Parboiled Rice Hull Mulch in Containers Reduces Liverwort and Flexuous Bittercress Growth[1]

James Altland and Charles Krause[2]

Abstract

Use of preemergence herbicides for weed control is not always possible; some crops and many enclosed production sites are not labeled for herbicide applications. The objective of this research was to determine the utility of parboiled rice hull mulch for controlling two of the most common weeds in nursery crop production, flexuous bittercress (*Cardamine flexuosa* With.) and liverwort (*Marchantia polymorpha* L.). Two experiments were conducted to determine control of flexuous bittercress and liverwort with 0, 0.6, 1.3, or 2.5 cm (0, 0.25, 0.5, or 1.0 in) depths of rice hull mulch applied to the surface of 15 cm (6 in) diameter pots on a greenhouse bench. In both experiments, one group of containers were potted each with a single rose (*Rosa* 'Radrazz') and another group was not potted (only substrate and rice hull mulch). Flexuous bittercress seed and liverwort gemmae were applied to the surface of the substrate or mulch. Rose response and weed growth were monitored for 8 weeks in both experiments. Substrate pH, rose foliar color, and rose growth were not affected in either experiment. Flexuous bittercress and liverwort establishment and subsequent growth decreased with increasing rice hull depth. Containers with either a 1.3 or 2.5 cm (0.5 or 1.0 in) depth of rice hulls provided nearly 100% weed control. Rice hulls provided effective bittercress and liverwort control for 8 weeks with no adverse effects on roses.

Index words: alternative weed control, non-chemical weed control, herbicides.

Significance to the Horticulture Industry

Preemergence herbicides are the primary tool for controlling weeds in containers. However, preemergence herbicides cannot be used on all crops, nor are they labeled for use in enclosed structures. Alternatives are needed for managing weeds where preemergence herbicides are either not labeled or cannot be used with a wide margin of safety. In particular, there are needs for weed control alternatives in propagation, hoophouses and other enclosed structures, and herbaceous perennials and other sensitive crops. Parboiled rice hulls applied at a depth of 1.3 to 2.5 cm (0.5 to 1.0 in) over the substrate surface prevented establishment of flexuous bittercress and liverwort from seeds or gemmae, respectively. Parboiled rice hulls at a 0.6 cm (0.25 in) depth provided only marginal control. Addition of parboiled rice hulls did not affect rose growth and development. Parboiled rice hulls are commercially available for horticultural use.

Introduction

The primary tool for weed management in container systems is the use of preemergence herbicides applied to the container substrate surface; however, herbicides are not acceptable in all production systems. Some crops such as hydrangea [*Hydrangea macrophylla* (Thunb.) Ser.], azalea [*Rhododendron obtusum* (Lindl.) Planch.], and many herba-

[1]Received for publication January 21, 2014; in revised form on May 30, 2014. Mention of proprietary products or company is included for the reader's convenience and does not imply any endorsement or preferential treatment by USDA/ARS.

[2]Research Horticulturist (james.altland@ars.usda.gov) and Research Leader for the Application Technology Research Unit in USDA-ARS, Ohio Agricultural Research and Development Center, 1680 Madison Ave., Wooster, OH 44691.

The *Journal of Environmental Horticulture* (ISSN 0738-2898) is published quarterly in March, June, September, and December by the Horticultural Research Institute, 1200 G Street NW, Suite 800, Washington, DC 20005. Subscription rate is $85.00 per year for scientists, educators and AmericanHort members; $130.00 per year for libraries and all others. For questions about subscriptions or changes to your contact information, notify Jennifer Gray, HRI, at: Horticultural Research Institute, 2130 Stella Court, Columbus, OH 43215, email JenniferG@americanhort.org, Phone: 614-884-1155, Fax: 614-884-1195.

ceous perennials are sensitive to preemergence herbicides (Moore et al. 1989), and no preemergence herbicide is labeled for use on container crops inside enclosed structures such as greenhouses. The most common alternative to herbicides is the use of mulches. Smith et al. (1998) demonstrated recycled paper pellets provided excellent weed control at a 2.5 cm (1 in) depth, with no adverse effects on two cultivars of azalea (*Rhododendron* spp.). Svenson (1998) reported effective liverwort (*Marchantia polymorpha* L.) suppression with 1.3 cm (0.5 in) of hazelnut or oyster shells, but poor control with coarse sand, peat moss, pumice, perlite, and rockwool. Research has demonstrated effective weed control with little or no adverse effects on ornamental crops using recycled shredded tires (File et al. 2000; Tatum et al. 1999), pelletized newspaper (Wooten and Neal 2000), kenaf stem, wheat straw, oat straw, cereal rye straw (File et al. 2000), pine bark, and cocoa hull mulch (Abbey and Mervosh 2002; Mervosh and Abbey 1999; Mervosh and Abbey 2002).

Parboiled rice hulls (Riceland Foods, Inc., Stuttgart, AK) are dry rice husks removed from rice grains with steam or hot water. Hereafter they will be referred to as rice hulls. Rice hulls are commercially available for horticulture, and are currently used as a component in greenhouse and nursery substrates. The influence of rice hulls on substrate chemical and physical properties varies by amendment rate and the parent substrate (Evans et al. 2011; Evans and Gachukia 2007), and they are often used with the intent of increasing substrate drainage. Rice hulls can also be used as a container mulch. One manufacturer (Riceland Foods) recommends a rice hull mulch depth of 3.8 to 5.0 cm (1.5 to 2 in) for effective weed control in container crops. Ahn and Chung (2000) demonstrated allelopathic suppression of barnyard grass [*Echinochloa crusgalli* (L.) P. Beauv.] from aqueous rice hull extracts; however, little research has documented the effectiveness of rice hulls for controlling weeds in the container environment. Samtani et al. (2007) reported that rice hulls at a depth of 0.5 cm (0.2 in) provided no control of annual bluegrass (*Poa annua* L.), common groundsel (*Senecio vulgaris* L.), or shepherd's purse [*Capsella bursa-pastoris* (L.) Medik.] in containers with a 70% pine bark, 20% sphagnum peat, and 10% coarse sand substrate. Ramkhelawan and Brathwaite (2001) observed poor control of perennial weeds with a 5 cm (2 in) depth of rice hulls in container-grown mandarin (*Citrus reticulata* Blanco) rootstock potted with topsoil. The perennial weeds in this study, primarily purple nutsedge (*Cyperus rotundus* L.), presumably originated from propagules in the soil. Weed species addressed by the three aforementioned papers are economically important in either field crops or turf areas, however, they are not common in container plant production in North America. The two objectives of this research were to 1) to determine the effects of rice hull mulch on the growth and development of recently potted rose liners; and 2) to determine the effect of rice hull mulch on establishment of liverwort and flexuous bittercress from propagules delivered over the mulch surface.

Materials and Methods

Experiment 1. On May 17, 2013, 15-cm (6-in) diameter pots were filled with Sunshine Mix #2 potting mix (Sun Gro Horticulture Canada Ltd., Seba Beach, AB, Can.) to within 2.5 cm (1 in) of the container top. Half of the 48 containers were potted with a single Knockout™ rose (*Rosa* 'Radrazz') from a 6.3 cm (2.5 in) square plug. On May 20, 2013, containers with and without roses were randomly assigned to receive rice hulls at a depth of 0, 0.6, 1.3, or 2.5 cm (0, 0.25, 0.5, and 1 in) by weighing 0, 11, 22, or 44 g (0, 0.39, 0.78, or 1.56 oz) of rice hulls and spreading them evenly over the surface. There were six single-pot replications per treatment arranged in a completely randomized design. Containers with roses were randomized and placed separately from containers without roses to ensure no shading of containers lacking a rose.

Containers were placed on a bench receiving overhead irrigation of city tap water injected with 100 mg·L^{-1} (100 ppm) N from a commercial fertilizer (20N-4.4P-16.6K-0.15Mg-0.02B-0.01Cu-0.1Fe-0.05Mn-0.01Mo-0.05Zn, JR Peters, Inc., Allentown, PA). Irrigation was run twice daily for 7 min, so that each plot received approximately 1 cm (0.4 in) water per day. Gemmae were applied over the rice hull mulch (or substrate for non-mulched controls) of each container weekly. Gemmae were collected by first scraping gemmae cups of vigorous liverwort stock plants and releasing the gemmae into a 250-ml (8.5 oz) bowl of tap water where they generally separated from their clumps and floated freely. A plastic spoon was then used to apply 5 ml (1 tsp) water from the bowl, which contained approximately 20 gemmae, across the surface of each container. Ten flexuous bittercress seed were applied to the surface of each container at the initiation of the experiment (after rice hulls were applied) and again at 4 weeks after potting. Bittercress used in this experiment were determined to be flexuous bittercress based on morphological traits, in particular, stamen number (Post et al. 2011).

Substrate pH of containers potted with a rose was determined 1, 4, and 8 weeks after potting (WAP) using the pour-through method (Wright 1986). Leachate pH from the pour-through was determined with a MA235 pH/Ion Analyzer (Mettler Toledo, Twinsburg, OH). Foliar chlorophyll levels were determined 4 and 8 WAP using a SPAD chlorophyll meter (Minolta-502 SPAD meter, Spectrum Technologies, Inc., Plainfield, IL) by taking a measurement on five leaves per pot and recording the mean. At 4 and 8 WAP, recently matured rose foliage was harvested for foliar nutrient analysis (10), rinsed with deionized water, then oven dried at 55C (131F) for 3 d. Samples were ground in a Tecator Cyclotec mill (Tecator AB, Hogenas, Sweden) through a 0.5 mm (0.02 in) screen. Foliar N was determined with a Vario Max CN analyzer (Elementar Americas, Mt. Laurel, NJ). Other macronutrients and micronutrients were determined with a Thermo Iris Intrepid ICP-OES (Thermo Fisher Scientific, Waltham, MA). Rose root and shoot dry weights were determined at the conclusion of the experiment 8 WAP by harvesting roots and shoots separately, and drying in a forced air oven at 72C for at least 3 days. Percent of container surface covered by liverwort thalli was estimated and germinated flexuous bittercress numbers were counted at 1, 4, and 8 WAP. Flexuous bittercress were counted if cotyledons were visible. At 4 and 8 WAP, flexuous bittercress were harvested and shoot fresh weights (SFW) were measured.

Experiment 2. The experiment was repeated with the following exceptions. Containers were filled and potted September 5, 2013. Rose liners were smaller in this experiment, averaging 9 cm (3.5 in) tall and 7 cm (2.8 in) wide. At the time of potting, roses were dormant without leaves. Foliar analyses on roses were conducted 8 WAP only. Liverwort gemmae and flexuous bittercress seed were not applied to containers potted with a rose.

Data were subjected to analysis of variance using the general linear model (GLM) procedure in SAS (SAS Version 8, SAS Institute, Cary, NC). Regression analyses were conducted with orthogonal contrast statements within the GLM procedure. The least significant difference (LSD) for treatment means was calculated using Fisher's protected LSD test where $\alpha = 0.05$.

Results and Discussion

Experiment 1. Repeated measures analysis indicated that substrate pH in containers with roses changed over time ($P < 0.0001$), but there was no rice hull treatment effect ($P = 0.6165$) (data not shown). Substrate pH average 7.0 across all treatments at 1 WAP, and decreased to 6.8 by 8 WAP. Rose foliar SPAD levels were similar across treatments and time ($P = 0.8395$), averaging 35.5 throughout the experiment (data not shown). Foliar nutrient concentrations were minimally affected by rice hull treatments (data not shown). At 4 WAP, foliar Ca, Mg, and Zn were affected by treatments. Foliar Mg and Zn were within recommended levels (Mills and Jones, 1996) for all treatments, despite some differences. Foliar Ca was lower than recommended levels for all treatments, ranging from 0.67 to 0.81% with no logical trend with respect to rice hull depth. By 8 WAP, only foliar K, Fe, and N were affected by rice hull treatment, but only foliar N was lower than recommended levels and ranged from 2.1 to 2.3% across treatments, with roses mulched at 2.5 cm (1 in) depth having the highest foliar N levels. At the conclusion of the experiment, rose root and shoot dry weights were not affected by rice hull depth ($P = 0.1180$ and 0.2589, respectively) (data not shown).

At 4 WAP, flexuous bittercress number decreased quadratically and linearly with increasing rice hull depth in containers with and without roses, respectively (Table 1). It was hypothesized that a plant canopy might allow the rice hull mulch to remain wetter for a longer period of time, resulting in greater weed establishment within rice hulls beneath a canopy compared to weed growth in an open container. While not compared statistically, there were greater numbers in non-mulched control pots with roses compared to non-mulched controls without roses. However, flexuous bittercress shoot fresh weights were greater in control pots without canopies compared to those with canopies. The rose canopy might have allowed for greater germination, but germinated flexuous bittercress were suppressed in growth due to competition for light, water, or nutrients from rose plants. Flexuous bittercress shoot fresh weight decreased quadratically and linearly in containers with and without canopies, respectively, with increasing rice hull depth.

By 8 WAP, flexuous bittercress numbers in containers with and without roses decreased with increasing rice hull depth (Table 1). In containers with roses, germination occurred primarily near the rose stem. This could have happened either because the rice hull layer near the stem was thinner due to swelling of the substrate around the stem, or because the rose liners used had flexuous bittercress seed, which increased the probability of establishment near the stem. Flexuous bittercress shoot mass was high in non-mulched controls without roses, and decreased linearly and quadratically with increasing rice hull depth. Among containers with roses, despite relatively high flexuous bittercress numbers, shoot mass was low due to poor growth beneath the rose canopy. While containers with 0 and 0.6 cm (0.25 in) rice hulls had 0.4 and 0.2 g (0.014 and 0.007 oz) flexuous bittercress shoot weight, respectively, all containers were statistically similar with no rate response to rice hull depth. Low flexuous bittercress shoot weight was due more to the extremely poor growth of flexuous bittercress beneath roses than any control that might have been exerted in non-mulched or lightly-mulched [0.6 cm (0.25 in)] containers.

Liverwort coverage of the substrate surface decreased quadratically with increasing rice hull depth throughout the

Table 1. Flexuous bittercress (*Cardamine flexuosa* With.) number and shoot fresh weight at 4 and 8 weeks after potting (WAP) in containers with a 0 to 2.5 cm parboiled rice hull mulch depth. Half of the containers were potted with a single rose (*Rosa* 'Radazz') while the other half were not.

		4 WAP		8 WAP	
Rose canopy	Rice hull depth (cm)	Bittercress count	Shoot fresh weight (g)	Bittercress count	Shoot fresh weight (g)
no	0	1.2	1.3	5.5	5.6
	0.6	0.2	0.0	1.3	0.9
	1.3	0.2	0.0	0.0	0.0
	2.5	0.0	0.0	0.0	0.0
	Rate response[z]	L***	L***	Q***	L***
	$LSD_{0.05}$	0.4	0.6	1.1	2.4
yes	0	3.3	0.4	3.7	0.4
	0.6	1.0	0.1	4.5	0.2
	1.3	0.0	0.0	1.5	0.0
	2.5	0.0	0.0	0.8	0.0
	Rate response	Q***	Q**	L***	NS
	$LSD_{0.05}$	0.8	0.2	NS	NS

[z]Rate response in each column to increasing depth of rice hull mulch, where NS, L, and Q represent non-significant, linear, and quadratic rate response, respectively; and *, **, and *** represent significance where $P < 0.05$, 0.01, and 0.001, respectively.

Table 2. Liverwort (*Marchantia polymorpha* L.) coverage of the container surface at 1, 4, and 8 weeks after potting (WAP) in containers with a 0 to 2.5 cm parboiled rice hull mulch depth. Half of the containers were potted with a single rose (*Rosa* 'Radazz') while the other half were not.

Rose canopy	Rice hull depth (cm)	1 WAP	4 WAP	8 WAP
no	0	3.2	33.3	95.8
	0.6	0.0	1.3	20.0
	1.3	0.0	0.0	0.0
	2.5	0.0	0.0	0.0
	Rate response[z]	Q***	Q***	Q***
	$LSD_{0.05}$	1.0	4.7	5.5
yes	0.0	2.2	25.0	74.2
	1.6	0.0	1.3	12.5
	3.2	0.0	0.0	1.7
	6.5	0.0	0.0	0.0
	Rate response	Q**	Q***	Q***
	$LSD_{0.05}$	1.1	5.2	24.3

[z]Rate response in each column to increasing depth of rice hull mulch, where Q indicates a quadratic rate response, respectively; and *, **, and *** represent significance where P < 0.05, 0.01, and 0.001, respectively.

experiment, in containers with and without rose canopies (Table 2). Repeated measures ANOVA indicated a treatment by time interaction for liverwort coverage in containers with and without rose canopies ($P < 0.0001$). Liverworts began to colonize non-mulched control pots almost immediately, with small colonies present by 1 WAP. By 8 WAP, liverwort coverage was nearly complete in non-mulched control pots without rose canopies. Liverwort establishment in containers with 0.6 cm (0.25 in) rice hulls occurred in small gaps in the rice hull barrier. At a depth of 0.6 cm (0.25 in), the irregular surface of the potting mix resulted in some exposed areas of substrate. Liverwort growth in these containers was limited to those gaps. In some cases, liverwort colonies that successfully established in gaps in the mulch barrier would slowly expand and grow over the mulched region. However, colonies were never able to establish directly on the rice hull mulch. Liverwort growing in containers with a rose canopy followed a similar trend to those growing in containers without a canopy.

Experiment 2. Similar to Experiment 1, substrate pH and rose foliar SPAD levels were not affected by rice hull treatments ($P = 0.6792$ and 0.6353, respectively) (data not shown). Roses in this trial were leafless when potted. Mulched roses tended to leaf out a few days later than non-mulched controls. A possible reason for delayed leafing, although not measured in this experiment, was potentially lower substrate temperatures due to mulching of the substrate surface. Despite this qualitative observation, rose root and shoot mass were similar across all treatments at 8 WAP when the experiment was terminated. Foliar Mn concentration was affected by rice hull depth (data not shown), although levels ranged from 73 to 116 $mg \cdot kg^{-1}$ (ppm) and thus were well within recommended range (Mills and Jones 1996). Similar to Experiment 1, roses growing with 2.5 cm (1 in) rice hulls had higher foliar N concentrations than non-mulched controls (3.4 vs. 3.0%) (data not shown). Despite a few significant yet trivial differences in foliar nutrient concentrations in rose leaf tissue, rice hull mulch had no affect on the growth of roses over an eight-week production cycle.

Flexuous bittercress germination was low in Experiment 2 compared to Experiment 1 (data not shown). Throughout the study, only 1.3 flexuous bittercress per pot germinated in non-mulched controls. At the conclusion of the experiment, the fresh weight of flexuous bittercress in control containers was 23.7 g (0.84 oz), with no flexuous bittercress in mulched containers. No flexuous bittercress were observed in mulched containers with or without a rose canopy.

Repeated measures analysis indicated a treatment by time interaction for liverwort coverage of the substrate surface for containers with and without rose canopies ($P < 0.0001$) in Experiment 2. Among containers with no canopies, liverwort established in non-mulched controls immediately with 5.7% coverage by 1 WAP (Table 3). By 8 WAP, liverwort had established with the highest percent coverage in non-mulched controls, with smaller colonies in containers mulched with 0.6 cm, and no establishment in containers mulched with 1.3 or 2.5 cm (0.5 or 1.0 in). Liverwort growth was more rapid and thorough in containers with a rose, although these containers never received any applied gemmae. All liverwort infestations probably came from the potted liner. While containers with and without rose canopies were not compared statistically, this does demonstrate an important attribute of rice hull mulch. A common problem with weed control in container crops is not the influx of seed or weed propagules that germinate once they reach a container surface, but instead the introduction of weed propagules from within the potted liners. In this case, the rice hulls controlled liverwort applied via gemmae dispersed on the container surface by us, as well as liverwort propagules within the liner.

Rice hulls applied to the substrate surface in depths up to 2.5 cm (1.0 in) do not affect the growth of potted roses

Table 3. Liverwort (*Marchantia polymorpha* L.) coverage of the container surface at 1, 4, and 8 weeks after potting (WAP) in containers with a 0 to 2.5 cm parboiled rice hull mulch depth. Half of the containers were potted with a single rose (*Rosa* 'Radazz') while the other half were not.

Rose canopy	Rice hull depth (cm)	1 WAP	4 WAP	8 WAP
no	0	5.7	20.8	47.5
	0.6	0.0	2.5	20.0
	1.3	0.0	0.0	0.0
	2.5	0.0	0.0	0.0
	Rate response[z]	Q**	Q***	Q***
	$LSD_{0.05}$	2.9	7.6	12.9
yes	0.0	12.5	40.0	99.2
	1.6	0.0	0.7	2.5
	3.2	0.0	0.0	0.0
	6.5	0.0	0.0	0.0
	Rate response	Q**	Q***	Q***
	$LSD_{0.05}$	5.5	11.4	3.9

[z]Rate response in each column to increasing depth of rice hull mulch, where Q indicates a quadratic rate response, respectively; and *, **, and *** represent significance where P < 0.05, 0.01, and 0.001, respectively.

over an eight-week production cycle. Others have shown container mulches to either have no effect, or a positive effect on ornamental plant growth. Altland and Lanthier (2007) reported either similar or improved hydrangea [*Hydrangea macrophylla* 'Fasan' (Thunb.) Ser.] growth with a variety of mulch products when the controlled release fertilizer was placed beneath the mulch compared to non-mulched controls. Smith et al. (1998) similarly showed pelleted or crumbled recycled newspaper applied to containers at 1.3 to 2.5 cm (0.5 or 1.0 in) depth resulted in either similar or improved azalea [*Rhododendron indicum* ×'Fashion' (L.) Sweet. or *R.* ×'Girard's Rose'] growth compared to non-mulched controls. Specific to rice hulls, Samtani et al. (2007) showed 0.5 cm (0.2 in) rice hulls did not injure or reduce growth of container growth 'Goldflame' spirea (*Spiraea japonica* L.f.), 'Hetz Midget' American arborvitae (*Thuja occidentalis* L.), and 'Snowmound' spirea (*Spiraea nipponica* Maxim.). Ramkhelawan and Brathwaite (2001) reported that 5 cm (2 in) of rice hulls reduced mandarin rootstock growth and number of plants suitable for budding compared to the control practice of routine hand-weeding. However, reduced growth was likely a function of weed competition due to poor control of perennial weeds in mulched containers. This particular research (Ramkhelawan and Brathwaite 2001) did not segregate the effects of mulch and weed competition in its evaluation.

Rice hulls at 1.3 cm (0.5 in) provided excellent flexuous bittercress and liverwort control throughout both experiments, while 2.5 cm (1 in) provided nearly perfect control. The flexuous bittercress seed density in nursery production sites could be higher than those applied in these experiments (Bachman and Whitwell 1994), thus rice hulls should be evaluated under higher weed pressures in the future. Weed control with rice hulls at 0.6 cm (0.25 in) was limited, in part due to gaps in the rice hull barrier that allowed liverwort and flexuous bittercress to establish. Similarly, Mathers (2003) reported that recycled newspaper mulch and sheep-wool mulch provided commercially acceptable weed control at 1.3 cm (0.5 in), while reduced and commercially unacceptable weed control when applied at 0.6 cm (0.25 in) depth. Samtani et al. (2007) reported that rice hulls at a depth of 0.5 cm (0.2 in) over a container substrate provided poor control of annual bluegrass, common groundsel, and shepherd's purse. This generally agrees with our results, in that the 0.5 cm (0.2 in) applied by Samtani et al. (2007) and the 0.6 cm (0.25 in) layer used in our experiments ultimately resulted in poor weed control. Ramkhelawan and Brathwaite (2001) reported that 5 cm (2 in) of rice hull mulch in container-grown mandarin rootstocks reduced weed growth by approximately 50%, but provided less control than a plastic disk or bagasse mulch. However, Ramkhelawan and Brathwaite (2001) used a substrate comprised of over 50% topsoil that was not sterilized prior to potting. The most prevalent weed reported was purple nutsedge which establishes primarily from buried tubers. Poor control was likely a result of purple nutsedge and other weed species regenerating from vegetative propagules in the soil, rather than a failure of the rice hulls to inhibit seed germination and establishment on the substrate surface.

Rice hulls applied in a layer 1.3 to 2.5 cm (0.5 to 1.0 in) thick will provide excellent flexuous bittercress and liverwort control from seed and gemmae propagules, respectively, introduced onto the mulch surface. Furthermore, excellent control at these depths can be expected over a duration of at least 8 weeks. Additional research is ongoing to determine the efficacy of rice hulls for preventing establishment of a broader range of weed species and over a longer period of time. Research is also ongoing to determine if rice hulls will prevent establishment of weeds from seed and propagules already on or within the substrate at the time of rice hull application.

Literature Cited

Abbey, T.M. and T.L. Mervosh. 2002. Mulches for weed suppression in containers of herbaceous perennials. Proc. Northeast. Weed Sci. Soc. 56:76.

Ahn, J.K. and I.M. Chung. 2000. Allelopathic potential of rice hulls on germination and seedling growth of barnyardgrass. Agron. J. 92:1162–1167.

Altland, J.E. and M. Lanthier. 2007. Influence of container mulches on irrigation and nutrient management. J. Environ. Hort. 25:234–238.

Bachman, G. and T. Whitwell. 1994. Hairy bitttercress (*Cardamine hirsuta*) seed production and dispersal in the propagation of landscape plants. Proc. South. Nur. Assoc. Res. Conf. 39:299–302.

Evans, M.R., J.S. Buck, and P. Sambo. 2011. The pH, electrical conductivity, and primary macronutrient concentration of sphagnum peat and ground parboiled fresh rice hull substrates over time in a greenhouse environment. HortTechnology 21:103–108.

Evans, M.R. and M.M. Gachukia. 2007. Physical properties of sphagnum peat-based root substrates amended with perlite or parboiled fresh rice hulls. HortTechnology 17:312–315.

File, S.L., P. Knight, C. Gilliam, D. Reynolds, and J. Altland. 2000. Evaluation of alternative weed control options for ornamentals grown in large containers. Proc. South. Nur. Assoc. Res. Conf. 45:397–402.

Mathers, H.M. 2003. Novel methods of weed control in containers. HortTechnology 13:28–34.

Mervosh, T.L. and T.M. Abbey. 2002. Weed management alternatives for container-grown shrubs. Proc. Northeast. Weed Sci. Soc. 56:75.

Mervosh, T.L. and T.M. Abbey. 1999. Evaluation of fabric discs, mulches, and herbicides for preventing weeds in containers. Proc. Northeast. Weed Sci. Soc. 53:122.

Mills, H.A. and J.B. Jones. 1996. Plant Analysis Handbook II. MicroMacro Publishing. Athens, GA. p. 213–214.

Moore, B.A., R.A. Larson, and W.A. Skroch. 1989. Herbicide treatment of container-grown 'Gloria' azaleas and 'Merritt Supreme' hydrangeas. J. Amer. Soc. Hort. Sci. 114:73–77.

Post, A.R., R. Ali, A. Krings, J. Xiang, B.R. Sosinski, and J.C. Neal. 2011. On the identity of the weedy bittercresses (*Cardamine* : Brassicaceae) in United States nurseries: Evidence from molecules and morphology. Weed Sci. 59:123–135.

Ramkhelawan, E. and R. Brathwaite. 2001. Weed management in container-grown Cleopatra Mandarin rootstocks with mulches. Trop. Fruits Newsletter 41:23–26.

Samtani, J.B., G.J. Kling, H.M. Mathers, and L. Case. 2007. Rice hulls, leaf-waste pellets, and pine bark as herbicide carriers for container-grown woody ornamentals. HortTechnology 17:289–295.

Smith, D.R., C.H. Gilliam, J.H. Edwards, J.W. Olive, D.K. Eakes, and J. Williams. 1998. Recycled waste paper as a nonchemical alternative for weed control in container production. J. Environ. Hort. 16:69–75.

Svenson, S.E. 1998. Suppression of liverwort growth in containers using irrigation, mulches, fertilizers and herbicides. Proc. South. Nur. Res. Conf. 43:396–398.

Tatum, D., K. Johnson, and N. Winter. 1999. The use of crum rubber for weed control in ornamental containers. Proc. South. Nur. Assoc. Res. Conf. 44:388.

Wooten, R.E. and J. Neal. 2000. Evaluations of PennMulch, Wulpack and Geodisc for weed control in containers. Proc. Northeast. Weed Sci. Soc. 54:96.

Wright, R.D. 1986. The pour-through nutrient extraction method procedure. HortScience 21:227–229.