experimental station in Geneva – New York State, USA, got negative results, which were interpreted as influenced by the climatic conditions there and the soil rich in mineral nutrients.

The average weight of Gala apples varied from year to year (Fig. 3). The heaviest fruits were obtained in 1998. In the year 1995, irrespective of the fertilizer used, the heaviest fruits were produced by the fertigated trees. The increased fruit weight was a result of a lower yield in that season. None of the examined factors had any influence on the average weight of the fruits for the whole period of the experiment.

Table 3. Yields [kg tree^{-1}] from apple trees cv. 'Gala'

Treatment	Years			
	1994-1995	1996-1997	1998-1999	1994-1999
Type of fertilizer				
N	6.68 a*	25.67 a	27.73 a	60.08 a
NPK	5.32 a	29.01 b	30.53 a	71.98 a
Fertilizer application method				
Broadcast	6.96 b	24.72 a	27.02 a	58.7 a
Fertigation	5.04 a	29.96 b	31.24 b	66.24 b
Nitrogen – broadcast	7.40 b	22.49 a	24.50 a	54.39 a
Nitrogen – fertigation	5.96 ab	28.86 c	30.96 b	65.77 b
Complete fertilizer – broadcast	6.52 b	26.95 bc	29.53 b	63.00 b
Complete fertilizer – fertigation	4.12 a	31.06 c	31.53 b	66.71 b

*For explanations, see Table 2

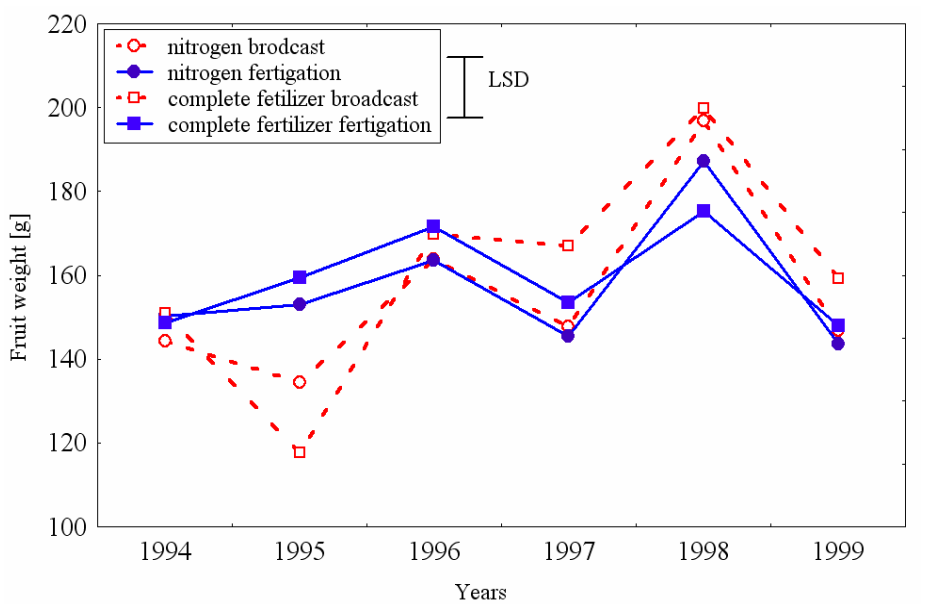

Figure 3. Mean fruit weight in the years 1994-1999 – cultivar 'Gala'

Nitrogen content of leaves

The total nitrogen content in the leaves was optimal or high (Sadowski et al., 1990). Detailed analysis of the relevant work has been presented by Treder and Olszewski (2004). The experiment did not reveal any significant influence of the kind of fertilizer used or the method of fertilization on the average nitrogen content in the leaves. The nitrogen content decreased with the age of the

trees and depended on tree vigour and yield size. The strong and high yielding trees grow very slowly and as a result accumulate more assimilates in their leaves, which was demonstrated by Pieniążek and Łaźniew-ska (1960), and Tagliavini et al. (1992).

Phosphorus content of leaves

All the investigated combinations showed that the phosphorus content of the leaves was optimal (Fig. 4). Only in the year 1997, the amounts of phosphorus in the leaves reached a high level. Analysis of the main effects revealed that the kind of fertilizer used did not have any significant influence on the phosphorus concentration in the leaves (Tab. 4). However, there was high variability in the analysis results from one year of cultivation to another. In the years 1994 and 1999, fertilization with the complete fertilizer caused the levels of phosphorus to rise compared with nitrogen fertilization. In 1997, the reverse situation was observed. Compared with broadcast fertilization, fertigation caused higher concentrations of phosphorus in the leaves not only in the years 1995, 1996, 1999, but the difference was also reflected in the averages for all the years of the experiment.

Potassium content of leaves

The highest concentrations of potassium in the leaves were found in the first year of cultivation. In the subsequent years, a tendency to lower its content was observed, but all the combinations showed high potassium levels (Fig. 5). The kind of fertilizer used and the way of its application did not significantly influence the potassium content in the leaves both in each successive year and the whole period of the investigation (Tab. 5).

The levels of mineral nutrients changed significantly in the successive years of the experiment. Many authors have written about the influence of the years in which experiments are carried out on the concentration of macro elements in the leaves of fruit trees (Kłossowski, 1972; Pacholak, 1986; Ugolik, 1995). Both the nitrogen and potassium content were found to decrease with the age of trees. Similar results were also obtained by Olszewski (2001). Kłossowski and Czynczyk (1974) reported that the nitrogen content in one-year-old apple trees is significantly higher than in the leaves of two-year-old trees. The level of nitrogen in the leaves is influenced by the yield. Pieniążek and Łaźniewska (1960) explain this as a result of higher dry weight of the leaves of poorly yielding trees. Lack of fruiting may cause higher concentrations of assimilates in the leaves. Sadowski et al. (1995) state that in the years of poor cropping the leaves of apple trees contain not only more nitrogen but also phosphorus. However, the phosphorus content in the leaves of cv. 'Gala' did not depend on the level of yielding. Despite the numerous publications concerning the effectiveness of fertigation in apple orchards, the data describing the effects of this fertilizer

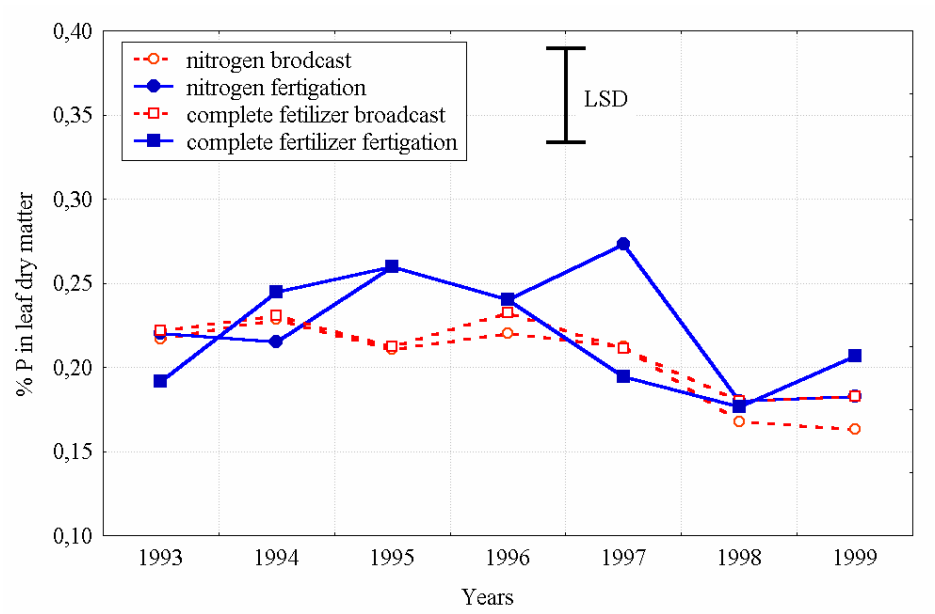

Figure 4. Phosphorus content in the leaves of 'Gala' apple trees

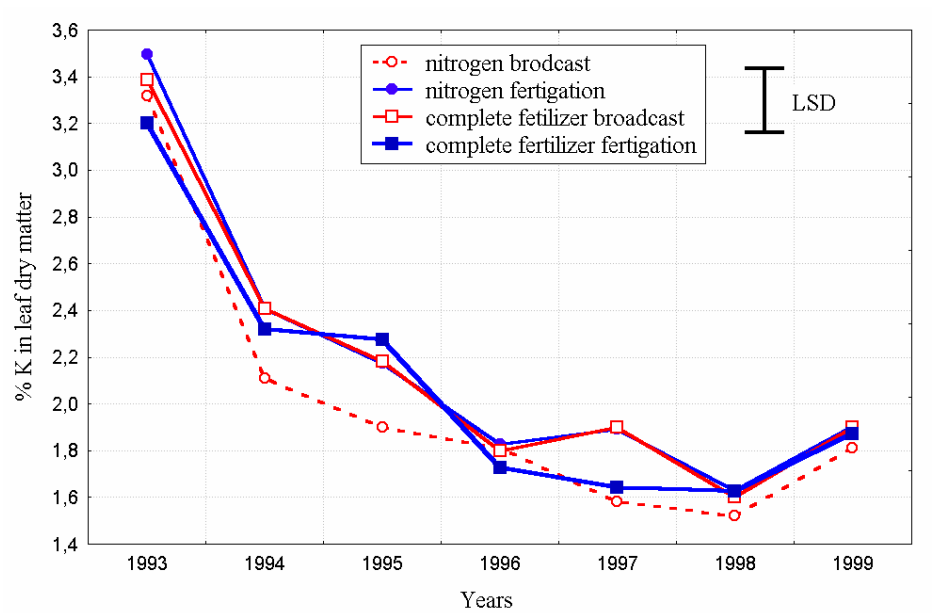

Figure 5. Potassium content in the leaves of 'Gala' apple trees

Table 4. The effect of fertilizer type and application method on phosphorus content in the leaves of 'Gala' apple trees [% d.m.]

Factor	1993	1994	1995	1996	1997	1998	1999	Mean
Type of fertilizer								
N	0.22	0.22	0.24	0.23	0.24	0.17	0.17	0.21
NPK	0.21	0.24	0.23	0.24	0.20	0.18	0.19	0.22
Significance	NS	*	NS	NS	*	NS	**	NS
Fertilizer application								
Broadcast	0.22	0.23	0.21	0.23	0.21	0.17	0.17	0.21
Fertigation	0.21	0.23	0.26	0.24	0.23	0.18	0.19	0.22
Significance	NS	NS	**	*	NS	NS	**	*
Interaction (NxS)	NS	*	NS	NS	NS	NS	NS	NS

NS – not significant
**means significantly different at 0.01 level of significance
*means significantly different at 0.05 level of significance

Table 5. The effect of fertilizer type and application method on potassium content in the leaves of 'Gala' apple trees [% d.m.]

Factor	1993	1994	1995	1996	1997	1998	1999	Mean
Type of fertilizer								
N	3.41	2.26	2.04	1.82	1.73	1.57	1.85	2.10
NPK	3.29	2.36	2.20	1.81	1.68	1.69	1.87	2.14
Significance	NS	NS	*	NS	NS	NS	NS	NS
Fertilizer application								
Broadcast	3.34	2.26	2.01	1.85	1.64	1.64	1.83	2.10
Fertigation	3.35	2.36	2.23	1.78	1.77	1.62	1.89	2.14
Significance	NS	NS	*	NS	NS	NS	NS	NS
Interaction (NxS)	NS	NS	NS	NS	*	NS	NS	NS

NS, *For explanations, see Table 4

application method on the mineral content of the leaves are rather poor.

According to Wolf et al. (1990), fertigation with complete fertilizers causes a higher level of nitrogen content in apple tree leaves. The higher amounts of nitrogen in the leaves of cv. 'Cox's Orange Pippin', revealed by these authors, were maintained only in the first years of cultivation. A higher nitrogen content in the leaves of fertigated apple trees was also obtained by Hornig and Bünemann (1995), but only in the first year of cultivation. On the other hand, Dencker and Hansen (1994) did not observe any influence of fertigation on the concentration of macronutrients in apple tree leaves.

In this experiment, no influence of the type of fertilizer or the method of its application on the average nitrogen content in apple tree leaves was found. However, in the case of nitrogen, a significant influence of these factors was proven in some years of the experiment. The results show lower concentrations of nitro-

gen in the leaves of the trees fertilized by the irrigation system as well as higher levels of this element in the leaves of the trees fertilized only with the nitrogen fertilizer as opposed to the complete fertilizer. However, the investigation does not answer the question whether the ensuing levels of macro elements in the tree leaves result from the direct influence of the experimental factors applied, or if they are also an indirect results of the processes of tree growth and yielding as well as weather conditions, which, as a group of factors, might have had a significant effect.

CONCLUSIONS

1. Fertigation caused stronger growth of apple trees, irrespective of the fertilizer used.
2. Fertigation contributed to higher yields of cv. 'Gala' apples.
3. Nitrogen and potassium content in the leaves of apple trees cv. 'Gala' did not depend on the type of fertilizer used or the method of its application.

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WPŁYW FERTYGACJI NAWOZAMI AZOTOWYM I WIELOSKŁADNIKOWYM NA WZROST I OWOCOWANIE JABŁONI ODMIANY ‘GALA’

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S T R E S Z C Z E N I E

Intensywne nowoczesne sadownictwo wymaga bardzo efektywnych systemów nawadniania i nawożenia. Zaletą fertygacji jest możliwość kontrolowania dawek i częstotliwości nawożenia w zależności od wymagań roślin, ich wieku, fazy rozwojowej, czy też warunków klimatycznych. Celem prowadzonych badań była ocena efektywności stosowania fertygacji nawozem azotowym i wieloskładnikowym w sadzie jabłoniowym w porównaniu z nawożeniem posypowym. Badania prowadzono w Sadzie Doświadczalnym w Dąbrowicach w latach 1993-1999 na drzewach jabłoni odmiany ‘Gala’ zaszczepionych na podkładce M.9. Do nawożenia zastosowano 2 rodzaje nawozów: saletrę amonową lub nawóz wieloskładnikowy (NPK). Nawożono posypowo lub przez system kroplowego nawadniania.

Zastosowana w doświadczeniu fertygacja istotnie wpłynęła na wzrost i plonowanie drzew. Rodzaj zastosowanego nawozu miał istotny wpływ tylko na wzrost drzew. Początkowo (pierwsze dwa lata uprawy) silniejszy wzrost wykazywały drzewa nawożone tylko azotem. W latach następnych silniejszy wzrost drzew stwierdzono na poletkach nawożonych nawozem wieloskładnikowym, co spowodowało, że po siedmiu latach uprawy drzewa te miały większą powierzchnię przekroju pni w porównaniu z drzewami nawożonymi tylko azotem.

Słowa kluczowe: nawadnianie kroplowe, fertygacja, jabłoń ‘Gala’