VARIATION IN SOIL pH, CALCIUM AND MAGNESIUM STATUS INFLUENCED BY DRIP IRRIGATION AND FERTIGATION

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ABSTRACT

Modern methods of orchard cultivation require more effective ways of irrigation and fertilization. The optimization of using drip irrigation and fertigation requires some knowledge of the effect of drip irrigation on the soil chemistry. The experiments were performed to evaluate the effects of drip irrigation and fertigation using nitrogen and complete fertilizers compared with traditional, surface fertilizer application in apple orchard. Experiment was conducted on apple varieties 'Jonagold' grafted on rootstock M.9 during seven years (1993-1999) in Experimental Orchard located in Dąbrowice – Poland. The obtained results showed that both factors: type of fertilizers and kind of application significantly influenced soil chemical properties. Application of nutrients as a form of fertigation with complete fertilizer decreased pH in the soil zone, just under drippers whereas traditional, surface nutrient application, followed by irrigation with alkaline water without fertilizers resulted in increase of soil pH. The presence of calcium and magnesium ions, naturally occurred in irrigation water, resulted in higher accumulation of these elements in soil under drippers.

Key words: drip irrigation, fertigation, pH, EC, soil, apple

INTRODUCTION

The climate of Poland is highly variable, especially in terms of total precipitation and its distribution during a vegetation season. In these weather conditions, intensive orchards have to be irrigated (Treder and Czynczyk, 1997).

Modern methods of orchard cultivation require more effective ways of irrigation and fertigation. Fertigation means application of nutrient solution to growing plants by means of an irrigation system. The advantage of this technology is that the dose and frequency of application can be regulated according to plant requirements depending on: plant age, growth cycle and weather conditions (Haynes, 1985).

In Poland, the most popular irrigation system for orchards is drip irrigation. Since drip irrigation applies water only to a small volume of soil, it is expected to be much more efficient than micro-sprinkler and overhead irrigation (Alva and Obreza, 1993).

In Poland, most soils used for fruit production are sandy loams, loamy sands, or sands with low content of organic matter (Strzemski et al., 1973). These soils are also low in buffering capacity, so pH may fluctuate with the continuous addition of bicarbonate with the irrigation water. The quality of the irrigation water affects soil properties and productivity.

In soils like these, drip irrigation can cause a variety of management problems, especially by changing soil pH (Neilsen and Stevenson, 1983; Neilsen et al., 1993; Treder et al., 1997). Soil pH affects the availability of plant nutrients, and thereby plant growth and productivity (Mengel and Kirkby, 1983).

In Poland, ground water is the most common source for orchard drip irrigation. Deep well water contains high levels of calcium and magnesium bicarbonate. After drip irrigation of plums with water, which contained a high amount of calcium (60 mg l^{-1}) and magnesium (15 mg l^{-1}), soil pH increased to over 6.8 within the entire wetted soil (Treder et al., 1997). The availability of most soil micronutrients is reduced when the pH goes above 7. For apples, keeping the the soil pH between 6.0 and 6.5 is recommended (Kłossowski, 1972).

On the other hand, some authors have reported that acidification may occur after fertigation (Belton and Goh, 1992; Alva and Obreza, 1993; Neilsen et al., 1993; Komosa et al., 1999). Rapid and extreme acidification of sandy soils fertilized with NH_4-N and urea can limit growth in crops under drip fertigation (Haynes and Swift, 1987; Belton and Goh, 1992). Acidification of orchard soil increases the solubility of toxic elements such as manganese and aluminum (Ross et al., 1985)

Optimizing drip irrigation and fertigation requires some knowledge of the effect of drip irrigation on soil chemistry. Farmers have to know how manage soil pH, salinity and fertility by monitoring water quality and choosing the right fertilizers when using different drip irrigation systems.

The aim of this study was to evaluate the effects of drip irrigation and fertigation on soil pH, calcium content and magnesium content inside the dripper wetting zone.

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 'Jonagold' grafted on M.9 dwarfing rootstock were planted 3.5 x 1.25 m apart (2286 trees per hectare). The orchard was planted on light sandy loam soil. Weeds in the tree rows were controlled with herbicides, and the grassy interrows were mowed. The trees were trained as spindles.

Two kinds of fertilization were used, one containing only nitrogen (N), and the other a complete fertilizer containing all macronutrients (CF). All nutrients were applied by means of a drip irrigation system or conventionally by means of surface application. Additionally, as control treatments, two combinations were set up: plants were either irrigated with pure water without fertilizers or grown without irrigation and fertilization.

The scheme of the experiment was as follows:

Fertilizers used:

F_N: ammonium nitrate (30 g nitrogen per tree), or

F_{CF}: complete fertilizers (30 g nitrogen, 4 g phosphorus, 37 g potassium, 6 g magnesium and 4 g calcium per tree)

Fertilizer application:

A_b: broadcasting, or

A_f: fertigation

Control treatments:

C_{DI}: drip irrigation without fertilization

C_0: control without fertilization and irrigation.

In the first year, one third of the above rates was applied, and in the second year, two thirds were applied.

The symbols of the treatments used in this paper are as follows:

F_NA_B	Nitrogen broadcast with drip irrigation
F_NA_F	Nitrogen fertigation
$F_{CF}A_B$	Complete fertilizer broadcast with drip irrigation
$F_{CF}A_F$	Complete fertilizer fertigation
C_{DI}	Drip irrigation (without fertilization)
C_0	Control (without fertilization and irrigation)

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). Water was supplied at a rate sufficient to maintain a soil water potential of between 0 and -0.02 MPa at a depth of 20 cm. Water delivery was controlled by tensiometers. Fertigation depended on weather conditions and was conducted from May to July at least once a week.

In 1994 and 1997, soil samples were collected in August at depths of 0-20 cm and 20-40 cm directly under the drippers placed 30 cm from the trunks of the trees.

In 1998, soil samples were also collected in August at depths of 0-20 cm and 20-40 cm directly under the drippers and also places 17 and 35 cm away from the dripper.

Soil samples collected from each replication plot. The composite soil samples were thoroughly mixed, air-dried, and screened through a 2 mm sieve. Soil pH was measured potentiometerically in a suspension of one part soil and one part water. Magnesium was extracted by the Schachtschabel method (Nowosielski, 1968). Calcium was extracted with 0.03 M acetic acid (Ostrowska et al., 1991). Cations in the filtrates were measured using atomic absorption spectrophotometry (SP09 Pye Unicam).

The experiment was carried out in split block design with four replicates of seven trees per experimental plot. Data were elaborated using analysis of variance, followed by Duncan's multiple range t-test or Student's t-test. The functions of variability for pH, Mg content and Ca content in soil profile were analyzed using the Statistica 5.0 package.

RESULTS AND DISCUSSION

Irrigation and fertigation introduce water into soil along with salts dissolved in it. During irrigation, water with micro- and macro-elements is evenly spread on the surface of the field. However, in the case of drip-irrigation, water is applied in one spot. Therefore, only this area of the soil gets wet, which introduces a lot of Ca and Mg (Tab. 1).

Soil pH

Irrigation and fertigation influenced the chemical properties of the soil. The pH of the soil was lower after seven years of a sprinkling method of nitrogen fertilization, fertigation with a complex fertilizer, and the non-irrigated and non-fertilized control. Irrigation with water of high pH significantly increased the pH of the soil directly under the drippers (Tab. 2) After two years of cultivation, the pH of the subsoil right under the drippers on the plots where ammonium nitrate fertigation was applied was lower than at the beginning, although it slowly went up in subsequent years (Fig. 1).

The distribution of pH in the soil profile shows significant differences between the combinations (Fig. 2). On the plots fertigated with complex fertilizer and on the plots broadcast with ammonium nitrate, the pH was lower in a large area where the soil was wet. On the plots which were only irrigated, the pH was high and even throughout the whole wetted area. On the plots without fertilization or irrigation, the soil surface was acidified.

Fertigation with ammonium nitrate did not cause strong acidification, probably because relatively small, individual doses of the fertilizer were applied and because the water used for irrigation was alkaline (pH 7.4).

T a b l e 1 . Water, Mg and Ca supply

Parameter	Years						
	1993	1994	1995	1996	1997	1998	sum
Supply of water [mm]	24	37	31	48	39	46	225
Supply of water [$l \cdot dripper^{-1}$]	58.8	90.6	75.9	117,6	95.5	112.7	511.1
Mg from water [$g \cdot dripper^{-1}$]	0.82	1.27	1.06	1.65	1.34	1.58	4.19
Mg from fertilizer [$g \cdot dripper^{-1}$]	1.12	2.24	3.36	3.36	3.36	3.36	15.8
Sum Mg for $F_{CF}A_F$ [$g \cdot dripper^{-1}$]	1.94	3.51	4.42	5.01	4.7	4.94	24.52
Ca from water [$g \cdot dripper^{-1}$]	5.0	7.7	6.45	10.0	8.12	9.58	46.85
Ca from fertilizer [$g \cdot dripper^{-1}$]	0.74	1.48	2.22	2.22	2.22	2.22	11.1
Sum Ca for $F_{CF}A_F$ [$g \cdot dripper^{-1}$]	5.74	9.18	8.67	12.22	10.34	11.8	57.95

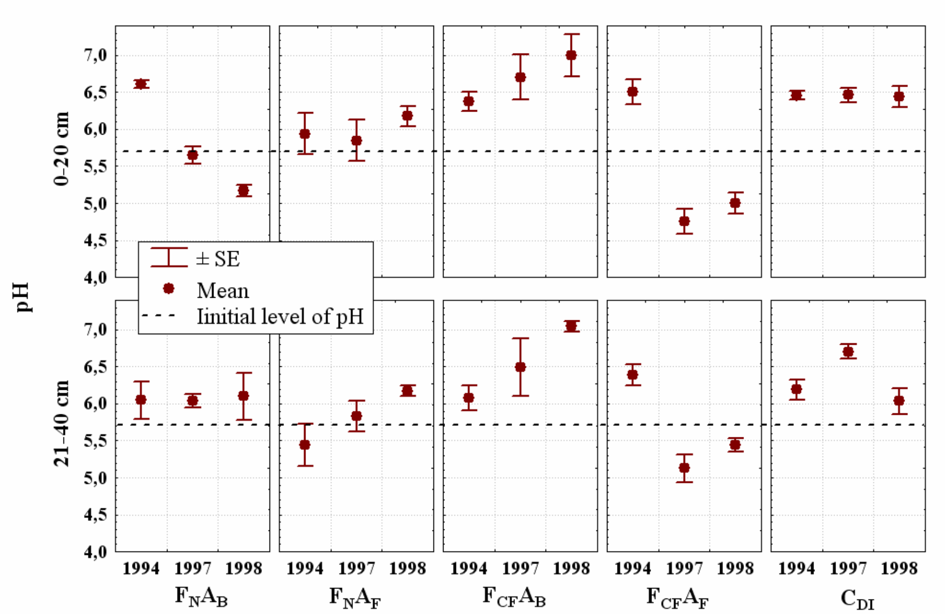

Figure 1. Changes of soil pH directly under dripper

T a b l e 2 . Changes of pH of soil after 6 years of experiment (1998) in comparison to initial analysis in year 1993 (1) (in 1998 average of three distances from dripper, n=12)

Treatment	Arable layer			Subsoil		
	initial analysis	1998	difference	initial analysis	1998	difference
F_NA_B	5.7	4.92 ab*	-0.78	5.7	5.76 cde	+0,06
F_NA_F		5,77 cde	+0.07		5.82 de	+0,12
$F_{CF}A_B$		6.16 ef	+0.46		6.44 f	+0,74
$F_{CF}A_{FI}$		5.32 bc	-0.38		5.82 de	+0,12
C_{DI}		6.25 ef	+0.55		6.01 ef	+0,31
C		4.74 a	-0.95		5.43 cde	-0,27

*Means marked with the same letters do not differ significantly. Duncan's multiple range t-test at 5% level of significance

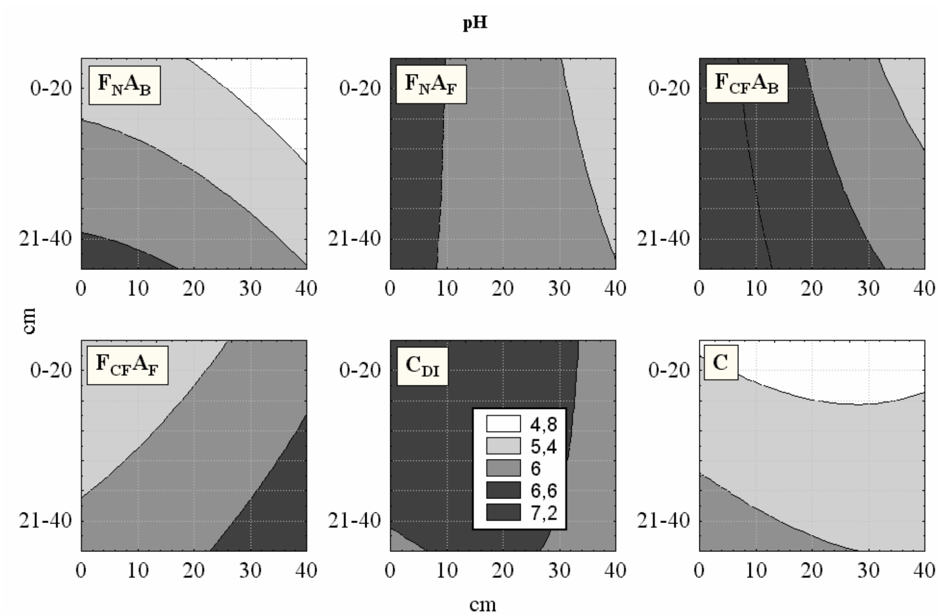

Figure 2. Simulation contour line of pH variability in soil profile in the year 1998 (n=24)

Furthermore, the soil samples were collected only two months after the fertigation was over.

Widmer and Krebs (1999) also reported that the fertilizer used and the manner it was applied did not affect soil pH.

In an experiment carried out under Polish conditions, Zydlik and Pacholak (2000) found that fertigation with ammonium nitrate did not lower soil pH compared with control.

Belton and Goh (1992) reported that pH dropped by 1.6 units under the dripper after a year of fertigation with 33.8 g N (amide form) through an individual dripper in only four applications.

Neilson et al. (1993) also used ammonium sulfate in high doses from 23.7 to 47.0 g N per dripper in four applications.

Fallahi (2000) applied high doses of ammonium nitrate to apple trees spaced 3.7 x 6.7 m apart. Although irrigation system is not described in detail, the highest dose of 590 g N tree^{-1} applied through the drip irrigation system probably corresponds to about 100 g N per dripper.

Neilsen et al. (1995) suggest that non-acidifying fertilizers be used and the area of wetting be enlarged using a proper dripper spacing in order to limit soil acidification during fertigation.

Lowered soil pH while using a complex fertilizer may result from an intensive removal of alkaline elements along with the crop (Buckman and Brady, 1971; Lityński and Jurkowska, 1982). The cations are then replaced with hydrogen ions.

A higher soil pH was recorded in the wetting area where only irrigation was applied, which agrees well with earlier results reported by Kidder and Hanlon (1985) and Treder et al. (1995 and 1997). In both this study and in the earlier studies cited above, the increase in soil pH was caused by the accumulation of magnesium and calcium.

After six years of cultivation, the pH was lower in the cultivated layer of the non-fertilized and non-irrigated soil. This phenomenon is common in the temperate zone where precipitation is higher than evaporation. Magnesium and calcium are leached down the soil profile, which lowers the pH in the surface layer.

Soil magnesium content

At the end of the experiment, the lowest magnesium level was found in the soil profile of the arable layer of the plots fertilized broadcast with ammonium nitrate. In this combination, the magnesium level was lower than it was at the beginning of the experiment. On the other hand, in plots fertigated with nitrogen or complex fertilizer, the magnesium level was higher than at the beginning. The highest magnesium levels were found in the plots which were irrigated but not fertilized. In plots which were fetilized but not irrigated, the magnesium level in the arable layer was lower than at the beginning (Tab. 3).

In 1994, the magnesium level in the arable layer of the soil taken directly from under the drippers was higher than at the beginning in all combinations. However, in subsequent years, there was a significant drop in the magnesium level in this layer in plots broadcast with ammonium nitrate or complex fertilizer (Fig. 3). In the other combinations, the magnesium level in 1998 was higher than at the beginning. In plots broadcast with complex fertilizer, which contains magnesium, and in plots which were irrigated, the magnesium level in the subsoil layer was higher than at the beginning.

Figure 4 presents the simulated distribution of magnesium in the soil profile. Broadcasting with fertilizer containing magnesium caused magnesium accumulation throughout the subsoil and near the dripper in the arable layer. Fertigation with the complex fertilizer caused an accumulation of magnesium at the edges of the wetted area. The magnesium level was significantly lower closer to the dripper. Magnesium also accumulated throughout the wetted area of the control plots ($F_{CF}A_F$).

The increase in magnesium level in the wetted area of the soil may be explained by the quality of the water used for irrigation, which contained 14 mg Mg l^{-1}.

In earlier studies, magnesium accumulated in the wetted area after several years of drip-irrigating (Treder et al., 1995, 1997; Pacholak, 1991; Pacholak and Komosa, 1993; Pacholak and Łysiak, 1993; Małecka and Różalski, 1998). Fertigation with ammonium nitrate caused leaching of magnesium directly underneath the dripper and accumulation of magnesium 20-40 cm from the dripper (Komosa et al., 1999ab). Leaching of magnesium under the dripper also occurred when urea was applied (Belton and Goh, 1992).

T a b l e 3. Changes of available magnesium content in soil after 6 years of experiment (1998) in comparison to initial analysis [mg/100 g] (in 1998 average of three distances from dripper, n=12)

Treatment	Arable layer			Subsoil		
	initial analysis	1998	difference	initial analysis	1998	difference
F_NA_B	5.9	3.40 a	-2.5	5.7	4.73 ab	-0.97
F_NA_F		6.28 b-d	+0.38		5.99 b-d	+0.29
$F_{CF}A_B$		7.22 de	+1.32		8.65 e	+2.95
$F_{CF}A_{FI}$		6.97 c-e	+1.07		7.15 de	+1.45
C_{DI}		8.51 e	+2.61		7.99 e	+2.29
C		5.32 bc	-0.58		6.24 b-d	+0.54

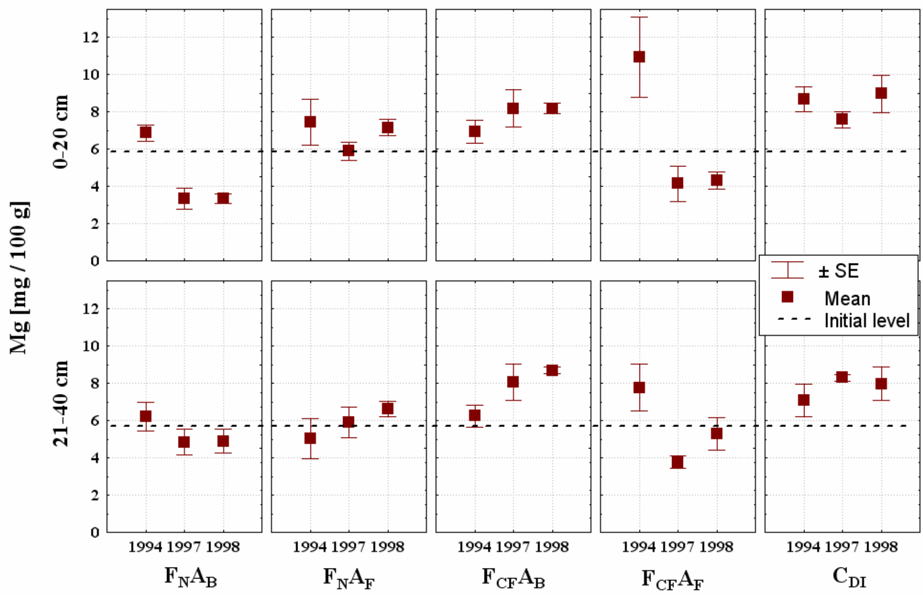

Figure 3. Content of available magnesium in the arable layer and subsoil under dripper

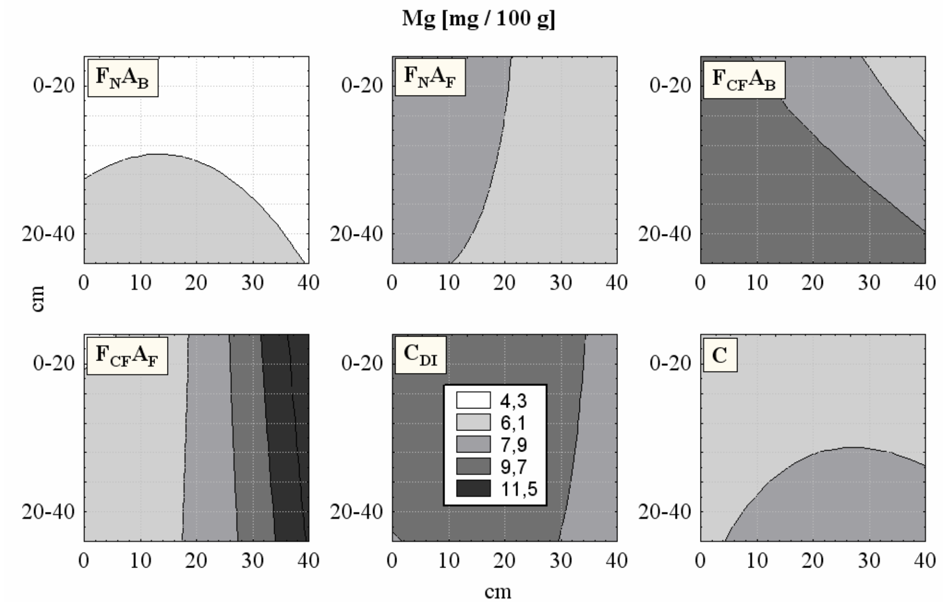

Figure 4. Simulation contour line of available magnesium distribution in soil profile in the year 1998 (n=24)

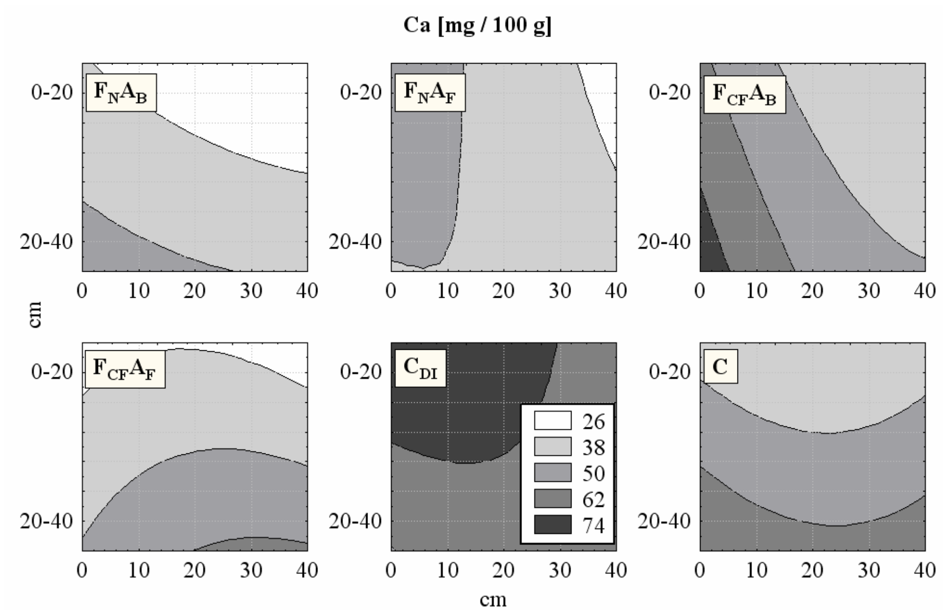

Figure 5. Simulation contour line of available calcium distribution in soil profile in the year 1998

In the experiments on fertigation with ammonium nitrate, there was no increase in available magnesium directly under the dripper. On the contrary, a higher magnesium level was found. These conflicting results are probably due to the fact that soil pH was not the same in these experiments.

In this experiment, relatively small amounts of ammonium nitrate were applied over a long time without acidifying the soil under the dripper. Belton and Goh (1992) write that in areas with lower magnesium levels, the pH was low. According to Parchomchuk et al. (1993), with fertigation with ammonium nitrate, the drop in pH initially increases the level of magnesium ions in the soil solution, and they are transported vertically and horizontally along with the water. Treder et al. (1998) investigated changes in magnesium level in the soil solution and found that soon after fertigation with ammonium nitrate, the magnesium level rapidly increased, and then dropped when the fertigation was stopped.

The distribution of calcium in the soil profile in the combinations of this experiment is shown in Figure 5. Irrigation with water with a high calcium level caused calcium accumulation in the soil profile. This did not happen when fertilization was applied. Even though calcium is a mobile element (Nielsen and Stevenson, 1983), in the experiment it accumulated in the wetted area of the soil. Alva and Obreza (1993) report that the calcium level increased in the area of the soil wetted with hard water. Hoyt and Neilsen (1985) and Łabędowicz (1998) report that there is a strong correlation between the soil pH and calcium level. The results of this experiment confirm this correlation, which shows that indirect measurements of soil pH may indicate the accumulation of magnesium and calcium in the soil.

CONCLUSIONS

The type of fertilizer and method of application significantly influence soil chemical properties.

1. Application of nutrients by fertigation with complete fertilizer decreased soil pH directly under the drippers, whereas traditional application by broadcasting followed by irrigation with alkaline water increased soil pH.
2. The presence of naturally occuring calcium and magnesium ions in irrigation water caused a greater accumulation of these elements in the soil under the drippers.

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WPŁYW NAWADNIANIA KROPLOWEGO I FERTYGACJI NA ZMIENNOŚĆ pH GLEBY ORAZ ZAWARTOŚĆ W NIEJ WAPNIA I MAGNEZU

Waldemar Treder

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

Intensywna uprawa sadów wymaga efektywniejszych sposobów nawadniania i nawożenia. Dla zoptymalizowania tych zabiegów niezbędna jest wiedza dotycząca ich wpływu na właściwości chemiczne gleby. Badania miały na celu określenie wpływu stosowania nawadniania kroplowego i fertygacji na odczyn gleby oraz na zawartość w niej wapnia i magnezu. Doświadczenie przeprowadzono w latach 1993-1999 w Sadzie Doświadczalnym w Dąbrowicach na jabłoniach odmiany 'Jonagold' zaszczepionych na podkładce M.9. Zastosowano dwa rodzaje nawozów (azotowy i wieloskładnikowy) oraz dwa sposoby nawożenia (nawożenie posypowe oraz fertygację). Zarówno rodzaj zastosowanego nawozu, jak i sposób nawożenia istotnie wpłynęły na pH oraz zmiany zawartości wapnia i magnezu w profilu glebowym. Fertygacja nawozem wieloskładnikowym spowodowała obniżenie pH gleby pod emiterem, natomiast przy nawożeniu posypowym i stosowaniu nawadniania kroplowego wodą o odczynie zasadowym obserwowano wzrost pH gleby. Wysoka zawartość wapnia i magnezu w wodzie do nawadniania powodowała akumulację tych pierwiastków w glebie pod emiterem.

Słowa kluczowe: nawadnianie kroplowe, fertygacja, pH, EC, gleba, jabłoń