Monolithic Slag as a Substrate for Rooting and Bare-Rooting Stem Cuttings[1]

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Abstract

Stem cuttings of *Hydrangea paniculata* Sieb., *Rosa* L. 'Red Cascade', *Salvia leucantha* Cav., and *Solenostemon scutellarioides* (L.) Codd 'Roseo' were inserted into six rooting substrates: monolithic slag, sand, perlite, vermiculite, Fafard 3B, or fine pine bark. Rooting, initial shoot growth, and ease of dislodging substrate particles from root systems upon bare-rooting by shaking and washing cuttings rooted in monolithic slag were compared to cuttings rooted in the five other substrates. Rooting percentage, number of primary roots per rooted cutting, and total root length per rooted cutting for cuttings rooted in monolithic slag were generally similar to the five other substrates. Particles of monolithic slag were dislodged more readily from root systems by shaking than were the other substrates. Gentle washing removed almost all particles of monolithic slag and sand from the root systems of all taxa and removed almost all particles of pine bark from all taxa except *S. scutellarioides* 'Roseo'. Monolithic slag had a bulk density similar to sand, retained less water than the other substrates, and was similar to perlite, vermiculite, and pine bark in particle size distribution.

Index words: adventitious rooting, bare-rooting, industrial byproducts, vegetative propagation, waste products.

Taxa used in this study: 'Red Cascade' miniature rose (*Rosa* L. 'Red Cascade'); panicle hydrangea (*Hydrangea paniculata* Sieb.); Mexican bush sage (*Salvia leucantha* Cav.); 'Roseo' coleus (*Solenostemon scutellarioides* (L.) Codd 'Roseo').

Significance to the Nursery Industry

A variety of organic and mineral components may be used as rooting substrates in cutting propagation provided they have adequate water-holding capacity, maintain substrate aeration, are free of pests and pathogens, and are not phytotoxic. Composted organic wastes and inorganic byproducts may serve as suitable substrate components in areas where such materials are available and inexpensive. For growers who produce rooted cuttings for export as bareroot plants or prefer marketing and lower shipping costs of bareroot plants for sale on the domestic market, the ability to remove substrate particles from root systems with a minimum of labor may also be a desirable property of a substrate.

Monolithic slag, a fused cordierite [$(Mg,Fe)_2Al_4Si_5O_{18}$] produced as a byproduct of smelting operations, has characteristics that can be suitable as a substrate for cutting propagation in areas where it is locally available. Our research has shown that rooting of stem cuttings of selected taxa in monolithic slag is comparable to results obtained with other substrate components. Particles of monolithic slag can be dislodged readily from root systems, without the need for extensive washing with pressurized water, when rooted cuttings must be shipped in a soil-free form. Monolithic slag is comparable to sand in weight and comparable to coarse perlite and vermiculite in particle size distribution, but has a lower water-holding capacity than these conventional substrate components.

Introduction

Substrates for propagating plants by cuttings typically include both an organic component (peat, bark, or coir) and a coarse mineral (inorganic) component. Mineral components (perlite, vermiculite, shale, sand, pumice, polystyrene, or rockwool) are sometimes used alone as rooting substrates. Selection of substrate components can be based on water-holding capacity, aeration, cost, and availability (5). Growing substrate may also be selected based upon the ease with which plants may be removed from the substrate as bareroot plants for storage, planting, or shipping (8).

Bare-rooting of plants can reduce shipping costs due to less weight and space in comparison to plants shipped in containers and growing substrate, and is often required for import into the United States and export to other countries (8). A typical requirement under the United States Department of Agriculture's Animal and Plant Health Inspection Service regulations is that imported plant material be free of soil to minimize the import of plant pests and pathogens (6). This practice is performed commonly using one to several washings with moderate to high-pressure water sprays to remove adhering substrate particles, followed by a drying process. Bare-rooting can be facilitated by selection of substrate components that are removed readily from the root systems. A commercial, kiln-fired calcined clay ceramic aggregate has been used effectively for this purpose; reuse of the material was suggested due to its cost (8).

Composted organic wastes have been evaluated and found suitable as substrates for rooting cuttings (2, 4). Inorganic wastes and byproducts, including various forms of slag, have also been used successfully as substrate components for plant propagation and production (1, 3). Results of trials conducted by Dr. Ken Tilt at Auburn University (unpublished) have indicated that monolithic slag can be incorporated into growing substrates for container-grown plants, and suggest that the material might also be suitable for cutting propagation.

Monolithic slag is a product of smelting operations and is sold as a byproduct for use as an aggregate for fill lines, drainage lines, and driveways. Composed of fused cordierite [$(Mg,Fe)_2Al_4Si_5O_{18}$], the material is black in color, odorless, and nonhazardous (7). Personal protective equipment specified for general handling of monolithic slag includes work

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gloves, safety glasses, and a dust respirator. Cost of the material is similar to that of sand [Craig Miller, Miller Sand and Landscape Supply, DeArmanville, AL (personal communication, April 30, 2004)]. Therefore, the objectives of the following research were to compare adventitious rooting and initial shoot growth response of stem cuttings of four ornamental taxa rooted in monolithic slag compared with five common substrates and evaluate the amount of substrate particles that remain attached to root systems of these same cuttings upon bare-rooting.

Materials and Methods

Six substrates were used for rooting stem cuttings: monolithic slag (Multimetco, Inc., Anniston, AL), fill-grade construction sand (Lafarge Building Materials, Auburn, AL), Sunshine coarse perlite (Sun Gro Horticulture, Seneca, IL), Sunshine coarse vermiculite (Sun Gro Horticulture, Seneca, IL), Fafard 3B mix (a blend of peat, perlite, vermiculite, and pine bark; Conrad Fafard, Inc., Agawam, MA), or fine pine bark [particle size ≤ 0.64 cm (0.25 in); Albertville Wood Products, Albertville, AL]. Fafard 3B mix contained manufacturer-incorporated fertilizer; otherwise, no fertilizer was blended into the substrates. Six random samples (approximately 500 cm^3 per sample) of each substrate were dried for 24 hr at 46C (115F), with 250 cm^3 measured from each dried sample with a 250 ml graduated cylinder for further analysis. Three of these samples were used for determination of bulk density and measurement of water and air content at container capacity (content after thorough saturation with water and draining by gravity). The other three samples were used for determination of particle size distribution by manual sifting through No. 8, 10, 20, and 50 U.S.A. standard testing sieves (Fisher Scientific Co., Pittsburgh, PA).

Containers (Landmark Plastics, Akron, OH) used for propagation were X-3.5SP sheets of square pots [384 cm^3 (23 in^3) soil vol per pot] for stem cuttings of *Solenostemon scutellarioides* 'Roseo' and X-3SQSP sheets of square pots [181 cm^3 (11 in^3) soil vol per pot] for stem cuttings of all other taxa, with pots placed into L1020NCR polystyrene trays. Substrate-filled pots were hand-watered thoroughly with tap water prior to placement in the trays using a completely randomized design, with three additional pots of each substrate set aside for initial evaluation of pH and electrical conductivity (EC). Upon harvest of rooted cuttings, three pots of each used substrate per taxon were collected for final determination of pH and EC. A saturated paste of each sample was prepared with deionized water and pH and EC were measured using a Model 63 pH/conductivity/temperature meter (YSI Incorporated, Yellow Springs, OH).

Cutting material was collected from greenhouse, container-grown stock plants (*Rosa* 'Red Cascade' and *S. scutellarioides* 'Roseo') or landscape stock plants (*Hydrangea paniculata* and *Salvia leucantha*) on the campus of Auburn University, Auburn, AL [lat. 32°36'N, long. 85°29'W (USDA Hardiness Zone 8a)] on May 25, 2002. Semi-hardwood stem cuttings of *H. paniculata* were prepared as 3.8 cm (1.5 in) long, single-node subterminal cuttings with 2.5 cm (1 in) of stem below the node, inserted into rooting substrates, and harvested after 36 days. Semi-hardwood stem cuttings of *Rosa* 'Red Cascade' were prepared as 7.6 cm (3 in) long, three-node subterminal cuttings with 1.9 cm (0.75 in) of stem below the basal node, inserted into rooting substrates, and harvested after 26 days. Semi-hardwood stem cuttings of *S. leucantha* were prepared as 5 cm (2 in) long, two-node subterminal cuttings with 2.5 cm (1 in) of stem below the basal node, inserted into rooting substrates, and harvested after 19 days. Herbaceous stem cuttings of *S. scutellarioides* 'Roseo' were prepared as 9 cm (3.5 in) long, terminal cuttings with leaves removed from the basal node, inserted into rooting substrates, and harvested after 19 days. Ten cuttings of each taxon were inserted to a depth of 1.9 cm (0.75 in) into each of the six rooting substrates in individual pots for a total of 60 cuttings per taxon on May 25, 2002. No root-promoting compounds were used to treat the cuttings. Harvest dates were determined based on prior observation of the time required to established well-rooted plants of each taxon from cuttings inserted into Fafard 3B substrate.

Cuttings of all taxa were placed under a greenhouse mist system providing overhead mist with municipal tap water (pH ~7.0) for 6 seconds every 20 minutes during daylight hours. Rooting cuttings were fertilized twice per week beginning 7 days (*S. leucantha* and *S. scutellarioides* 'Roseo') or 14 days (*H. paniculata* and *R.* 'Red Cascade') after insertion using Pro-Sol 20–20–20 water-soluble fertilizer (Pro-Sol, Ozark, AL) applied as a drench at a rate of 100 ppm N. Maximum photosynthetically active radiation measured in the greenhouse on the cutting bench with a LI-6200 portable photosynthesis system (LI-COR, Inc., Lincoln, NE) was 600 μmol/m^2/sec and daily maximum/minimum temperatures in the greenhouse were 27 ± 6C (80 ± 10F)/18 ± 3C (65 ± 5F).

Upon harvest, each rooted cutting was removed from its rooting substrate and, holding each cutting by the stem base, was shaken for 5 sec to dislodge substrate particles from the root system. The root system was laid on a flat, white surface and the percentage of the root system surface covered by adhering soil particles was estimated by visual inspection to the nearest 5%. The root system of each cutting was then submerged in water and gently agitated by hand for 5 sec to further dislodge substrate particles. The root system was again laid on a flat, white surface and the percentage of the root system surface covered by adhering soil particles was estimated by visual inspection to the nearest 5%. Number of rooted cuttings was determined for each substrate. A cutting was classified as rooted if it produced at least one root of 10 mm in length or longer. Number of primary roots, total root length, and total new shoot length were also determined for each rooted cutting.

Results from cuttings rooted in the monolithic slag substrate were compared to cuttings rooted in each of the other five substrates using Fisher's Exact Test for number rooted and Dunnett's Test for all other measures. Least squares means were calculated when sample sizes differed (due to < 100% rooting). Bulk density, water and air content at container capacity, pH, EC, and particle sizes for the monolithic slag were also compared to each of the other five substrates using Dunnett's Test. Statistical analyses were conducted using the SAS® System, Release 8.2 (SAS Institute, Inc., Cary, NC).

Results and Discussion

Particle size distribution of monolithic slag was similar to perlite, vermiculite, and pine bark (Table 1), while its bulk density was similar to sand and greater than all other substrates (Table 2). Water-holding capacity of monolithic slag was less than that of all other substrates, while air space at

Table 1. Particle size distribution (percent by weight) of six rooting substrates.[z]

Substrate	> 2.36 mm (> 0.094 in) (%)	> 2.00 to 2.36 mm (> 0.079 to 0.094 in) (%)	> 0.85 to 2.00 mm (> 0.033 to 0.079 in) (%)	> 0.30 to 0.85 mm (> 0.012 to 0.033 in) (%)	= 0.30 mm (= 0.012 in) (%)
Monolithic slag	68	5	15	8	4
Sand	13*	4^{ns}	29*	46*	8^{ns}
Perlite	67^{ns}	8*	17^{ns}	5^{ns}	3^{ns}
Vermiculite	72^{ns}	12*	13^{ns}	2^{ns}	1^{ns}
Fafard 3B	34*	5^{ns}	27*	23*	11*
Pine bark	70^{ns}	4^{ns}	17^{ns}	8^{ns}	1^{ns}

[z]Means (of three samples per substrate) within a column were significantly different (*) or not significantly different (ns) from the mean of the monolithic slag substrate according to Dunnett's Test (two-tailed; $P \leq 0.05$).

Table 2. Bulk density, water content at container capacity, and air space at container capacity of six rooting substrates.[z]

Substrate	Bulk density (g/cm^3)	Water content at container capacity (% by vol)	Air space at container capacity (% by vol)
Monolithic slag	1.54	16	25
Sand	1.53^{ns}	29*	3*
Perlite	0.09*	27*	38*
Vermiculite	0.12*	33*	34*
Fafard 3B	0.15*	56*	11*
Pine bark	0.21*	20*	33*

[z]Means (of three samples per substrate) within a column were significantly different (*) or not significantly different (ns) from the mean of the monolithic slag substrate according to Dunnett's Test (two-tailed; $P \leq 0.05$).

container capacity was greater than sand and Fafard 3B and less than perlite, vermiculite, and pine bark (Table 2).

At the start of the experiment, monolithic slag had a pH of 6.7; vermiculite was similar, perlite was higher, and sand, Fafard 3B, and pine bark were lower (Table 3). Previous measurements of the pH of monolithic slag had shown pH values > 8.0 (data not presented), but high pH values were not recorded at any time during this experiment. The watering-in process that preceded pH determination might have leached calcium from the material, thus lowering pH. By harvest time, pH had decreased or remained the same in the monolithic slag, perlite, and vermiculite; and increased or remained the same in the sand, Fafard 3B, and pine bark. There was less variability in pH among the substrates for any one taxon at the time of harvest (primarily in the range of 6 to 7) than that exhibited at the start of the experiment.

Soluble salt levels, as measured by electrical conductivity (EC), were similar at the start of the experiment in all substrates, except Fafard 3B which was notably higher due to pre-incorporation of fertilizer by the manufacturer (Table 3).

Table 3. Substrate pH and electrical conductivity (EC) at the start of the trial and at harvest of stem cuttings of four taxa rooted in six substrates.[z]

Substrate	Starting reference	*Hydrangea paniculata* (26 DAI[y])[x]	*Rosa* 'Red Cascade' (36 DAI)[x]	*Salvia leucantha* (19 DAI)[x]	*Solenostemon scutellarioides* 'Roseo' (19 DAI)[w]
			pH		
Monolithic slag	6.7	$6.8^{[ns]}$	$5.9^{[*]}$	$6.0^{[*]}$	$6.3^{[ns]}$
Sand	6.0^{ns}	$7.1^{ns[*]}$	$6.1^{ns[ns]}$	$6.6^{*[*]}$	$6.3^{ns[*]}$
Perlite	7.3*	$6.7^{ns[*]}$	$5.9^{ns[*]}$	$6.4^{*[*]}$	$6.1^{ns[*]}$
Vermiculite	6.9^{ns}	$6.8^{ns[ns]}$	$6.1^{ns[*]}$	$6.4^{*[*]}$	$6.2^{ns[*]}$
Fafard 3B	5.8*	$6.4^{*[*]}$	$6.0^{ns[ns]}$	$6.4^{*[*]}$	$6.1^{ns[ns]}$
Pine bark	4.4*	$6.1^{*[*]}$	$5.8^{ns[*]}$	$6.0^{ns[*]}$	$5.4^{*[*]}$
			EC (µS/cm)		
Monolithic slag	43.6	$86.9^{[ns]}$	$64.3^{[ns]}$	$52.6^{[ns]}$	$132.6^{[*]}$
Sand	6.5^{ns}	$32.4^{*[*]}$	$26.8^{*[*]}$	$17.4^{*[ns]}$	$28.8^{*[*]}$
Perlite	17.9^{ns}	$124.7^{*[*]}$	$149.8^{*[*]}$	$80.2^{*[*]}$	$211.1^{*[*]}$
Vermiculite	38.6^{ns}	$177.6^{*[*]}$	$196.6^{*[*]}$	$112.8^{*[*]}$	$268.2^{*[*]}$
Fafard 3B	883.0*	$212.9^{*[*]}$	$163.7^{*[*]}$	$79.0^{*[*]}$	$220.8^{*[*]}$
Pine bark	222.9^{ns}	$36.5^{*[*]}$	$39.8^{*[*]}$	$32.9^{*[*]}$	$54.3^{*[*]}$

[z]Means (of three samples per substrate) within a column for pH and EC were significantly different (*) or not significantly different (^{ns}) from the mean pH and EC, respectively, of the monolithic slag substrate according to Dunnett's Test (two-tailed; $P \leq 0.05$). Means within a row were significantly different ([*]) or not significantly different ([ns]) from the mean of the starting reference according to Dunnett's Test (two-tailed; $P \leq 0.05$).

[y]Days after insertion of cuttings into the substrate.

[x]Cuttings rooted in square pots [181 cm^3 (11 in^3) soil vol. per pot].

[w]Cuttings rooted in square pots [384 cm^3 (23 in^3) soil vol. per pot].

Table 4. Rooting response, initial shoot growth response, and adhesion of substrate particles to root systems of stem cuttings of four taxa rooted in monolithic slag compared to five common rooting substrates.

Substrate	Rooting (%)[z]	Roots/cutting[y]	Total root length/cutting (mm)[y]	Total new shoot length/cutting (mm)[y]	Root system with attached particles after shaking (%)[y]	Root system with attached particles after washing (%)[y]
			***Hydrangea paniculata* (26 DAI[x])[w]**			
Monolithic slag	100	30.0	890	0.0	21.5	2.9
Sand	100[ns]	30.5[ns]	526[ns]	1.3[ns]	87.0*	4.0[ns]
Perlite	100[ns]	18.8[ns]	403[ns]	0.0[ns]	81.5*	37.0*
Vermiculite	100[ns]	34.0[ns]	1375[ns]	1.3[ns]	62.0*	15.5*
Fafard 3B	100[ns]	39.0[ns]	1426[ns]	9.5a	99.0*	90.0*
Pine bark	80[ns]	8.6*	231[ns]	0.0[ns]	53.8*	4.9[ns]
			***Rosa* 'Red Cascade' (36 DAI)[w]**			
Monolithic slag	80	11.3	616	44.1	7.5	0.5
Sand	100[ns]	9.9[ns]	514[ns]	49.8[ns]	6.0[ns]	0[ns]
Perlite	100[ns]	8.9[ns]	599[ns]	70.1[ns]	33.0*	2.8*
Vermiculite	80[ns]	9.1[ns]	711[ns]	68.3[ns]	8.8[ns]	3.6*
Fafard 3B	100[ns]	11.5[ns]	772[ns]	134.0*	48.0*	3.8*
Pine bark	50[ns]	6.8[ns]	248[ns]	8.0[ns]	8.0[ns]	1.2[ns]
			***Salvia leucantha* (19 DAI)[w]**			
Monolithic slag	100	19.3	856	84.3	7.0	0.5
Sand	100[ns]	13.1[ns]	849[ns]	106.0*	24.5*	0[ns]
Perlite	100[ns]	17.8[ns]	1104[ns]	86.9[ns]	40.0*	2.6*
Vermiculite	100[ns]	16.9[ns]	1068[ns]	92.2[ns]	16.0*	2.6*
Fafard 3B	100[ns]	17.5[ns]	1306[ns]	135.8*	69.0*	3.3*
Pine bark	100[ns]	22.6[ns]	1510*	78.9[ns]	17.5*	0.3[ns]
			***Solenostemon scutellarioides* 'Roseo' (19 DAI)[v]**			
Monolithic slag	100	39.0	2000[ns]	113.0	25.5	3.9
Sand	100[ns]	41.5[ns]	2700[ns]	116.5[ns]	91.0*	1.4[ns]
Perlite	100[ns]	30.5[ns]	1842[ns]	105.0[ns]	72.0*	23.5*
Vermiculite	100[ns]	31.5[ns]	2595[ns]	107.5[ns]	53.0*	11.0*
Fafard 3B	100[ns]	44.0[ns]	4320*	142.5*	95.0*	38.0*
Pine bark	100[ns]	32.0[ns]	1330[ns]	93.0*	81.0*	14.5*

[z]Ten cuttings per treatment per taxon. Number of rooted cuttings in the monolithic slag substrate was compared to each of the other substrates for each taxon using Fisher's Exact Test. No statistical differences were found.

[y]Least squares means (calculated using rooted cuttings only) within a column and taxon were significantly different (*) or not significantly different (ns) from the mean of the monolithic slag substrate according to Dunnett's Test (two-tailed; $P \leq 0.05$).

[x]Days after insertion of cuttings into the substrate.

[w]Cuttings rooted in square pots [181 cm³ (11 in³) soil vol. per pot].

[v]Cuttings rooted in square pots [384 cm³ (23 in³) soil vol. per pot].

Despite liquid fertilization during the experiment, EC of the monolithic slag did not increase significantly by harvest, apparently due to its lower water retention; an exception occurred with *S. scutellarioides* 'Roseo', likely due to development of a more extensive, fibrous root system that could have retained more of the applied fertilizer solution. Sand, perlite, and vermiculite showed higher EC readings at harvest compared to initial values; however, EC values from the sand remained lower than those for monolithic slag. Fafard 3B and pine bark showed lower EC values at harvest compared to initial values, apparently due to flushing by the intermittent mist and liquid fertilization.

Rooting percentages (compared as counts using Fisher's Exact Test) were similar across all treatments and taxa (Table 4). An exception was cuttings of *R.* 'Red Cascade' which rooted at only 50% in the pine bark. Total root length per rooted cutting in monolithic slag was mostly similar to other substrates for all taxa. Total new shoot length on all taxa rooted in monolithic slag was less than that of cuttings rooted in Fafard 3B (probably due to availability of the pre-incorporated fertilizer content of the commercial blend), and mostly similar with all other substrates. Greater shoot growth might not be an advantage if rooted cuttings are to be bare-rooted and shipped due to the additional weight of the tissue.

Upon harvest, substrate was most readily dislodged from cuttings rooted in the monolithic slag upon being shaken (Table 4). The thick, fibrous root systems of *S. scutellarioides* 'Roseo' and *H. paniculata* cuttings were observed to retain the monolithic slag particles close to the base of the cuttings. Gentle washing by agitation in water further dislodged particles of all substrates. Cuttings rooted in monolithic slag and sand retained almost no substrate particles after washing. With the exception of *S. scutellarioides* 'Roseo' cuttings, similar results were obtained with pine bark.

Overall, rooting and initial shoot growth of cuttings of all taxa in the monolithic slag was very satisfactory in comparison to the other substrates. If bare-rooting of cuttings with maximum removal of substrate particles without washing is an objective, monolithic slag appears to provide the best results. If maximum removal of substrate particles must be accomplished, use of monolithic slag or sand, combined with a gentle washing, can give optimal results. Pine bark can also be suitable, depending on the taxon and the size and extent of the root systems; however, results might be different with other grades of pine bark. In addition to its potential use in commercial production of bare-root cuttings, monolithic slag as a rooting substrate may be useful in cultural and nutritional studies that require removal of substrate particles prior to collection of data on root systems (e.g., dry weights or volume). Monolithic slag appears to be a suitable substitute in cases where sand is used as the sole substrate for rooting cuttings. Perlite or vermiculite would be better choices of inorganic substrates if weight is an issue. Further research should determine whether monolithic slag is suitable for use in substrate blends for both propagation and production. Also, the ability to reuse this material for repeated crops needs to be investigated.

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