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TEMPORAL CHANGES IN SOIL N OF DRIP IRRIGATED AVOCADO INDICATE SEASONAL DIFFERENCES IN N UPTAKE.

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SUMMARY

Optimal Avocado fertigation should satisfy the crop nitrogen (N) requirements and minimize deep percolation of N that pollutes the ground water. A field study conducted in an avocado orchard in Israel, with the CV. Ettinger grafted on the salt tolerant VC51 rootstock, tested the effect of 20, 40 and 60 ppm N on temporal changes of N in the soil-solution. Nitrogen concentration of the soil-solution increased with increased levels of N fertilization with clear seasonal interaction. N-level of the soil solution was lowest at the beginning of the irrigation season and increased with time. It remained relatively steady in the midst of the summer and later increased with time until the end of the irrigation season (in the fall). The N/Cl ratio in of the soil solutions increased as well towards the end of the irrigation season suggesting a reduced N-uptake capacity at that time. Our results suggest temporal changes in N uptake by the crop. Most important is the slow uptake toward the end of the summer that needs to be taken into account in the seasonal fertigation planing to avoid increased N percolation and ground water contamination. We recommend in-situ monitoring of soil N and salinity as feedback for managing fertigation of avocado.

KEY WORDS: *Persea americana* Mill. nitrogen, nutrition

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INTRODUCTION

Nitrogen (N) is a major nutrient in the growth, development and productivity of horticultural crops. N fertilizer is universally applied to horticultural fields, and in common practices its application rates often exceed those required for maximum yield and sustainable production (Huett, 1966). Weinbaum *et al.* (1992) defined over-fertilization as the application of fertilizer N in excess of tree capacity to use it for optimal productivity. In addition to the economic significance of wasteful application of the fertilizer, over-fertilization of fruit trees with N is undesirable since it might stimulate vegetative production on account of reproductive production. Another environmentally and very significant aspect of N-overfertilization, is the potential it hold for increasing the extent of N-leaching from the root-zone layer, and therefore the contamination of sub-surface water aquifers.

Avocado is an important crop, planted in an area of important ground water aquifers in Israel. It is long suggested to be sensitive to N fertigation (Embelton *et al*., 1955, 1958, 1959). The very shallow root system of Avocado (7-40 cm deep, Zilberstaine, Bernstein and Meiri unpublished; Borys, 1985) induces high sensitivity to fluctuations in water content of the top soil layer. This and the high sensitivity of avocado to salinity, drive commercial avocado irrigation practices to include frequent irrigation pulses (every 24-48 hrs) and large enough volumes of water per pulse to ensure nutrient leaching from the root zone. Avocado plantations in Israel are fertigated 8 months each year from mid spring to the beginning of the fall.

The annual winter rainfall, in the avocado area, which usually exceeds 500 mm per year, leaches the soil in the root zone layer from soluble salts and nutrients. The leaching of N from the root zone layer by rain, or by drainage of the irrigation solution may therefore contribute to aquifer contamination. The extent of leaching depends on the seasonal element and water application from the irrigation pulses and their uptake by the crop. The ground water contamination is hence very sensitive to the fertigation management applied.

Optimal N fertigation of avocado should maximize production and minimize deep percolation. Seasonal variations in response to N and its uptake are well documented for annual and perennial crops (Huett, 1996). Such information for avocado is needed for development of proper fertigation management. Limited available experimental data and field experience leads to diverse recommendations for changes in seasonal N application. Total annual N application in the range of 20-40 $g \cdot msq^{-1}$ is usually applied. Current fertigation recommendations suggest N-fertigation during the spring through the first half of the summer (March-June), limited or no N-application on July-August (to minimize excessive vegetative growth) and an additional N pulse-at the end of the irrigation season, in the autumn (September). The intensive N autumn application is aimed to allow the tree to accumulate N reserves to be utilized in the following spring when soil N is low due to the winter leaching.

More is known about the seasonal changes in water demands of the avocado tree and the way they may affect seasonal variations in excessive water seepage and Na and Cl leaching, than is known about the avocado tree nutrient requirements and hence the potential of N leaching.

In this study, we followed the affects of the N fertigation level on soil-solution N concentrations, in a commercial avocado orchard, and assess N seasonal uptake capacities.

MATERIALS AND METHODS

Avocado fertigation study in Kibbutz Hamapil in the coastal plain of Israel compares the effect of 3 levels of N (20, 40, 60 $mg \cdot liter^{-1}$) throughout the irrigation season on N content of the soil solution. The 3 desired N levels are obtained by injecting solution of NH_4NO_3 and KNO_3 in the right volumetric proportions into the water supplied from a local well, which contain 17 mg·liter^{-1} N (NO_3, Table I). The fertigation is applied to the field every other day by a surface drip system. Trees are spaced 6 X 6 m and each row is irrigated trough 2 laterals located 0.5 m from both sides of the trunks with emitters of 2.3 liter·h^{-1} discharge spaced 1 m along each lateral. The watering levels of all treatments on 1996 and 1996 were 1.5, 2, 3.5, 4, 3 mm per day during the periods of 1-30/4, 1-31/5, 1/6-15/7, 16/7-30/9 and 1-30/10, respectively. The soil in the experimental field is sandy Hamra and the avocado cultivar is Ettinger grafted on the salt tolerant rootstock VC51. The experimental design is 4 randomized blocks.

In this paper we present results of soil-solution chemical analysis during the first two seasons of the study.

N, Cl and EC in the soil solution was monitored. Soil solution samples were extracted through suction cups installed at 20 cm distance from an emitter under the south side of the canopy at 30 and 60 cm depths. Solution samples from both depths were analyzed 9, 5 or 2 times for EC, Cl and N levels respectively during the 1st season, and 7 times for all components during the 2nd season. Soil water was determined by two different methods 9 times during the irrigation season: a) Matric potential was measured by tensiometers installed at similar locations as the suction cups. b) Volumetric moisture content was measured by Neutron scatterer through excess tubes inserted to 150 cm depth at similar distance from the emitter. All measurements showed high water content and low tension and therefore the paper present only the field capacity obtained by the neutron scattering.

Since Cl uptake by the plant is negligible, and since it does not interact with the soil complex, changes in Cl concentrations of the soil solution are the result of water uptake by the trees. Leaching fraction (LF) was calculated from the Cl data as Cl concentration in the irrigation water, divided by its concentration in the soil solution at 30 or 60-cm depths, (equation 1).

$$[1] \qquad LF = Cl_i/Cl_{ss}$$

when i denotes irrigation water and ss denotes soil solution.

Steady states of chloride content in the profile and of leaching fractions were assumed to occur during the days chosen for soil- solutions sampling (reasoned in the result and discussion section). The ratio of Cl concentrations in the irrigation water and in the soil solution can therefore provide the leaching fraction (USSL 1956).

For data presentation, sampling dates were counted as day of year (DOY) as running days from January 1st.

RESULTS AND DISCUSSION

Table 1 present the chemical characteristic of the irrigation water (well water) used in this study. The well water were at the high range of salinity for Avocado, contained relatively high N and no P (Table 1).

Table 1. The composition of the local well water.

SAR	*EC* dS·m^{-1}	*Cl* mg·liter^{-1}	*Na* meq·liter^{-1}	*Ca+Mg* meq·liter^{-1}	*K* mg·liter^{-1}	*P* mg·liter^{-1}	*N(NO)$_3$* mg·liter^{-1}
1.4	1.40	247	3.0	11.0	7.0	-	17

Table 2 describes the cumulative, seasonal, amount of water, Cl, N, P and K, applied to the 3 different N treatments. The cumulative irrigation volume was similar in all treatments. Same is true for cumulative inputs of Cl, K, and P. The seasonal input of N was larger in the higher N treatments, in accordance with the level of the N fertilizer in the irrigation water.

Table 2. Cumulative seasonal water and nutrients application at the different treatments

Water mm	*N* g·m^{-2}	*P* g·m^{-2}	*K* g·m^{-2}	*Cl* g·m^{-2}	Treatment
660	15.0	5.20	13.1	163	20 mg·liter^{-1} N
666	28.4	5.50	13.4	163	40 mg·liter^{-1} N
664	43.1	5.30	16.4	164	60 mg·liter^{-1}N

Table 3. Effect of N fertilizer levels on the salinity and nutrients levels in the soil root zone. Data are means of 2 sampling days (197 and 268 days of year, DOY) and 2 sampling depths (30 and 60-cm). Water samples were extracted with suction cups.

EC dS·m^{-1}	*Cl* meq·liter^{-1}	*Na* meq·liter^{-1}	*N-NO$_3$* mg·liter^{-1}	*K* meq·liter^{-1}	Treatment
2.21	13.5	6.3	13.6	0.29	20 mg·liter^{-1} N
2.28	13.3	6.4	39.0	0.24	40 mg·liter^{-1} N
2.74	13.6	8.8	79.3	0.38	60 mg·liter^{-1} N

Table 3 presents the means of salinity, N and K levels in the soil solutions for two sampling days and two depths (197 and 268 DOY at 30 and 60-cm depths) during the 1st season. The irrigation seasons started in the end of March and terminated in the end of October. 197 DOY is in mid July (middle of the summer season in Israel) and 268 DOY is at the end of September (end of the summer). Increased N fertigation resulted in higher N and EC in the soil solutions, but had no affect on soil-solution Cl. The differences in N accounted for the differences in EC.

Table 4 presents changes in soil solution N concentrations, and calculated values of the Leaching Fraction (LF) for Cl at two different days (197 and 268 DOY) and at two soil depths (30 and 60 cm). As expected, higher N concentrations in the irrigation water, resulted in higher N-concentrations in the soil solution. N-concentration in the soil-solution is higher at the end of summer (day 268) than during the middle of summer (day 197). With the exception of day 197 at the lowest N application treatment, N-concentration of the soil solution increases with soil depth. This increase is highest in the high N application treatment (60 $mg \cdot liter^{-1}$).

Data of Cl concentrations in the soil-solution (not presented) were used for calculation of the leaching fraction. Such calculations require the assumption of steady state of Cl in the sampled volume near the suction cups during the sampling days (LF-USSL 1954). The following reasons allowed this assumption: The volume of an irrigation pulse of an emitter was 12-14 liters; The cumulative volume of water applied by irrigation were 795 and 1656 liters/emitter, up to 197 and 268 DOY respectively; The calculated LF's at 30 and 60 cm depth were at the ranges of 0.66 to 0.25 on day 197, and 0.82 to 0.66 on day 268, i.e. higher on the later sampling date; The soil water holding capacity (measured by Neutron Scattering) for the wetting volume to 20 cm radius and 60 cm depth is about 21 liters and for wetting radius of 50 cm and 60 cm depth is about 130 liters. With these water volumes inert ions with little uptake, like Cl, must reach steady states. The stable Cl levels during these periods in the 1^{st} season (not shown) and in the 2^{nd} season (Table 5) confirm the steady state assumption.

Both N levels and the LF's (calculated from the Cl data) were higher, in both depths, on day 268 than on day 197 DOY despite the higher LF in day 268 (Table 4). If we assume similar rates of N losses to the atmosphere during most of the summer the differences in N concentrations between the two days must be the result of seasonal differences in N uptake by the trees. The increase in N concentration of the soil solution between the two sampling days hence suggest decreased N-uptake.

Lower N concentration in the soil solution than in the irrigation water, at a given depth, indicate higher rates of N (uptake + losses) than of water losses. In such a case,

$$N_{(uptake + losses)}/ET > Ni/V_i;$$

when ET is evapotranspiration, Ni is N content in an irrigation pulse and V_i the volume of water applied by irrigation.

In the specific case where the element concentration is the irrigation solution (C_i) is similar to its concentration in the drainage solution (C_{dr}), we suggest to define the specific element concentration as C_{iso} [eq 2]. In such a case, the rates of N (uptake + losses) must be similar to rates of water losses so to maintain the iso-concentration (eq 3).

[eq 2] $$C_{iso} = C_i = C_{dr}$$

[eq 3] $$N_{(uptake + losses)}/ET = N_i/V_i = C_{iso}$$

when C_i is element concentration in the irrigation water, C_{dr} is element concentration in the drainage solution, and ET is evapotranspiration.

In our experimental system, the results presented in table IV demonstrate that C_{iso} condition hold for day 197 at the highest N application treatment. The concentration of N in the soil solution extracted from 60-cm depth of the 60 ppm N-input treatment was 59 mg·liter^{-1}. On day 268, C_{iso} -conditions held for the lowest N-input treatment (20 mg·liter^{-1} N) also at 60 cm depth. The concentration of the soil solution extracted from 60 cm depth in the 20 mg·liter^{-1} N-treatment was 19 ppm N.

At the lowest N treatment, C_{dr} (soil solution) concentrations were always lower than C_i concentration. At the end of the irrigation season, C_{dr} have reached C_{iso}. In the higher N treatments C_{iso} concentration was reached earlier during the season. This observation becomes clearer with the second year data (Table 5).

The increase of N concentration with depth (Table 4) is a result of higher ratio of N to water uptake at 30 cm than 60 cm depth. This demonstrates a higher N uptake at the lowest soil depth (30 cm) which corresponds well with avocado root distribution in the soil profile.

Table 4. Seasonal changes in soil solution N content and in calculated values of the leaching fraction at the 3 different N fertilizer levels applied. The Leaching Fraction (LF) was calculated from the Cl data as described in the Material and Methods section. Data accumulated during the 1st season.

N mg·liter^{-1}: 268 DOY		N mg·liter^{-1}: DOY 197		Leaching Fraction, calculated for Cl: 268 DOY		Leaching Fraction, calculated for Cl: DOY 197		
60 cm	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm	30 cm	Treatment
19	16	8	12	0.66	0.82	0.25	0.66	20 mg·liter^{-1} N
56	38	34	10	0.34	0.73	0.39	0.61	40 mg·liter^{-1} N
133	44	59	23	0.44	0.66	0.34	0.62	60 mg·liter^{-1} N

Table 5. Seasonal changes in N and Cl content and N/Cl ratio of the soil solution at 60-cm depth at the 3 N fertilizer levels applied. Data accumulated during the 2nd season.

		Day of the year (DOY)						
Parameter	Treatment	141	169	190	212	236	264	282
N	20 mg·liter^{-1} N	2.7	5.3	10.3	14.7	10.7	16.3	28.2
	40 mg·liter^{-1} N	7.7	28.3	33.7	52.0	37.0	40.3	51.7
	60 mg·liter^{-1} N	7.5	51.5	57.0	55.3	62.0	74.5	114.5
Cl	20 mg·liter^{-1} N	438	867	674	624	617	618	562
	40 mg·liter^{-1} N	337	536	517	590	454	451	465
	60 mg·liter^{-1} N	439	673	802	486	557	709	703
N/Cl	20 mg·liter^{-1} N	0.008	0.011	0.021	0.027	0.019	0.027	0.051
	40 mg·liter^{-1} N	0.024	0.059	0.071	0.075	0.081	0.089	0.113
	60 mg·liter^{-1} N	0.013	0.073	0.054	0.104	0.102	0.121	0.191

Throughout the irrigation season of the following year soil-solution samples were collected more frequently and analyzed for N and Cl, to evaluate temporal interactions between the level of N-fertilizer in the irrigation system and the concentration of N in the soil solution. Table V presents data from 7 different sampling days, of soil solution extracted from 60 cm depth.

N-level of the soil solution was lowest at the beginning of the irrigation season and increased with time until 190 DOY. N-level was relatively steady between day 190 and 236 (the midst of the summer season in Israel) and later increased with time from day 264 to the end of the irrigation season (at the last leg of the summer and beginning of the fall season). The concentration of N in the soil solution during the time period when N was steady with time (day 190-236) is lower than the iso-concentration at the 20 ppm treatment by about 50% (about 9 $mg \cdot liter^{-1}$). In the two higher N-treatments (40 and 60 $mg \cdot liter^{-1}$ N), the concentration of N in the soil solution is similar to the concentration of the irrigation solution (i.e. 40 and 60 $mg \cdot liter^{-1}$).
Similar to N level, Cl level was lowest at the beginning of the irrigation season and increased with time. Cl in the soil-solution reached stable levels sooner than N, on day 169 and remained relatively steady throughout the irrigation season.

The increase in N and Cl concentrations at the beginning of the irrigation season is the result of element accumulation after the winter soil leaching. The lag of N behind Cl is the result of the differences in uptake rates between the two ions.

Since Cl is an inert ion, and its uptake by the plant is negligible in relation to the soil solution concentration, the ratio of N/Cl can be used to normalize N concentrations for changes in water uptake or losses. When Cl concentration remains constant with time, water uptake and losses are steady. When Cl concentrations increases with time, water (losses + uptake) increases with time. Transformation of the N data to N/Cl ratio therefore allows evaluation of trends of changes in N concentrations regardless of the extent of changes in water (uptake + losses). An increase in N/Cl ratio suggests a reduction in N uptake, and a decreased N/Cl ratio suggests an increase in N uptake. If we assume that by approximation, N losses throughout the irrigation season are steady, than valuation of changes in N/Cl ratios throughout the irrigation season allows estimation of changes in N-uptake by the plants. In our study, N/Cl ratio increased until day 190 and after day 236.

The 1st increase involves period of built up of N and Cl in the soil solution, when steady state calculations don't hold, with probably high rates of N-uptake. Between day 190 and 236 N uptake was stable and increased with soil N. After day 236, toward the fall, the plants were able to take up less N. Heavy N dressing during this period will not load the trees with N towards the low soil N in the spring.

The lowest N-input treatment in this study, 20 ppm N, is the recommended N-fertilization level for avocado in Israel. During the end of the irrigation season, N and N/Cl ratio of the soil solution was higher than in the irrigation water in all treatments. The increase in N/Cl ratio by the end of summer is progressively higher in the higher N-inputs treatments suggesting that higher N-inputs than the recommended level during this period of year might not result in increased N-accumulation by the tree. In contradiction, at the beginning of the summer, N and N/Cl levels were very low in all 3 treatments, suggesting that the plant might benefit from higher N application in this time of year.

The increase in N/Cl ratios with time and their range (0.008 – 0.191) indicates much larger differences than can be explained by the LF. The seasonal mean LF for all treatments was 0.39 and the N/Cl ratios in the irrigation water were 0.08, 0.16 and 0.24 for the 3 N levels.

CONCLUSIONS

There are significant changes in the seasonal uptake of N by avocado trees. During the spring and mid summer the trees can take up more N than toward the end of the summer.

Rain events during the winter in the avocado growing area in Israel leaches the N from the soil root zone. Therefore, at the end of winter, and the beginning of the tree growth season, the amount of N available in the soil is much below its uptake potential. Common agrotechnical practices recommends intensive N-fertilization at the end of the irrigation season, to allow the plant to accumulate N reserves to be available at the beginning of the next growth season. If the uptake potential correlates with the requirements for production, heavier N dressing in the spring will be justified. On the other hand, this study do not justify intensive N-fertilization at the end of the irrigation season, aimed at loading the tree with N reserves to be utilized at the beginning of the next growth season.

The results of the present study suggests that the plant capacity for N uptake during the end of the irrigation season is limited, and intensive N fertilization at this time might not result in the desired elevated accumulation of the nutrient in the plant.

Alternatively, the higher extent of N-uptake by the plant at the beginning of the irrigation season, demonstrated by the lower N/Cl levels suggests that intensive N-application at the beginning of the irrigation season might be a preferred practice.

We do not yet have evidence that the seasonal change in uptake capacity of N is also the optimal N uptake for yield production, such study is currently in progress.

The analysis of suction cup extracts of N and Cl can indicate the temporal changes in uptake of N and water, and guide the seasonal fertigation recommendations.

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