EC or nitrate-N concentration of leachate from inorganic media, such as rockwool or perlite, in bag culture. Because of the potential environmental concerns of high nitrate-N concentrations in leachate, earlier research in our greenhouses focused on the leachate nitrate-N concentrations that resulted from feeding various N concentrations to 'Midal' peppers (*Capsicum annuum* L.) grown in rockwool. We found that feeding N at 175 mg·L⁻¹ resulted in 2.5- to 3.5-fold increases in leachate nitrate-N concentration compared to feeding N at 120 mg·L⁻¹ (Schon et al., 1994). Ku and Hershey (1991) used a sphagnum moss, vermiculite, and perlite-based medium and found that leachate EC from potted poinsettia increased as LF decreased from 0.4 to 0.1. Note that these results with an organic, peat-based medium are contrary to the results we found in rockwool or perlite. They also monitored leachate pH and found that it decreased from 6.1 initially to 5.1 before harvest but that LF did not affect leachate pH. We did not detect consistent changes in leachate pH over time.

At the same LF, cucumbers grown in perlite did not differ in yield or in WUE compared to those grown in rockwool. Cucumber yield was reduced when using a lower LF only in Expt. 1, when nutrients were provided at lower concentrations. Under the conditions of these experiments, a LF of 17% can be used to grow cucumbers in rockwool or perlite without a resulting salt buildup or pH effect in the growing bags. The volume (LF) and concentration of nutrient solution delivered to the cucumbers in these experiments were factors in meeting the plants' nutrient requirements. Yelanich and Biernbaum (1993, 1994) came to the same conclusion when growing container-grown plants in peat-based media. This nutrient management concept for greenhouse production is important to remember as LFs are reduced to conserve water and to curb environmental problems due to nitrate leaching.

Literature cited

- Adams, P. 1990. Hydroponic systems for winter vegetables. *Acta Hort.* 287:181-189.
- Biernbaum, J.A. 1992. Root-zone management of greenhouse container-grown crops to control water and fertilizer use. *HortTechnology* 2:127-132.
- Burns, I.L., E.R. Muller, E. Bell, and S. Novak. 1990. A weighing lysimeter for evapotranspiration monitoring and irrigation control. *Proc. Third Intl. Conf. Computers Agr.* 1:73-78.
- Hershey, D.R. and J.L. Paul. 1982. Leaching-losses of nitrogen from pot chrysanthemums with controlled-release or liquid fertilization. *Scientia Hort.* 17:145-152.
- Ku, C.S.M. and D.R. Hershey. 1991. Leachate electrical conductivity and growth of potted poinsettia with leaching fractions of 0 to 0.4. *J. Amer. Soc. Hort. Sci.* 116:802-806.
- Littell, R.C., R.J. Freund, and P.C. Spector. 1991. SAS System for linear models, 3rd ed. SAS Inst., Cary, N.C.
- McAvoy, R.J. 1994. Nitrate nitrogen movement through the soil profile beneath a containerized greenhouse crop irrigated with two leaching fraction and two wetting agent levels. *J. Amer. Soc. Hort. Sci.* 119:446-451.
- Schacht, H. and M.K. Schenk. 1990. Control of nitrogen supply of cucumber (*Cucumis sativus*) grown in soilless culture, p. 753-758. In: M.L. van Beusichem (ed.). *Plant nutrition—Physiology and applications*. Kluwer Academic Publishers.
- Schon, M.K. and M. Peggy Compton. 1996. Nitrogen and phosphorus requirements for rockwool-grown cucumbers trained with a double stem method. *HortTechnology* 6:33-39.
- Schon, M.K., M. Peggy Compton, E. Bell, and I. Burns. 1994. Nitrogen concentrations affect pepper yield and leachate nitrate-nitrogen from rockwool culture. *HortScience* 29:1139-1142.
- Schulte, E.E., J.B. Peters, and P.R. Hodgson (ed.). 1987. Wisconsin procedures for soil testing, plant analysis and feed & forage analysis. Dept. Soil Sci., Univ. of Wisconsin, Madison.
- Smith, D.L. 1987. Rockwool in horticulture. Grower Books, London.
- Sonneveld, C. 1981. Irrigation and nutrition of glasshouse cucumbers in the Netherlands. *Proc. 1981 Annu. Western Greenhouse Vegetable Conf.*, Fresno, Calif., 18-20 Aug. 1981.
- Straver, W.A. 1989. The double stem training system for seedless cucumbers. *Proc. 1989 Annu. Amer. Greenhouse Veg. Growers Conf.*, Sacramento, Calif., 9-11 Aug. 1989.
- Yelanich, M.V. and J.A. Biernbaum. 1993. Root-medium nutrient concentration and growth of poinsettia at three fertilizer concentrations and four leaching fractions. *J. Amer. Soc. Hort. Sci.* 118:771-776.
- Yelanich, M.V. and J.A. Biernbaum. 1994. Fertilizer concentration and leaching affect nitrate-nitrogen from potted poinsettia. *HortScience* 29:874-875.
- Wright, R.D. 1992. Researcher's perspective on current and future water quality research. *HortTechnology* 2:84.

Nitrogen and Phosphorus Requirements for Rockwool-grown Cucumbers Trained with a Double-stem Method

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ADDITIONAL INDEX WORDS. *Cucumis sativus*, hydroponics, greenhouse

SUMMARY. Four experiments were conducted from 1992 to 1994 to determine the concentrations of N and P required to maximize yields of rockwool-grown cucumbers (*Cucumis sativus* 'Vetomil') trained with a double-stem method. Concentrations of N and P in rockwool slabs were monitored throughout growth of greenhouse-grown cucumbers. The onset and duration of nutrient depletion in the slabs were related to cucumber yield. In Expt. 1, treatment-1 plants received a two-step solution containing N at 90 and 175 mg·L⁻¹ during successive growth phases, while treatment-2 and -3 plants were grown with N at a constant 175 or 225 mg·L⁻¹. Phosphorus was provided at 50 mg·L⁻¹ in all treatments. Treatment 1 was excluded from Expt. 2. In Expts. 3 and 4, plants were grown with N at 225 or 275 mg·L⁻¹ and P at 75 mg·L⁻¹. Onset of N and P depletion (to <10 mg·L⁻¹) in the growing slabs occurred during the early fruiting stage of cucumber, 1 to 8 days before first harvest. The duration of N and P depletion decreased, and cucumber yields increased with increasing N and P concentrations. When plants were grown with N and P at 275 and 75 mg·L⁻¹, respectively, N was depleted in the growing slabs during only one

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experiment and then for only 4 days, and slab P concentration remained $>10 \text{ mg}\cdot\text{L}^{-1}$. Therefore, under Florida conditions, when growing cucumbers in rockwool using a double-stem training technique, N and P should be provided at 275 and 75 $\text{mg}\cdot\text{L}^{-1}$, respectively, to minimize depletion of these nutrients from the growing medium.

Cucumbers rank second in production behind tomatoes in the greenhouse vegetable industry in Canada and the United States (Hickman, 1992; Khosla and Ferguson, 1991). Most greenhouse vegetable acreage in Florida is devoted to the long-fruited seedless cucumber (Hochmuth, 1990). The most common training method for seedless cucumbers is the single-stem method, but to reduce production costs, some European and Canadian growers have used the double-stem training method (Straver, 1989). With this method, the grower increases plant spacing within the row, and trains the lateral shoot from the fifth or sixth node to form the second stem. Straver found that the single-stem and double-stem methods produced similar cucumber yields, even though the plant population was decreased from $>13,000$ to <9000 plants/ha when using the double-stem method, which resulted in increased profits with the double-stem method due to less initial costs for seeds and rockwool.

Sonneveld (1981) recommended a nutrient solution containing N at 170 $\text{mg}\cdot\text{L}^{-1}$ and P at 40 $\text{mg}\cdot\text{L}^{-1}$ for growing single-stem cucumbers in rockwool in The Netherlands. Similarly, Adamson and Maas (1981) recommended that N and P be provided at 168 and 37 $\text{mg}\cdot\text{L}^{-1}$, respectively, for soilless culture of greenhouse cucumbers in Canada. Ottosson (1977) grew single-stem cucumbers in rockwool in Sweden with nutrient solutions ranging in N from 90 to 330 $\text{mg}\cdot\text{L}^{-1}$, and obtained the highest yields when N was provided at 150 or 210 $\text{mg}\cdot\text{L}^{-1}$. The double-stem method of training was implemented for cucumber production in The Land greenhouses at Epcot in Walt Disney World, Lake Buena Vista, Fla., in 1991. When two cucumbers are planted in each rockwool bag, this training method results in four fruit-producing stems per bag, rather than two with the single-stem method. Therefore, previ-

ous nutrient recommendations may not be adequate to meet the needs of the plants when a double-stem method is used.

Our objectives were to monitor the levels of N and P in rockwool slabs throughout cucumber growth and to relate the onset and duration of nutrient depletion to cucumber yield. The ultimate goal was to determine the N and P concentrations required to minimize depletion of these nutrients from the growing medium.

Materials and methods

CONDITIONS FOR PLANT GROWTH. Cucumber seeds ('Vectomil') were sown in $3.5 \times 3.5 \times 3.8$ -cm rockwool cubes (Agrodynamics, New Brunswick, N.J.), and the seedlings in cubes were set into $7.6 \times 7.6 \times 6.4$ -cm rockwool blocks 5 d later, when seedlings were 5 cm tall. Seedlings were watered with a complete nutrient solution containing N at 60 $\text{mg}\cdot\text{L}^{-1}$ (Table 1) to maintain the rockwool at moisture capacity. Plants were transplanted onto $5.1 \times 20.3 \times 91.4$ -cm rockwool growing slabs (two seedlings per slab) 9 to 11 d after seeding and randomly assigned to one of the treatments. Plants were maintained using the double-stem training method (Straver, 1989) and were grown to a height of 3.9 m using strings for support. All axillary shoots (vegetative and flowering) were removed from the lower four to five nodes of the main stem. Thereafter, vegetative shoots were removed; one flower was allowed to develop at every other node. All experiments were conducted in a greenhouse with dual polyethylene roof and polycarbonate siding under natural photoperiod conditions in Florida. Expts. 1 to 4 were conducted from June to Aug. 1992, July to Sept. 1993, Apr. to June 1994, and June to Aug. 1994, respectively.

In Expt. 1, treatment 1 plants received a two-step nutrient regime that contained N at 90 $\text{mg}\cdot\text{L}^{-1}$ and then at 175 $\text{mg}\cdot\text{L}^{-1}$ (Table 1). Nitrogen was increased from 90 to 175 $\text{mg}\cdot\text{L}^{-1}$ when weekly sampling of the slab solution indicated that the average NO_3^- -N concentration had fallen to $<10 \text{ mg}\cdot\text{L}^{-1}$. Concentrations of K, Ca, and Mg were increased with the increase in N (Table 1) to maintain adequate concentrations of these nutrients (Hochmuth, 1991). Plants in treatments 2 and 3 were grown with N at a constant 175 or 225 $\text{mg}\cdot\text{L}^{-1}$ (Table

1). Experiment 2 compared plants grown with N at 175 $\text{mg}\cdot\text{L}^{-1}$ to N at 225 $\text{mg}\cdot\text{L}^{-1}$ for the entire growth period. Phosphorous was provided at 50 $\text{mg}\cdot\text{L}^{-1}$ in all treatments in Expts. 1 and 2. In Expts. 3 and 4, plants were grown with N at 225 or 275 $\text{mg}\cdot\text{L}^{-1}$, with P and K concentrations at 75 and 325 $\text{mg}\cdot\text{L}^{-1}$, respectively (Table 1).

The pH of all solutions was adjusted to 5.5 using nitric acid. The N contribution from the nitric acid was included in the total N concentration for each nutrient solution treatment (Table 1). Increases in solution N concentrations from 175 to 225 $\text{mg}\cdot\text{L}^{-1}$ in Expts. 1 and 2 and from 225 to 275 $\text{mg}\cdot\text{L}^{-1}$ in Expts. 3 and 4 were accomplished by increased use of nitrate salts and decreased use of chloride and sulfate salts. Chloride (Cl) concentrations in resulting solutions ranged from 8 to 107 $\text{mg}\cdot\text{L}^{-1}$. Sonneveld and van der Burg (1991) reported that the yield of cucumbers grown in hydroponic solutions was not affected by increasing Cl from 5 to 12.5 $\text{mmol}\cdot\text{L}^{-1}$ (177 to 444 $\text{mg}\cdot\text{L}^{-1}$). Therefore it is unlikely that the range of Cl concentrations that we used in our experiments affected cucumber yields.

Sulfate-S concentrations in resulting solutions ranged from 16 to 118 $\text{mg}\cdot\text{L}^{-1}$. Ward (1976) studied the responses of greenhouse cucumbers to a range of 0 to 48 $\text{mg}\cdot\text{L}^{-1}$ sulfate-S in the nutrient solution and also included a 480 $\text{mg}\cdot\text{L}^{-1}$ sulfate-S treatment in an attempt to induce toxicity. He reported a cucumber leaf tissue S concentration of 0.6% in the control plants (those receiving S at 48 $\text{mg}\cdot\text{L}^{-1}$). The leaf tissue S concentrations in our experiments ranged from 0.6% to 0.9% during early fruit stage and from 0.7% to 1.6% during late fruit stage. Therefore, it is likely that S was sufficient in all treatments. Ward (1976) found that the excessive S treatment caused severely curled cucumber leaf tips, necrotic spotting, and growth depression. These symptoms were absent in the plants receiving the higher S concentrations in our experiments.

Treatments were arranged in a randomized complete-block design with 14, 20, 12, and 12 blocks in Expts. 1, 2, 3, and 4, respectively. There was one experimental unit (slab) per treatment in each block. Plants received a 1-min irrigation four times daily during the first 8 to 12 d following transplanting onto the growing

slabs. A weighing lysimeter controlled irrigation frequency for each treatment thereafter (Burns et al., 1990). An irrigation event was triggered by a 500-mL depletion of nutrient solution by evapotranspiration from one slab in each treatment. Each irrigation event replaced the depleted 500 mL and provided an additional 200 mL to leach from the slab. To maintain acceptable slab pH and nutrient balance, Smith (1987) suggested that enough solution must be provided to allow $\geq 15\%$ to 20% of the total volume to drain. Prior work in our greenhouses indicated that leaching up to 30% of the total volume was necessary to maintain rockwool slab pH in an acceptable range.

Emitter (woodpecker pressure compensating dripper; Netafim Irrigation, Valley Stream, N.Y.) flow rates for each rockwool slab were calibrated to within 10% of the mean flow rate for each treatment by irrigating for 3 min and measuring the volume of solution delivered to each slab (two emitters).

ANALYSIS OF SLAB SAMPLES. Nutrient solution was drawn from randomly selected growing slabs (three per treatment in Expt. 1; four per treatment in Expts. 2 to 4) twice per week using a syringe and spinal needle. Samples for all treatments were collected within the same block of time. The timing of sampling varied within the irrigation cycle for each treatment due to each treatment having separate lysimeter-controlled irrigation events. However, in additional trials, when samples were taken from slabs at timed intervals beginning 10 min after one irrigation event and continuing until the next (40 min later), there was not a downward trend in N or P concentrations in the slabs during the period. Using the weighing lysimeter system provides

frequent replenishment of the nutrient solution in the growing slabs throughout the day. During the harvest period, the mean number of irrigations per day was 8, 10, and 13 for the N at 90 to 175, 175, and 225 mg·L⁻¹ treatments, respectively, during Expt. 1, and seven and nine irrigations per day for the N at 175 and 225 mg·L⁻¹ treatments, respectively, in Expt. 2. During Expt. 3, the mean number of irrigations per day was 6 and 7 for the N at 225 and 275 mg·L⁻¹ treatments, respectively, and 7 mean irrigations per day for N at 225 and 275 mg·L⁻¹ treatments in Expt. 4.

In Expt. 1, samples were analyzed for pH and electrical conductivity (EC) before combining the two weekly samples from each slab into one sample for determination of nitrate-N and phosphate-P concentrations. In Expts. 2 to 4, growing slabs again were sampled twice weekly; individual samples were analyzed for pH, EC, nitrate-N, and phosphate-P concentrations. Anion chromatograph (model 4500i; Dionex, Sunnyvale, Calif.) was used to determine nutrient concentrations in slab samples. In all experiments, depletion of a nutrient within the rockwool slabs was defined as $< 10 \text{ mg} \cdot \text{L}^{-1}$. Massy and Winsor (1980) provided evidence that N concentrations as low as $10 \text{ mg} \cdot \text{L}^{-1}$ were adequate to maintain yields in hydroponic culture if the N was continuously available to the root systems. They found that tomato plants grown in recirculating, flowing solutions that contained nitrate-N at 10, 20, 40, 80, 160, or 320 mg·L⁻¹ produced similar total fruit mass.

NUTRIENT ANALYSIS OF TISSUE. Leaf samples were collected during early and late fruit stages (six to eight repli-

cations per treatment). Each sample consisted of the two most recently matured leaves (one leaf per plant, two plants per slab) from a nonfruiting node on the main stem. Leaves were washed in tap water, rinsed three times in deionized water, and dried for 48 h at 60 °C. Plant tissue was analyzed at the Soil and Plant Analysis Laboratory, Madison, Wis. Tissue was analyzed for total N using a semi-micro Kjeldahl procedure. Following HNO₃/HClO₄ digestion, all other nutrient concentrations were determined using an inductively coupled plasma emission spectrometer (model 34000; Applied Research Laboratories-Fison, Valencia, Calif.).

GROWTH AND YIELD DATA. During Expt. 1, plant height and the number of nodes per plant were recorded at 23 d after transplant (DAT) for 10 randomly chosen plants per treatment. In Expts. 1 and 2, fruit that was $> 4.5 \text{ cm}$ in diameter were harvested daily. During Expts. 3 and 4, fruit was harvested at $> 5.0 \text{ cm}$ in diameter four times weekly. Fruit count and fruit mass data were determined on a per-slab (two plant) basis since this was considered the experimental unit. The total harvest period for each experiment was 4 weeks. Following the final harvest in Expt. 1, 13 fruit per treatment were chosen randomly and were analyzed for soluble solids concentration on a digital refractometer (Atago, Tokyo). A 2.5- to 5.0-cm segment was cut from the middle of each fruit, and juice was squeezed onto the refractometer.

All data were analyzed using the general linear models procedure of the Statistical Analysis System (Littell et al., 1991); the Student-Newman-Keuls test was used for mean separation. Throughout the text, significance is indicated if $P \leq 0.05$.

Table 1. Nutrient concentrations (in milligrams per liter) for rockwool-grown cucumbers, Expts. 1 to 4.^z

Nutrient	Seedlings all expts.	Expt. 1 (treatment no.)				Expt. 2 (treatment no.)		Expts. 3 and 4 (treatment no.)	
		1 (step)				1		1	
		1	2	2	3	1	2	1	2
N	60 ^y	90 ^y	175 ^y	175 ^y	225 ^y	175 ^y	225 ^y	225 ^x	275 ^x
P	50	50	50	50	50	50	50	75	75
K	150	150	180	180	180	180	180	325	325
Ca	150	150	180	180	180	180	180	180	180
Mg	40	40	60	60	60	60	60	60	60

^zIron, Cu, Mn, Zn, B, Mo at 2.0, 0.2, 0.8, 0.3, 0.5, 0.05 mg·L⁻¹, respectively, for all solutions.

^yTotal N derived from 95 NO₃-N : 5 NH₄-N.

^xTotal N derived from 92 NO₃-N : 8 NH₄-N.

Fig. 1. Nitrate-N concentrations (in milligrams per liter) in the rockwool growing slabs for 'Vetomil' cucumbers in Expts. 1 to 4. Phosphorus was provided at 50 mg·L⁻¹ in Expts. 1 and 2 and at 75 mg·L⁻¹ in Expt. 3 and 4. Arrows indicate first harvest. Dotted lines indicate 10 mg·L⁻¹, the concentration defined as the depletion level for nitrate-N in the growing slabs.

Results and discussion

In Expt. 1, when plants were grown with solutions containing N at 90 and then 175 mg·L⁻¹, onset of N depletion (<10 mg·L⁻¹) in the growing slabs occurred at 19 DAT and N remained <10 mg·L⁻¹ for the duration of the experiment. When N was provided at 175 or 225 mg·L⁻¹, onset of N depletion occurred at 26 DAT, and the duration of the depletion decreased as solution-N concentration increased (Fig. 1.1).

Growth data and Brix soluble solids concentrations were collected only for Expt. 1. Twenty-three DAT, plants grown using the 90 to 175 mg·L⁻¹ step N solutions had fewer nodes (15.6) than plants provided N at 175 or 225 mg·L⁻¹ throughout the experiment (17.4 and 17.5, respectively). Differences in plant height (152.5, 164.0, and 162.5 cm for plants grown with solutions containing N at 90- to 175-step, 175, and 225 mg·L⁻¹, respectively) were not significant. There were

no differences in soluble solids (means from 3.4 to 3.6) in fruit harvested from the three treatments.

During Expt. 2, when N was provided at 175 or 225 mg·L⁻¹, onset of N depletion in the growing slabs was first noted 18 and 22 DAT, respectively, and N remained depleted for the duration of the experiment (N at 175 mg·L⁻¹ or until 39 DAT (N at 225 mg·L⁻¹), (Fig. 1.2). In Expt. 3, when N was provided at 225 mg·L⁻¹, onset of depletion occurred at 22 DAT and continued until 43 DAT (Fig. 1.3). In Expt. 4, N depletion occurred only on 22 DAT (Fig. 1.4). When N was provided at 275 mg·L⁻¹, N depletion was noted only on 29 DAT during Expt. 3; N was never depleted in Expt. 4 (Figs. 1.3 and 1.4).

In Expts. 1 and 2, P was provided at 50 mg·L⁻¹ to all plants in all treatments. In Expt. 1, P in the growing slabs was depleted to <10 mg·L⁻¹ by 26 DAT and remained depleted until at least 33 DAT (Fig. 2.1). In Expt. 2, P was depleted by 22 and 25 DAT in

the plants receiving N at 175 and 225 mg·L⁻¹, respectively; P remained depleted for the duration of the experiment in slabs provided N at 175 mg·L⁻¹ and until 39 DAT in slabs provided N at 225 mg·L⁻¹ (Fig. 2.2). Since cucumbers consistently depleted P in the growing slabs during the first two experiments, the concentration of P provided during Expts. 3 and 4 was increased to 75 mg·L⁻¹. At this concentration, P in growing slabs was never depleted to <10 mg·L⁻¹ (Figs. 2.3 and 2.4). Analyses of slab samples also indicated that when K was provided at 180 mg·L⁻¹, depletion of K in the slab to <10 mg·L⁻¹ (data not shown) was occurring, so the K concentration provided to the cucumbers was increased to 325 mg·L⁻¹ during the last two experiments.

In Expts. 1 to 3, the mean total number and mass of fruit harvested per slab increased as solution N concentrations provided to the plants increased (Table 2). However, when N treatments at 225 vs. 275 mg·L⁻¹ from

Fig. 2. Phosphate-P concentrations (in milligrams per liter) in the rockwool growing slabs for 'Vetomil' cucumbers in Expts. 1 to 4. Phosphorus was provided at 50 mg·L⁻¹ in Expts. 1 and 2 and at 75 mg·L⁻¹ in Expts. 3 and 4. Arrows indicate first harvest. Dotted lines indicate 10 mg·L⁻¹, the concentration defined as the depletion level for phosphate-P in the growing slabs.

Expt. 3 were repeated during Expt. 4, there were no significant differences in either number or mass of fruit per slab (Table 2). Therefore, this series of experiments indicated that highest yields were obtained under our growing conditions when N was provided at 225 to 275 mg·L⁻¹.

In each experiment, N concentration in leaves removed during the early fruiting stage of growth was higher in plants that were provided higher solution N concentrations (Table 3). In Expt. 3 only, differences in leaf-N were also seen in leaves removed during late fruiting. In all four experiments, leaf-N concentrations were within or above the adequate range (2.5% to 5.0%) established for field-grown cucumbers (Hochmuth et al., 1991; Locascio, 1993; Weir and Cresswell, 1993). Since these N treatments resulted in significantly different cucumber yields, the acceptable leaf N concentrations for hydroponically grown cucumbers may need to be established independently

from field-grown cucumbers. Schacht and Schenk (1990) reported cucumber leaf N concentrations in the range of 4.3% to 6.3% when they grew greenhouse cucumbers using nutrient film technique, and they had the highest yield when leaf dry matter contained 5.9% N.

Phosphorus concentrations in tissue removed during Expts. 1 and 2 (when P was provided at 50 mg·L⁻¹) ranged from 0.8% to 1.0% during early fruiting and 0.6% to 0.7% during late fruiting. These ranges in leaf tissue P concentration did not change when P provided to the cucumbers was increased to 75 mg·L⁻¹ during Expts. 3 and 4. Phosphorous may not have been limiting to the plants during Expts. 1 and 2, even though P in the rockwool slabs was being depleted to >10 mg·L⁻¹. Roorda van Eysinga and Smilde (1969) reported a range of P concentration from 0.35% to 0.74% and sometimes ≤1.0% in healthy leaves of greenhouse-grown cucumbers and

only 0.13% P in leaves of P-deficient plants. Sonneveld (1981) listed 0.5% P as the guide value, or critical value, for greenhouse-grown cucumbers. All leaf P values in our experiments were between or >0.25% and 0.7%, the range described by Hochmuth et al. (1991), Locascio (1993), and Weir and Cresswell (1993) as adequate for field-grown cucumbers.

Within an experiment, there were no consistent differences in either P or K concentrations in leaf tissue due to treatments. Phosphorous and K leaf tissue concentrations were higher during early fruiting than late fruiting. During Expts. 1 and 2, when K was provided at 180 mg·L⁻¹, the ranges for leaf K concentrations were 2.1% to 2.5% during early fruiting and 1.4% to 1.9% during late fruiting. When the K concentration in the nutrient solutions was increased to 325 mg·L⁻¹ during Expts. 3 and 4, the ranges of leaf K concentrations increased to 3.4% to 4.5% during early fruiting and 3.0% to

3.2% during late fruiting. Roorda van Eysinga and Smilde (1969) found 2.5% to 5.4% K in the leaves of healthy, greenhouse-grown cucumbers. They reported yield reductions but no visible K deficiency symptoms on the foliage when cucumber leaves contained 2.1% K. Sonneveld (1981) also listed 2.5% K as the critical value for leaf tissue from greenhouse-grown cucumbers. These values indicate that K may have been limiting cucumber yields during Expts. 1 and 2. Leaf tissue K concentrations during these experiments were in the adequate range (1.6% to 6.0%) as described for field-grown cucumbers (Hochmuth et al., 1991; Locascio, 1993; Weir and Cresswell, 1993).

In conclusion, the onset of N and P depletion to $<10 \text{ mg} \cdot \text{L}^{-1}$ in the growing slabs occurred during the early fruiting stage of the cucumber, 1 to 8 d before first harvest (see arrows, Figs. 1 and 2). Within an experiment, cucumber yield corresponded to the duration of N or P depletion in the rockwool slab, indicating that nutrients were the limiting factor. When cucumbers are grown using a double-stem training technique under Florida growing conditions, N and P should be provided at 275 and 75 $\text{mg} \cdot \text{L}^{-1}$, respectively, to minimize depletion of N and P from rockwool slabs.

Literature cited

- Adamson, R.M. and E.F. Maas. 1981. Soilless culture of seedless greenhouse cucumbers and sequence cropping. Can. Dept. Agr. Publ. 1725/E.
- Burns, I.L., E.R. Muller, E. Bell, and S. Novak. 1990. A weighing lysimeter for evapotranspiration monitoring and irrigation control. Proc. 3rd Intl. Conf. Computers Agr. 1:73-78.
- Hickman, G.W. 1992. Growth is slow, census shows. Amer. Veg. Grower. 40:84-86.
- Hochmuth, G. 1990. Florida...A leader in greenhouse vegetable production. Citrus Veg. Mag. October:9-11, 15, 40, 41.
- Hochmuth, G. 1991. Fertilizer programs for tomatoes in Florida. Proc. 1990 Annu. Amer. Greenhouse Veg. Growers. Assn. Conf. and Trade Show, Jacksonville, Fla., 1-3 Nov. 1990.
- Hochmuth, G., D. Maynard, C. Vavrina, and E. Hanlon. 1991. Plant tissue analysis and interpretation for vegetable crops in Florida. Fla. Ext. Bul. SS-VEC-42.

Table 2. Effects of solution nutrient concentrations on yield in 'Vetomil' cucumbers grown in rockwool.

Treatment N ($\text{mg} \cdot \text{L}^{-1}$)	Yield ^a							
	Expt. 1		Expt. 2		Expt. 3		Expt. 4	
	No.	Mass (kg)	No.	Mass (kg)	No.	Mass (kg)	No.	Mass (kg)
90 to 175	26.1 a	9.21 a	---	---	---	---	---	---
175	35.3 b	12.39 b	26.1	9.21	---	---	---	---
225	45.0 c	15.04 c	36.0	12.47	29.0	16.33	24.3	13.7
275	---	---	---	---	33.8	18.07	26.4	14.6
Significance	***	***	***	***	**	*	NS	NS

^aAll means represent two plants (4 weeks of harvest) and are the mean values from 10 to 18 replicates. Mean separation within columns at $P \leq 0.05$, Student-Newman-Keuls test. When two treatments, significance was determined by F test.

NS, *, **, *** Nonsignificant or significant F test at $P < 0.05$, 0.01, and 0.001, respectively.

Table 3. Effect of nutrient concentrations in solution on N concentrations (percentage) in most recently matured 'Vetomil' cucumber leaves removed during early fruit and late fruit stages.

Treatment N ($\text{mg} \cdot \text{L}^{-1}$)	Leaf N (%) ^a							
	Expt. 1		Expt. 2		Expt. 3		Expt. 4	
	Early	Late	Early	Late	Early	Late	Early	Late
90 to 175	4.25 a	4.90 a	---	---	---	---	---	---
175	5.54 b	4.95 a	5.10	5.23	---	---	---	---
225	5.88 c	4.65 a	5.80	5.41	4.62	5.08	5.18	4.35
275	---	---	---	---	4.97	5.40	5.58	4.03
Significance	***	NS	***	NS	**	*	*	NS

^aEarly fruit stage = 22 to 23 d after transplant (DAT); late fruit stage = 49 to 50 DAT. Mean values of six to eight replicates. Mean separation within columns at $P \leq 0.05$, Student-Newman-Keuls test. When two treatments, significance was determined by an F test.

NS, *, **, *** Nonsignificant or significant F test at $P < 0.05$, 0.01, 0.001, respectively.

Khosla, S. and G. Ferguson (eds.). 1991. Greenhouse vegetable newsletter. Ont. Ministry Agr. and Food Circ. no. 5.

Littell, R.C., R.J. Freund, and P.C. Spector. 1991. SAS system for linear models, 3rd ed. SAS Inst., Cary, N.C.

Locascio, S.J. 1993. Cucurbits: Cucumber, muskmelon, and watermelon, p. 123-130. In: W.F. Bennett (ed.). Nutrient deficiencies & toxicities in crop plants. APS Press, St. Paul, Minn.

Massey, D. and G.W. Winsor. 1980. Some responses of tomatoes to nitrogen in recirculating solutions. Acta Hort. 98:127-137.

Ottosson, L. 1977. Vegetable production on mineral wool. Acta Hort. 58:147-152.

Roorda van Eysinga, J.P.N.L. and Smilde, K.W. 1969. Nutritional disorders in cucumbers and gherkins under glass. Cent. Agr. Publ. and Documn., Wageningen.

Schacht, H. and M.K. Schenk. 1990. Control of nitrogen supply of cucumber (*Cucumis sativus*) grown in soilless culture, p. 753-758. In: M.L. van Beusichem (ed.).

Plant nutrition-physiology and applications, Kluwer Academic Publishers.

Smith, D.L. 1987. Rockwool in horticulture. Grower Books, London.

Sonneveld, C. 1981. Irrigation and nutrition of glasshouse cucumbers in the Netherlands. Proc. 1981 Annu. Western Greenhouse Veg. Growers Conf., Fresno, Calif. 18-20 Aug. 1981.

Sonneveld, C. and A.M.M. van der Burg. 1991. Sodium chloride salinity in fruit vegetable crops in soilless culture. Netherlands J. Agr. Sci. 39:115-122.

Straver, W.A. 1989. The double stem training system for seedless cucumbers. Proc. 1989 Annu. Amer. Greenhouse Veg. Growers Conf., Sacramento, Calif., 9-11 Aug. 1989.

Ward, G.M. 1976. Sulphur deficiency and toxicity symptoms in greenhouse tomatoes and cucumbers. Can. J. Plant Sci. 56:133-137.

Weir, R.G. and G.C. Cresswell. 1993. Plant Nutrient disorders 3, vegetable crops. Inkata Press, Melbourne, Australia.