Evaluating Rhizon Soil Solution Samplers as a Method for Extracting Nutrient Solution and Analyzing Media for Container-grown Crops

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Summary. The rhizon soil solution sampler (RSSS) currently is being used for in situ extraction of the soil solution for nutrient analysis of mineral soils used to produce field-grown crops. In this study, laboratory and greenhouse experiments were conducted to test the effectiveness of the RSSS for in situ solution extraction from soilless container root media and to compare an RSSS extraction method for measuring root-medium pH, electrical conductivity (EC), and NO_3-N and K concentrations with that measured with the saturated media extract (SME) method. A near 1:1 correlation was found between the pH, EC, and NO_3-N and K concentrations measured in the extracted solution of the RSSS and SME method in media without plants and in media from ten species grown using three water-soluble fertilizer concentrations applied by subirrigation. More testing is needed with the RSSS, perhaps using composite samples from several pots for analysis. The RSSS shows promise for nutrient extraction in container-grown crops because it is fast, nondestructive, simple, economical, and has minimal effect on the nutritional status of the medium in the pot.

Changes in the irrigation and fertilization strategies used in container-plant production have led to a greater reliance on root-medium analysis (Biernbaum et al., 1993). Many methods exist for extracting and analyzing nutrients from container root media, including the saturated-media extract (SME) method (Warncke, 1986), the pour-through extract method (Wright, 1986), the 1:1.5 volume extract method (Sonneveld et al., 1974), the 1:2 volume extract method (Biernbaum et al., 1993), and bulk solution displacement (Nelson and Faber, 1986). One problem with root-medium analysis is that the method frequently used in laboratory analysis (SME) is not the same as that frequently used in the greenhouse for on-site medium analysis (1:2 volume extract). Difficulties arise in the interpretation of results from a combination of the two methods primarily because of the difference in the volume of water used to prepare the sample.

The rhizon soil solution sampler (RSSS) currently is being used as a method for soil solution extraction in situ for field-grown crops (Meijboom and van Noordwijk, 1992; A. Smucker, personal communication). The RSSS is a narrow-diameter, cylindrical microporous tube made of a hydrophilic polymer that can be inserted directly into the soil. With the RSSS, the soil solution is sampled directly, without the addition of water, which is required by many other nutrient extraction methods. The RSSS may provide the container-plant producer a fast and accurate method of nutrient extraction and may also be useful in plant nutrition research for container-grown crops since repetitive, nondestructive sampling from the same pot is possible.

To our knowledge, no research has been conducted to show the accuracy and effectiveness of the RSSS as a method of extracting nutrient solution from greenhouse-grown ornamental crops. The objectives of this study were to evaluate the RSSS for nutrient extraction as a possible on-site testing method and to compare the pH, electrical conductivity (EC), and NO_3-N and K concentrations measured with the RSSS and the standard SME method.

Materials and methods

The RSSS (Ben Meadows, Atlanta, Ga.) used in this experiment consisted of a 12-cm-long × 0.1-cm-outside-diameter microporous (0.1-µm) tube attached to a 12-cm-long × 0.1-cm-diameter PVC tube. The entire apparatus could be connected to a 0.050-L syringe. When the plunger on the syringe was pulled back, a vacuum was created, which caused the soil solution to move through the microporous tube and to be collected in the syringe. Once pulled back, the plunger on the syringe could be braced using a 5-cm-tall sample vial to maintain the vacuum during the sampling period. A typical RSSS extraction from these experiments started 1 h after an irrigation and lasted 30 min. Under these conditions, 0.005 to 0.010 L of solution was collected from the root medium. The RSSS and syringes were rinsed between each sample by drawing reverse-osmosis (RO) purified water through the apparatus until the 0.050-L syringe was filled. The syringe was emptied and air was drawn through the apparatus until water was no longer apparent in the RSSS tube. The syringe was emptied again and was ready for reuse.

The comparative method was the SME method using RO purified water as the extractant (Warncke, 1986). With the SME method, water was added to the sample until the medium slid easily from a spatula, glistened, flowed when tilted, and contained little or no free water. One hour after saturation, the solution was removed from the medium with vacuum extraction. In all experiments unless otherwise noted, pH, EC, and NO_3-N and K concentrations were measured in the

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extracted solution obtained from the RSSS and SME method using Cardy flat electrode ion meters (Spectrum Technologies, Plainfield, Ill.) (Yelanich and Biernbaum, 1993).

EXPERIMENT 1. The pH, EC, and NO_3-N and K concentration of nutrients extracted with the RSSS from a medium at three moisture contents was compared to the that measured using the same medium with the SME method. A commercially available Canadian sphagnum peat–perlite medium (Sunshine no. 1, Sun Gro Horticulture, Bellevue, Wash.) containing lime and preplant nutrient charge fertilizers was used. For the RSSS, air-dried medium was placed into a 9-cm-tall × 12-cm-wide (0.5-L) container and settled with three taps on a bench. Sufficient RO water was added from the top to bring the moisture content to 100%, 80%, or 60% of saturation (v/v). A cover was placed on the container to eliminate water loss because of evaporation. The medium was allowed to equilibrate for 1 h before extraction. Solutions were extracted by inserting the RSSS directly into the root medium. For the SME method, the same volume of dry medium was used and the solution was extracted as described previously. Three pots were sampled for each of the four treatments.

EXPERIMENT 2. Medium pH, EC, and NO_3-N and K concentrations were measured with the RSSS or SME method and were compared. In part 1, a range of pHs was obtained by incorporating a microfine dolomitic hydrated lime ($Ca(OH)_2$ and MgO) (National Lime and Stone, Cary, Ohio) at 0, 0.6, 1.2, 1.8, 2.4, or 3.0 kg·m^{-3} into a (by volume) 70% Canadian sphagnum peat (Fisons professional black bale peat, Sun Gro Horticulture) and 30% perlite medium. In addition to the lime, a 4.4N–6.0P–5.5K–8.6Ca–0.7Mg commercially available preplant nutrient charge fertilizer (Greencare Fertilizers, Chicago) at 2.0 kg·m^{-3} and a granular wetting agent (Aquagro "G", Aquatrols, Cherry Hill, N.J.) at 0.6 kg·m^{-3} were incorporated at mixing. Based on previous research, sufficient RO water was added at mixing to bring the moisture content of the medium to 40% to 50% of container capacity, and the medium was allowed to equilibrate for 2 d.

In part 2, a range of EC, NO_3-N, and K concentrations was obtained by incorporating the preplant fertilizer described previously at 0, 0.25, 0.5, 1.0, 2.0, 2.9, or 3.9 kg·m^{-3}. In addition to the fertilizer, the dolomitic hydrated lime at 1.8 kg·m^{-3} and the granular wetting agent at 0.6 kg·m^{-3} were incorporated at mixing. Sufficient RO water was added at mixing to bring the moisture content of the medium to 40% to 50% of container capacity, and the medium was allowed to equilibrate for 2 d.

Each lime or fertilizer treatment was used to fill ten 10-cm-tall × 10-cm-wide (0.7-L) plastic pots. The unplanted pots were placed on subirrigation benches and irrigated with RO water. Five pots per treatment were used for the RSSS and the other five pots were used for the SME method. During an irrigation, benches filled for 2 min to a depth of 2 cm and drained in 6 min. The medium was sampled 1 h after the benches had fully drained. For the RSSS, a hole was drilled into the pots 5 cm below the rim and the RSSS was inserted at a 45° downward angle to achieve a more representative sample of the root zone (bottom half of the pot). For the SME method, all root medium was removed from the pot and cut horizontally in half and the bottom sample was used.

Medium pH from the RSSS was tested in the extracted solution, while with the SME method an ion-specific electrode (model 91-02; Orion Research, Cambridge, Mass.) was inserted directly into the paste. The same ion-specific electrode was used to measure the RSSS solution pH. Medium EC

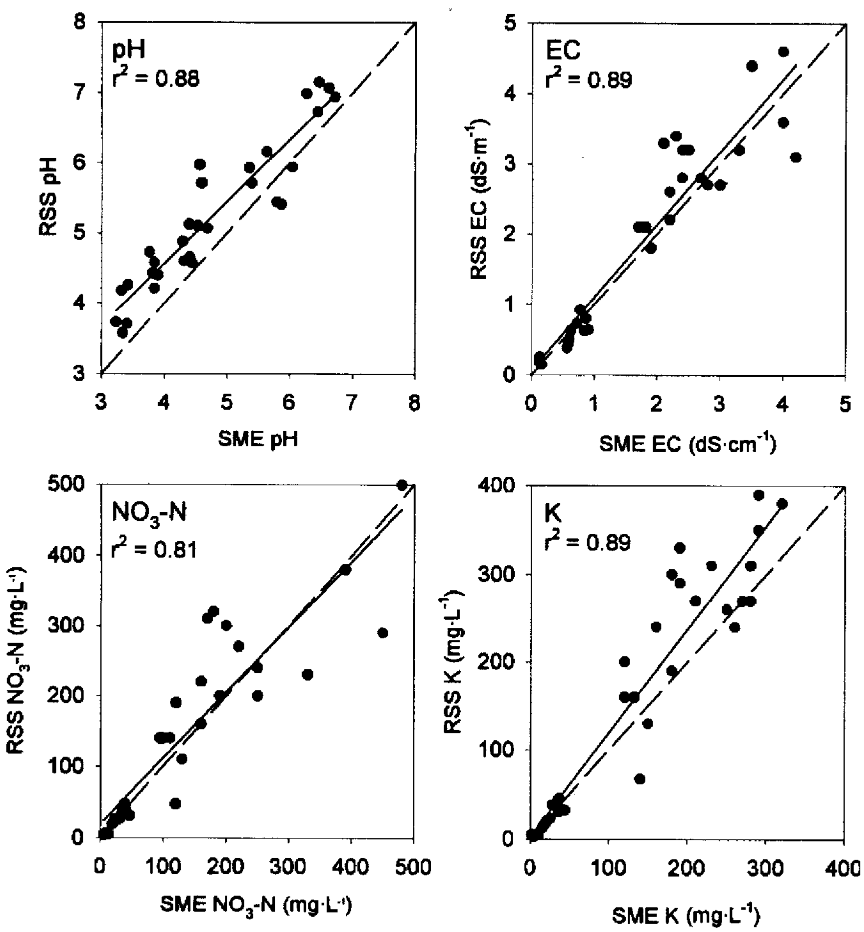

Fig. 1. Comparison of root-medium pH, electrical conductivity (EC), and NO_3-N and K concentrations measured in solutions obtained with the rhizon soil solution sampler (RSSS) and saturated-media extract (SME) method from Expt. 2. The range of media pH values were obtained with six lime incorporation rates and the range of EC and NO_3-N and K concentrations were obtained with seven fertilizer incorporation rates. The solid line represents the value obtained with the linear regression analysis and the dotted line represents a 1:1 correlation. Parameters from the linear regression analyses are presented in Table 1.

Table 1. Linear regression analysis from the comparison of root-medium pH, electrical conductivity (EC), and NO_3-N and K concentrations measured in solutions obtained with the rhizon soil solution sampler (RSSS) and saturated-media extract (SME) method from Expt. 2. Data are presented in Fig. 1.

Parameter	Slope	Intercept	CV	Units
pH	0.9	1.0	7.2	pH
EC	1.0	0.2	24.4	$dS{\cdot}m^{-1}$
NO_3-N	0.9	19	42.3	$mg{\cdot}L^{-1}$
K	1.2	2	29.7	$mg{\cdot}L^{-1}$

and NO_3-N and K concentrations in the extracted solution were measured with the Cardy ion meters. In addition, to determine how the RSSS affected the overall nutrient status of the pot, medium from pots that were sampled using the RSSS was collected and tested using the SME method as described previously. Data were analyzed with SAS's linear regression (REG) procedure (SAS Institute, Cary, N.C.).

Experiment 3. Medium pH, EC, and NO_3-N and K concentrations measured with the RSSS and SME method under production conditions were compared for ten plant species grown with three water-soluble fertilizer (WSF) concentrations and six pots per treatment for a total of sixty pots. The experiment was conducted at Michigan State University, East Lansing, in a well-ventilated glass greenhouse with constant air circulation and cement floors from 1 Sept. 1993 to 1 Jan. 1994. The species tested were 'Galaxy Ultra Violet' African violet (*Saintpaulia ionatha* Wendl.), 'Sierra Deep Red' cyclamen (*Cyclamen persicum* Mill.), 'Dark Bronze Charm' chrysanthemum (*Dendranthema grandiflora* Ramat.), 'Midget' exacum (*Exacum affine* Balf.f.), 'Red Delight' gerbera (*Gerbera jamesonii* H. Bolus ex Hook.f.), 'Red Velvet' gloxinia (*Sinnigia speciosa* (Lodd) Hiern.), 'Telestar Red' kalanchoe (*Kalanchoe blossfeldiana* Poelln.), 'Annette Hegg Dark Red' poinsettia (*Euphorbia pulcherrima* Willd.), 'Pacific Giant Yellow' primula (*Primula ×polyantha* Hort.), and 'Red Mini' rose (*Rosa hybrida* Karmina Minimo). Rooted cuttings or plugs of each species were planted in a commercially available Canadian sphagnum peat and perlite medium (Sunshine no. 1, Sun Gro Horticulture). A commercial WSF (20N–4.3P–16.6K peatlite special (Scotts, Marysville, Ohio) at a constant N concentration of 50, 100, or 200 $mg{\cdot}L^{-1}$ was applied at every irrigation. Plants were subirrigated as needed by placing a volume of fertilizer solution that could be absorbed within 15 min in a plastic saucer under each pot. Root medium was sampled beginning 15 Nov. All treatments from an individual species were sampled on a single day. Pots were subirrigated 1 h before sampling with the fertilizer solution. For each treatment, six pots were sampled, three using the RSSS and three using the SME method, as described previously. Medium pH, EC, and NO_3-N and K concentrations were measured in the extracted solution with both sampling methods using the Cardy ion meters.

Results and discussion

Medium pH was not affected by the moisture level of the medium before extraction but was 0.1 pH units higher when measured in the extracted solution of the RSSS instead of directly in the paste with the SME method. The EC of the solution extracted with the RSSS was 2.7, 1.9, or 1.5 $dS{\cdot}m^{-1}$ with the medium moisture content of 60%, 80%, or 100%, respectively, compared to that measured with the SME of 1.7 $dS{\cdot}m^{-1}$. Based on a comparison of the RSSS and SME data, a similar EC would have been measured in the medium with the RSSS and SME method with 85% to 90% moisture content. Our interpretation of these results is that the time to take an RSSS would be soon after an irrigation, when the moisture content of the medium is as high as possible. It has been our experience that, 1 h after an irrigation, the medium used to prepare the SME (lower half of the pot) requires little if any water to achieve saturation. For all additional experiments, the RSSS and SME samples were taken 1 h after the irrigation to allow an equilibrium to be reached between the applied solution and the medium.

In pots without plants, the medium pH that was measured by placing the electrode directly in the saturated medium averaged 0.5 pH units lower 1 h after an irrigation than that measured in the extracted solution from the RSSS (Fig. 1, Table 1). We have observed this phenomenon before. The difference in measuring the pH before or after the extraction procedure may be due to the degassing and loss of CO_2 associated with the saturated medium or because of differences in the junction potential of the electrode–solution interface between the two sampling methods.

Medium EC and NO_3-N concentration were similar with both sampling methods. Medium K concentrations were similar with both sampling methods at concentrations <100 $mg{\cdot}L^{-1}$, but at higher concentrations the K con-

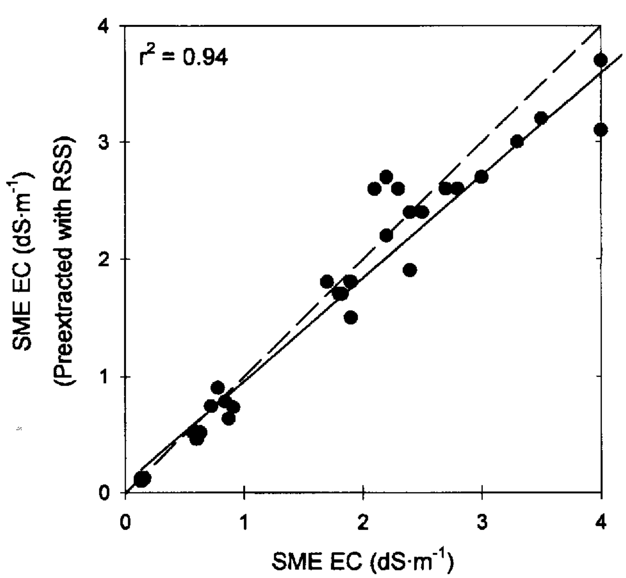

Fig. 2. Comparison of solution electrical conductivity (EC) extracted from medium using the saturated-media extract (SME) method with or without preextraction of solution using the rhizon soil solution sampler (RSSS). The solid line represents the value obtained with the linear regression analysis and the dotted line represents a 1:1 correlation.

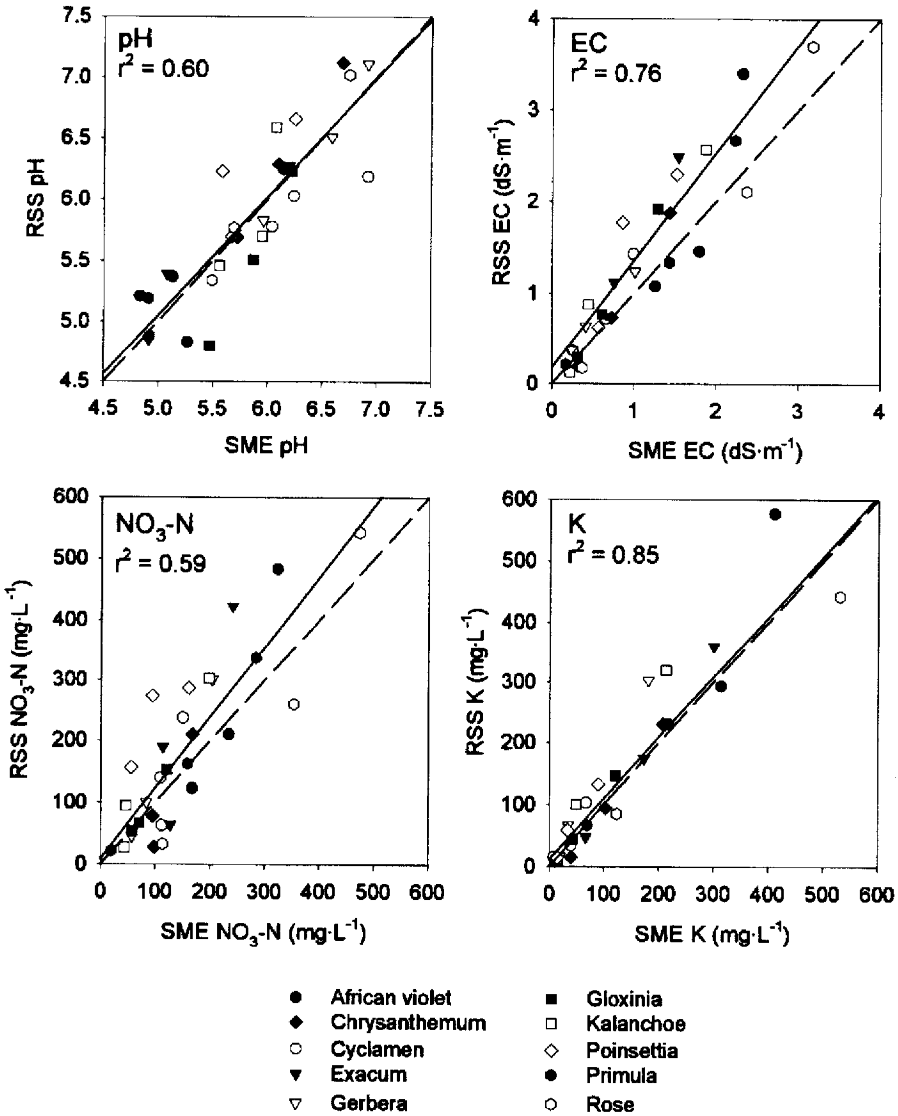

Fig. 3. Comparison of root-medium pH, electrical conductivity (EC), and NO_3-N and K concentrations measured in solutions obtained with the rhizon soil solution sampler (RSSS) and saturated-media extract (SME) method from Expt. 3. Samples were obtained from ten species subirrigated with three fertilizer concentrations for 12 weeks. Separate pots were used for the RSSS and SME measurements. Data are means of three measurements for each sampling method. The solid line represents the value obtained with the linear regression analysis and the dotted line represents a 1:1 correlation. Parameters from the linear regression analyses are presented in Table 2.

centration of the RSSS was higher than that of the SME samples.

In a study very similar to ours, Holcomb et al. (1982) extracted solution from an unplanted, saturated medium by placing the pot onto a vacuum funnel, and the extracted solution was compared to that measured with the standard SME method. Nitrate, K, and EC were consistently lower from the whole-pot vacuum extraction samples than from the SME samples. The authors reportedly expected the whole-pot samples to be higher since some water usually had to be added to the SME samples to reach saturation. In their research, the contents of the pot were mixed for the SME sample while only the lower part of the pot was sampled by the extraction method. In our research, pots were also subirrigated, but only medium from the lower portion of the pot was sampled. Very little if any water was added to the SME samples to achieve saturation. In the work of Holcomb et al. (1982), even though the pots were covered to prevent evaporation during the saturation period, it is likely that some fertilizer stratification within the pot occurred when the pots were saturated from below. Yelanich (1995) reported that salt stratification with subirrigation was due partially to evaporation from the medium surface but was also present in the absence of evaporation in unplanted medium. In the Holcomb et al. (1982) study, fertilizer salts that migrated toward the top of the pot would have been sampled with the SME method but likely were not measured with the vacuum extraction method, resulting in the lower readings.

While not tested in this study, with top watering, salts in the top medium layer are washed into the root zone (Argo and Biernbaum, 1995) and may be sampled with the RSSS after an irrigation, resulting in a higher EC reading than if root medium is collected from the lower part of a pot before an irrigation, as is normally recommended. Further research is needed to test to what degree this occurs, but it may provide for a better measure of actual medium nutrient availability than traditional testing methods based on sampling before an irrigation.

The EC of the solution extracted by SME method after an RSSS extraction was similar to that measured in the solution extracted from the same medium without an RSSS extraction (Fig. 2). The minimal effect that the RSSS had on the overall nutritional status of the medium was probably because only a small volume (0.005 to 0.010 L) of solution was removed. The RSSS could be inserted into five to ten representative plants within a crop at planting and these pots could be used for nutritional monitoring for the duration of the crop. Sampling the same location within the same pots should decrease the variability often associated with media analysis (Biernbaum et al., 1993).

In pots containing plants, the pH measured with the RSSS was similar to that measured in the extracted solution of the SME (Fig. 3, Table 2). These results are different than in Expt. 2 where the pH of the SME sample was measured directly in the saturated medium (Fig. 1). Medium K was also similar with both sampling methods. Medium EC and NO_3-N concentration were generally higher with the

Table 2. Linear regression analysis from the comparison of root-medium pH, electrical conductivity (EC), and NO_3-N and K concentrations measured in solutions obtained with the rhizon soil solution sampler (RSSS) and saturated-media extract (SME) methods measured in ten species grown with three fertilizer concentrations methods from Expt. 3. Data are presented in Fig. 3.

Parameter	Slope	Intercept	CV	Units
pH	0.9	0.2	7.7	pH
EC	1.1	0.2	38.5	$dS \cdot m^{-1}$
NO_3-N	1.1	8	52.0	$mg \cdot L^{-1}$
K	1.0	16	39.7	$mg \cdot L^{-1}$

RSSS compared to that measured with the SME method, but the differences tended to be small (0.1 $dS \cdot m^{-1}$ difference per 1 $dS \cdot m^{-1}$ increase in EC, 10 $mg \cdot L^{-1}$ difference per 100 $mg \cdot L^{-1}$ increase in NO_3-N).

Conclusion

The RSSS was found to be an acceptable method of nutrient extraction from soilless container root media and the pH, EC, and NO_3-N and K concentrations measured with the RSSS were similar to those measured by the standard SME method. The RSSS also is fast, nondestructive, and economical ($6 to $7 per RSSS tube). A protocol could be used with the RSSS that would significantly reduce sampling variability by leaving the probe in the same pots over the duration of a crop or by inserting the probe into the same location in different pots.

There were some limitations to using the RSSS. The RSSS can be damaged by scraping against the side of hole made in the pot for insertion into root medium, bent by use of excessive force or rapid insertion into the medium or damaged by being left in the sun for long periods of time. With the RSSS, the medium must have a high moisture content (such as just after an irrigation) before a sample can be extracted, which limits when the sample can be taken. The pot-to-pot variability was consistent with what we have observed with SME and 1:2 testing methods, where medium is removed from a pot. Therefore, under commercial conditions, we suggest using a composite sample from five to ten pots, as is recommended with other sampling methods currently used, to measure the nutrition levels in container media (Biernbaum et al., 1993).

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Factors Affecting Propagation of *Clematis* by Stem Cuttings

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Additional index words. media, node position, root emergence

Summary. Effect of media type, cultivar, and indole-3 butyric acid (IBA) application on *Clematis* spp. stem cutting rooting was studied. Cutting survival across all treatments was highest on 'Comtesse de Bouchard' and 'Gypsy Queen' cuttings and lowest on 'Jackmani' cuttings. Cutting survival was greatest in perlite and lowest in peat–perlite–vermiculite. IBA application increased 'Jackmani' cutting survival only. Time of root emergence was longest on 'Jackmani' and least on 'Gypsy Queen' cuttings across treatments. Root emergence occurred first in sand and perlite and last in peat–perlite across treatments. Root dry mass on cuttings from 'Jackmani' and *Clematis viticella* purpurea plena elegens plants were unaffected by medium type. In contrast, root dry mass on 'Comtesse de Bouchard' cuttings was highest in perlite and root dry mass on 'Gypsy Queen' cuttings was highest in sand, perlite, and peat–perlite–vermiculite. The best media for propagating clematis were sand and perlite. Benefits to rooting cuttings in sand or perlite were similar, except rooting cuttings in perlite resulted in higher cutting root dry mass.

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