

# Development of the Press Extraction Method for Plug Substrate Analysis: Quantitative Relationships Between Solution Extraction Techniques

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**Abstract.** Substrate electrical conductivity (EC), pH, and nutrient content should be monitored frequently during seedling plug production. Current testing methods are either complicated, unsuited to plug production, or interpretation standards do not exist. This study compares the press extraction (PE) method developed at North Carolina State Univ. with the saturated media extract (SME) method and the 1 substrate : 2 water suspension method (1:2). These solution extraction methods were applied to plug trays containing peat-based germination mix treated with four levels of fertilizer. Two sample sizes of 20 or 60 plug cells were used to determine if the smaller, less destructive sample size would produce satisfactory results. Resulting pH values varied within 0.3 units among methods, but variability in EC and nutrient content was greater. The PE method resulted in the highest values for EC,  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^-\text{-N}$ , K, Ca, and Mg while sample size had little effect on analyses. The three extraction methods were then compared on peat- and coir-based substrates. Within substrates, pH, EC, and nutrients tested were similar for the PE and the SME. The coir extract had a higher pH and much higher levels of K and Na than did the peat extract but was lower in N, P, Ca, and Mg. Overall, fairly strong correlations among testing methods were found, especially between the SME and PE.

Maintaining optimum fertility levels is difficult for plugs because: 1) cell volumes are small, resulting in little buffering of nutrients by substrates; and 2) the large seedling : substrate volume ratio results in either rapid uptake of nutrients or dilution/leaching effects from watering (Compton and Nelson, 1997). Substrate pH and soluble salts should be monitored weekly, as seedlings are especially sensitive to extreme levels of soluble salts (Fonteno et al., 1995). Substrate electrical conductivity (EC) is a reliable indicator of the soluble salts concentration (Poole and Chase, 1987). Substrate pH, EC, and nutrient concentrations can be monitored by analyzing samples in the greenhouse or sending samples to a labora-

tory. However, appropriate procedures at both the sampling and analysis stage are necessary to obtain consistent and reliable results (Lang, 1996). Current greenhouse (peat-based) substrate pH and soluble salts interpretation ranges are based on: 1) 1 substrate : 2 water (v/v) suspension (1:2) (Lang, 1996); 2) the saturated media extract (SME) method (Warncke, 1986); or 3) the pour-through extraction method (Wright et al., 1990). Interpretive standards for nutrient content are only available for SME.

The press extraction method (PE) is a viable alternative to conventional testing methods. A variation on this method had been introduced as the “squeeze” extraction by researchers at North Carolina State Univ. (Compton and Nelson, 1997; Fonteno et al., 1995). The PE is very simple and quick. One hour after liquid fertilizer is applied, while the substrate is still at or close to container capacity, the grower picks up a representative tray and presses several plugs, collecting the expelled solution for immediate analysis. Precedent for press-type testing does exist, as Sonneveld et al. (1974) used solution expelled by a hydraulic press as the “standard closest to the actual root zone solution” with which to compare the 1:1.5 and 1:25 suspension methods. In previous experiments (Scoggins et al., 2000), varying the force applied within a range likely to be manually applied by growers did not affect the pH, EC, or nutrient analysis of the extracted solution.

The saturated media extract (SME) is most commonly used by commercial laboratories (Warncke, 1986). Greenhouse growers can test for pH and EC on-site by the 1:2 method (Nelson, 1998). Neither method is particularly suited to plug production. Both the SME and 1:2 methods require removal of the substrate from the plug tray and the subjective addition of water (Fonteno et al., 1995). Also, as plugs reach transplant size (especially for trays with  $\geq 288$  cells), roots comprise much of the volume of the cell, making removal of enough substrate to perform either method difficult. The pour-through method (Wright et al., 1990) of root-zone solution displacement is rapidly gaining acceptance for bedding and pot plant testing. However, this method is difficult for plug systems. The short substrate column limits the effectiveness of using gravity as the solution extraction force (Fonteno, 1996). In addition, vigorous shoot growth in the later stages of plug production often covers the tray, leaving little or no surface area for applying the displacing water (personal observation).

Depending on the extraction method used, alternative substrates such as coir may yield differing results. Properties of peat and coir have been compared (Evans et al., 1996; Handreck, 1993; Meerow, 1995); however, the impact of different extraction methods on the resulting solution has not.

Protocol for the SME method suggests using 400 mL of substrate per sample (Warncke, 1986). This would require  $\approx 70$  plugs from a 288-cell tray. A smaller sample would reduce the grower's losses associated with testing.

The objectives of this study were to: 1) compare SME and 1:2 methods with PE for use in the analysis of a greenhouse substrate; 2) examine the relationships between these methods if a different substrate component (coir) were used; and 3) determine if sample size (number of plugs per analysis) affected the results.

## Materials and Methods

### Comparisons among extraction methods—peat-based substrate (Expt. 1)

Plug flats (288 cells, 5.7 mL/cell) were filled with commercial peat-based germination mix containing dolomitic limestone and a preplant nutrient charge (4-P; Fafard, Anderson, S.C.). The flats were placed in watertight trays on a greenhouse bench and fertilizer (20N–4.3P–16.6K; Peter's Peat-Lite Special, Scotts, Marysville, Ohio) was applied via subirrigation at four concentrations (50, 100, 150, and 200  $\text{mg}\cdot\text{L}^{-1}$  N). Flats were removed from trays after 30 min. After 24 h, flats were again subirrigated with the fertilizer treatments (1 h prior to testing), removed from trays, and allowed to drain.

There were five replications (plug flat = experimental unit) for each fertilizer rate. Samples for the three substrate solution extraction methods (SME, 1:2, and PE) were collected from each flat. The extract was analyzed for pH and EC (EXTECH 695 pH/

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Conductivity Meter, Waltham, Mass.) using the following protocol for each method. To inhibit further nitrification of  $\text{NH}_4^+\text{-N}$  present in the solution, 3.0 N HCl was added to each sample to lower pH to  $\approx 3.0$ . The extract was tested for  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^-\text{-N}$  (Lachat Quik Chem 8000; Zellweger Analytics, Milwaukee, Wis.), and P, K, Ca, and Mg (Plasma 2000; Perkin Elmer Corp., Norwalk, Conn.).

**SME.** Samples from 20 or 60 cells were chosen randomly and placed in a beaker. Deionized water was added while gently mixing until the sample was saturated to the point of "glistening," then allowed to equilibrate for 30 min (Warncke, 1986). The sample was transferred to a Büchner funnel lined with filter paper (Whatman #1), placed over a vacuum flask, and the solution removed under vacuum. The extract was then tested for pH and EC, and sent on for nutrient analysis.

**1:2.** Again, substrate from 20 or 60 plug cells was randomly removed from the flat and placed in a beaker. The plugs were gently stirred (broken up) to determine volume (around 110 mL for 20 plugs and 330 mL for 60 plugs), and deionized water was added at a rate of twice the substrate volume. The sample was stirred thoroughly and allowed to equilibrate for 30 min. The pH and EC electrodes were placed directly into the slurry. Nutrient analysis was not performed on 1:2 samples, as most commercial laboratories in the United States do not have interpretive standards for this method.

**PE.** Plug trays were held over a beaker, 20 or 60 cells were pressed to expel the solution, and pH and EC readings were taken on the unfiltered extract. Solution samples were later filtered as required for the nutrient analysis.

Data were analyzed as a split-plot. The plug tray treatments of different fertilizer rates, the main plot factor, were arranged in a randomized complete-block design (RCBD). Sample size and solution extraction methods were subplot factors. Data were subjected to analysis of variance (ANOVA) using the general linear model procedure (SAS Institute, Cary, N.C.). When analysis showed a significant main effect or interaction, Fisher's protected LSD was used to compare the means of the qualitative factors (extraction method and sample size). Means of the quantitative factor, fertilizer rate, were subjected to trend analysis.

### Comparisons among extraction methods—coir- vs. peat-based substrates (Expt. 2)

Plug trays (288 cells, 5.7 mL/cell) were cut into sections of 72 cells and filled with 3 sphagnum peat : 1 perlite (v/v) or 3 coir : 1 perlite (v/v). No lime or nutrient amendments were added. Four fertilizer treatments of 0 (water), 100, 200, and 300  $\text{mg}\cdot\text{L}^{-1}$  N from 15N-2.15P-12.45K-5Ca-2Mg (Miracle Gro Excel Cal-Mag®; Scotts) were randomly assigned within each block. Increments between fertilizer rates were increased relative to Expt. 1, to ensure that changes in EC and nutrient content could be detected. Trays were subirrigated with appropriate fertilizer treat-

ments until the substrate was saturated, drained to container capacity, and equilibrated for 1 h before testing. The treatments were arranged in a factorial design of 2 (substrates)  $\times$  4 (N rates) in a RCBD with five replications on greenhouse benches.

The three previously described solution extraction methods were used on each plug tray with 20 plugs removed for SME and 1:2 and 20 plugs pressed for PE. The solution pH and EC were recorded for all three methods and the SME- and PE-extracted solution analyzed for  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^-\text{-N}$ , P, K, Ca, Mg, and Na content as previously described. ANOVA for pH, EC, and nutrient concentration were performed according to the split-plot experimental design with combinations of substrate by fertilizer rate as whole-plot factors and solution extraction method as the subplot factor. When model analysis showed a significant main effect or interaction, substrate and method means were compared using Fisher's protected LSD, and rate means were subjected to trend analysis.

## Results and Discussion

### Comparisons among extraction methods—peat-based substrate (Expt. 1)

**pH and EC.** Extraction method significantly affected pH (Tables 1 and 2). Although pH values obtained by the three methods differed statistically, the difference between SME and PE methods was only 0.1 pH unit. Differences in pH among fertilizer rates or between sample sizes, and interactions among treatments were all insignificant (Table 1). The fertilizer used in this experiment did not contain Ca or a significant amount of Mg; this, coupled with the relatively narrow range of fertilizer concentrations, may account for the lack of a rate effect on pH.

Extraction method had a much greater effect on EC, accounting for 86% of the total treatment mean squares (MS) (Table 1). Increasing fertilizer rates increased EC for SME and PE but not for the 1:2 method, a probable reason for the significant rate  $\times$  method interaction (Table 1). The substantial dilution inherent in the 1:2 method resulted in the highest

Table 1. Mean square from analysis of variance for comparison of pH and electrical conductivity (EC) among press extraction (PE), saturated media extraction (SME), and 1:2 method [1 substrate : 2 water (v/v)] (Expt. 1) (df = degrees of freedom).

Source	df	Mean Square	
		pH	EC
Rep	4	0.04 <sup>ns</sup>	0.39 <sup>***</sup>
Rate (R)	3	0.17 <sup>ns</sup>	1.14 <sup>*</sup>
Error A	9	0.32	0.32
Sample Size (SS)	1	0.01 <sup>ns</sup>	0.27 <sup>*</sup>
Method (M)	2	0.78 <sup>***</sup>	15.30 <sup>***</sup>
SS $\times$ R	3	0.01 <sup>ns</sup>	0.01 <sup>ns</sup>
R $\times$ M	6	0.01 <sup>ns</sup>	0.24 <sup>***</sup>
SS $\times$ M	2	0.01 <sup>ns</sup>	0.03 <sup>ns</sup>
SS $\times$ R $\times$ M	6	0.01 <sup>ns</sup>	0.01 <sup>ns</sup>
Error B	60	0.30	0.05
Total		1.66	17.74

<sup>ns, \*</sup> Nonsignificant or significant at  $P \leq 0.05$  or 0.001, respectively.

pH and lowest EC (Table 2). This agrees with Warncke's (1990) observations when comparing the SME and 1:2 methods. Differences in EC between the PE and SME methods ranged from 0.3 to 0.6  $\text{dS}\cdot\text{m}^{-1}$ . Though these were significant, the variations are within acceptable EC interpretation values (0.75–1.99  $\text{dS}\cdot\text{m}^{-1}$ ) for plugs tested with the SME procedure (Fonteno et al., 1995). Again, there was a greater degree of dilution with SME as EC values were consistently lower than results obtained with PE.

**Nutrients.** Although statistically significant, the differences between SME and PE extraction methods for  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^-\text{-N}$ , and K are relatively small (Tables 3 and 4). Compared with SME, PE yielded somewhat higher levels of K and both N forms but twice the levels of Ca and Mg (Table 3). As the PE extract was not filtered until the time of nutrient analysis, further dissolution of lime particles present in the extract may have occurred. Warncke (1990), however, noted the greater difficulty of detecting available Ca and Mg than of available K with water extracts because of the divalent nature (thus tighter bonding) of these nutrients. Extraction method had the least impact on P, probably because of its lower solubility and therefore relatively weak response to dilution (Sonneveld, 1990). As expected,  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^-\text{-N}$ , P, and K increased with increasing fertilizer rate (Table 3). The only significant interaction among or between rate, sample size, or method of extraction was a negligible interaction between rate and method for  $\text{NH}_4^+\text{-N}$  (Table 4). Sample size, though significant for  $\text{NH}_4^+\text{-N}$ , P, and K, accounted for <1% of the total variation among treatments for these nutrients. Given the limited effect sample size has on nutrient concentration, 20 plugs are recommended for the PE method to limit destruction of plant material. Because of the significant replication effect for pH, EC, and several nutrients, taking samples from several flats is recommended to better measure existing spatial variation.

### Comparisons among extraction methods—coir- vs. peat-based substrates (Expt. 2)

**pH and EC.** Substrate, fertilizer rate, and extraction method affected pH (Table 5). In-

Table 2. Effect of extraction methods on pH (no rate effect) and electrical conductivity (EC) (by rate) for press extraction method (PE), saturated media extraction (SME), and 1:2 method [1 substrate : 2 water (v/v)] (Expt. 1).

pH	PE	SME	1:2
		5.7 c	5.8 b
Rate ( $\text{mg}\cdot\text{L}^{-1}$ N)	EC ( $\text{dS}\cdot\text{m}^{-1}$ )		
	50	1.7 a <sup>z</sup>	1.2 b
100	1.8 a	1.2 b	0.4 c
150	1.9 a	1.4 b	0.4 c
200	1.9 a	1.6 b	0.5 c
Significance	Q <sup>**</sup>	Q <sup>**</sup>	NS

<sup>z</sup> Means separation within rows by LSD at  $P \leq 0.05$  (n = 10).

<sup>ns, \*\*</sup> Nonsignificant or significant within column at  $P \leq 0.01$ ; Q = quadratic (n = 40).

Table 3. Effects of press extraction method (PE) vs. saturated media extraction (SME) and rate of N applied as macronutrient content of substrate (mg·L<sup>-1</sup>) (Expt. 1).

Rate (mg·L <sup>-1</sup> N)	NH <sub>4</sub> <sup>+</sup> -N		NO <sub>3</sub> <sup>-</sup> -N		P		K		Ca		Mg	
	SME	PE	SME	PE	SME	PE	SME	PE	SME	PE	SME	PE
50	25	37*	58	91*	24	31*	118	75*	51	121*	50	104*
100	30	36*	74	93*	32	35	137	176*	50	101*	50	91*
150	39	44*	96	113*	37	40	167	198*	56	122*	53	106*
200	44	51*	110	137*	48	50	194	228*	59	114*	56	100*
Significance	L***	L***	L***	L***	L***	L***	L***	L**	NS	NS	NS	NS

\*Mean significantly different from SME at same N rate at  $P \leq 0.05$  ( $n = 10$ ).

ns, \*\*, \*\*\*Nonsignificant or significant at  $P \leq 0.01$  or  $0.001$ ; no quadratic responses observed.

Table 4. Mean squares from analysis of variance for solution macronutrient content between press extraction (PE) and saturated media extraction (SME) (Expt. 1).

Source	df	NH <sub>4</sub> <sup>+</sup> -N	NO <sub>3</sub> <sup>-</sup> -N	P	K	Ca	Mg
Rep	3	304***	2796***	32.2 <sup>ns</sup>	6588***	3357***	3388***
Rate (R)	3	1145**	9690**	1641***	16,572*	567 <sup>ns</sup>	331 <sup>ns</sup>
Error A	9	162	1493	119	3297	1588	1391
Sample Size (SS)	1	80.6*	536 <sup>ns</sup>	64.4*	1757**	27.1 <sup>ns</sup>	282 <sup>ns</sup>
Method (M)	1	10,871***	11,724***	299***	32,361***	70,864***	45,530***
SS × R	3	4.1 <sup>ns</sup>	32.3 <sup>ns</sup>	6.9 <sup>ns</sup>	36.9 <sup>ns</sup>	177 <sup>ns</sup>	79 <sup>ns</sup>
R × M	3	56.1*	243 <sup>ns</sup>	21.2 <sup>ns</sup>	716 <sup>ns</sup>	501 <sup>ns</sup>	240 <sup>ns</sup>
SS × M	1	0.6 <sup>ns</sup>	2.5 <sup>ns</sup>	6.8 <sup>ns</sup>	86.1 <sup>ns</sup>	86 <sup>ns</sup>	0.1 <sup>ns</sup>
SS × R × M	3	10.4 <sup>ns</sup>	71.8 <sup>ns</sup>	15.2 <sup>ns</sup>	73.2 <sup>ns</sup>	150 <sup>ns</sup>	61.9 <sup>ns</sup>
Error B	60	15.6	135	15.7	364	192	182
Total MS		12,649	26,724	2221	61,851	77,509	51,485

ns, \*, \*\*, \*\*\*Nonsignificant or significant at  $P \leq 0.05$ ,  $0.01$ , or  $0.001$ , respectively.

creasing the increments between fertilizer rates (from 50 to 100 mg·L<sup>-1</sup> N) and use of a fertilizer supplying additional Ca and Mg resulted in changes in pH detectable by all three methods (Fig. 1). Again, though statistically significant, the difference between SME and PE for both substrates was only a 0.1 pH unit. The significant extraction method main effect for EC is due to the difference between the 1:2 and the other two methods. The EC values for PE and SME were not significantly different (Fig. 1). These results point to probable differences in levels of saturation between Expt. 1 and Expt. 2. Apparently less water was needed to reach the saturation point for the SME samples. There is no specific protocol other than the qualitative judgement of the tester as to the degree of saturation for the SME, although the quantity of water used can influence soluble salt concentration (Warncke, 1986).

The substrate main effect was significant for pH but not for EC. The pH of the coir substrate averaged about 1.0 unit higher than that of peat across rates and methods. Handreck (1994) and Meerow (1995) noted that coir has a higher pH than sphagnum peat moss, though Stamps and Evans (1997) found no difference between peat- or coir-based mixes when dolomitic lime was added.

Substrate had no effect on EC, though increased fertilizer rates elevated soluble salts as expected (Fig. 1). The relationships between pH and EC in PE and SME extracts were strong, with high  $r^2$  values for both peat and coir (Table 6). Development of interpretive standards for the PE could be aided if these relationships remain similar in future experiments.

**Nutrients.** Extraction method significantly affected all macronutrients except NH<sub>4</sub><sup>+</sup>-N and K (Table 7). However, method accounted for 2% or less of the variation for any nutrient, therefore nutrient means for individual extraction methods are not presented here. Substrate

Table 5. Mean squares from analysis of variance for comparison of extraction methods with two substrates and four fertilizer rates (Expt. 2).

Source	df	pH	EC
Rep	4	0.11***	0.06***
Substrate (S)	1	39.22***	0.01 <sup>ns</sup>
Rate (R)	3	1.91***	3.18***
S × R	3	0.10*	0.02 <sup>ns</sup>
Error A	28	0.03***	0.01
Method (M)	2	0.73***	3.96***
M × S	2	0.07**	0.01 <sup>ns</sup>
M × R	6	0.01 <sup>ns</sup>	0.30***
M × S × R	6	0.03***	0.03***
Error B	64	0.01	0.01
Total		42.22	7.58

ns, \*, \*\*, \*\*\*Nonsignificant or significant at  $P \leq 0.05$ ,  $0.01$ , or  $0.001$ , respectively.

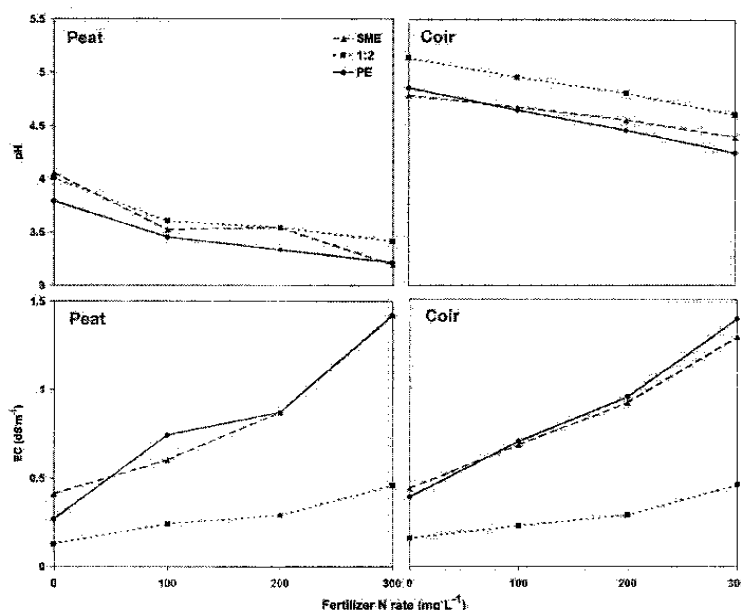


Fig. 1. Effects of N rate, substrate, and extraction method on substrate pH and EC (Expt. 2).

Table 6. Relationship between the press extraction method (PE) vs. saturated media extraction (SME) for pH and electrical conductivity (EC) values of peat- and coir-based substrates (Expt. 2).

	Substrate	Equation <sup>a</sup>	R <sup>2</sup>
pH	Peat	$y = -0.39x^2 + 3.5x - 4.02$	0.90
	Coir	$y = -1.58x - 2.71$	0.92
EC	Peat	$y = 0.87x + 0.13$	0.87
	Coir	$y = 1.14x - 0.09$	0.96

<sup>a</sup>For pH,  $y = \text{pH}$  for the PE method and  $x = \text{pH}$  for the SME method; for EC,  $y = \text{EC}$  for the PE method and  $x = \text{EC}$  for the SME method.

had a significant effect (Table 7). Across all N levels, the average level of NH<sub>4</sub><sup>+</sup>-N was 5.6 times greater in peat than in coir (Table 8). The peat solution was also higher in NO<sub>3</sub><sup>-</sup>-N, Ca, and Mg, but the coir extract contained higher levels of K and Na. Levels of K and Na in Coir vary with source (Konduru et al., 1999) and

are often relatively high when compared with those in sphagnum peat (Evans et al., 1996). Fertilizer rate had the greatest influence on extract concentrations of NO<sub>3</sub><sup>-</sup>-N, P, Ca, and Mg. The slope of PE across fertilizer rates for these elements differed from the slope of SME; however, significant interactions between fer-

Table 7. Mean squares from analysis of variance for macronutrient content of peat- vs. coir-based substrate (Expt. 2).

Source	df	NH <sub>4</sub> <sup>+</sup> -N	NO <sub>3</sub> <sup>-</sup> -N	P	K	Ca	Mg	Na
Rep	4	5.67	78.00	15.84**	239.30	19.36**	10.33**	26.42**
Substrate (S)	1	5,015.40***	714.27**	101.48***	22,470.90***	1,087.84***	705.47***	14,243.00***
Rate (R)	3	551.07***	42,018.71***	1608.08***	5,849.30***	1,753.51***	1,659.11***	8,420.40***
S × R	3	105.65***	143.63	10.18**	2,560.70***	276.78***	103.34***	188.82***
Error A	28	3.18	64.43	2.06	92.65	4.56	3.34	6.07
Method (M)	1	20.62	1,100.02**	16.15**	344.15	139.42***	41.83***	504.43***
M × S	1	34.37*	241.84	1.89	3,012.15***	27.06*	9.01	93.87**
M × R	3	3.09	412.3**	20.31***	447.98**	126.56***	11.42*	15.21
M × S × R	3	2.41	15.97	1.01	293.08	5.72	6.06	1.27
Error B	31	5.13	87.30	1.79	89.24	173.72	2.55	10.04
Total		5,746.59	44,876.47	1,778.80	35,399.45	3,608.59	2,552.46	23,509.53

\*, \*\*, \*\*\*Significant at  $P \leq 0.05$ , 0.01, or 0.001, respectively.

Table 8. Effects of substrate and rate of N application on nutrient content (mg L<sup>-1</sup>) of substrate (Expt. 2) [peat (P), coir (C)].

N rate (mg L <sup>-1</sup> N)	NH <sub>4</sub> <sup>+</sup> -N		NO <sub>3</sub> <sup>-</sup> -N		P		K		Ca		Mg		Na	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C
0	11*	2	5*	4	5*	4	9*	88	6	6	4	4	19*	40
100	18*	3	29*	27	11*	9	33*	136	10	7	10*	5	24*	50
200	24*	4	71*	58	18*	15	63*	174	18*	9	18*	9	27*	54
300	29*	9	115*	107	27*	24	111*	245	36*	18	30*	19	28*	64
	L***	Q***	Q*	Q***	Q*	Q**	Q**	Q*	Q***	Q***	Q***	Q***	Q*	L*

\*Significantly different from corresponding value for coir,  $P \leq 0.05$ .

\*, \*\*, \*\*\*Significant at  $P \leq 0.05$ , 0.01, or 0.001, respectively; L = linear, Q = quadratic.

tilizer rate and extraction method main effects were small (<1% of total MS) (Table 7).

Strong correlations between the PE and SME in Expt. 2 suggest that existing SME standards could be used to interpret nutrient analysis results for a PE extract. The PE method is a practical and logical alternative to current testing methods; however, standards for its use must be generated. The PE is a low-dilution extraction method, similar to the pour-through (PT) method. Results from this study parallel those found by researchers comparing PT with SME and other substrate: water slurries. Wright et al. (1990) found that the PT extract higher in EC and tested nutrients, but the pH was quite similar to that for SME in potted poinsettia (*Euphorbia pulcherrima* Willd. Ex Klotzsch.) production. Yeager et al. (1983) noted similar results when testing a pine bark substrate. Though the PT may not be feasible for plug testing, research results are analogous to the PE. Future work can yield greenhouse pH and EC standards adaptable to both methods. However, current standards for seedlings exist only for the SME and 1:2 methods. Understanding the relationships among these methods is an important step in the development and implementation of the PE for plug production.

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