Research Updates

Comparison of Cucumbers Grown in Rockwool or Perlite at Two Leaching Fractions

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Additional index words. *Cucumis sativus*, hydroponics, greenhouse

Summary. Cucumbers (*Cucumis sativus* L. 'Vetomil') were grown in rockwool or perlite to evaluate these media for efficient hydroponic cucumber production under Florida greenhouse conditions. Plants were grown using a double-stem training method, and the frequency of irrigations was controlled by a weighing lysimeter for each treatment. In Expt. 1, plants were grown in rockwool with 29% or 17% leaching fraction (LF) and in perlite with a 17% LF. Nitrogen, P, and K concentrations in the complete nutrient solution were 175, 50, and 180 mg·L^{-1}, respectively. In Expt. 2, N, P, and K concentrations were increased to 225, 60, and 225 mg·L^{-1}, respectively. Other nutrient concentrations and LFs remained as in Expt. 1. In Expt. 1, yields (fruit count and total fruit mass) were higher from plants grown in rockwool at 29% LF than from plants grown in rockwool or perlite at 17% LF. However, in Expt. 2, when nutrient concentrations were higher, total fruit mass was greater from plants grown at the lower LF, although there was no difference in fruit number. In both experiments, cucumber yield did not differ when grown at the same LF in either rockwool or perlite. Electrical conductivity (EC) and pH of the nutrient solution from the growing bags were not affected when LFs were decreased. In Expt. 1, the pH and EC ranged from 6.1 to 7.0 and from 0.9 to 1.6 mS·cm^{-1}, respectively, across all treatments. In Expt. 2, pH and EC ranged from 5.3 to 6.9 and from 0.6 to 2.5 mS·cm^{-1}, respectively, across all treatments.

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Rockwool and perlite are soilless media commonly used in bag culture for hydroponic vegetable production. It is common practice in bag culture to allow some nutrient solution from each irrigation event to leach from the bottom of the bag. This leaching prevents accumulation of soluble salts within the media and maintains an acceptable nutrient balance (Smith, 1987). This portion of nutrient solution, called the leaching fraction (LF), is defined as the volume of nutrient solution leached ÷ total volume of solution delivered (Hershey and Paul, 1982).

We are unaware of any published studies reporting on the effects of LF on production of hydroponically grown vegetable crops in bag culture. Smith (1987) recommended an LF of 15% to 20% for a commercial crop growing in rockwool and stated that 30% to 35% may be necessary at times, while Adams (1990) stated that up to 40% excess nutrient solution may be needed to allow for non-uniformity of emitters. Schon et al. (1994) described a rockwool growing system for peppers that used a 29% LF and indicated that this percentage was necessary to maintain an acceptable pH in the bags. Studies conducted with containerized crops in the floriculture industry have tested LFs as high as 0.4 to 0.6 (Ku and Hershey, 1991; Yelanich and Biernbaum, 1993). Throughout the greenhouse industry, leaching of water containing dissolved nutrient salts from potted plants or bag culture has lead to concerns about potential groundwater contamination and inefficient water and fertilizer use (Biernbaum, 1992; McAvoy, 1994; Schon et al., 1994; Wright, 1992).

In bag culture, rockwool and perlite are managed differently because they differ in structure and water-holding capacity (Adams, 1990). Our objective was to compare the efficiency of perlite and rockwool as growing media for hydroponic production of cucumbers using two LFs.

Materials and methods

Conditions for plant growth. Cucumber seeds (*Cucumis sativus* 'Vetomil') were sown in 3.5 × 3.5 × 3.8-cm rockwool cubes (Agrodynamics, New Brunswick, N.J.), and the seedlings in cubes were set into 7.6 × 7.6 × 6.4-cm rockwool blocks 5 d later, when they were ≈5 cm tall. Seedlings were irrigated with a complete nutrient solution containing N at 60 mg·L^{-1} (Table 1) to keep the rockwool moist. All nutrient solutions were adjusted to a pH of 5.5 using nitric acid. Seedlings were transplanted onto either 5.1 × 20.3 × 91.4-cm rockwool growing bags or 12.0 × 27.3 × 92.5-cm perlite growing bags (two seedlings per bag) 11 to 13 d after seeding. Each growing bag was placed in a tray designed to catch and channel leachate to a drainage system.

Before transplanting, irrigation emitters were calibrated by running the irrigation system for 3 min, measuring the combined output of the two emitters in each bag, and replacing emitters that were not within ±5% of the mean output volume. Rockwool bags were saturated with nutrient solution (Table 1) and then slit twice along the bottom to allow any excess solution (leachate) to drain freely from the rockwool.

Perlite bags were filled with nutrient solution (Table 1) to saturate the perlite. A horizontal drainage slit then was made in the end of each perlite bag so that a reservoir of nutrient solution 2.0 to 2.5 cm deep remained in the bag.

A weighing lysimeter (Burns et al., 1990) controlled the irrigation frequency for each treatment. For the first 10 to 12 d after transplant (DAT), the lysimeters for all treatments were set to irrigate following the depletion of 100 mL of nutrient solution from the bag by evapotranspiration; 22 s of irrigation replaced the 100 mL. After this initial growth period, all treatments were irrigated following 500-mL depletions of nutrient solution. Each irrigation event replaced the depleted 500 mL and provided an additional 200 mL (29% LF) or 100 mL (17% LF) that leached from the bags. Plants were grown in rockwool at 29% or 17% LF or in perlite at 17% LF. Treatments were arranged in a randomized complete-block design, with 14 blocks and one experimental unit (bag) per treatment in each block.

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; and one fruit 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. Experiments 1 and 2 were conducted Nov. 1993 through Feb. 1994 and Aug. 1994 through Nov. 1994, respectively. Greenhouse environmental data was collected from 23 Dec. through 5 Feb. during Expt. 1 and during all of Expt. 2. Mean light values (0900 to 1700 HR, daily) were 475 and 522 $\mu mols \cdot s^{-1} \cdot m^{-2}$ for Expts. 1 and 2, respectively. Mean temperature and relative humidity readings (0700 to 1800 HR, daily) were 23.9 °C and 73.7%, respectively, for Expt. 1, and 31.8 °C and 78.4%, respectively, for Expt. 2.

NUTRIENT SOLUTION ANALYSIS. Pans set under the growing bag trays (chosen randomly) collected leachate from eight bags per treatment in Expt. 1 and six bags per treatment in Expt. 2. Leachate volume per bag was recorded daily, and a 5-mL sample per bag was collected daily and combined into one weekly sample per treatment for analysis of pH, electrical conductivity (EC), and nitrate-N concentrations. An ion chromatograph (model DX-100; Dionex , Sunnyvale, Calif.) was used to determine nitrate-N concentrations.

Nutrient solution was drawn from randomly selected growing bags (four per treatment), using a syringe and a spinal needle for rockwool and a pipette for perlite. The 100 mL removed from each bag was replaced immediately with 100 mL of fresh nutrient solution. Samples were collected weekly and were analyzed individually for pH, EC, nitrate-N, and phosphate-P concentrations using the ion chromatograph.

NUTRIENT ANALYSIS OF TISSUE. In Expt. 1 only, leaf samples were collected from plants in six bags per treatment at 50 DAT. 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 Kjedahl procedure (Schulte et al., 1987). Following HNO_3/$HClO_4$ digestion, P and K concentrations were determined using an inductively coupled plasma emission spectrometer (model 34000; Applied Research Laboratories-Fison, Valencia, Calif.).

YIELD DATA. Fruit were harvested at >5.0 cm in diameter four times weekly. Total harvest period was 4 and 3 weeks in Expts. 1 and 2, respectively.

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

Results and discussion

In Expt. 1, when cucumbers were grown at N, P, and K concentrations of 175, 50, and 180 $mg \cdot L^{-1}$, yields were greater from plants grown in rockwool at 29% LF than from plants grown in rockwool or perlite at 17% LF. The yield increase was due to a greater number of fruit produced by the higher LF treatment. Fruit count and total fruit mass did not differ for cucumbers grown in perlite or rockwool at the same LF (Table 2).

Analysis of nutrient solution samples drawn from the bags indicated that plants grown with 17% LF depleted N and K within the media to <10 $mg \cdot L^{-1}$ and P to <20 $mg \cdot L^{-1}$. Nitrogen concentrations were lower for these treatments than for the 29% LF treatment on 39 and 67 DAT (data not shown). Depletion of media N to this level may have limited yields. Schon et al. (1994) reported that yields of rockwool-grown peppers were significantly reduced when N concentration in the slabs was depleted to 15 $mg \cdot L^{-1}$ before N supply to the plants was increased. Schon and Compton (1996) found that yields of rockwool-grown cucumbers were reduced when N in the slabs was depleted to <10 $mg \cdot L^{-1}$. They found that the longer the duration of depletion, the more yield was limited.

In this experiment, there were no differences in N concentrations in leaf tissue for the three treatments. Leaves were sampled at 50 DAT during late fruit set. Schon and Compton (1996) also reported that cucumbers grown with various N concentrations had significant yield differences but similar cucumber leaf N concentrations during late fruit set. There were differences in leaf N only during early fruit stage. The mean N concentration in our experiment (6.1%) was within the range of cucumber leaf N concentrations (4.3% to 6.3%) reported by Schacht and Schenk (1990) for greenhouse cucumbers. They found the highest yield when leaf dry matter contained 5.9%.

In this experiment, there were no differences in P or K concentrations in leaf tissue for the three treatments.

Table 1. Nutrient concentrations used for 'Vetomil' cucumbers grown in rockwool and perlite (Expts. 1 and 2).[z]

	Solutions ($mg \cdot L^{-1}$)		
Nutrient	Seedlings	Expt.1	Expt. 2
N[y]	60	175	225
P	50	50	60
K	150	180	225
Ca	150	180	180
Mg	40	60	60

[z]Iron, Cu, Mn, Zn, Mo at 2.0, 0.2, 0.8, 0.3, 0.5, 0.05 $mg \cdot L^{-1}$, respectively.
[y]Total N derived from 95 NO_3-N : 5 NH_4-N.

Table 2. Comparison of nutrient solution use and yield for 'Vetomil' cucumbers grown in rockwool and perlite at two leaching fractions (LF) (Expts. 1 and 2).[z]

Treatment	Nutrition solution used[y] (L)	Yield No.	Yield Mass (kg)	Yield WUE[x]
	Expt. 1			
Rockwool 29% LF	155.8	19.3 a[w]	9.67 a	0.06
Rockwool 17% LF	143.2	17.1 b	8.70 b	0.06
Perlite 17% LF	129.1	15.8 b	8.17 b	0.06
	Expt.2			
Rockwool 29% LF	122.5	14.8 a	7.13 a	0.06
Rockwool 17% LF	111.2	15.4 a	7.36 ab	0.07
Perlite 17% LF	119.8	16.6 a	8.18 b	0.07

[z]All values are per bag (two plants).
[y]Nutrient solution used = total volume delivered – total volume leached.
[x]Water use efficiency = yield (kilograms) ÷ water use (liters).
[w]Within an experiment, mean separation within columns at $P \leq 0.05$ by Student–Newman–Keuls test. Mean values represent 10 to 14 replicates.

Mean concentrations for P and K were 0.9% and 2.8%, respectively. These P and K values are above the critical values (0.5% P and 2.5% K) listed by Sonneveld (1981) for greenhouse-grown cucumbers.

Research performed with container-grown plants in peat-based media showed that fertilizer concentration and LF play a role in determining the nutrient concentration in the media (Yelanich and Biernbaum, 1993, 1994). Therefore, it may be that when concentrations of nutrients (especially N) were limiting during Expt. 1, a reduction in LF from 29% to 17% decreased media nutrient concentration enough to subsequently reduce yields.

Analysis of nutrient samples drawn from the growing bags weekly from 18 to 67 DAT during Expt. 1 revealed ranges in solution pH of 6.1 to 6.6, 6.2 to 6.7, and 6.4 to 7.0 for the rockwool 29% LF, rockwool 17% LF, and perlite 17% LF treatments, respectively. The pH values from the perlite 17% LF treatment were higher than those from the rockwool treatments only on 25 DAT (data not shown). Reducing LF from 29% to 17% did not affect the pH of nutrient solution in the rockwool growing bags.

Analysis of the nutrient solution samples taken from the growing bags weekly from 18 to 67 DAT indicated ranges in EC of 1.1 to 1.6, 1.0 to 1.4, and 0.9 to 1.2 $mS \cdot cm^{-1}$ for the rockwool 29% LF, rockwool 17% LF, and perlite 17% LF treatments, respectively. Since the initial EC of the nutrient solution was 1.91 $mS \cdot cm^{-1}$, the previously mentioned ranges indicate that salt buildup was not a problem in our experiment.

During Expt. 1, the total volume of nutrient solution used for each growing bag (two plants) tended to decrease with a reduction in LF (Table 2). The water use efficiency (WUE) (or yield ÷ water use), however, did not differ for the treatments because of the lower yields in the 17% LF treatments. In Expt. 1, plants grown in perlite at 17% LF required less solution than those grown in rockwool at 17% LF (Table 2).

In Expt. 2, solution concentrations of N, P, and K were increased to 225, 60, and 225 $mg \cdot L^{-1}$, respectively. Weekly nutrient solution sampling showed that nitrate-N was depleted to <10 $mg \cdot L^{-1}$ only in the rockwool treatments at 24 and 30 DAT; nitrate-N concentration in the 17% LF perlite bags was higher than in both rockwool treatments on 17, 24, 30, and 38 DAT (data not shown). At these higher N, P, and K concentrations, LF did not affect the number of cucumbers produced but resulted in a higher total fruit yield from plants grown in perlite at 17% LF than from plants grown in rockwool at 29% LF (Table 2). As in Expt. 1, cucumber yield did not differ when grown in either rockwool or perlite at the same LF.

Analysis of nutrient samples drawn from the growing bags weekly from 17 to 45 DAT during Expt. 2 showed ranges in solution pH of 6.1 to 6.9, 6.4 to 6.9, and 5.3 to 6.6 for the rockwool 29% LF, rockwool 17% LF, and perlite 17% LF treatments, respectively. The pH values from the perlite 17% LF treatment were lower than those from the rockwool treatments on 24, 30, 38, and 45 DAT (data not shown). As in Expt. 1, a reduction in LF from 29% to 17% did not affect the pH of nutrient solution in the rockwool growing bags. Adams (1990) stated that 20% to 40% LF was generally necessary in rockwool to maintain pH. Apparently, the frequent irrigations (up to 10 and 20 irrigations per day in Expts. 1 and 2, respectively) that were triggered by the high evapotranspiration of these cucumbers under Florida greenhouse growing conditions made 17% LF sufficient to flush the bags and maintain pH.

Analysis of the weekly nutrient solution samples drawn from the bags from 17 to 45 DAT during Expt. 2 indicated EC ranged from 0.6 to 2.4, 0.6 to 2.5, and 0.9 to 2.5 $mS \cdot cm^{-1}$ for the rockwool 29% LF, rockwool 17% LF, and perlite 17% LF treatments, respectively. The initial EC of the nutrient solution was 2.0 $mS \cdot cm^{-1}$. According to Smith (1987), it is typical for the conductivity of the slab solution to be 125% to 150% higher than the input solution. Therefore, salt buildup did not become a problem in the bags even at the lower LF. Again, this may have been due to the frequent irrigations triggered by the lysimeters.

As in Expt. 1, the total volume of nutrient solution used for each growing bag tended to decrease with a reduction in LF (Table 2). In Expt. 2, yields did not differ between the two rockwool treatments, and WUE was similar for all treatments. Contrary to Expt. 1, the plants grown in perlite at 17% LF tended to use more solution than those grown in rockwool at 17% LF.

In our experiments, mean values of leachate EC from rockwool bags were unaffected as LF was reduced from 29% to 17% (data not shown). The mean leachate nitrate-N concentrations were 14 and 10 $mg \cdot L^{-1}$ higher from the rockwool 29% LF treatment than from the rockwool 17% LF treatment during Expts. 1 and 2, respectively. When comparing the two 17% LF treatments, mean leachate EC from perlite bags was similar to that from rockwool bags (data not shown). Mean leachate nitrate-N concentrations were 18 and 11 $mg \cdot L^{-1}$ higher from the perlite 17% LF treatment than from the rockwool 17% LF treatment during Expts. 1 and 2, respectively.

We are not aware of any other studies that look at the effect of LF on

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 $mg \cdot L^{-1}$ resulted in 2.5- to 3.5-fold increases in leachate nitrate-N concentration compared to feeding N at 120 $mg \cdot L^{-1}$ (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.

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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 $mg \cdot L^{-1}$ during successive growth phases, while treatment-2 and -3 plants were grown with N at a constant 175 or 225 $mg \cdot L^{-1}$. Phosphorus was provided at 50 $mg \cdot L^{-1}$ in all treatments. Treatment 1 was excluded from Expt. 2. In Expts. 3 and 4, plants were grown with N at 225 or 275 $mg \cdot L^{-1}$ and P at 75 $mg \cdot L^{-1}$. Onset of N and P depletion (to <10 $mg \cdot L^{-1}$) 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 $mg \cdot L^{-1}$, respectively, N was depleted in the growing slabs during only one

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