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Investigations on Fertigation of Peach on Three Soils I. Migration and Localization of Nitrogen

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Abstract

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The experiment was carried out in lysimeters on three soil types: alluvial-meadow soil (Fluvisol) – sandy loam, cinnamon-forest soil (Luvisol) – clay loam, and smolnitsa (Vertisol) – clay. The fertilizers – urea [$CO(NH_2)_2$] and phosphoric acid (H_3PO_4), were supplied through the irrigation system, the annual amounts being partitioned to monthly doses.

It was found that, under favorable temperature conditions in the soil (30-32°C), the applied by the irrigation water urea was rapidly hydrolyzed and the obtained ammonium ions were intensively oxidized to nitrates. The easy-movable nitrate nitrogen migrated with the water flows to the periphery of the wetted soil volume where it accumulated in depots of increased nitrate content. The localization of nitrate nitrogen and its concentration in the zones of accumulation proved to be substantially influenced by the root-system's spatial distribution. Two-three weeks after fertigation, the applied nitrogen was completely depleted along the skeletal roots and zones of increased nitrate content were found at the periphery of the areas of intensive root extraction, appearing in the same time inner for the wetted soil volume. The local depletion of the applied nitrogen in the root zone necessitates a greater partitioning of the annual fertilization rate during vegetation in order to provide an optimal nutrition of the plants.

Key words: drip-irrigation, fertigation, urea, lysimeters, peach, root extraction

Introduction

When micro-irrigation is in use, it is a common practice fertilizers to be introduced into root zone by the irrigation water (fertigation). Among the available nitrogen fertilizers, urea is preferred because it is easy-soluble in water and because, taking place in chemical reactions, it does not form insoluble precipitations. Compared to the ammonium fertilizers, urea is not strongly adsorbed by the soil and can easily move to greater depths (Bacon and Davey, 1982). After hydrolysis, the obtained ammonium ion is adsorbed by the soil colloids. Under soil temperatures of 25-30°C it is biologically transformed to nitrates, usually in two-three weeks (Rolston et al., 1986). The nitrates move easily with the wetting front and, after larger water applications, the nitrate nitrogen can be washed out of the root zone (Goldberg et al., 1971; Dochev et al., 1979; Bucks et al., 1982). Hence, the optimal regime of plant nutrition as well as the risk of eventual nitrate-pollution of the soil and the ground waters depend on the possibilities for control on the wetted soil volume. Both, the irrigation management and the soil properties are substantial for this behavior (Bresler, 1977; Rolston et al., 1986).

The objectives of this article are nitrogen's migration and localization, after application of urea in the root zone of a peach tree, determined by the soil wetting and the specific soil characteristics of three soil types, basic for the peach-growing in Bulgaria. The irrigation water redistribution in the soil with a view to the application efficiency and the spatial distribution of root water uptake were discussed in a previous article (Koumanov et al., 1998). The present results were obtained at the Institute of Fruit-Growing in Plovdiv during the period 1994-1997.

Material and Methods

The experimental work was carried out in a concrete lysimetric unit with cells 2.00x3.00 m filled up to 1.00 m with soil (Koumanov et al., 1998), and on three soil types: alluvial-meadow soil (Fluvisol), cinnamon-forest soil (LUvisol), and smolnitsa (Vertisol). According to their texture, these soils are determined respectively as sandy loam, clay loam, and clay, after the USDA-classification (Soil Survey Staff, 1975). Some chemical characteristics of the investigated soils are presented in Table 1 while their water and physical properties are given in Koumanov et al. (1998).

In the spring of 1994 single peach trees (cultivar Redhaven on GF-677 rootstock) were planted in every one of the lysimetric cells. The plants were supplied with water and fertilizers through a drip-irrigation system: one emitter per tree, with an average discharge of 4.6 l/h, and located at 0.75m from the tree trunk.

Urea [$CO(NH_2)_2$] and phosphoric acid (H_3PO_4) were used to provide annual fertilization rates of 165g N/tree and 84g P_2O_5/tree. The annual fertilizer amounts were partitioned to monthly doses according to the scheme presented in Table 2. The nitrogen application was conformed to the average monthly values of peach evapotranspiration while the phosphorus was uniformly distributed along the vegetation period. Nutrient solution was injected in the irrigation system by an automatic dosing pump (DOSATRON INTERNATIONAL, Bordeaux, France) thus providing concentrations in the irrigation water of respectively 0.4% $CO(NH_2)_2$ and 0.9% H_3PO_4.

The migration and the localization of applied nitrogen were examined by soil

Table 1
Chemical properties of the investigated soils

Soil properties	Soils		
	Alluvial-meadow	Cinnamon forest	Smolnitsa
Content of clay* (< 0.002mm), %	10.9	34.2	51.1
Soil reaction (ph)	7.9	7.5	7.3
Humus content, %	0.9	1.0	2.2
Mobile phosphorus (P_2O_5), mg/100g	4.5	1.4	4.7
Mobile potassium (K_2O) mg/100g	9.4	7.8	10.0
Exchange capacity, mgeq/100g	25.4	47.4	62.1

* According to the classification of the USDA (Soil Survey Staff, 1975).

Table 2
Fertilization rates (grams/tree) supplied in each lysimeter and their partitioning during the months of the irrigation season (in % from the total)

Year	Ferti-lizers	Fertil. rate, g/tree	Monthly parts of the fertil. rate					
			April, %	May, %	June, %	July, %	Aug., %	Sep., %
Provided scheme	N	165.0	12	18	28	18	14	10
	P_2O_5	84.0	17	17	17	17	16	16
1995	N	115.5	–	–	28	18	14	10
	P_2O_5	55.4	–	–	17	17	16	16
1996	N	165.0	12	18	28	18	14	10
	P_2O_5	84.0	17	17	17	17	16	16
1997	N	125.4	12	8	28	8*		
	P_2O_5	57.1	17	17	17	17*		

*The experiment was ceased on 02.08.1997.

sampling 20 hours after the last water application. In 1995 and 1996, soil samples were taken by drilling radially from the dripper at 10cm, 25 cm, 50 cm, 75 cm, and 100 cm, and by layers of 10 cm. In 1995 it was done weekly – four times after the maximal fertilization dose, and to 30 cm in depth. In 1996 soil sampling was done three weeks after the maximal fertilization doze, to depth of 80 cm. In 1997 soil samples were taken from a soil profile in 10 cm square grid, after digging a trench along the line tree-dripper. Root-system's configuration throughout the profile was also established.

The content of mineral nitrogen (N-NH_4+ N-NO_3-) in the soil samples was determined by the distillation method of Cotte und Kahane (1946).

Results and Discussion

The changes of the ammonium-nitrogen's content in the layer 0-30 cm can be traced out on Figures 1 to 3, where the distribution of N-NH_4+ in the investigated three soil types is presented respectively one, two, three, and four weeks after applying of the maximal fertilization dose in 1995.

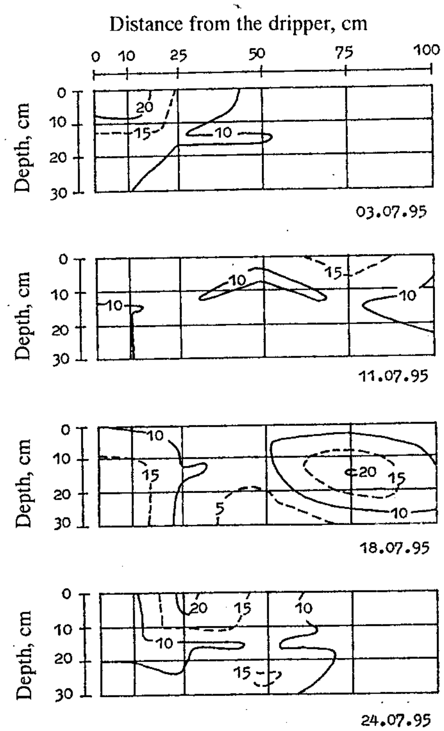

Fig. 1. Migration of the ammonium nitrogen (N-NH_4+) in the alluvial-meadow soil after applying of the maximal fertilization dose on 26.06.1995; mg/kg

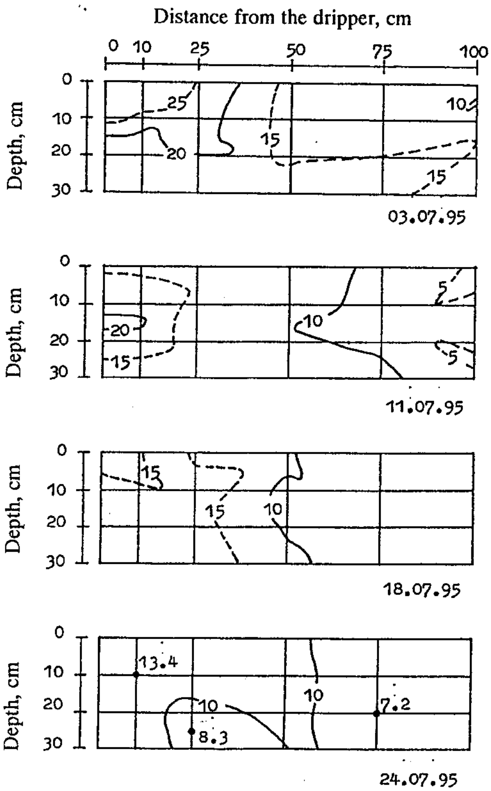

Fig. 2. Migration of the ammonium nitrogen ($N\text{-}NH_4+$) in the cinnamon-forest soil after applying of the maximal fertilization dose on 26.06.1995; mg/kg

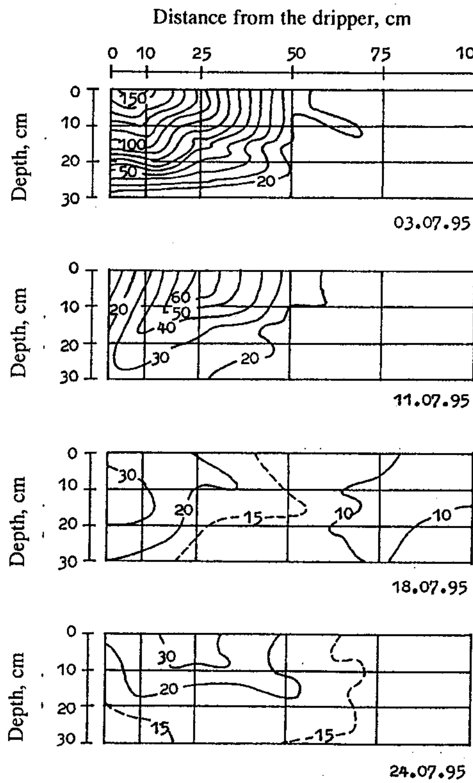

Fig. 3. Migration of the ammonium nitrogen ($N\text{-}NH_4+$) in the smolnitsa after applying of the maximal fertilization dose on 26.06.1995; mg/kg

At the end of the first week, an increasing of the ammonium nitrogen is seen in the zone around the point of dripping, the highest concentrations being found immediately under the dripper, respectively 24 mg/kg in the alluvial-meadow soil, 28 mg/kg in the cinnamon-forest soil, and 150 mg/kg in the smolnitsa. The registered variations in the distribution of this nitrogen form are due mostly to the hydraulic soil properties which determine different intensities and directions of water flows in the three soil types (Koumanov et al., 1998).

During the next three weeks, the content of ammonium nitrogen decreases in all investigated zones of the three soils, the rates of process being reciprocal to the distance from the point of dripping. This fact should be explained with nitrification of the ammonium ion as well as with the intensive leaching regime in the transmission zone (Koumanov et al., 1998).

For the same period, the nitrate-nitrogen's migration is presented on Figures 4 to 6. One week after supplying of the maximal fertilization dose, the nitrates in alluvial-meadow soil (Figure 4) are situated concentrically around the point of dripping, with maximal concentration of 55 mg/kg. On the soil surface they are spread radially to 100 cm, apparently due to the superficial spill of irrigation water found in this soil type under this

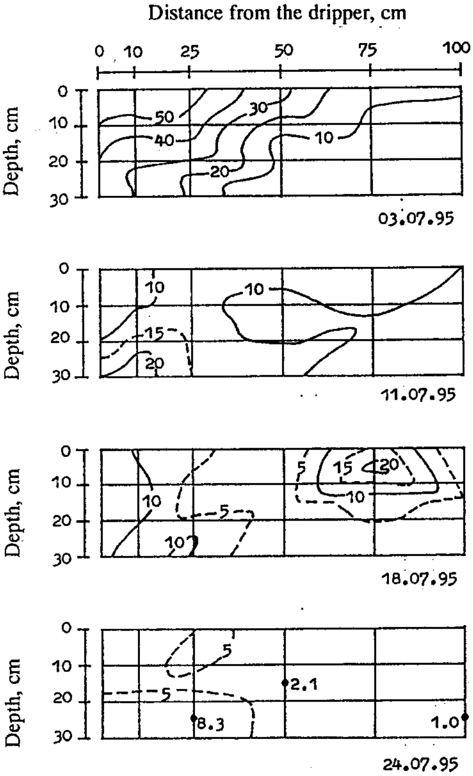

Fig. 4. Migration of the nitrate nitrogen ($N-NO_3$-) in the alluvial-meadow soil after applying of the maximal fertilization dose on 26.06.1995; mg/kg

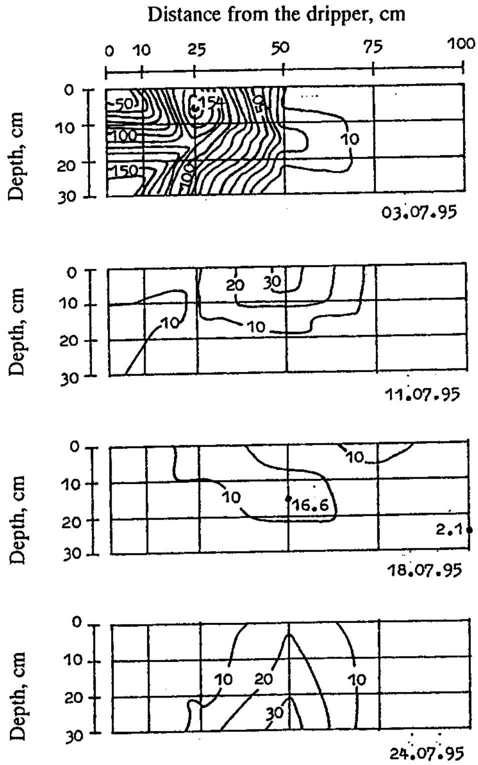

Fig. 5. Migration of the nitrate nitrogen ($N-NO_3$-) in the cinnamon-forest soil after applying of the maximal fertilization dose on 26.06.1995; mg/kg

experimental treatment (Koumanov et al., 1998). In depth, the zone of increased content of nitrate nitrogen exceeds the investigated thirty-centimeter layer, the radius of influence being 30cm at its lower boundary. On the same date, the topography of nitrate nitrogen in the cinnamon-forest soil (Figure 5) and in the smolnitsa (Figure 6) shows some deformation in the pattern of concentric distribution. Due to the higher infiltration rates and to the smaller zones of superficial ponding, larger amounts of fresh water have entered the soil during the seven-day period and have started driving the nitrates to the periphery of the wetted soil volume. In both soil types, zones of high concentration are seen at 25 cm laterally from the point of dripping as well as below it, in the layer 20-30 cm. The nitrate concentrations in these zones exceed significantly that in the alluvial-meadow soil: respectively 154 mg/kg and 161 mg/kg in the cinnamon-forest soil, and about 100 mg/kg in the smolnitsa. In the same time, the concentrations under the point of dripping are lowered respectively to 50 mg/kg and 80 mg/kg. Horizontally, the influence of fertigation reaches 50 cm from the point of dripping while in depth it stretches beyond the investigated 30 cm soil layer.

The obtained one week after fertigation data show that the supplied urea is rapidly being hydrolyzed in the soil and, in a short

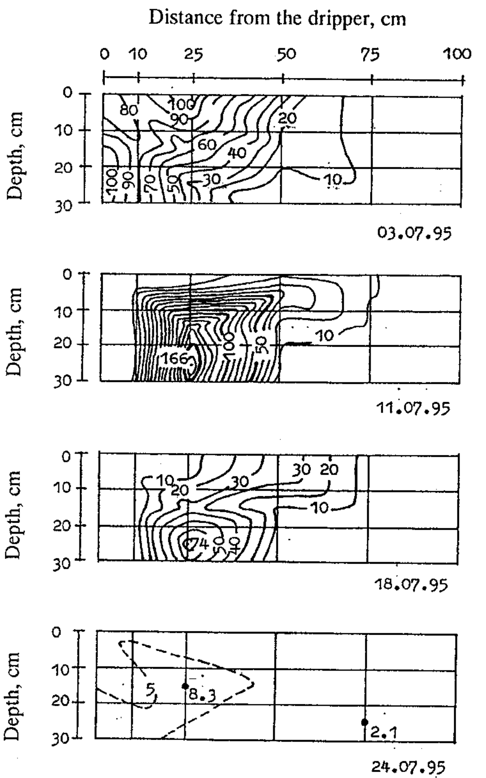

Fig. 6. Migration of the nitrate nitrogen (N-NO3-) in the smolnitsa after applying of the maximal fertilization dose on 26.06.1995; mg/kg

period, the obtained ammonium ions are being oxidized to nitrates.

Both, the lateral and the vertical migration of nitrate nitrogen continue also during the next three weeks, accompanied by leaching into deeper soil layers and, of course, by an active root extraction. As a result, one month after applying of the fertilizer, the nitrate concentrations throughout the investigated profile are reduced to the usual for the three soils values of 2-8 mg/kg.

The zone of secondary saturation with nitrate nitrogen, registered in the cinnamon-forest soil (Figure 5), is probably due to an upward water flow from the more wet deeper layers, induced by the four-day drying period preceding soil sampling.

In the smolnitsa (Figure 6), considerable nitrate amounts migrate diagonally from the point of dripping, probably after washing a part downward by the transit water flow under the point of dripping.

The localization of mineral nitrogen throughout the soil profile was investigated in 1996, when soil samples were taken to depth of 80 cm. Data for the distribution of ammonium nitrogen are illustrated on Figures 7 to 9. Two weeks after applying of the maximal fertilization dose, the concentrations of ammonium nitrogen in the alluvial-meadow soil and in the cinnamon-forest soil are reduced to their natural values, showing a relatively uniform spatial distribution. In the smolnitsa, still there are zones of increased concentration but the maximal values are also relatively low. This results confirm the established in 1995 fact of rapid hydrolysis of supplied in the soil urea, followed by an intensive nitrification of the obtained ammonium ions. The relatively high rates of these processes are due to an extremely favorable temperature regime of the soil. Significant warming of the superficial soil layers was registered in the sunny days, reaching 30-32^{0}C at 10cm below the soil surface, which took place during the water applications as well as in the periods between applications (readings were done in the cinnamon-forest soil).

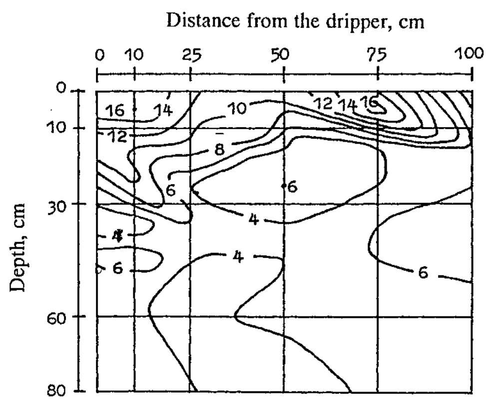

Fig. 7. Field of the ammonium nitrogen (N-NH$_4$+) in the alluvial-meadow soil two weeks after applying of the maximal fertilization dose; 10.07.1996; mg/kg

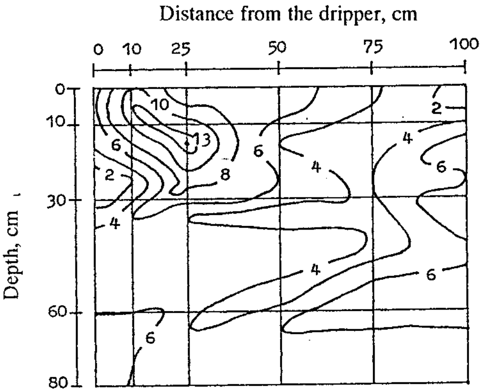

Fig. 8. Field of the ammonium nitrogen (N-NH_4+) in the cinnamon-forest soil two weeks after applying of the maximal fertilization dose; 10.07.1996; mg/kg

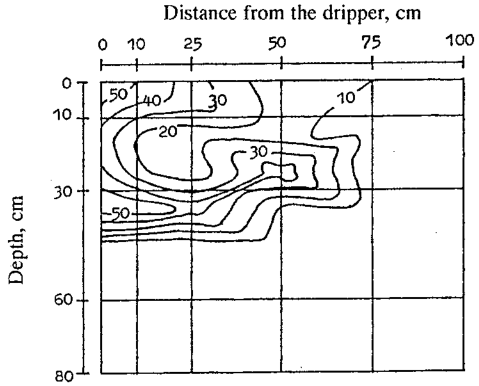

Fig. 10. Field of the nitrate nitrogen (N-NO_3-) in the alluvial-meadow soil two weeks after applying of the maximal fertilization dose; 10.07.1996; mg/kg

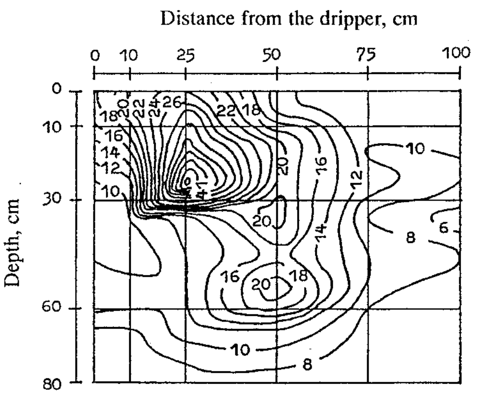

Fig. 9. Field of the ammonium nitrogen (N-NH_4+) in the smolnitsa two weeks after applying of the maximal fertilization dose; 10.07.1996; mg/kg

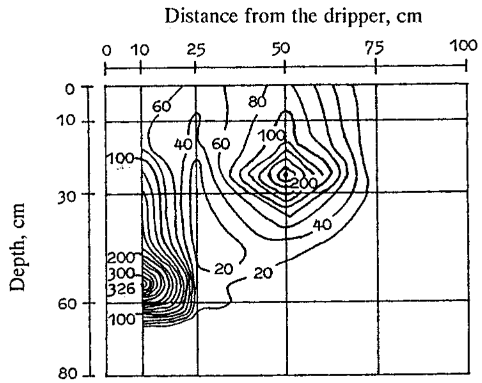

Fig. 11. Field of the nitrate nitrogen (N-NO_3-) in the cinnamon-forest soil two weeks after applying of the maximal fertilization dose; 10.07.1996; mg/kg

The localization of nitrate nitrogen for the same period is shown on Figures 10 to 12. Depending on the water regime of investigated soils (Koumanov et al., 1998), the obtained considerable amounts of nitrates have been driven with different velocities in the plain of soil profile, thus generating specific for each soil type patterns of distribution.

For two weeks, the nitrate form of applied as urea nitrogen has spread in the alluvial-meadow soil to 45 cm downward and horizontally to almost 75 cm (Figure 10). Accumulation of nitrates is found under the point of dripping and their increased content reaches the periphery of the wetted soil volume. The established localization of nitrates in this soil practically eliminates the possibility of nitrogen losses, by leaching, during the vegetation.

The higher permeability of cinnamon-forest soil and especially the induced regime

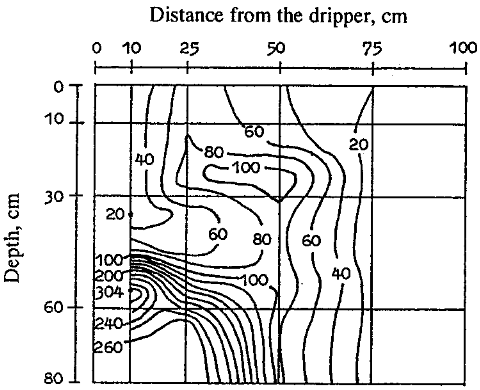

Fig. 12. Field of the nitrate nitrogen (N-NO_3-) in the smolnitsa two weeks after applying of the maximal fertilization dose; 10.07.1996; mg/kg

of leaching in the smolnitsa determine a higher migration velocity of the nitrates and their transportation to a longer distance from the point of dripping (Figures 11 and 12). Again, the accumulation of nitrate nitrogen is found at the front of wetting. Furthermore, the two main directions of migration, already discussed in relation to the results from 1995, are readily outlined in all three soils:

- The larger part of nitrates move in depth with the vertical water flow and, under eventual regime of overirrigation, they can be washed downward, out of the root zone. In the investigated soils, the highest concentrations of nitrate nitrogen are located at depths of respectively 35 cm in the alluvial-meadow soil (60 mg/kg), 55 cm in the cinnamon-forest soil (326 mg/kg), and also 55 cm in the smolnitsa (304 mg/kg).
- Another part of nitrates remain outside the main vertical transport and, additionally driven by horizontal water flows, migrate diagonally from the point of dripping. In all three soils, they are deposited in zones situated at depth of 25 cm and 50 cm aside from the point of dripping.

However, the results obtained in 1995-1996 and the relevant discussion do not consider manifestly the impact of the root activity on the migration and the localization of nitrogen in the root zone. More comprehensive notion about the processes taking pace is given by the investigations in 1997, which juxtapose the distribution of mineral nitrogen with both the pattern of soil wetting and the configuration of the peach-tree's root system.

As it was already noted, two-three weeks after applying of the fertilization dose only the natural content of ammonium nitrogen could be found in the three investigated soils (data not presented).

According to the results for nitrate nitrogen, two weeks after fertigation the applied in alluvial-meadow soil nitrogen is completely depleted and the nitrate concentrations throughout the soil profile are reduced to the usual for this soil values below 10mg/kg (Figure 13). The localization of nitrate nitrogen in the cinnamon-forest soil and in the smolnitsa, established three weeks after fertigation, is illustrated on Figures 14 and 15. Again, the high nitrate concentrations are found in zones of steeply decreasing soil moisture, despite the complicated patterns of soil wetting (Koumanov et al., 1998). The opposite, applied nitrogen is completely depleted in the zones of intensive root extraction where the nitrate concentrations are extremely low. Apparently, the extraction of nitrate nitrogen is characterized with the same spatial irregularity as that of the irrigation water. Furthermore, its distribution in the soil volume is determined in great extent also by the spatial distribution of plant's root system (Koumanov et al., 1998). It may well be that the plants experience temporal deficit of mineral nitrogen, although such a statement has not been proven in the present study. Probably, the roots grow towards the areas with unexhausted nitrate nitrogen which accounts for the decreasing of nitrate content in the zones of high concentration, taking place in the absence of leaching processes.

It strikes that the content of mineral nitrogen in the alluvial-meadow soil is considerably lower, in all years of the experiment, than that in the cinnamon-forest soil and in the smolnitsa. Possibly, this fact could be explained by an uneven partitioning of the

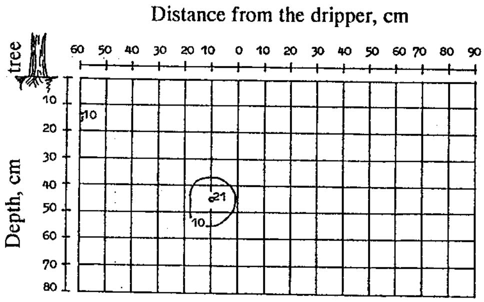

Fig. 13. Field of the nitrate nitrogen ($N\text{-}NO_3$-) in the alluvial-meadow soil two weeks after applying of the maximal fertilization dose; 04.08.1997; mg/kg

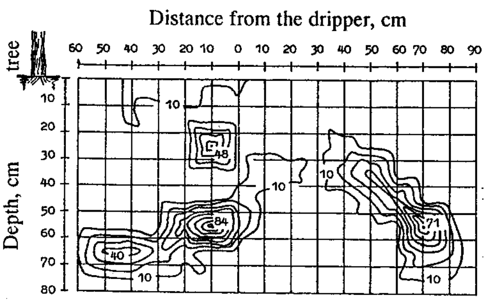

Fig. 14. Field of the nitrate nitrogen ($N\text{-}NO_3$-) in the cinnamon-forest soil three weeks after applying of the maximal fertilization dose; 15.07.1997; mg/kg

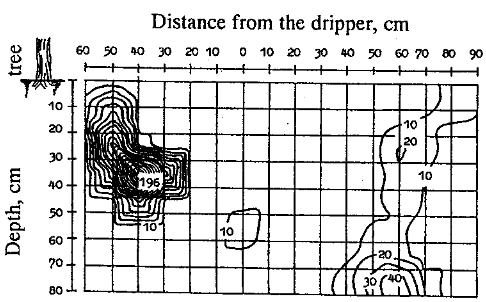

Fig. 15. Field of the nitrate nitrogen ($N\text{-}NO_3$-) in the smolnitsa three weeks after applying of the maximal fertilization dose; 14.07.1997; mg/kg

nutrient solution between the three lysimeters due to a laminar regime of water flow in the irrigation pipe after the dosing pump. However, repeated measurements of the emitter discharge as well as of the electrical conductivity of the irrigation water proved a relatively uniform distribution of the fertilizer amounts between the lysimeters. The differences in concentration values between the three soils could be explained also with differences in the soil chemical and physical properties as well as with the microbiological activity, i.e. with the urea's transformation rate. Other explanations, acceptable and experimentally proved, were not found.

It should be noted that the commented quantitative differences between the investigated soil types have not influenced in principle the mineral-nitrogen's spatial distribution in the soil under fertigation.

Conclusions

Applied in the root zone by the irrigation water, urea is being hydrolyzed in a short time and the obtained ammonium nitrogen accumulates in areas below the point of dripping. Under favorable temperature conditions, the ammonium ions are rapidly being oxidized to nitrates and, in two-three weeks after applying of the fertilization dose, the natural content of ammonium nitrogen is being regained throughout the root zone.

In a short time after fertigation, considerable amounts of nitrates replace the ammonium nitrogen, accumulating under the point of dripping. The easy-movable nitrate nitrogen migrates with the water flows to the periphery of the wetted soil volume where it accumulates in depots of increased nitrate content. Nitrates can reverse their migration when soil moisture in the bulb becomes lower than in the surrounding soil, e.g. under irrigation regimes with longer periods between water applications.

The common principles of nitrogen's migration and localization manifest themselves with specific for each soil concentrations, velocities of translocation, and patterns of distribution, determined by the characteristics of the concrete soil type. In the deficient in nutrients alluvial-meadow soil, the maximal nitrogen dose is being depleted in two-three weeks which requires an increasing of the fertilization dose respectively the annual fertilization rate.

The absorption and the localization of nitrate nitrogen under peach trees are appreciably influenced by the root-system's spatial distribution. In two-three weeks after fertigation, the applied nitrogen is being completely depleted along the skeletal roots and zones of increased nitrate content are being formed at the periphery of the areas of intensive root extraction, appearing in the same time inner for the wetted soil volume. The local depletion of supplied in the root zone nitrogen necessitates a greater partitioning of the annual fertilization rate during the vegetation in order to provide optimal nutrition of the plants.

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