HortScience 24(2):292–295. 1989.

Predicting Physical and Chemical Properties of Container Mixtures

J.R. Jenkins
Soil and Environmental Sciences, University of California, Riverside, CA 92521

W.M. Jarrell
Environmental Sciences and Engineering, Oregon Graduate Center, Beaverton, OR 97006-1999

Additional index words. bulk density, air-filled porosity, container capacity, available water, saturated hydraulic conductivity, pH, cation exchange capacity, sandy loam, sand, bark, perlite

Abstract. **This paper describes a system for predicting container mixture physical and chemical properties from component properties. An additive model is presented that assumes that a mixture property is the weighted sum of the properties contributed by the individual components. To test this hypothesis, 24 combinations of sandy loam soil (Typic Xerothent), sand (Typic Xeropsamment), bark, and perlite were tested for bulk density, total and air-filled porosities, container capacity, available water, saturated hydraulic conductivity, pH, and cation exchange capacity. The measured experimental data were compared with values predicted from the additive model. Measured and predicted values were in good agreement for most properties, except saturated hydraulic conductivity and air-filled porosity for mixtures with low total porosity. Application of the same approach also worked well for previously published data.**

Soil, usually high in sand, is often one of the basic components in container media for many outdoor nursery growers and research institutions. It is often amended with organic and mineral materials to improve physical and chemical characteristics to meet the demanding requirements of container-grown plants. Important physical properties include bulk density, total and air-filled porosities, water retention, and saturated hydraulic conductivity (K_{sat}). Critical chemical properties are pH and cation exchange capacity (CEC).

Though these properties are considered important and practical for routine testing, there have been few attempts to determine the mathematical relationship between properties of a mixture and those of its components (1, 13, 14). There is a need for an accurate method to create the ideal mixture for a container grower's particular situation and components at hand. In answer to this need, a straightforward mathematical model was formulated to predict potting mix properties.

$$\text{Mixture property} = \sum_{i=1}^{n} (\text{component volume ratio}_i)(\text{component property}_i)$$

where n = number of observations and i = observation index.

Pokorny et al. (13) successfully applied this approach to predict one mix property, but they also included an empirical term for shrinkage. The ideal container mixture has properties that most closely match the needs of the crop at the least cost. Our model may allow container mix producers and users to custom-formulate suitable mixes more cheaply and with less trial and error than previously possible. Reliable and accurate prediction of container mix properties would be a significant contribution to mix formulation (14).

This study was undertaken to test the hypothesis that each component in a mixture proportionally adds its own property to that of the mixture; e.g., mixture characteristics are linear resultants of the weighted sum of component properties. Previously published data, as well as original data, were used to test the model hypothesis.

Components used in this study were: Delhi fine sand (Typic Xeropsamment), Hanford sandy loam [Typic Xerothent, 72.2 sand : 21 silt : 6.8 clay (by volume)], white fir bark hammermilled through a 6.35-mm screen (98.6% organic matter, 0.22% total N), and medium-grade perlite, Hortiperl No. 4 (Redco, Inc., N. Hollywood, Calif.). Component combinations (Table 1), moistened with a fine mist of deionized water, were blended for 3 min in an electric soil mixer and stored in plastic bags.

Container capacity. Each component or mixture was added to a 3.8-liter plastic pot. One-ply cheesecloth covered the inside of the four slotted drainage openings in each pot to prevent loss of medium. Treatments were replicated three times. The 72 pots were placed inside a greenhouse and arranged in a completely randomized block design. Since potting mixture characteristics can change rapidly during the first few weeks after potting, containers were irrigated with tap water every other day to induce natural settling. Irrigation was by means of a water breaker held about 50 cm above the pots. Additional medium was added after each watering as needed to maintain the medium depth at 14 cm. After 30 days, the containers were thoroughly irrigated, covered, and allowed to drain freely for 2 hr. Differences in wet and oven-dry (subsamples dried at 105C for 24 hr) weights gave the weight of water retained by each medium at container capacity. Volume percentage moisture retention was then calculated from the weight of water per unit of dry medium and the appropriate bulk density (BD) (17).

Bulk density. Bulk density was determined in duplicate by oven-drying a known volume of sample taken before irrigation. In addition, BD was determined on a core sample of known volume taken from each pot in the container capacity experiment.

Total and air-filled porosities. The standard particle and BD method (16) was used for total porosity measurement. Air-filled porosity was calculated as the difference between total porosity and container capacity.

Saturated hydraulic conductivity. K_{sat} of water-settled samples was determined by the constant-head method (8).

pH. The normal saturated paste method was used, with two replicates per medium (15).

Cation exchange capacity. A modified sodium acetate method was used (4). Medium (20 cm³) was mixed with 125 ml of 1 N sodium acetate (pH 8.2) and allowed to equilibrate overnight. The medium was washed with five 40-ml increments of sodium acetate. Excess sodium was removed with five 40-ml ethanol washings. Exchangeable sodium was displaced with 40-ml increments

Table 1. Component ratios for 24 soil mixtures.

Mix no.	Volume ratios
	Soil–bark–perlite
1	10–0–0
2	8–2–0
3	8–0–2
4	8–1–1
5	6–4–0
6	6–0–4
7	6–2–2
8	4–6–0
9	4–0–6
10	4–3–3
11	2–8–0
12	2–0–8
13	2–4–4
	Sand–bark
14	10–0
15	8–2
16	6–4
17	4–6
18	2–8
19	0–10
	Bark–perlite
20	8–2
21	6–4
22	4–6
23	2–8
24	0–10

Received for publication 21 Mar. 1988. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Table 2. Mean and SD of component bulk density, porosity, container capacity, available water, saturated hydraulic conductivity (K_{sat}), pH, and cation exchange capacity.

Component	Bulk density ($t \cdot m^{-3}$)		Porosity (vol. %)		Container capacity (vol %)	Available water (vol %)	K_{sat} ($cm \cdot hr^{-1}$)	pH	Cation exchange capacity [cmol(+)/m^3]
	Pre-irrigation	Post-irrigation	Total	Air-filled					
Sandy loam	1.56 ± 0.02	1.66 ± 0.01	0.384 ± 0.005	0.15 ± 0.017	0.370 ± 0.016	0.316 ± 0.018	3.2 ± 0.5	7.33 ± 0.00	9.81 ± 0.07
Sand	1.62 ± 0.04	1.64 ± 0.05	0.386 ± 0.018	0.100 ± 0.020	0.286 ± 0.012	0.258 ± 0.012	28.5 ± 2.9	7.36 ± 0.01	5.29 ± 0.06
Bark	0.23 ± 0.01	0.19 ± 0.003	0.806 ± 0.003	0.392 ± 0.029	0.414 ± 0.031	0.281 ± 0.026	643.9 ± 48.4	3.94 ± 0.01	10.58 ± 0.12
Perlite	0.17 ± 0.01	0.17 ± 0.01	0.910 ± 0.006	0.461 ± 0.030	0.449 ± 0.028	0.390 ± 0.041	4330.4 ± 378.1	6.76 ± 0.01	2.64 ± 0.22

Table 3. Multiple regression equations showing the relationship between measured properties (y) and component variables, linear regression analysis of agreement between model predicted (y) and actual(x) property values, and comparative indices for model evaluation.

Property	Mixture[z]	Multiple	Linear	R^2[y]	r^2[x]	P/M[w]	D[v]
Pre-irrigation bulk density ($mg \cdot m^{-3}$)	sl–b–p	$y = 0.62 + 0.65sl - 2.14b - 2.98p$	$y = 0.12 + 0.86x$	0.961**	0.961**	0.99	7.9
	s–b	$y = 1.14 + 0.12s - 3.36b$	$y = 0.23 + 1.38x$	0.954**	0.954**	0.96	9.7
	b–p	$y = 0.20 + 0.14b - 0.41p$	$y = 0.09 + 0.58x$	0.914**	0.717**	0.97	10.4
Postirrigation	sl–b–p	$y = 0.39 + 0.79\ sl - 1.85b - 0.63p$	$y = 0.09 + 0.89x$	0.956**	0.928**	1.00	9.4
	s–b	$y = 1.54 + 0.08s - 6.72b$	$y = 0.02 + 0.98x$	0.990**	0.985**	1.10	5.2
	b–p	$y = 0.001 + 1.03b + 0.85p$	$y = 0.11 + 0.37x$	0.644**	0.543**	1.07	7.8
Total porosity (vol. %)	sl–b–p	$y = 37 + 1.84sl + 1.40b + 1.32p$	$y = 8.75 + 0.93x$	0.894**	0.897**	1.09	9.3
	s–b	$y = 5.3 + 0.78s + 0.69b$	$y = 11.40 + 1.00x$	0.522*	0.569**	1.24	23.4
	b–p	$y = 45.9 + 0.04b - 0.31p$	$y = 76.14 + 0.09x$	0.648**	0.000	0.99	1.2
Air-filled porosity (vol. %)	sl–b–p	$y = 6.09 + 0.42sl + 0.81b + 0.92p$	$y = 12.20 + 0.78x$	0.682*	0.689**	1.85	117.2
	s–b	$y = 16.8 + 0.04s - 0.51b$	$y = 32.20 - 0.87x$	0.606**	0.618**	2.06	956.2
	b–p	$y = 50.8 - 0.46b + 0.21p$	$y = 33.30 + 0.20x$	0.810**	0.205	0.88	11.4
Container capacity (vol. %)	sl–b–p	$y = 41.2 + 0.04sl + 0.20b + 0.10p$	$y = 37.37 + 0.06x$	0.011	0.000	0.87	13.1
	s–b	$y = 94.0 - 3.02s - 0.61b$	$y = 22.20 + 0.27x$	0.806**	0.907**	0.77	20.8
	b–p	$y = 45.9 + 0.04b - 0.31p$	$y = 50.90 - 0.19x$	0.649**	0.032	1.08	12.1
Available water (vol. %)	sl–b–p	$y = 39.6 - 0.17sl + 0.05b + 0.22p$	$y = 24.79 + 0.18x$	0.278	0.041	0.83	18.1
	s–b	$y = 70.6 - 1.92s - 0.57b$	$y = 0.04 + 1.13x$	0.863**	0.865**	0.71	26.6
	b–p	$y = 35.9 - 0.02b - 0.13p$	$y = 47.80 - 0.43x$	0.000	0.020	1.01	11.6
K_{sat} ($cm \cdot hr^{-1}$)	sl–b–p	$y = 46 - 30.5sl + 0.43b - 0.12p$	$y = 732 + 4.50x$	0.632**	0.428**	12.31	6767.7
	s–b	$y = 109 - 6.5s + 0.31b$	$y = 191 + 1.28x$	0.760**	0.771**	2.96	333.5
	b–p	$y = 680 - 260b + 0.18p$	$y = -717 + 3.23x$	0.806**	0.811**	2.50	144.4
pH	sl–b–p	$y = 0.97 + 0.90\ sl + 1.07b + 0.98p$	$y = -2.09 + 1.21x$	0.944*	0.932**	0.92	8.7
	s–b	$y = 6.24 - 0.68s$	$y = 0.09 + 1.13x$	0.863**	0.882**	1.15	15.2
	b–p	$y = 3.38 + 0.44p$	$y = 1.19 + 0.86x$	0.883**	0.882**	1.10	10.5
CEC [mol(+)/m^3 × 10]	sl–b–p	$y = 3.51 + 0.55sl + 0.92b - 0.37p$	$y = 2.61 + 0.67x$	0.856**	0.793**	0.98	12.4
	s–b	$y = 8.7 - 1.06s + 0.34b$	$y = -1.12 + 0.93x$	0.906**	0.914**	0.80	20.6
	b–p	$y = 2.17 + 0.87b + 0.18p$	$y = 0.86 + 0.82x$	0.874**	0.884**	0.95	8.2

[z] Sandy loam–bark–perlite (sl–b–p), sand–bark (s–b), and bark–perlite (b–p) mixtures.
[y] Coefficient of multiple determination, adjusted for degrees of freedom.
[x] Linear correlation coefficient, adjusted for degrees of freedom.
[w] Ratio of the total average predicted to the total average measured values.
[v] Average percent difference between individual predicted and measured values.
*,**Significant at the 5% and 1% levels, respectively.

of 1 N ammonium acetate (pH 7.0) and diluted with deionized water to 250 ml. Three determinations were made for each medium and the results expressed on a volume basis.

Available water. Media were added to 3.8-liter pots as described in the container capacity methods. Pots were placed inside a greenhouse and seeded with sunflower (*Helianthus annuus*). After establishment, all but one plant was removed from each pot. Plants were periodically fertilized with one-half strength Hoagland's solution. Permanent wilting point for each medium was determined in triplicate (12). After the sunflower roots extended to the pot bottom, each pot was thoroughly irrigated, allowed to drain, and enclosed in a plastic bag to minimize evaporative water loss. When the sunflowers failed to recover from wilting overnight, the shoots were removed at the soil line and the pots weighed. Available water was calculated as the difference between container capacity and permanent wilting point.

Statistical analysis. Multiple regression was used to determine the relationship between the measured properties and the following variables: X_1 = (volume ratio of sandy loam)(sandy loam property), X_2 = (volume ratio of sand)(sand property), X_3 = (volume ratio of fir bark)(fir bark property), X_4 = (volume ratio of perlite)(perlite property). Linear regression analysis was used to determine the relationship between the measured and model predicted data. Two types of indices were used. The ratio of the average predicted over the average measured data (P/M) indicated whether the model results were on average too high or low. The average percent difference between individual observations (D) was also calculated (9).

Means and SDs of the basic physical and chemical properties of the components alone are presented in Table 2.

Comparison of predicted and measured values for current experiment. The two approaches to predicting mixture characteristics frequently produced similar values when relating predicted and measured values (Table 3).

Physical properties. There was good agreement between predicted and measured

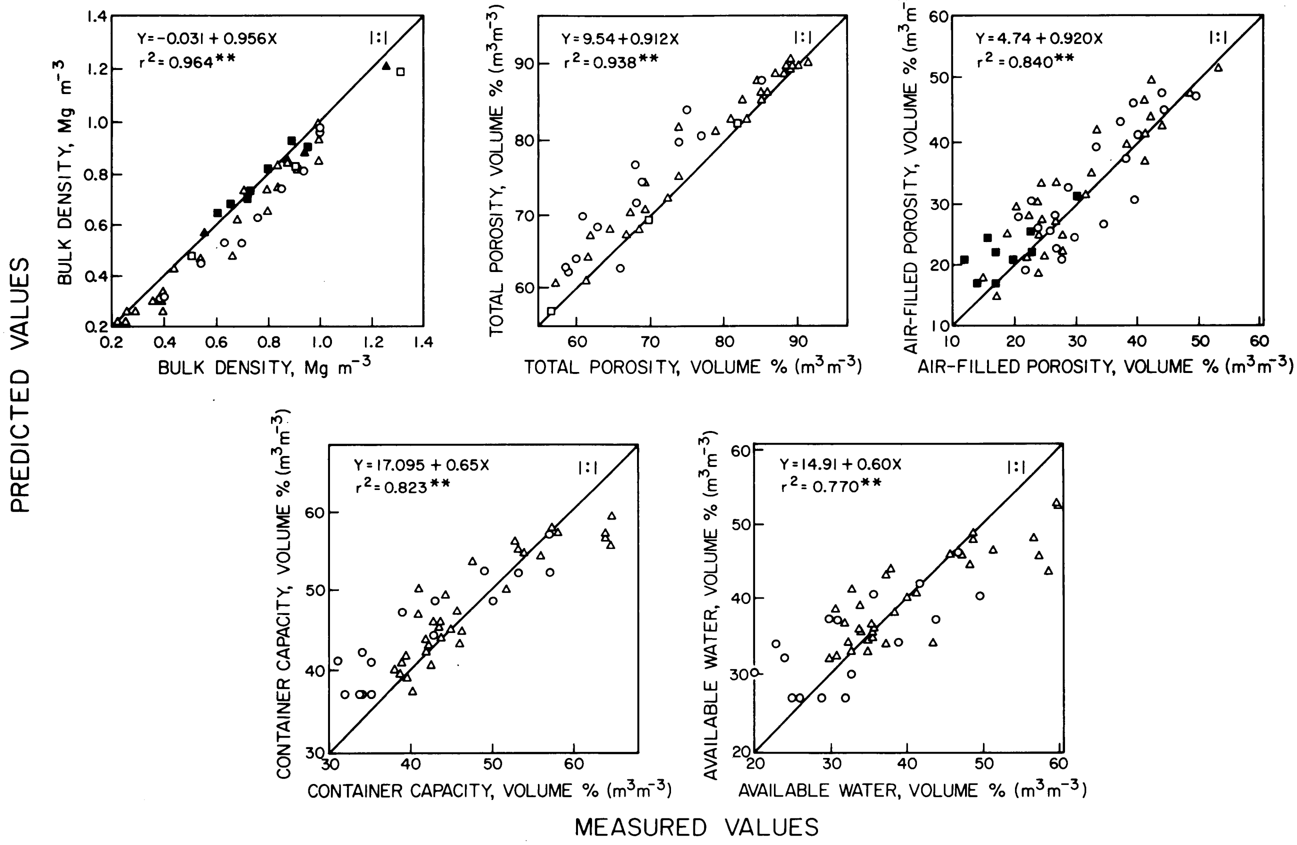

Fig. 1. Mixture properties calculated from the additive model plotted against published measured values. Symbols and references: ■ (1); ▲ (3); □ (7); ▲ (3); △ (17).

values, as indicated by mixture group P/M and D indices for BD, total porosity, container capacity and available water (Table 3). Air-filled porosity for the sandy loam and sand mixtures and K_{sat} were greatly over-predicted by the model. Air-filled porosity for the sandy loam mixtures is related positively to the bark and perlite components. The negative correlation between air-filled porosity for the sand mixtures and the fir bark component suggest that fir bark addition increased water retention of the medium at the expense of aeration. Mixture K_{sat} was negatively influenced to a great degree by the fine-textured components, sandy loam, and sand. Low regression coefficients for bark–perlite total and air-filled porosities and most of the container capacity and available water relationships seem to be due to narrow value ranges.

Chemical properties. Both pH and CEC have highly significant regression coefficients for all the mixture groups. The P/M ratios are close to unity, though the model slightly over-predicted pH and under-predicted CEC. Values predicted by the model deviated relatively little from the measured values.

Comparison of predicted and measured values for previously published research. To determine if the model were valid for published data (1, 3, 7, 11, 17), additive model predicted values were plotted against measured values (Fig. 1) and evaluated using the comparative indices. A diverse array of components had been used in the published studies, including clay loams, sands, perlite, sawdust, and peatmosses.

Physical properties. The model tended to slightly under-predict BD (Table 3), with relatively little deviation from the measured values (D = 10.3%). Averages of the predicted and measured values were close (P/M = 1.04). The average predicted total porosity was within 4.6% of average measured total porosity. No significant interaction between components was found. The P/M ratio for air-filled porosity from the data gathered in this experiment was substantially greater (1.56) than the previously published research (1.03). To determine how aeration

Table 4. Optimum ranges for container mixture properties.

Property	Units	Optimum range	Factors affecting optimum range in addition to plant type	Ref.
Bulk density	$t \cdot m^{-3}$	0.15–1.3	Texture, compaction, structure	5
Total porosity	vol. %	60–75		2
Air-filled porosity	vol. %	10–20	Depth, texture, structure	2
Container capacity	vol. %	50–65	Depth, texture, structure	2
Available water	vol. %	>30	Depth, texture, structure	2
Saturated hydraulic conductivity	$cm \cdot hr^{-1}$	>5	Texture, compaction, structure	6
pH	pH	5.0–6.0	Organic matter content	10
Cation exchange capacity	[mol(+)/m³ × 10]	>10		6

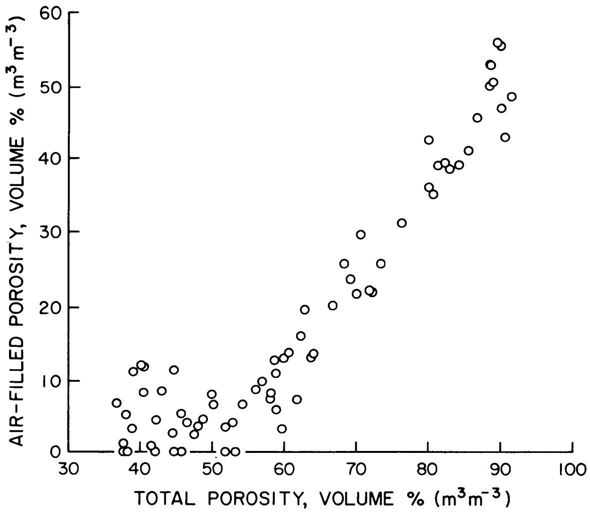

Fig. 2. The relationship between air-filled porosity and total porosity from the experimental data derived in this study.

is related to total porosity, air-filled porosity was plotted against total porosity (Fig. 2). A scatter diagram of the data indicated that much of the deviation from linearity is associated with media total porosities below 57% by volume. This coincides with the lowest mixture total porosity reported in three published studies (1, 11, 17). Also, the minimum recommended total porosity is near this value (2). Ignoring experimental air-filled porosity values of mixtures below 57% total porosity reduced the overall P/M ratio from 1.56 to 1.24.

Container capacity and literature data on available water, illustrate a significant linear correlation between predicted and measured properties (Fig. 1). Output of the model comparison with measured data was P/M = 1.03 and D = 8.0% for container capacity and P/M = 0.99 and D = 11.0% for available water. These results are consistent with the experimental data indicating a tendency for slight under-prediction of available water and increased deviation as compared to the container capacity prediction.

Unfortunately, insufficient literature data were found to effectively evaluate model predictions of saturated hydraulic conductivity, pH, and cation exchange capacity. Though researchers often determine these properties for mixtures, the values of the property for individual components are often not reported.

The results of this study indicate that the additive model hypothesis is valid for several important physical and chemical properties of container mixtures. Component interaction was not significant in most cases, even though a wide range of typical components were analyzed. Model prediction was unsatisfactory for saturated hydraulic conductivity and air-filled porosity for mixtures with total porosity below 57%. For prediction of these properties, the appropriate multiple regression equation could be used if the mixture components are of similar type.

The two approaches for prediction of bulk density, the additive model and equation proposed by Pokorny et al. (13), gave similar, good results, despite the absence of a shrinkage factor in the additive model and differences in test media.

In conjunction with component cost information, the model could serve as a useful tool in formulation of cost-effective mixtures with as many desirable properties as possible (Table 4). This could be accomplished using a computer simulation program, designed to find mixture combinations with desirable characteristics according to the additive model formula.

Further work is needed to better characterize the properties of commonly used components for different container sizes. This published information would further enhance the use of the proposed model for container growers, since less costly and time-consuming component testing would be necessary.

Literature Cited

1. Beardsell, D.V., D.G. Nichols, and D.L. Jones. 1979. Physical properties of nursery potting mixtures. Scientia Hort. 11:1–8.
2. Bowman, D.C. and J.L. Paul. 1983. Understanding of container media vital knowledge for growing successful plants. Pacific Coast Nurseryman and Garden Supply Dealer. Mar. p. 48–50.
3. Brown, E.F. and F.A. Pokorny. 1975. Physical and chemical properties of milled pine bark and sand. J. Amer. Soc. Hort. Sci. 100(2):119–121.
4. Chapman, H.D. and P.F. Pratt. 1961. Methods of analysis for soils, plants, and water. Univ. of Calif. Press, Riverside.
5. Conover, C.A. 1967. Soil mixes for ornamental plants. Fla. Flower Grower 4(4):1–4.
6. Furuta, T. 1974. Environmental plant production and marketing. Cox, Arcadia, Calif.
7. Juncker, P.H. and J.J. Madison. 1967. Soil moisture characteristics of sand–peat mixes. Soil Sci. Soc. Amer. Proc. 31:5–8.
8. Klute, A. 1965. Laboratory measurement of hydraulic conductivity of saturated soil, p. 210–220. In: C.A. Black (ed.). Methods of soil analysis. Part 1. Agronomy 9, Amer. Soc. of Agron., Madison, WI.
9. Letey, J., A. Dinar, and K.C. Knapp. 1985. Crop-water production function model for saline irrigation waters. Soil Sci. Soc. Amer. J. 49:1005–1009.
10. Lucas, R.E. and J.K. Davis. 1961. Relationship between pH values of organic soils and availabilities of 12 plant nutrients. Soil Sci. 92:177–182.
11. Nelson, G.C. 1976. Physical properties of greenhouse container media. MS Thesis, Colorado State Univ., Fort Collins.
12. Peters, D.B. 1965. Water availability, p. 279–285. In: C.A. Black (ed.). Methods of soil analysis. Part 1. Agronomy 9, Amer. Soc. of Agron., Madison, WI.
13. Pokorny, F.A., P.G. Gibson, and M.G. Dunavent. 1986. Prediction of bulk density of pine bark and/or sand potting media from laboratory analyses of individual components. J. Amer. Soc. Hort. Sci. 111(1):8–11.
14. Spomer, L.A. 1974. Optimizing container soil amendment: the "threshold proportion" and prediction of porosity. HortScience 9:532–533.
15. U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Government Printing Office, Washington, D.C. USDA Agr. Hdbk. 60.
16. Vomocil, J.A. 1965. Porosity, p. 299–314. In: C.A. Black (ed.). Methods of soil analysis. Part 1. Agronomy 9, Amer. Soc. of Agron., Madison, WI.
17. White, J.W. and J.W. Mastalerz. 1966. Soil moisture as related to container capacity. Proc. Amer. Soc. Hort Sci. 89:758–765.