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Physical and Chemical Properties of Coal Cinders as a Container Media Component

J.C. Neal[1] and D.F. Wagner[2]
Department of Horticulture, Clemson University, Clemson, SC 29631

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Abstract. **Selected physical and chemical properties of pine bark, 2 sources of coal cinders, and mixtures thereof, were evaluated as container media components. Bulk density, air-filled pore space, particle-size distribution, cation exchange capacity, and soluble salt levels were quantified. Aged and freshly combusted cinders demonstrated no major physical or chemical disadvantages when used in container media. Acid and water extracts indicated that both sources of coal cinders released significant amounts of micronutrients and heavy metals. The concentrations of certain metals were sufficiently high to warrant concern over the possibility of plant nutritional disorders; whereas, other released elements resembled those of a supplemental micronutrient fertilizer.**

Pine bark has become a popular organic growing medium. Sand and other inorganic aggregates commonly mixed with pine bark provide mass and improved moisture retention characteristics, but result in heavy mixes which are difficult to handle and costly to ship. Coal cinders, often locally available at competitive prices, is a sterile inorganic material lighter in weight than sand, which appears to be suitable for use as a container media amendment. Coal cinders is defined as ash remaining following coal combustion, and is referred to as "bottom ash" by the Duke Power Company, Charlotte, N.C. The increased usage of coal as a fossil fuel (11) will ensure future availability of this material.

There have been numerous attempts to characterize "ideal" potting media. Many of these efforts have focused on physical and chemical properties of potting media because of their enormous impact on plant quality. Joiner and Conover (7) described ranges for bulk density (BD), percentage of organic matter (% OM), and cation exchange capacity (CEC). DeBoodt and Verdonck (5) concentrated their efforts on pore space and available water, while Spomer (10) utilized porosity and air-filled pore space to characterize container media. These data have been used to define acceptable media characteristics and have promoted the identification of potential problems associated with various materials. Our objective was to evaluate important physical and chemical characteristics of coal cinders, from 2 chronologically different origins, and plant growing media containing these cinders.

The media components utilized were a hammer milled pine bark and coal cinders of 2 distinct ages: 1) aged cinders, a material burned about 40 years ago; and 2) fresh cinders, one derived from recent combustion. Pine bark was used exclusively as a control and mixed with each of the cinders to create media containing ⅓, ½, and ⅔ cinders by volume (Table 1). A bark + sand medium (1:1 v/v) was included for comparison.

The BD and particle distribution of each substrate were determined according to the procedures of Brown and Pokorny (2). Ten 100-ml replicates were used for BD determinations and four 50-ml replicates were used for sieve analysis. Air-filled pore space was calculated using Buscher and Van Doren's equation (4):

$$\% \text{ air-filled pore space} = (W_1 - W_2)/(W_4 - W_3) \times 100$$

where W_1 = weight of saturated medium + pot; W_2 = weight of medium + pot, following 24 hr drainage; W_3 = weight of empty pot; and W_4 = weight of pot + volume of H_2O, equal to the volume of medium. The CEC of each medium and its components was determined by a modified ammonium acetate method (1). Ten-g replicates of media were used instead of the recommended 25-g replicates because of low bulk densities. We used 10% KCL instead of 10% NaCl to displace the absorbed NH_4^+ from the NH_4^+ saturated media. Eighteen acid extractable and water-soluble elemental components were compared by plasma emission spectroscopy as described by Jones (8). Soluble salt levels, NH_4^+–N and NO_3^-–N, were also determined with aqueous media extracts, as described by Jones (9). Buffer curves were established by adding 0, 1, 2, 3, 4, and 5 g/liter of $Ca(OH)_2$ to 500-ml aliquots of each medium. Three media replicates were moistened and allowed to equilibrate for 48 hr prior to extraction and pH determination.

Bulk density. Media BD increased with each increase in the percentage of cinders (Table 1). The BD values, however, were within the range of acceptable values (0.35 g/cm³ to 1.3 g/cm³) recommended for container media by Bunt, Furuta, and Joiner (3, 6, 7). All media containing coal cinders possessed lower BD values than the bark + sand mixture.

Particle distribution. Particle distributions for each component indicated that more than 55% (by weight) of fresh cinders passed through a 420-μm mesh screen (Table 1). BD increased as the amount of fine particles accumulated. Aged cinders contained fewer fine particles (42%) than fresh cinders (55%), but more than pine bark (23%).

Cation exchange capacity. CEC values for cinder media (Table 2) were within the 10 to 30 meq/100 g range recommended for container media by Furuta (6). Volumetric values for all media were greater than or within the range of 5 to 13 meq/100 cm³, determined to be acceptable for pine bark + sand media (2). CEC of aged cinders was higher than that of the fresh cinders (10.25 vs. 1.85 meq/100 cm³). A similar difference was observed with the bark + cinders mixes. Whether the CEC of the cinders was due to a true ion exchange capacity or was a result of its moisture-holding characteristics, as has been speculated for pine bark (F.A. Pokorny, personal communication), is not certain.

Air-filled pore space. The air-filled pore space did not vary greatly between media (Table 2). Pine bark had a greater percentage of air-filled pore space than did those media containing coal cinders (by orthogonal contrast, P = 2%). No difference between cinder sources was detected through orthogonal contrasts or mean comparisons. High variability associated with these measurements (CV = 25.8%), resulted in nonsignificant differences between individual treatment means.

Extract analysis. Elemental analysis of pine bark and both cinder materials, by HNO_3–HCl digestion, indicated that cinders were

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[1]Former Graduate Research Assistant. Present address: Department of Horticultural Science, North Carolina State University, Raleigh, NC 27650.
[2]Associate Professor of Horticulture.

Table 1. Bulk densities and particle distributions of media and media components.

Media components or media	Bulk density (g/cm³)	Particle distribution (% by wt) Standard sieve number and size 8 (2.38 mm)	10 (2.00 mm)	18 (1.00 mm)	20 (841 μm)	30 (595 μm)	40 (420 μm)	Pan	LSD[z] 5%
Component									
Pine bark	0.34	32.26	5.85	17.80	4.69	7.74	7.52	24.16	6.93
Aged cinders	0.99	21.02	4.27	15.74	3.87	6.80	6.80	42.06	1.66
Fresh cinders	0.95	17.60	3.10	10.96	2.67	5.13	5.18	55.36	2.43
LSD[y]	0.02	7.83	1.56	0.83	0.60	1.06	1.64	5.79	
Media[w,x]									
Control	0.38	25.53	5.26	18.48	5.69	9.79	8.48	26.76	5.79
Aged cinders									
33.3%	0.64	18.74	4.26	16.92	4.64	8.74	8.18	38.55	4.51
50.0%	0.80	16.95	3.92	16.40	4.90	6.63	7.61	43.45	2.81
66.7%	0.85	17.46	3.72	15.32	4.58	7.38	7.42	44.10	3.22
Fresh cinders									
33.3%	0.66	24.83	3.95	12.79	3.74	6.18	6.18	42.00	6.53
50.0%	0.71	19.35	2.72	11.46	3.37	5.64	6.42	51.04	3.37
66.7%	0.82	16.16	3.08	11.14	3.36	5.71	6.22	54.20	2.67
Bark + sand (1:1 v/v)	1.21	9.58	3.24	26.59	9.76	18.58	13.75	18.49	1.94
LSD[y] 5%	0.04	5.90	0.96	2.15	3.01	1.46	0.84	7.38	

[z]LSD for mean comparisons within rows.
[y]LSD for mean comparisons within columns.
[x]Percentages represent % cinders; control = 0% cinders (100% pine bark).
[w]Each medium was amended with lime, gypsum, superphosphate, and Esmigran micronutrient mix in preparation for use in growth studies.

higher in elemental composition than pine bark (Table 3). Acid extracts of fresh cinders were about 5 times greater in P than those of aged cinders. Acid extracts of aged cinders, however, contained higher values for Fe, Mn, Zn, Cu, Na, Al, Co, Cr, Ni, and Pb. Water extracts of fresh cinders were higher than aged in K, Ca, Mg, Mn, Zn, Cu, B, Na, Ba, Co, Cr, Ni, Pb, and Sr. The water-soluble extracts of fresh cinders contained a higher total elemental content than the aged cinders. Calcium (water extract) content in fresh cinders was more than 9 times that of aged cinder extracts. These findings suggest that nutrients and metals contained in fresh cinders were more available, and more easily leached. Saturation extracts of the bark control and cinder media at pH 5.0 ± 0.1 demonstrated levels of soluble salts ranging from 2.9 to 3.8 mmhos/cm, and NO_3–N levels for all media ranged from 0.16 to 0.48 ppm. These values were well within limits obtained by Jones (9), indicating no potential phytotoxicity.

pH buffer curves. The pine bark medium appeared to have a pH buffer effect at about pH 7 (Fig. 1). Coal cinders from either source, mixed with pine bark, resulted in increased media pH when evaluated with the pine bark control; thus, incorporation of lime to adjust pH should be reduced appropriately as the amount of cinders is increased. Since the initial pH of aged cinders was higher than that of fresh cinders, media containing large portions of aged cinders rapidly approached the theoretical limit for soil alkalinity (pH 8.3 for $CaCO_3$ limed soil), where the CO_3^{-2} and OH^- concentrations are theoretically at equilibrium with atmospheric CO_2. Buffer curves for aged cinder media, (with the addition of liming material) indicate linear increases in pH (slope = +0.2). Addition of fresh cinders to pine bark increased the pH from 3.9 to 5.5 for the 66.67% cinder medium, with pH buffer curves resembling that of the 100% pine bark medium. This suggests that fresh cinders had no inherent pH buffering capacity.

Table 2. Air-filled pore space and CEC of media and components.

Media components or media	CEC (meq/100 g)	CEC (meq/100 cm³)	Air-filled pore space (%)
Component			
Bark	70.61	24.15	---
Aged cinders	10.37	10.25	---
Fresh cinders	1.96	1.85	---
LSD[z] 5%	3.23	2.56	---
Medium[y,x]			
Control	45.15	17.20	14.99
Aged cinders			
33.3%	26.21	16.77	10.97
50.0%	16.58	13.21	10.14
66.7%	13.23	11.28	11.04
Fresh cinders			
33.3%	18.02	11.93	12.51
50.0%	14.56	10.44	12.01
66.7%	12.35	10.13	10.82
LSD[z] 5%	2.63	2.26	4.17

[z]LSD for mean comparisons within columns.
[y]Each medium was amended with lime, gypsum, superphosphate, and Esmigran micronutrient mix in preparation for use in growth studies.
[x]Percentages represent % cinders; control = 0% cinders (100% pine bark).

Data obtained indicated that the physical properties of pine bark media containing coal cinders do not restrict its utility as a plant growth medium. The addition of cinders to pine bark improves the physical properties of the growing medium similarly to the improvements obtained with sand (2). Cinders increase media BD, thus reducing blowdown of container nursery stock while enhancing the bark's ability to retain moisture, possibly restricting nutrient leaching. The CEC, which aged coal cinders may contribute to container media, could also reduce fertilizer leaching.

High concentrations of micronutrients and metallic ions were extracted from both sources of coal cinders. The potential use of coal cinders in container media could result in nutritional imbalances. High levels of micronutrients in a container medium component could eliminate the need for micronutrient supplements.

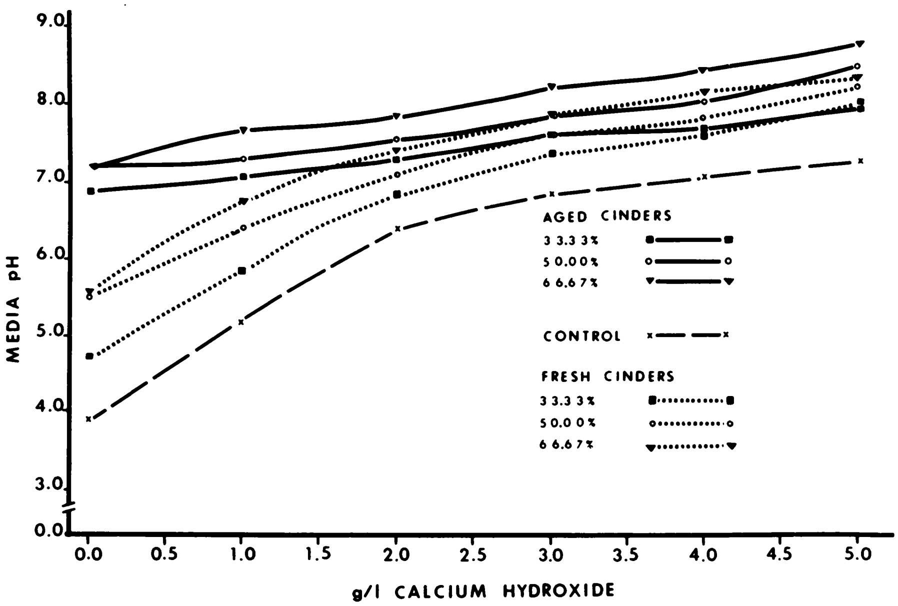

Fig. 1. pH buffer curves for 6 media containing coal cinders and one pine bark medium. Percentages represent percentage of cinders; control = 0% cinders (100% pine bark).

Table 3. Acid and water extracts from pine bark, aged cinders, and fresh cinders.

	Acid extraction			Water extraction		
Element	Pine bark	Aged cinders	Fresh cinders	Pine bark	Aged cinders	Fresh cinders
			%			
P	0.002	0.040	0.192	0.00069	0.00003	0.00007
K	0.009	0.270	0.240	0.00388	0.00062	0.01184
Ca	0.020	2.376	0.401	0.00194	0.00406	0.03732
Mg	0.003	0.320	0.520	0.00073	0.00059	0.00352
			ppm			
Fe	53.1	15730.0	11160.0	0.61	0.2976	0.0360
Mn	5.8	140.0	20.0	0.90	0.0177	0.8874
Zn	6.2	40.0	20.0	0.36	0.0014	1.2707
Cu	9.3	180.0	170.0	0.33	0.0034	0.0210
B	0.5	40.0	60.0	1.10	0.1799	7.7130
Na	1.3	1500.0	320.0	8.20	6.6900	34.6100
Al	112.8	8400.0	6600.0	6.50	0.7079	0.1466
Si	50.6	1190.0	490.0	3.30	7.9930	6.7120
Ba	1.3	250.0	400.0	0.07	0.0390	0.1119
Co	0.9	80.0	60.0	0.04	0.0013	0.3030
Cr	1.9	90.0	40.0	0.12	0.0147	0.1429
Ni	0.4	100.0	80.0	0.27	0.0000	0.5566
Pb	12.4	160.0	130.0	0.27	0.0039	0.0055
Sr	0.7	300.0	760.0	0.06	0.3992	11.1100

Coal cinders offer growers a sterile, relatively light-weight, locally available, and inexpensive inorganic aggregate for use in containerized plant production media. Additionally, utilization of this by-product is an attractive alternative to the economic burden associated with present disposal methods and the environmental hazards resulting from runoff at disposal sites. Research is being conducted to ascertain the direct effects of coal cinders on plant growth.

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