EVALUATION OF HORTICULTURE APPLICATIONS OF LIGHT EXPANDED

CLAY AGGREGATES

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EVALUATION OF HORTICULTURE APPLICATIONS OF LIGHT EXPANDED CLAY AGGREGATES

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EVALUATION OF HORTICULTURE APPLICATIONS OF LIGHT EXPANDED

CLAY AGGREGATES

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Jeremy Martin Pickens, brother of John Pickens, and son of Larry and Ramona Pickens of Grand Bay, AL, was born on February 4, 1983 in Mobile Alabama. He graduated in May 2001 from Mobile Christian School in Mobile, AL. Upon entering Auburn University Fall Semester of 2001, he enrolled in the College of Agriculture and earned a Bachelor of Science degree in Horticulture in December 2005. Jeremy continued his time at Auburn University to pursue a Master's Degree in Horticulture. While there, he was initially employed as a graduate research assistant and then employed as an agricultural technician and received his Master of Science degree in Horticulture on May 10, 2008.

THESIS ABSTRACT

EVALUATION OF HORTICULTURE APPLICATIONS OF LIGHT EXPANDED CLAY AGGREGATES

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People involved in the nursery industry continue to seek more sustainable options to implement into production regimes. This search has been provoked by environmental and economic reasons. Several areas of popular nursery production practices have been explored to reduce cost and/or decrease environmental impact. The objective of these studies was to evaluate light expanded clay aggregates (LECA) as container mulches and as a bare rooting substrate.

In the first experiment, two mulch depths of LECAwere applied to the surface of substrate in container plant production as a non-herbicide weed control strategy compared to a single pre-emergent herbicide. Twenty-five *Oxalis stricta* seeds were applied to the substrate surface in each container pre- or post-weed control method depending on the treatment. Results indicate that HydRocks®, at a mulch depth of 2.5

cm (1.0 in.) provided successful control of oxalis when seeds were already present in the substrate but only limited control of oxalis when seeds were applied on top of mulch. There were no visual differences in plant growth between treatments in the first experiment and no statistical differences found in plant growth in the second experiment.

In a second experiment to compare yield and time to bare root, *Ophiopogon japonicus* and *Ophiopogon japonicus* 'Nana' bare root bibs were grown in common horticultural substrates and compared to the clay aggregates HydRocks® and Profile™. Results indicate that clay materials such as HydRocks® and Profile™, when compared to conventional substrates can provide suitable yields while also decreasing labor cost by decreasing time to bare-root.

In two experiments, the light weight aggregate, HydRocks® was evaluated as a rooting substrate when compared to conventional rooting substrates. The first experiment focused on large HydRocks® (0.25 in) and combinations of sand. The second experiment compared a smaller (0.18 in) HydRocks® aggregate to several conventional rooting substrates. In both experiments shoot growth, root growth, and ease of dislodging substrate particles were compared to conventional methods of producing bare root liners. While the results of cutting quality vary depending on species, these studies suggest that HydRocks® can be used as a successful rooting substrate.

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I. LITERATURE REVIEW

Expanded Clay Aggregates in Horticulture

Lightweight Expandable Clay Aggregates (LECA) are formed by firing clay through rotary kilns. Temperatures that are used to form LECA produce a ceramic aggregate that does not break down over time. The ability of certain clays and shale to expand when fired was first discovered in 1908 by Stephen Hayde, a British brick maker. Hayde saw the potential for expanded clay to be used as a lightweight aggregate. Lightweight aggregates have been used in structural concrete since the times of the early Greeks to lighten concrete without sacrificing strength. Since Hayde's discovery, advancements in the calcining process have lead to the development of Lightweight Expandable Clay Aggregates (LECA) (Bragdon, 1996).

Gases form as clay materials are fired, causing an expansion that, when cooled, leaves a cellular pore structure in the interior and exterior of the aggregates. The end result of the process is a structural grade lightweight aggregate with a low bulk density (Spomer, 1998).

Current horticulture applications of LECA

LECA has been used in structural concrete throughout the world for many years, but has just recently entered the horticulture industry. LECA products have chemical and physical properties that might provide additional applications not yet realized in the horticulture industry. Clay aggregates have been used successfully in high value turf applications such as golf courses and other athletic fields. Manufactured clay products have been used to alleviate compaction in high traffic turf areas while also increasing soil porosity (Wehtje et al., 2003). LECA has also been used successfully in green roof technology. Lightweight aggregates provide a lighter alternative to field soil while also providing a long lasting stable environment that cannot be achieved with organic based substrates (Thuring, 2005).

LECA used as a component of container substrates

The nursery and greenhouse industry has come a long way from the use of field soil in container production. Instead, substrate blends used in container plant production throughout the nation are primarily composed of pine bark. Quality plants can be grown in 100% pine bark but when needed, components such as sand, perlite, peat, and vermiculite are added to manipulate porosity, water holding capacity, stability, and cation exchange capacity (CEC). Non-clay lightweight aggregates such as perlite, vermiculite, and pumice are most commonly used as amendments to container substrates to increase porosity and drainage.

Aeration is an important factor in container substrates due to the high degree of respiration resulting from the use of organic material components. Increased air filled pore space is needed in order for CO_2 to be replaced by O_2 during irrigation cycles (Argo, 1998). Pine bark and peat moss also have a low cation exchange capacity (CEC) when compared to native soils. A sufficient CEC is needed to buffer sudden changes in pH and nutrient concentrations in organic substrates (Argo, 1998). Some ceramic clay products have also been used successfully to increase water holding and substrate cation exchange capacity (Whitcomb, 2003).

Several expanded clay products are currently available, the most common including: Stalite®, HydRocks®, Livlite®, Gravelite®, Profile™, and Turface™ (Arcillite). The parent clay material and the firing temperature play a significant role in both the chemical and physical properties of the final product. Expanded clay products that are currently available have produced inconsistent results from product to product when used as an amendment to conventional substrates (Breedlove et al., 1999; Catanzaro and Bhatti, 2005; Joiner and Nell, 1980; Poole and Conover, 1979; Warren and Bilderback 1992).

Stalite®, an expanded clay aggregate, was evaluated as a replacement for peat moss. Stalite® lowered container capacity and provided less available water than conventional bark and peat based substrate (Breedlove et al., 1999). Catanzaro and Bhatti (2005) reported different results when using Arcillite. Several studies have shown Arcillite, a calcined montmorillonite and illite clay, when used as an amendment in a pine bark substrate) produced superior plants by increasing container capacity, available water, and nutrient retention (Catanzaro and Bhatti, 2005; Warren and Bilderback, 1992).

LECA's ability to provide water to plants under drought conditions is uncertain. Aggregate interior pores can take months to become fully saturated under normal saturation procedures (Holm et al., 2004). The release rate of water through these small pores to the outside of the aggregate follows a similar rate as that of the initial absorption (Spomer, 1998). Spomer (1998) used pressure plate methods to determine a water release curve of LECA aggregates. Spomer reported that surface pores control the absorption and release of water from the inter-pores and as a result slows water movement in and out of the aggregate. Spomer (1998) concluded that water release is too slow to sustain plants as an alternative to normal irrigation cycles involved in container production. Bigelow et al. (2004) evaluated inorganic amendments of putting greens and reported that clay amendments did not increase available water in amended sands. Bigelow et al. (2004) questioned the pressure plate method's effectiveness to measure available water in calcined clay aggregates and concluded that porous inorganic amendments contained more available water than was correctly measured using pressure plate methods.

LECA's high bulk density limits its use in container substrates. However, LECA has potential as a replacement to perlite in certain substrate blends (Whitcomb, 2003). LECA aggregates provide pore space similar to perlite within a substrate blend, however whereas perlite has a tendency to float to the top of the substrates, LECA does not. Also unlike perlite, LECA does not break down over time and could also provide stability to substrates with an intended long life such as indoor planters and container plants. Limiting factors for LECA use as a substrate amendment for container production include availability, cost, and high bulk density.

LECA as a Bare Root Substrate for Propagation

Cutting propagation is the primary means of propagation for most of the plant material produced in the U.S. nursery industry. A considerable cost in the nursery industry is the production or purchase of liners. Propagation of cuttings requires a variety of specialized substrates depending upon species, and substrate components are a major cost consideration in liner production (Whitcomb, 2003). Canadian sphagnum peat moss, a common component in rooting substrates was reported to have cost the U.S. nursery and greenhouse industry $115,000,000 in imports in 1996 (Jasinki, 2005). Also, petroleum costs have caused a steady increase in the transportation costs of substrate materials and the cost of petroleum based plastic containers.

An alternative to the cost associated with container grown liners is producing bare-root liners. The purchase of bare root liners is generally less expensive than cost of "buying in" container liners due to weight and space requirements that in turn lowers shipping cost (Tilt et al., 2001). Bare root liners are exempt from several current U.S. policies that slow the shipment of plant material. Current U.S. regulations require that no soil/substrates can be imported into or exported out of the country to prevent the introduction of new soil born pathogens and pests. Also, due to federal plant pest regulations, growers in states within the fire ant quarantine zone are not allowed to export soil/substrates outside the quarantine zone without extensive pesticide application (Agriculture, 2002).

Disadvantages associated with the use of bare root liners are slower initial growth and increased mortality rates due to shock and stress brought on by the bare rooting process (Thiffault et al., 2004). Some species also have specific refrigeration requirements depending upon time of harvest. Not all species will tolerate the stress of being bare rooted because of hardiness or already weak root systems.

Generally bare root cuttings are grown in field beds with substrate subsequently removed through washing of roots with high pressured water. Rooting substrates provide several fundamental functions: support, moisture availability and aeration. Water uptake and retention is a major requirement in maintaining turgidity (Loach, 1985). The moisture content in a rooting substrate influences the capacity of stem cuttings to take up water and produce and support adventitious roots (Rein et al., 1991). Aeration is an important factor in container substrates due to the high degree of respiration that results from degradation of organic material and root respiration. Increased air filled pore space is needed in order for CO_2 to be replaced by O_2 during irrigation cycles (Argo, 1998). Conventional substrates provide considerable pore space to provide sufficient drainage and support gaseous diffusion (Loach, 1985). Substrates generally contain a large portion of organic material (sphagnum peat moss or pine bark) combined with smaller percentages of inorganic materials (sand, perlite, pumice, and vermiculite). Organic materials sustain plant life by retaining and providing nutrients and moisture. In addition to serving as a limited reservoir for water and nutrients, inorganic materials provide stability while also increasing porosity necessary for aeration and water movement (Hartman et al., 2002).

In some situations selection of substrate materials can be influenced by the level of ease required to bare root materials grown in the substrate (Tilt et al., 2001). Recently, work has been done to evaluate certain inorganic materials for production of bare root cuttings. Inorganic materials with larger particle sizes have been shown to be easily removed from roots while still producing a quality cutting (Blythe et al., 2005; Tilt et al., 2001).

Monolithic slag, a byproduct of the smelting process, can be used successfully as a substrate for rooting of cuttings. Monolithic slag outperformed pine bark, peat moss, perlite and vermiculite in root quality and ease of substrate removal (Blythe et al., 2005).

Monolithic slag has similar particle size distribution compared to LECA. LECA does, however have some moisture retention capacity that could provide a more favorable rooting environment than monolithic slag (Pickens and Sibley, 2006).

Ornamental grasses are grown in ground beds or large containers as stock plants to be later harvested for divisions (Hoffman et al., 1983). Many groundcover plant materials are sold as bare root divisions. A study using Profile™, a ceramic clay aggregate, when used as a bare root substrate, outperformed conventional methods of bare root divisions of *Ophiopogon japonicus*. Treatments containing Profile™ produced more offshoots and were removed of substrate with greater ease when compared to conventional substrates (Fain and Paridon, 2004).

Some Oregon nurseries have converted entire greenhouse floors into in-ground pumice beds where cuttings are directly stuck (Buamscha and Altland, 2005). These cuttings are easily removed of the pumice aggregate at harvest and the pumice is reused for many years without being replaced (personal observation). The particle distribution and bulk density of pumice (bulk density of 0.4-0.5g/cc) is similar to LECA (bulk density of 0.5-0.6 g/cc) (Gunnlaugsson and Adalsteinsson, 1995). LECA could be used in place of pumice in in-ground propagation beds in areas of the country where pumice is not readily available. Like pumice, LECA’s stable properties could allow it to be re-used for many years without replacement, possibly providing a more sustainable and cost effective approach to bare root liner production.

LECA as a Hormone Carrier

Propagation is one of the most labor intensive areas of the nursery industry. With the exception of seeds, mechanization is difficult to achieve because of the diverse shapes and sizes of propagules. Stem cuttings not only have to be taken from stock plants, but also pruned to the correct size and treated with rooting hormones. Auxin application to stem cuttings has traditionally been applied in the form of a basal quick dip or a talc powder. Labor involved with quick dip and powder applications requires only a few seconds for a bundle of cuttings, but a few seconds add up when considering the application of thousands of cuttings. Recently newer methods of application, such as foliar sprays and auxin saturated substrate, have been explored in an effort to improve automation and decrease human contact with auxin-based chemicals (Blythe et al., 2003). EPA worker protection standards require the use of personal protective equipment when handling agriculture chemicals. Protective equipment is generally cumbersome and uncomfortable in a typical propagation environment. Decreased human contact with auxins may reduce the need for protective equipment (Blythe et al., 2003).

Low concentration of auxin incorporated into rooting substrates has been proven successful on several species (Blythe et al., 2004). Auxin in an ethanol solution has been shown to be absorbed throughout the epidermis as well as the cut surface at the base of the stem (Geneve, 2000). Incorporation of auxin into a rooting substrate provided equal to or higher quality cutting when compared to the traditional quick dip (Blythe et al., 2004). Also cuttings inserted into auxin-incorporated substrate demonstrated higher rooting percentages, root number and root length when compared to conventional basal quick-dip techniques (Blythe et al., 2004). LECA presoaked in auxin might provide a reservoir of hormones available in the rooting substrate. Presoaked LECA might also provide the base of the cutting with a more prolonged exposure to the auxin, increasing rooting percent.

LECA as a weed barrier

The retail consumer demands weed free plant material and with continually increasing cost of labor, nursery growers are searching for new alternatives to current weed control practices (Simpson et al., 2004). Weeds are not only aesthetically problematic; some weed species can significantly reduce the growth of woody plants grown in containers with as little as one weed in a container (Berchielli et al., 1990). Weeds can also harbor and aid in the over wintering of some pathogens and insect pests. Weed control in container plant production is typically accomplished using broadcast applications of granular pre-emergent herbicides with a cyclone type spreader three to five times a year (Mathers, 2003). In the past, growers sought herbicides that covered a broad spectrum of weeds with little to no phytotoxic effects on the desirable crops; however in recent years growers have begun to accept weed control strategies that target only a single weed species (Simpson et al. 2004).

Due to the growing concern of environmental and ecological impact, there is an increasing interest in non-chemical weed control strategies in container plant production. Run-off, drift, and leaching are problems facing many nursery growers who desire to employ best management practices (Mathers, 2003; Yeager et al., 2007). Application of pre-emergent herbicides to large containers is not generally cost effective with spacing practices associated with large plant material due to the considerable amount of non target loss. Gilliam et al. (1992) reported that as much as 23% non-target loss of granular herbicides due to granules falling through spaces when containers were jammed container to container and non target loss as much as 80% with an increase to normal spacing practices.

In addition to non-target loss, labor involved with hand weeding has led growers to search for economical alternatives (Richardson et al., 2005). In a survey of weed control practices in container nurseries Gilliam et al. (1990) reported weeding labor $608-$1401 ha ($246-$567 a) annually with hourly wages ranging from $3.53-$3.97, while application of Rout, a common herbicide, cost $1398 ha ($566 acre) for 3 applications. However the projected cost of weed control was increased by hand removal of weeds not controlled by Rout to a total of $2006-$2800 ha ($812-$1133 acre). Weed control costs accounted for almost one-third of the total production costs in container production (Gilliam et al., 1990). Annually weeding labor costs for North Carolina was reported to range from $387-$891 ha ($967-$2,228 a) based on hourly wage of $14.75 (Judge et al., 2004). Furthermore, there are currently no pre-emergent herbicides available for use in covered structures such as greenhouses.

Mulches have been used extensively in the landscape and in vegetable production to control weeds. Mulches reduce soil moisture loss, lower soil temperatures, reduce erosion and suppress weed emergence (Robinson, 1988). A number of mulch materials have been evaluated as an alternative to hand weeding and conventional herbicide applications in nursery plant production. Lohr and Pearson-Mimms (2001) observed that organic mulches in containers reduce irrigation frequency needed for young plants before canopy effectively covered container surface. Mulches also play a role in photoinhibition by reducing light. Germination of many weed species can be promoted when seeds are exposed to light. Several different phytochrome types are responsible for photoinhibition of germination (Juroszek and Gerhards, 2004). Mulches reduce light penetration into the soil. Some reports indicate light penetration into the soil profile might play a role in photocontrol of weeds depending on the weed seeds depth and soil type but several other reports do not find light to be a major contributing factor in weed control (Juroszek and Gerhards, 2004).

Previous studies have evaluated coco discs, recycled newsprint pellets, ground rubber tires, geo-textile disks, and large pine bark nuggets as weed barriers (Atland and Lanthier, 2007; File et al., 2000; Richardson et al., 2005). Pine bark nuggets applied as surface mulch in combination with a single pre-emergent application was shown to provide excellent weed suppression 180 days after treatment (Richardson et al., 2005). In a separate study, herbicide treated bark provided 1.5 fold efficacy and 2.2 fold improvement in phytotoxic reduction compared to a conventional herbicide treatment (Mathers, 2003). Mulches are not effective on all weed species, as some weeds overcome mulch suppression by anatomical differences such as stolons or tubers. A study by Broshat (2007) reported that mulch significantly reduced dicot weed numbers in the landscape but was less effective on stoloniferous grasses.

Weed barriers should be made of course materials that dry out quickly, contain little nutrients, and be resistant to decomposition (Altland, 2005). HydRocks®, a light weight fired clay, used as a mulch layer to freshly potted plants could create an unfavorable environment for weed seed germination and establishment. Physical properties of HydRocks® prevent aggregates from breaking down and thus would require only a single application at potting. Because HydRocks® is resistant to breaking down it could be utilized in planters or when growing plant materials that require extended production times. Organic mulches deteriorate over time, can reduce soil pH, and have also been shown to reduce soil nitrogen in the landscape (Billeuad and Zajicek,1989; Duryea, 1999). HydRocks® has no significant nutritive value and has a low cation exchange capacity (5.12 meq/100ml).

HydRocks® is very flowable, such that automatic application at potting could easily be mechanized. The highly automated German nursery industry is already mechanically applying mulches for weed prevention in container production (Altland et al., 2005). HydRocks® applied as mulch to containerized plants could provide an economical and environmentally safe substitute to current weed control measures. HydRocks® applied as mulch could be used under covered structures where currently there are no pre-emergent herbicides available for use in covered structures such as greenhouses.

Conclusion

LECA is readily available in most of the United States. LECA could replace current horticulture aggregates and provide some novel horticulture uses. The amount of research on LECA's applications in horticulture is limited. The objective of the studies presented in the following chapters was to evaluate potential horticulture applications for LECA.

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II. USE OF LIGHTWEIGHT AGGREGATE HYDROCKS® AS A WEED BARRIER

Abstract

HydRocks® application to container grown plants was evaluated as a non-herbicide weed control strategy. Two depths, 1.27 cm (0.5 in) and 2.54 cm (1.0 in), of the clay aggregate HydRocks® were evaluated and compared to a single application of Broadstar (flumioxizin 0.25%) (0.375 lb ai/A). Twenty-five *Oxalis stricta* seeds were applied to the substrate surface in each container on top or below weed control method depending on the treatment. Oxalis were counted 120 days after placement (DAP) in the first experiment and 45, 65, 90 DAP in the second experiment. In the first study, HydRocks® applied as a surface mulch at 2.54 cm (1.0 in) provided successful control of oxalis when seeds were already present in the substrate but only limited control of oxalis when seeds were applied on top of mulch. In control of oxalis germination there was no difference found between the Broadstar application and the HydRocks® mulched at 2.54 cm (1.0 in). In the second study no differences were found after 90 days in oxalis weed counts and shoot fresh weight of oxalis seedlings among any of the weed control treatments. There were no visual differences in plant growth among any treatment in either experiment.

Index Words: Expanded clay, weed control, container mulch, herbicide substitutes, best management practices

Species used in this study: *Gardenia jasminoides* 'Daisy', *Lagerstroemia x* 'Tuscarora', *Rhododendron* x 'Midnight Flare', *Nandina domestica* 'Firepower' and *Oxalis stricta*

Chemicals used in this study: Broadstar (flumioxizin 0.25%), 2-[7-fluoro-3, 4-dihydro-3-oxo-4-(2-propynyl)-2*H*-1, 4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione

Significance to Industry

There is an increasing interest for non-chemical weed control strategies in container production of nursery plants. Previous studies have evaluated a number of materials as weed barriers. The results of this study indicate that an application of HydRocks® at 2.54 cm (1 in) thick on top of the substrate, controls oxalis seed already present on the substrate surface and provides partial control of subsequent infestations of seed when applied at a depth of 1.27 cm (0.5 in) and 2.54 cm (1 in).

Introduction

The retail consumer demands weed free plant material and with continually increasing cost of labor nursery growers are searching for new alternatives to current weed control practices (Simpson et al., 2004). Weeds are not only aesthetically problematic; some weed species can significantly reduce the growth of woody plants grown in containers with as little as one weed in a container (Berchielli et al., 1990). Weeds can also harbor and aid in the over wintering of some pathogens and insect pests.

Weed control in container production is typically accomplished using broadcast applications of granular pre-emergent herbicides with a cyclone type spreader. Successful weed control with herbicides can require from three to five applications a year (Mathers, 2003). In the past, growers sought herbicides that covered a broad spectrum of weeds with little to no phytotoxic effects on the desirable crops; however in recent years growers have begun to accept weed control strategies targeting only a single weed species (Simpson et al. 2004).

Due to the growing concern of environmental and ecological impact, there is an increasing interest in non-herbicide weed control strategies in container plant production. Run-off, drift, and leaching are problems facing many nursery growers who desire to employ best management practices (Mathers, 2003; Yeager et al., 2007). Also with increasing demand of organically grown agricultural products alternatives to chemical control are becoming more cost effective.

Application of pre-emergent herbicides to large containers is not generally cost effective with spacing practices associated with large plant material due to the considerable amount of non-target loss. Gilliam et al. (1992) reported as much as 23 % non-target loss of granular herbicides due to granules falling through spaces when containers are jammed container to container, with non-target loss as much as 80 % with increased spacing required to finish some plants. In addition to non-target loss, labor involved with hand weeding has led growers to search for economical alternatives (Richardson et al., 2005). In a survey of weed control practices in container nurseries

Gilliam et al. (1990) reported weeding labor $608-$1401 ha ($246-$567 a) annually with hourly wages ranging from $3.53-$3.97, while three applications of Rout, a common herbicide, cost $1398 ha ($566 a). Weed control costs accounted for almost one-third of the total production costs in container production in 1990 (Gilliam et al., 1990). Annually weeding labor costs for North Carolina was reported to range from $387-$891 ha ($967-$2,228 a) based on hourly wage of $14.75 (Judge et al., 2004). Furthermore, there are currently no pre-emergent herbicides available for use in covered structures such as greenhouses.

Mulches have been used extensively in the landscape and in vegetable production to control weeds. Mulches reduce soil moisture loss, lower soil temperatures, reduce erosion and suppress weed emergence (Robinson, 1988). A number of mulch materials have been evaluated as an alternative to hand weeding and conventional herbicide applications in nursery plant production. Lohr and Pearson-Mimms (2001) observed that organic mulches in containers reduce irrigation frequency needed for young plants before canopy effectively covered container surface. Mulches are also believed to reduce light penetration into the soil as a result inhibit some weed seed germination (Juroszek and Gerhards, 2004). Exposure to light promotes the germination of many weed species (Bewley and Black, 1994).

Previous studies have evaluated coco discs, recycled newsprint pellets, ground rubber tires, geo-textile disks, and large pine bark nuggets as weed barriers (Atland and Lanthier, 2007; File et al., 2000; Richardson et al., 2005). Pine bark nuggets applied as surface mulch in combination with a single pre-emergent application was shown to provide excellent weed suppression 180 days after treatment (Richardson et al., 2005). In a separate study, herbicide treated bark provided 1.5 % fold efficacy and 2.2 fold improvement in phytotoxic reduction compared to a conventional herbicide treatment (Mathers, 2003). Mulches are not effective on all weed species, as some weeds avoid mulch suppression by anatomical differences such as stolons or tubers. A study by Broshat (2007) reported that mulch significantly reduced dicot weed numbers in the landscape but was less effective on stoloniferous grasses.

Weed barriers should be made of course materials that dry out quickly, contain little nutrients, and are resistant to decomposition (Altland, 2006). HydRocks® (Big River Industries Alpharetta, GA) used as a mulch layer to freshly potted plants could create an unfavorable environment for weed seed germination and establishment. HydRocks® is lightweight porous aggregate formed by calcining clay at temperatures reaching 1093 ºC (2000° F). Hydrocks® is produced from several quarries in the southeast. The material for this study was produced Livingston, Alabama. Physical properties of HydRocks® prevent aggregates from breaking down and thus would require only a single application at potting. Because HydRocks® is resistant to breaking down it could be utilized in planters or when growing plant materials that require extended production times. Organic mulches deteriorate over time, can reduce soil pH and have also been shown to reduce soil nitrogen in the landscape (Billeuad and Zajicek, 1989; Duryea, 1999). HydRocks® has no significant nutritive value and has a cation exchange capacity of 5.12 meq/100ml.

HydRocks® is very flowable, such that automatic application at potting could easily be mechanized. The highly automated German nursery industry is already mechanically applying mulches for weed prevention in container production (Altland et al., 2006). The objective of this study was to evaluate the use of HydRocks® as a weed barrier when compared to conventional pre-emergent herbicides to determine if HydRocks® applied as mulch to containerized plants could provide an economical and environmentally safe substitute to current weed control measures.

Material and Methods

This study was conducted in Auburn, Alabama and repeated at the Ornamental Horticulture Research Center, Mobile, AL in 2007. On December 18, 2006, at the Paterson Greenhouse Complex, Auburn University (USDA Cold Hardiness Zone 8) 8.89 cm (3.5 in.) diameter containers of crapemyrtle (*Lagerstroemia x* 'Tuscarora'), azalea (*Rhododendron* x 'Midnight Flare'), and nandina (*Nandina domestica* 'Firepower') were potted into full gallon containers (7695 $cm^{3)}$. The substrate used was a 6:1 pine bark:sand (v:v) amended with 9.9 kg/m^3 (16.7 lb/yd^3) of 18N-2.6P-9.9K (18-6-12 Polyon NPK), 3.0 kg/m^3 (5 lb/yd^3) of dolomitic lime, and 0.9 kg/m^3 (1.5 lb/yd^3) of Micromax®. Plants were potted approximately 3.81 cm (1.5 in) below the top of the pot. Containers were irrigated after potting and allowed to settle 24 hours before treatments were applied. Twenty-five oxalis seeds were applied to the surface of each container before application of the following treatments: granular pre-emergent herbicide application of Broadstar (0.375 lb ai/a); HydRocks® mulch at 1.27 cm (0.5 in) or 2.54 cm (1.0 in) depth; no mulch or herbicide; and two treatments where 25 oxalis seeds were scattered across the surface of each container after application of HydRocks® mulch. One treatment consisted of no oxalis seed application, no mulch and no herbicide. Prior to use, HydRocks® aggregates were removed by screening to include only particles less than 0.635 cm (0.25 in). All treatments were irrigated prior to mulch and herbicide application. Each treatment consisted of 10 single pot replications for crapemyrtle and azalea and 6 single pot replications for nandina. On April 11, 2007, 120 days after potting, oxalis seedlings were counted.

The study was repeated with slight modifications at the Ornamental Horticulture Research Center in Mobile, AL on August 24, 2007. In this study trade gallon containers (3207 cm^3) were filled with 3:1 pine bark:peat substrate amended with 8.3 kg/m^3 (14 lb/yd^3) of 17N- 3.0P-9.9K (17-7-12 Osmocote), 3.5 kg/m^3 (6 lb/yd^3) of dolomitic lime and 0.9 kg/m^3 (1.5 lb/yd^3) of Micromax. This study was divided into two separate tests. In the first test treatments were applied to containers with substrate only to evaluate weed control. In the second test containers were potted with *Gardenia jasminoides* 'Daisy' to evaluate effects of weed control methods on plant growth. Substrate only container treatments were treated the same as previously described and consisted of 10 single pot replications. Gardenia containers received the same weed control treatments but no oxalis seeds were sown and consisted of 10 single pot replications. Containers were arranged in a complete randomized block design and placed in full sun under overhead irrigation. Weed counts were taken on substrate only containers at 45, 60 and 90 days after potting. Growth indices were taken on gardenia plants 100 days after potting. All data was analyzed using the GLM procedure with mean separation by Waller-Duncan K-ratio test (SAS Version 9.1 SAS Institute, Cary, NC).

Results and Discussion

In the first experiment, with data pooled across species, there was no difference in oxalis control 120 days after placement (DAP) between the herbicide treatment and the 2.54 cm (1.0 inch) thick HydRocks® treatment with oxalis seeds applied before mulching (Table 1). Across species the no weed control treatment with seeds applied had the highest number of oxalis seedling per container. Also, across species the Broadstar treatment and HydRocks® mulched to 2.54 cm (1 in) provided superior control of oxalis. In azalea and nandina containers both 1.27 cm (0.5 in) and 2.54 cm (1 in) mulch depths provided poor oxalis control when seed were applied on top of mulch. Nandina potted containers had the fewest number of oxalis seedlings over all treatments compared to the other two species. This could be attributed to the nandina's thicker canopy preventing light from contacting container surfaces. In control of oxalis, there was no difference between HydRocks® mulch treatments of 0.5 inch and 2.54 cm (1.0 in) with oxalis seeds applied post mulch application and HydRocks® mulch treatments of 0.5 inch with oxalis seeds applied pre mulch application. No difference in plant growth was seen in visual observations across species.

In the second experiment oxalis control was similar among all treatments except the non-treated control containers at 45, 60, and 90 DAP (Table 2). Fresh weights of oxalis taken at 90 DAP showed similar results. All mulch depths and the herbicide treatment effectively controlled weeds for 90 days after planting when compared to containers that had no weed control and were sown with oxalis seeds. No difference in growth of gardenia plants occurred between any of the treatments, indicating that HydRocks® mulching does not affect plant growth of *Gardenia jasminoides* 'Daisy' (data not shown). HydRocks® applied at 2.54 cm (1.0 inch) had the greatest control of oxalis throughout the second experiment.

These studies demonstrate that HydRocks®, when used as surface mulch at 2.54 cm (1.0 in), can provide successful weed control for oxalis seeds already present on substrates. These studies also suggest that HydRocks® can provide limited control of oxalis seeds that are introduced post-mulch application.

In a different experiment conducted under shade, HydRocks® mulched at 2.54 cm 1 inch was less effective in the control of volunteer weeds but still provided better control than a single pre-emergent application after 160 DAP (data not shown). The shade might not allow HydRocks® mulch to effectively dry out enough between irrigation cycles, allowing some weed seed germination.

Soil disruption is common in garden centers and nurseries where containers require moving. Chemical pre-emergent herbicides provide excellent weed prevention with exception of the disturbance of the chemical barrier at the surface of the substrate. Container mulches similar to HydRocks® would greatly reduce the problems associated with the disruption of chemical barriers. HydRocks® also has some aesthetic qualities and could find a use in planters in the landscape, interior-scaping, and garden centers were chemical control of weeds is limited. HydRocks® resistance to decomposition could provide a reusable tool for weed prevention in container production and for weed control in large containers that would require an extended production time. Further testing is needed to provide a better understanding of what weed species HydRocks® could control when used as mulch in container production as well as evaluations on various sizes of HydRocks® aggregates.

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Table 1. Comparison of HydRocks® mulch and pre-emergent herbicide on establishment of *Oxalis stricta* Spring 2007.

				Oxalis (ct)[Z]			
Treatment	Seeded[Y]	Herbicide[X]	Mulch Depth[W]	Azalea	Crapemyrtle	Nandina	Pooled
1	None	None	0	3.00 c[V]	7.80 b	1.17 cd	4.42 c
2	Before	None	0	9.60 a	11.7 a	6.50 a	9.69 a
3	Before	Yes	0	0.10 d	0.20 d	0.67 d	0.26 d
4	Before	None	0.5	3.20 c	5.60 bc	2.83 bc	4.03 c
5	Before	None	1	0.50 d	0.90 d	0.00 d	0.53 d
6	After	None	0.5	5.60 b	7.00 b	4.17 b	5.81 b
7	After	None	1	6.50 b	3.70 c	3.50 b	4.73 bc

[Z]Number of oxalis per contaienr made 120 days after planting, highest counts equal greatest number of weeds.

[Y]Seeds were sown before or after application depending on treatment.

[X]Broadstar™ was applied at a rate of 150 lbs per acre.

[W]Mulch depth in inches.

[V]Means within column followed by the same letter are not significantly different (Waller-Duncan K-ratio t test $p \leq 0.05$).

Table 2. Comparison of HydRocks® mulch and pre-emergent herbicides on establishment of *Oxalis stricta* Fall 2007.

				Oxalis (ct)[Z]			Oxalis
Treatment	Seeded[Y]	Herbicide[X]	Mulch Depth[W]	45 DAP[V]	60 DAP	90 DAP	Fresh Weights (g)
1	None	None	0	0.0 b[U]	0.0 b	0.0 b	0.0 b
2	Before	None	0	3.7 a	5.3 a	6.7 a	31.6 a
3	Before	Yes	0	0.1 b	0.3 b	0.2 b	0.2 b
4	Before	None	0.5	0.0 b	0.1 b	0.1 b	0.1 b
5	Before	None	1	0.0 b	0.0 b	0.0 b	0.0 b
6	After	None	0.5	0.0 b	0.3 b	0.3 b	1.5 b
7	After	None	1	0.1 b	0.1 b	0.2 b	0.6 b

[Z]Number of oxalis per container

[Y]Seeds (25 per contianer) were sown before or after application depending on treatment, or not at all for Treatment 1.

[X]Broadstar™ was applied at a rate of 150 lbs per acre.

[W]Mulch depth in inches.

[V]Days after potting

[U]Means within column followed by the same letter are not significantly different (Waller-Duncan K-ratio t test ($p \leq 0.05$).

III. EVALUATION OF CLAY AGGREGATES IN PERENNIAL OFFSHOOT PRODUCTION

Abstract

In an effort to compare yield and bare rooting time, *Ophiopogon japonicus* and *Ophiopogon japonicus* 'Nana' bare root bibs were potted into 100% aged pine bark, 8:2 (v:v) pine bark:peat moss, 100% perlite, 100% fine grade Profile™ porous ceramic (Profile™ products LLC, Buffalo Grove, IL) , or 100% course grade Profile™ porous ceramic. In the second year experiment *Ophiopogon japonicus* was potted into: 100% aged pine bark, 100% 3/16 HydRocks® (Big River Industries Alpharetta, GA), fine grade 100% Profile™, 100% Perlite, 100% Sand, 8:2 (v:v) pine bark:peat moss, and 3:1 (v:v) 3/16 HydRocks®:sand. In 2007, fine grade Profile™ produced the highest number of total bibs per container and was similar to 8:2 pine bark:peat moss. HydRocks® was similar to pine bark in total bibs per container but was more efficiently removed from roots. HydRocks® took 50 % less time to bare root that pine bark:peat moss and 51 % less time to bare root than pine bark. HydRocks® took 23 % less time to bare root than fine grade Profile™. Results indicate that clay materials such as HydRocks® and Profile™, when compared to conventional substrates can provide suitable yields while also decreasing labor cost by decreasing time to bare-root.

Index of words: Profile™, HydRocks®, bibs, lightweight aggregate

Species used in this study: *Ophiopogon japonicus, Ophiopogon japonicus* 'Nana'

Significance to the Industry

Often perennial ground covers and other perennial dividing plants are mass produced and sold as bare root liners. Dividing and bare rooting these plants is labor intensive, costly and is often destructive to plant root structure. This is especially true when dividing from plants grown in soilless organic substrates in containers. In addition to labor cost, substrate costs that include peat moss and pine bark have increased with reduced availability and the growing cost of fuel (Perkowski, 2007). Light weight aggregates, such as Profile™, HydRocks®, pumice, and monolithic slag, have all shown potential to be re-used in bare root production (Blythe et al., 2005; Buamscha and Altland, 2005; Tilt et al., 2001). Results from these studies indicated clay products can provide suitable or better growing conditions for *Ophiopogon japonicus* and can decrease harvest time between 30 and 50% with less root damage when compared to other substrates.

Introduction

The U.S. nursery and greenhouse industry imported about $115,000,000 worth of sphagnum peat moss from Canada in 1996 (Jasinki, 2005). Peat moss is a major substrate cost component in production of container grown liners. Other costs of container production are the individual containers as well as labor and machinery involved in potting. Plastic containers are petroleum based products whose costs fluctuate with the price of crude oil.

An alternative to the expense associated with container grown liners is producing bare-root liners. Purchase cost of bare root liners is generally less expensive than the cost of "buying in" container liners due to weight and space (Tilt et al., 2001). Bare root liners are exempt from several current U.S. policies (providing they are completely free of soil) that slow the shipment of plant material (Agriculture 2002). Current U.S. regulations require that no soil/substrate can be imported into or exported out of the country to prevent the introduction of new soil born pathogens and pests. Also, due to federal plant pest regulations, growers in states within the fire ant quarantine zone are not allowed to export soil/substrate outside the quarantine zone without mandated pesticide application (Agriculture, 2002).

Disadvantages associated with the use of bare root liners are slower initial growth and increased mortality rates often due to shock and stress brought on by the bare rooting process (Thiffault et al., 2004). Some species also have specific refrigeration requirements depending upon time of harvest. Not all species will tolerate the stress of being bare rooted because of hardiness or species-specific weak root systems.

Generally bare root cuttings and offshoots are grown by either traditional container production methods with substrate subsequently removed through washing of roots with high pressured water or in inground beds of amended field soil. The level of difficulty in removing substrate from roots in bare root production is dependent on the root structure and substrate components. Recently, work has been done to evaluate certain inorganic materials for production of bare root cuttings. Inorganic materials such as monolithic slag and ceramic aggregates with stable large particle sizes have been shown to be easily removed from roots in cutting propagation, while still producing a quality rooted cutting (Blythe et al., 2005; Tilt et al., 2001).

Expanded clays are light weight aggregates formed by firing certain expandable clays in rotary kilns. Several expanded clay products are currently available, the most common including: Stalite®, HydRocks®, Livlite®, Gravelite®, Profile™, and Turface™ (Archilite). The parent clay material and the firing temperature play a significant role in both the chemical and physical properties of the final product. Expanded clay products that are currently available have produced inconsistent results from product to product when used as an amendment to conventional substrates (Breedlove et al., 1999; Catanzoro and Bahitti, 2005; Joiner and Nell, 1980; Poole and Conover, 1979).

Preliminary studies have shown that the porous nature of expanded clay HydRocks®, (Big River Industries Alpharetta, GA), allows it to absorb up to fifty percent of its own weight in water in a 24 h period. Subsequent availability of this absorbed water to roots is unknown. Aggregate interior pores can take months to become fully saturated under normal saturation procedures (Holm et al. 2004). Release rate of water through these small pores to the outside of the aggregate follows a similar rate as that of the initial absorption. As a result, release rate is thought to be too slow to sustain plants under normal irrigation cycles used in container production (Spomer, 1998). Bigelow et al., (2004) evaluated physical properties (using pressure plate methods) of inorganic amendments of putting greens and observed clay amendments did not increase water available to the plant in amended sands. Bigelow et al., (2004) questioned the pressure plate method's effectiveness to measure available water in calcined clay aggregates and concluded that porous inorganic amendments contained more available water than was correctly measured using pressure plate methods. Water absorbed by expanded clay aggregates may not provide sufficient water to sustain plants but may provide a favorable environment for root initiation by maintaining a moisture level to simulate the hydrology of organic substrates.

Expanded clay aggregates are essentially too heavy (0.64 g/cm^3) (Table 1) to be used in container production but would be better suited for in-ground growing or rooting beds. In preliminary studies, expanded clay aggregates were easily dislodged from roots when shaken (data not shown). If plant materials could be grown in expanded clay as successfully as conventional materials, expanded clays may provide a renewable substrate while also decreasing labor cost associated with bare rooting plant material.

Some Oregon nurseries have converted entire greenhouse floors into in-ground pumice beds where cuttings are directly stuck (Buamscha and Altland, 2005). These cuttings are easily removed of the pumice aggregate at harvest and the pumice is reused for many years without being replaced (personal communication). The particle distribution and bulk density of pumice (0.4 g/cc) is similar to expanded clay (0.64 g/cm^3; Table 1) (Gunnlaugsson and Adalsteinsson, 1995). Expanded clays could be used in place of pumice in in-ground propagation beds in areas of the country where pumice is not readily available. Like pumice, stable properties of expanded clays would allow re-use for many years without replacement, providing a more sustainable and cost effective approach to bare root liner production. The objective of this study was to evaluate

HydRocks® and Profile™ in the bare root production of *Ophiopogon japonicus* when compared to conventional substrates.

Materials and Methods

On February 23, 2003, three single bib bare root divisions of *Ophiopogon japonicus* and *Ophiopogon japonicus* 'Nana' were potted into 20.32 cm (8 in) wide by 13.97 cm (5-1/2 in) container at the Mississippi State University Truck Crops Branch Experiment Station in Crystal Springs, Mississippi. Substrate treatments included 100% aged pinebark, 8:2 (v:v) pine bark:peat moss, 100% perlite, 100% fine grade Profile™ porous ceramic (Profile™ products LLC, Buffalo Grove, IL) , or 100% coarse grade Profile™. Hardware cloth (2 mm x 2 mm) was used in the bottom of each container to avoid substrate loss from container holes. Eight replicates per treatment for each species were prepared and placed in a greenhouse and liquid fertilized with (15-5-15 Cal-Mag, The Scotts Co., Marysville, OH). On June 18, 2003, plants were transferred outdoors under an overhead irrigated shade structure (40% shade). Each container was top-dressed with 14g of 18N-2.5P-9.8K (18-6-12 The Scotts Co). The experiment was terminated on September 24, 2003. Two replications from each treatment were randomly assigned to four workers and time to bare root each container and total bib number per container was recorded. Bibs were graded on a scale from 1 to 3 based on the quality foliage and root density (1 being of highest grade and 3 the poorest). Containers of *Ophiopogon japonicus* 'Nana' were over wintered under the shade structure and fertilized on March 12, 2004 with 18g of 15N-1.7P-7.3K (15-4-9 Harrells, Sylacauga, AL), overhead irrigation as needed and harvested as described above on July 14, 2004.

The study was repeated with slight modifications in 2006-2007 at the Paterson Greenhouse Complex in Auburn, Alabama. In this experiment HydRocks® screened to 0.46 cm (3/16 in) , a light expanded clay aggregate marketed for horticulture applications available from Big River Industries (Alpharetta, GA), and fine grade Profile™, a ceramic clay aggregate, were compared to common propagation materials for ease of bare rooting and plant growth. HydRocks® is lightweight porous aggregate formed by calcining clay at temperatures reaching 1093 ºC (2000° F). Hydrocks® is produced from several quarries in the southeast. The material for this study was produced in Livingston, Alabama.

On November 21, 2006 three bare root *Ophiopogon japonicus* bibs were potted into 20.32 cm (8 in) wide by 13.97 cm (5.5 in) container. Substrate treatments consisted of 100% aged pine bark, 100% HydRocks® (≈0.46 cm), 100% Profile™, 100% Perlite, 100% Sand, 8:2 (v:v) pinebark:peatmoss, or 3:1 (v:v) 3/16 HydRocks®:sand. Each treatment was divided into nine replications. Hardware cloth (2 mm x 2 mm) was placed in the bottom of each container to prevent material loss through container holes. Containers were placed in a double layer polyethylene greenhouse with temperatures averaging 23.8 C (75 F°). Plants were hand watered daily as needed and liquid fertilized when watered (20-10-20 Pro Sol). On May 3, 2007, plants were transferred to an outdoor shade structure covered with 40% shade cloth, and top-dressed with 14g of 17.4N-5.8P-11.6K (18-6-12 Polyon NPK). One-half inch of overhead irrigation was applied daily. Bib counts were taken every 30 days for the first seven months until individual offshoot numbers were indistinguishable due to plant density. Particle size distribution was determined for each treatment substrate with a Camsizer® (Restsch® Technology, Haan

Germany) using three 100 gram samples. Treatment physicals properties including water holding capacity (WHC), total porosity (TP), air space (AP) and bulk density were determined using the North Carolina State University Porometer™ as described by Fonteno and Bilderback (1993).

On October 2, 2007, three workers were randomly assigned three replications from each treatment and instructed to bare root each container as fast as possible by shaking and using pressurized water. Bare rooting time for each container was recorded. Offshoot fresh weights were taken after harvest and offshoots were divided into quality grades 1, 2, and 3, based on density and foliage (1 being of the highest quality and 3 the lowest). Contrast of bare rooting time was performed using Proc Mix SAS System, Release 9.1, with worker as the random variable and substrate as the fixed variable, p-values determined using the pdiff statement. All other data was analyzed using Proc GLM SAS System, Release 9.1 (SAS 9.1, SAS Institute Inc., Cary, NC).

Results and Discussion

In 2003, 30 weeks after potting, no significant difference in total bibs (TB) was observed between any treatment with the exception of the fine grade Profile™ (14.6 TB) (Table 2). Pine bark:peat moss yielded the second highest TB (9.9) followed by course grade Profile™ (9.8) and perlite (9.8). Pine bark grown plants produced the least number of bibs, averaging 9 bibs per container. It took 2.4 times as long per bib to bare root pine bark grown plants than fine grade Profile™ and 1.9 times as long to bare root pine bark:peat moss than fine grade Profile™. Plants grown in fine grade Profile™ were bare rooted 60% faster than plants grown in pine bark per pot and 50% faster than plants grown in the 80:20 pine bark:peat moss substrate per pot (Table 3). No differences were observed between pine bark and pine bark:peat moss treatments in time to bare root (TBR) per bib. Pine bark and pine bark:peat were different in TBR per bib when compared to perlite, fine grade Profile™ and coarse grade Profile™. No differences were observed in TBR per bib between both grades of Profile™ and perlite. In general the three inorganic substrates (perlite, and both grades Profile™) were easier to dislodge from roots than both organic substrates (pine bark and pine bark:peat moss) (Table 3).

In 2004, 72 weeks after potting, fine grade Profile™ produced 16% more *Ophiopogon japonicus* 'Nana' bibs than pine bark and produced the same TB as the pine bark:peat substrate (Table 4). There was no difference observed in TB between pinebark, pine bark:peat, and both fine and course grade Profile™. Perlite (41.8 TB), however, had fewer bibs than all other treatments except course grade Profile™ (65.0 TB). Both fine and course grade Profile™ plants required 33% less TBR per bib than pine bark and pine bark: peat moss grown plants (Table 5). No differences were observed between pine bark, pine bark:peat moss and perlite. Both Profile™ treatments were different than TBR per bib than pine bark, pine bark:peat moss and perlite. In this study the inorganic substrates excluding perlite generally had less TBR per bib than the organic substrates. Perlite (1.51 sec.) had the longest TBR per bib of any treatment and was similar to pine bark (1.44 sec.) and pine bark:peat moss(1.45 sec.) in TBR per bib (Table 5).

In 2007, 45 weeks after potting, perlite, fine grade Profile™, HydRocks®, HydRocks®:sand and sand had the same shoot weights. Pine bark:peat moss was similar to all other treatments in shoot weight. No difference were observed across treatments in root weight. Profile™ had the highest total weight of all treatments and was similar to

HydRocks® (Table 5). Pine bark:peat moss had the highest root:shoot ratio and Profile™ had the lowest (Table5). The fine grade Profile™ produced the greatest TB per container (37.7) and was similar to pine bark:peat moss (32.6). (Table 6). In this study TB was similar among Profile™ and pine bark:peat moss. Profile™ took 31% less TBR than the pine bark: peat and 30% less TBR per bib than pine bark (Table 3). HydRocks® grown plants (28.0 TB) were similar to plants grown in pine bark, perlite, sand or HydRocks®:sand mix. HydRocks® had 50% less TBR per bib than pine bark:peat moss and 51% less TBR than pine bark. HydRocks® grown plants had 28% less TBR per bib than Profile™ grown plants. No difference was observed between pine bark and pine bark:peat moss in TBR per bib. No differences were observed between pine bark and perlite. No differences were found in TBR per bib when comparing perlite, Profile™, HydRocks®, HydRocks®:sand and sand. Profile™, HydRocks®, HydRocks®:sand and sand were different in TBR per bib when compared to pine bark and pine bark:peat moss. Similar to 2003, all inorganic substrates with the exception of perlite were more easily dislodged from roots than organic substrates (Table 3). In 2007, HydRocks® was similar to pine bark in TB yield but was more efficiently removed from roots (Table 6). HydRocks® had the fastest TBR of all substrates. During harvest HydRocks® required almost no water in bare-rooting, which made clean up less difficult.

The difference in TB between Profile™ and both bark-containing substrates varied between 2003 and 2007, but in both cases fine grade Profile™ yielded more TB than pine bark or pine bark:peat moss (Table 2 and 6). There was a 105 day difference in production time between 2003 and 2007, with 2007 having the longer production. This longer production time could explain the reason for the percentage difference between

2003 and 2007 studies. Difference in production time could also explain why perlite was similar to both organic substrates in TBR per bib. Although a different cultivar was used (*Ophiopogon japonicus* 'Nana') in 2004 than in 2003 and 2007, plants grown in perlite were again similar to those in both organic substrates and like 2007, the study was allowed an extended production time, 72 weeks. A longer production time produced a greater root density extending TBR. Extended production time may also cause the perlite to become more brittle and deteriorate into smaller particle sizes, making TBR more difficult. During harvest it was observed that finer particles in several substrates were more difficult to remove from root systems.

Physical Properties. Substrates in the 2007 study were analyzed using NC State Porometers. When compared to ranges defined in The Best Management Practices (BMP) Guide for Producing Container Grown Plants (Yeager et al., 2007), HydRocks®:sand and sand were the only substrates out of BMP ranges for total porosity (50-85 %) (Table 6). HydRocks®, HydRocks®:sand and sand were out of range for water holding capacity (46-65%). Profile™, sand, and HydRocks®sand were similar and considerably low in air space. In the case of Profile™, its high water holding capacity can be attributed to the aggregates ability to absorb water in aggregate micro-pores. The air space associated with Profile™, although lower than the recommended range, may not be accurately interpreted by standard means, since Profile™ desorption might allow an increase in airspace at a rate that meets roots oxygen needs with normal irrigation frequencies. Profile's™ high water holding capacity suggests lower water requirements. The opposite could be said of HydRocks®. HydRocks® had a low water holding capacity, but the interior pores of the aggregate provide more surface area that might allow for more water molecules to adhere to the aggregates surface. This may allow roots to stay moist enough between irrigation cycles. HydRocks® might produce higher yields using cyclic irrigation with increased frequencies. When 25% sand was incorporated into HydRocks®, total porosity was decreased and water holding capacity was increased. This however did not increase yield when compared to plants grown in 100% HydRocks® (Table 6).

Results of these studies indicate that inorganic substrates, with the exception of perlite, are more easily dislodged from root systems of *Ophiopogon japonicus* than organic substrates. HydRocks®, Profile™ and sand, produced yields comparable or better than pine bark and pine bark:peat moss in 2007. Profile™ produced high yields in all three studies and was moderately easy to remove from the root system. HydRocks® was more easily removed than any of the other substrates and produced TB similar to pine bark but lower than Profile™ and pine bark:peat moss, which is attributed to the lower water holding capacity of HydRocks®. HydRocks® ability to quickly dislodge from roots may offset slightly decreased yields. Sand also produced yields similar to pinebark and provided a moderately easy removal from the root system. Sand, HydRocks® and Profile™ each would provide ease of bare-rooting *Ophiopogon japonicus* while also providing yields comparable or better to that of conventional substrates.

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Table 1. Physical properties of 2007 substrate treatments.[Z]

Substrate	Air space[Y]	Container capicity[X]	Total porosity[W]	Bulk density (g/cm^3)[V]
Pine bark	38.9 a[U]	34.6 d	73.5 a	0.17 e
8:2 pine bark:peat moss (v:v)	24.2 c	50.4 b	74.7 a	0.18 e
Perlite	17.1 d	48.0 b	65.2 c	0.18 e
Profile (fine)	2.5 e	66.0 a	68.5 b	0.50 e
HydRocks® 3/16	31.6 b	30.7 e	62.0 d	0.64 c
3:1 HydRocks®:sand (v:v)	3.5 e	39.3 c	42.9 e	1.11b
Sand	2.2 e	27.2 f	29.4 f	1.51 a
Recommended range [T]	*10-30*	*46-65*	*50-85*	*0.19-0.70*

[Z] Analysis performed using the North Carolina State University porometer.

[Y] Air space is volume of water drained form the sample ÷ colume of the sample.

[X] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[W] Total porosity is container capcity + air space.

[V] Bulk density after forced-air drying at 105°C (221.0°F) for 48 h; $1 g \cdot cm^{-3} = 62.4274\ lb/ft^3$.

[U] Means with different letters within columns are signifacntly different, separated by Duncan's Multiple Range Test ($p \leq 0.05$).

[T] Recommended ranges as reported in Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2007).

Table 2. Bareroot bib production of container-grown *Ophiopogon japonicus* 2003.

Substrate	Total bibs	Bib Grades[Z] 1	2	3
Pine bark	9.0 b[Y]	2.0 b	3.8 ab	3.3 a
8:2 pine bark:peat moss (v:v)	9.9 b	4.1 a	2.6 b	3.1 a
Perlite	9.8 b	3.5 ab	3.0 ab	3.3 a
Profile (fine)	14.6 a	4.5 a	5.5 a	4.7 a
Profile (coarse)	9.8 b	2.8 ab	3.4 ab	3.6 a

[Z]Bibs were graded by a subjective quality rating of 1 to 3 following removal of the substrate (1 being of highest grade and 3 being of the lowest).

[Y]Means with different letters within columns are significantly different, separated by Duncan's Multiple Range Test ($p \leq 0.05$).

Table 3. Time required to bareroot container-grown *Ophiopogon japonicus* 2003 and 2007.

Substrate	Time to bareroot (sec)[z]		Time to bareroot per bib (sec)	
	2003	2007	2003	2007
1 - Pine bark	57.1	48.6	5.92	2.1
2 - 8:2 pine bark:peat moss (v:v)	43.0	61.1	4.77	2.15
3 - Perlite	27.9	39.8	2.97	1.59
4 - Profile (fine)	35.4	44.4	2.49	1.49
5a - HydRocks® (2007)	-	30.2	-	1.08
5b - Profile (coarse)(2003)	20.5	-	2.34	-
6 - 3:1 HydRocks®:Sand (v:v)	-	29.4	-	1.41
7 - Sand	-	40.1	-	1.53
Contrasts[y]				
1 vs 2	*[X]	*	NS	NS
1 vs 3	***	NS	***	NS
1 vs 4	**	NS	***	*
1 vs 5	***	**	***	**
1 vs 6	-	**	-	*
1 vs 7	-	NS	-	*
2 vs 3	*	***	**	*
2 vs 4	NS[W]	**	**	*
2 vs 5	**	***	**	**
2 vs 6	-	***	-	*
2 vs 7	-	***	-	*
3 vs 4	NS	NS	NS	NS
3 vs 5	NS	NS	NS	NS
3 vs 6	-	*	-	NS
3 vs 7	-	NS		NS
4 vs 5	*	*	NS	NS
4 vs 6	-	**	-	NS
4 vs 7	-	NS	-	NS
5 vs 6	-	NS	-	NS
5 vs 7	-	NS	-	NS
6 vs 7	-	*	-	NS

[Z]Time (in seconds) required to remove plants from container and wash substrate from roots.

[Y]Contrasts performed using proc mixed in SAS with worker as the random variable and substrate as the fixed variable, *p* -values determined using the pdiff statement in SAS.

[X]*, **, and *** represent significance where $P \leq 0.05$, 0.01, and 0.001.

[W]NS represents a nonsignificant treatment response.

Table 4. Container grown *Ophiopogon japonicus* 'Nana' bareroot bib production 2004.

Substrate	Total bibs	Bib grades[Y] 1	2	3
Pine bark	77.2 a	4.3 a	9.3 c	63.8 a
8:2 pine bark:peat moss (v:v)	92.5 a	2.0 a	12.8 b	77.8 a
Perlite	41.8 b	3.3 a	9.3 c	29.3 b
Profile (fine)	92.5 a	5.3 a	18.3 a	69.0 a
Profile (coarse)	65.0 ab	2.0 a	10.8 bc	52.3 ab

[Z]Means with different letters within columns are significantly different, separated by the Duncan's Multiple Range Test ($p \leq 0.05$).

[Y]Bibs were graded by a subjective quality rating of 1 to 3 following removal of the substrate (1 being of highest grade and 3 being of the lowest).

Table 5. Time required to bareroot container-grown *Ophiopogon japonicus* 'Nana' in 2004.

Substrate	Time to bareroot[Z]	Time to bareroot per bib
1 - Pine bark	135.5	1.44
2 - 8:2 pine bark:peat moss (v:v)	116.6	1.45
3 - Perlite	67.0	1.51
4 - Profile (fine)	74.6	0.86
5 - Profile (coarse)	65.4	0.96
Contrasts[Y]		
1 vs 2	NS[X]	NS
1 vs 3	***	NS
1 vs 4	**	**
1 vs 5	***	*
2 vs 3	***	NS
2 vs 4	***	**
2 vs 5	***	*
3 vs 4	NS	**
3 vs 5	NS	*
4 vs 5	NS	NS

[Z]Time (in seconds) required to remove plants from container and wash substrate from roots.

[Y]Contrasts performed using proc mixed in SAS with worker as the random variable and substrate as the fixed variable, *p* -values determined using the pdiff statement in SAS.

[X]NS, *, **, and *** represent non-significanct or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Table 6. Bareroot bib production of container-grown *Ophiopogon japonicus 2007*.

Substrate	Shoot Weight (g)[Z]	Root Weight (g)	Total Weight (g)	Root: Shoot[Y]	Total Bibs
Pine bark	15.3 a[X]	13.6 a	28.9 b	0.91 abc	25.8 bc
8:2 pine bark:peat moss (v:v)	17.7 ab	16.7 a	34.4 b	0.95 a	32.6 ab
Perlite	18.2 b	16.9 a	35.1 b	0.93 abc	27.1 bc
Profile (fine)	23.3 b	17.1 a	40.5 a	0.73 d	37.7 a
HydRocks®	19.5 b	16.0 a	35.5 ab	0.83 bcd	28.0 bc
3:1 HydRocks®:sand (v:v)	15.8 b	15.4 a	31.4 b	0.92 ab	22.4 c
Sand	18.2 b	14.5 a	32.7 b	0.80 dc	26.4 bc

	Bib grade[W]		
	1	2	3
Pine bark	7.1 b	10.2 abc	8.5 bc
8:2 pine bark:peat moss (v:v)	7.1 b	12.0 ab	12.2 ab
Perlite	8.4 ab	10.4 abc	8.2 bc
Profile (fine)	9.3 ab	14.6 a	13.7 ab
HydRocks®	10.2 a	8.5 bc	9.8 abc
3:1 HydRocks®:sand (v:v)	7.3 b	8.0 bc	7.1 c
Sand	10.2 a	6.7 c	9.0 bc

[Z]Weights recorded on oven dried samples, dried at 105°C for 48 h.

[Y]Root:shoot ratio = root weight ÷ shoot weight.

[X]Means with different letters within columns are significantly different, separated by Duncan's Multiple Range Test ($p \leq 0.05$).

[W]Bibs were graded by a subjective quality rating of 1 to 3 following removal of substrate (1 being the highest grade and 3 being the poorest).

Table 7. Analysis of particle size distribution of 2007 substrate treatments.

US standard sieve #	Sieve opening (mm)	Pinebark[Z]	Perlite	Profile	HydRocks®	Sand	8:2 PB:PM[W]	3:1 HYD:SD
1/2	12.50	0.1[Y] a[X]	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
3/8	9.50	0.8 a	0.0 b	0.0 b	0.0 b	0.1 b	0.0 b	0.0 b
1/4	6.30	10.6 a	1.0 c	0.0 c	0.0 c	0.1 c	1.4 b	0.0 c
6	3.35	28.8 a	22.7 b	0.1 d	19.2 b	1.8 d	10.7 c	23.0 b
8	2.36	14.8 c	17.6 c	0.4 d	34.1 a	2.7 d	26.9 b	24.7 b
10	2.00	6.4 d	6.8 d	0.3 f	15.6 a	1.8 e	13.4 b	8.2 c
14	1.40	11.8 b	11.2 b	1.1 d	21.3 a	5.4 c	5.3 c	10.7 b
18	1.00	8.4 ab	7.7 bc	2.8 e	6.9 cd	8.6 ab	9.7 a	6.0 d
35	0.50	10.7 de	13.9 c	66.7 a	2.1 f	36.2 b	7.1 e	12.8 cd
60	0.25	4.5 c	12.9 b	27.9 a	0.2 d	29.5 a	10.8 b	10 b
140	0.11	3.4 c	6.3 b	1.0 d	0.4 d	16.6 a	7.7 b	4.4 c
270	0.05	0.3 c	0.7 c	0.2 c	0.1 c	3.0 b	6.4 a	0.2 c
Pan	0.00	0.0 c	0.1 bc	0.0 c	0.0 c	0.2 b	0.7 a	0.0 c

[Z]Substrates were air dried at ambient room temperature under normal conditions for 20 days.

[Y]Mean percent weight of material retained on each screen.

[X]Means within row with different letters are not similar, separated by Duncan's Multiple Range Test ($p \leq 0.05$, n=3).

[W]PB:PM and HYD:SD represent the pine bark:peat moss and Hydrocks®:sand treatments respectively.

IV. LIGHT WEIGHT AGGREGATES A ROOTING SUBSTRATE: A NOVEL APPROACH TO ROOTING AND BARE ROOTING CUTTINGS

Abstract

HydRocks®, a lightweight expanded clay aggregate, was evaluated in two experiments as a rooting substrate compared to commercial substrates. Experiment one focused on a ≈0.63 cm HydRocks® (H1) aggregate and combinations of sand. Experiment two compared a smaller HydRocks® (≈0.47 cm) (H2) aggregate to several commercial rooting substrates. In both experiments root quality, shoot growth, root growth and rooting percentage were compared to conventional methods of producing bare root liners. Results of these studies suggest that HydRocks® can be used as a successful rooting substrate. Results of cutting quality vary depending on species. HydRocks® performed as well as conventional substrates in most cases across species in these studies. No differences were seen in rooting percentage between any treatment across species.

Index words: propagation, cuttings, lime, IBA, rooting hormones, HydRocks®

Growth regulators used in this study: Dip'N Grow®, 10,000 ppm indole-3-butryic acid, 5,000 ppm 1-naphthaleneacetic acid (NAA).

Species used in this study: *Elaeagnus* x *ebbingei*, *Forsythia* x *intermedia, Illicium parvifolium*, *Ilex cornuta* 'Burfordii Nana', and *Lagerstroemia* x 'Natchez'

Significance to the Industry

Some nursery growers produce liners in sand beds and some west coast growers often produce liners in pumice beds, perlite or vermiculite as an alternative to mineral soil or bark based rooting substrates. Materials such as pumice, perlite, and vermiculite are expensive to ship to the southeast. Lightweight aggregates such as HydRocks® are formed by firing certain expandable clays through rotary kilns. HydRocks® shows potential for bare root liner production due to the almost effortless removal of HydRocks® particles from the root systems of cuttings by a simple shake. HydRocks® is produced in the southeast and shows potential use as a pumice or perlite substitute for the southeastern states. HydRocks® resists deterioration. Aggregates could be collected after bare-rooting and re-used, eliminating the need to re-purchase expensive substrate components as well as containers and subsequently lower production cost of liners.

Introduction

Cutting propagation is the primary means of propagation for most woody plant material produced in the U.S. nursery industry. A considerable cost in the nursery industry is the production or purchase of liners. Propagation of cuttings requires a variety of specialized substrates depending upon species, and substrate components are a major cost consideration in liner production (Whitcomb, 2003). Canadian sphagnum peat moss, a common component in rooting substrates was reported to have cost the U.S. nursery and greenhouse industry $115,000,000 in imports in 1996 (Jasinki, 2005). Also, petroleum costs have caused a steady increase in the transportation costs of substrate materials and the cost of petroleum based plastic containers.

An alternative to the expense associated with container grown liners is producing bare-root liners in ground beds or directly in containers. Purchase cost of bare root liners is generally less expensive than the cost of "buying in" container liners due to weight and space (Tilt et al., 2001). Bare root liners are exempt from several current U.S. policies (providing they are completely free of soil) that slow the shipment of plant material (Agriculture, 2002). Current U.S. regulations require that no soil/substrate can be imported into or exported out of the country to prevent the introduction of new soil born pathogens and pests. Also, due to federal plant pest regulations, growers in states within the fire ant quarantine zone are not allowed to export soil/substrate outside the quarantine zone without mandated pesticide application (Agriculture, 2002).

Disadvantages associated with the use of bare root liners are slower initial growth and increased mortality rates often due to shock and stress brought on by the bare rooting process (Thiffault et al., 2004). Some species also have specific refrigeration requirements depending upon time of harvest. Not all species will tolerate the stress of being bare rooted because of hardiness or species-specific weak root systems.

Rooting substrates provide several fundamental functions: support, moisture availability and aeration. Water uptake and retention is a major requirement in maintaining turgidity (Loach, 1985). Moisture content in a rooting substrate influences the capacity of stem cuttings to take up water and produce and support adventitious roots (Rein et al., 1991). Aeration is an important factor in container substrates due to water management issues and the high degree of respiration that results from degradation of organic material and root respiration. Increased air filled pore space is needed in order for CO_2 to be replaced by O_2 during irrigation cycles (Argo, 1998).

Generally bare root cuttings and offshoots are grown by either traditional container production methods with substrate subsequently removed through washing of roots with high pressured water or in inground beds of amended field soil. In some situations selection of substrate materials can be influenced by the level of ease required to bare root materials grown in the substrate (Tilt et al., 2001). Recently, work has been done to evaluate certain inorganic materials for production of bare root cuttings. Inorganic materials with larger particle sizes have been shown to be easily removed from roots while still producing a quality cutting (Blythe et al., 2005; Tilt et al., 2001).

Monolithic slag, a byproduct of the smelting process, can be used successfully as a substrate for rooting of cuttings. Monolithic slag outperformed pine bark, peat moss, perlite and vermiculite in root quality and ease of substrate removal (Blythe et al., 2005). Monolithic slag has similar particle size distribution compared to lightweight expanded clay aggregates (LECA). LECA does however have some moisture retention capacity that could provide a more favorable rooting environment than monolithic slag (Pickens and Sibley, 2006).

Lightweight aggregates are formed by firing certain expandable clays in rotary kilns. Several expanded clay products are currently available, the most common including: Stalite®, HydRocks®, Livlite®, Gravelite®, Profile™, and Turface™. The parent clay material and the firing temperature play a significant role in both the chemical and physical properties of the final product. Expanded clay products that are currently available have produced inconsistent results from product to product when used as an amendment to conventional substrates (Breedlove et al., 1999; Catanzaro and Bhatti, 2005; Joiner and Nell, 1980; Poole and Conover, 1979).

HydRocks® (Big River Industries Alpharetta, GA) is lightweight porous aggregate formed by calcining clay at temperatures reaching 1093 ºC (2000° F). The high temperatures required to produce HydRocks® creates a light weight structural aggregate. HydRocks® cation exchange capacity is 5.12 meq/100ml. Hydrocks® is produced from several queries in the southeast. The material for this study was produced in Livingston, Alabama. HydRocks® porous natures allow aggregates to absorb and retain water. A study of HydRocks® physical properties revealed that aggregates have a potential to absorb 54 to 83 % of its own weight in water.

Some Oregon nurseries have converted entire greenhouse floors into in-ground pumice beds where cuttings are directly stuck (Buamscha and Altland, 2005). These cuttings are easily removed out of the pumice aggregate at harvest and the pumice is reused for many years without being replaced (personal observation). Particle distribution and bulk density of pumice (bulk density of 0.4 g/ cm^3) is similar to expanded clay (bulk density of 0.5-0.6 g/cm^3) (Gunnlaugsson and Adalsteinsson, 1995). Expanded clays could be used in place of pumice in in-ground propagation beds in areas of the country where pumice is not readily available. Like pumice, stable properties of expanded clays would allow re-use for many years without replacement, providing a more sustainable and cost effective approach to bare root liner production.

Preliminary studies have shown that the porous nature of expanded clay HydRocks®, allows it to absorb up to fifty percent of its own weight in water in a 24 h period. Subsequent availability of this absorbed water to roots is controversial. Aggregate interior pores can take months to become fully saturated under normal saturation procedures (Holm et al. 2004). Water release rate of through these small pores to the outside of the aggregate follows a similar rate as that of the initial absorption. As a result release rate is thought to be too slow to sustain plants under normal irrigation cycles involved in container production (Spomer, 1998). Bigelow et al., (2004) evaluated inorganic amendments of putting greens and reported that clay amendments did not increase available water in amended sands. Bigelow et al., (2004) questioned the pressure plate method's effectiveness to measure available water in calcined clay aggregates and concluded that porous inorganic amendments contained more available water than was correctly measured using pressure plate methods. Water absorbed by expanded clay aggregates may not provide sufficient water to sustain plant growth but may provide a favorable environment for root initiation by maintaining a moisture level to simulate the hydrology of organic substrates.

Expanded clay aggregates are essentially too heavy (0.56 - 0.64 g/cm^{-3}) to be used in container production but would be better suited for in-ground growing or rooting beds (Tables 1, 2). In preliminary studies, expanded clay aggregates were easily dislodged from roots when shaken (data not shown). If plant materials could be grown in expanded clay as successfully as conventional materials, expanded clays may provide a renewable substrate while also decreasing labor cost associated with bare rooting plant material. The objective of this study was to determine if the fired lightweight expanded clay HydRocks® could provide a more sustainable and economical rooting substrate for bare root liner production.

Materials and Methods

Experiment 1. Cuttings were collected from mature landscape plants (Auburn, Alabama) (*Lagerstroemia* x 'Natchez' and *Elaeagnus* x *ebbingei*). All cuttings were stuck into 606 cell packs (115 cm^3) (ST-I-0606; T.O. Plastics Clearwater, MN) filled with the following substrate treatments; 6:1 pine bark:sand, sand, HydRocks® (≈0.64 cm, 0.25 in., a light expanded clay aggregate, Big River Industries, Alpharetta, GA) (H1) and combinations of sand and HydRocks® 75:25 (v: v) H1:sand, 50:50 (v:v) H1:sand, 25:75 (v:v) H1:sand.

Physical properties including percent air space, water holding capacity, total porosity and bulk density were determined for each substrate treatment using the North Carolina State University Porometers™ as described by Fonteno and Bilderback (1993). Physical properties were determined using three representative samples of each substrate treatment. Particle size distribution was determined for each treatment substrate with a Camsizer® (Restsch® Technology, Haan Germany) using three air dried 100 gram samples.

On August 12, semi-hardwood terminal cuttings *Elaeagnus* x *ebbingei* were collected and prepared as 10.16 cm (4 in.) wounded cuttings with a minimum of 4 leaves and received a basal quick dip treatment of 1000 ppm indole-3-butyric acid (IBA) (Dip'N Grow®, Dip'N Grow Inc®., Clackamas OR). *Lagerstroemia* x 'Natchez', cuttings were collected from mature landscape grown stock plants. *L.* x 'Natchez' cuttings were prepared as 12.7 cm (5 in.) wounded intermediate cuttings with 3 leaves per cuttings. *L.* x 'Natchez' cuttings received a basal quick dip application of 1000 ppm IBA. On October 26, 2007 (112 days after sticking), *E.* x *ebbingei,* and *L.* x 'Natchez' cuttings were removed from mist. After removal from mist cuttings of each species were liquid fertilized (week days 1-5) with 20-10-20 (10N-4.37P-16.6K, Peters Professional, The Scotts Company, Maryville, OH) at a rate of 200 ppm nitrogen until harvest. Plain water was used on week days six and seven. *L.* x 'Natchez' and *E.* x *ebbingei* cuttings were harvested on January 28, 2008, (160 days after sticking) and roots were subsequently rated on a quality scale of one to five (1 = non-rooted cuttings and 5 = greatest quality). Quality of roots was rated respective to the population of cuttings being rated for each species. A cutting with a dense root system with many fine roots was considered to be of high quality. Cuttings with sparse root systems with few fine roots were considered to be of lower quality respective to the population being rated (Figure 1). Cuttings were allowed to air dry for 48 h at room temperature before shoot and root weights were collected.

The experimental design was a randomized complete block design with six treatments and six blocks. Each block contained a group of six cuttings (six subsamples) from each treatment that was used as the experimental unit. Data was analyzed using generalized linear mixed models [binomial distribution and logit link function for rooting response (presented as percent rooted); Normal distribution and identity link function for all other response variables] with the GLIMMIX procedure (June 2006 release) of SAS (Version 9.1; SAS Institute, Cary, NC). Substrate was included in the model as the fixed factor; block and block/substrate interactions were included as random factors. Comparison of least squares means was carried out with a multiple-comparison-adjusted significance level of 0.05 using the simulation-stepdown method.

Experiment 2. On September 23, 2007, cuttings were collected from the following mature landscape plants (Auburn, Alabama): *Elaeagnus* x *ebbingei, Forsythia* x *intermedia, Ilex cornuta* 'Burfordii Nana', *Illicium parvifolium* and *Lagerstroemia* x 'Natchez'. All cuttings were stuck in into 606 deep cell packs (205 cm^3) (ST-I-0606-DEEP; T.O. Plastics Clearwater, MN) filled with the following substrate treatments: pine bark fines (screened at 0.63 cm or 0.25 in), Fafard 3B (Fafard Inc., Anderson, SC), construction grade sand, perlite, vermiculite and HydRocks® (screened to 0.47cm or 0.19 in)(H2). Semi hard wood terminal cuttings *Elaeagnus* x *ebbingei* were collected and prepared as 10.16 cm (4 in) cuttings with a minimum of 4 leaves, wounded and treated with 1000 ppm IBA. *Lagersrtoemia* x 'Natchez', cuttings were collected from mature landscape grown stock plants. *L.* x 'Natchez' cuttings were prepared as 7.62 – 10.16 cm (3-4 in) wounded intermediate cuttings with 3 leaves per cuttings and were treated with 1000 ppm IBA. *Forsythia* x *intermedia* cuttings were collected from mature landscape grown stock plants and prepared as 7.16 cm (3 in), single node intermediate cuttings. *F.* x *intermedia* cuttings were treated with 1000 ppm IBA. *Illicium parviflorum* and *Ilex cornuta* 'Burfordii Nana' terminal cuttings were prepared as 7.62 – 10.16 cm (3-4 in) wounded cuttings and treated with 3000 ppm IBA. Dip'N Grow® (Dip'N Grow Inc., Clackamas OR) was used for all IBA formulations. Cuttings were placed under intermittent mist in a glass greenhouse at the Paterson Greenhouse Complex in Auburn, Alabama. Cuttings were harvested on February 12, 2008 (150 days after sticking) and roots were subsequently rated on a quality scale of one to five (1 = non-rooted cuttings and 5 = greatest quality). Quality of roots was rated respective to the population of cuttings being rated for each species. A cutting with a dense root system with many fine roots was considered to be of high quality. Cuttings with sparse root systems and with few fine roots were considered to be of lower quality respective to the population being rated (Figure 1). Fresh root and shoot weights were recorded and root:shoot ratio was calculated.

Physical properties including percent air space, water holding capacity, total porosity and bulk density were determined for each substrate treatment using the North Carolina State University Porometers. Physical properties were determined using three representative samples of each substrate treatment. Particle size distribution was determined for each treatment substrate with a Camsizer® (Restsch® Technology, Haan Germany) using three air dried 100 gram samples. Experiment design and statistical analysis was same as Experiment 1.

Results and Discussion

Experiment 1

Physical Properties. Physical properties were determined using the North Carolina State Porometer (Table 1). 100% HydRocks® had the highest air space and 100% sand had the lowest of any treatment. Treatments containing 50% sand or more were out of recommended ranges for air space (Yeager et al., 2007). The 6:1 pine bark:sand and 1:3 H1:sandtreatments had the highest container capacity of all treatments. 100% HydRocks® and 3:1 H1:sand treatments had the lowest container capacity of any treatments. With the exception of the 6:1 pine bark sand and the 1:3 H1:sand treatment all other treatments were out of recommended ranges for container capacity (Yeager et al., 2007). The 6:1 pine bark:sand and 100% HydRocks® treatments had the highest total porosity of all treatments. 100% sand and 1:1 H1:sand had the lowest total porosity of all treatments and were lower than recommended ranges. All other treatments were within the recommended range of total porosity (Yeager et al., 2007).

Elaeagnus x *ebbingei.* There were no differences across treatments in rooting percentage (Table 2). Cuttings rooted in 100% HydRocks® had similar root growth to all other treatments with the exception of 1:3 H1:sandand 100% sand. Cuttings stuck in 6:1 pine bark:sand and 3:1 H1:sandhad similar root weights. All treatments containing HydRocks® had similar shoot weight to 6:1 pine bark:sand. 6:1 pine bark:sand and 3:1 H1:sandhad the same root:shoot ratio (Table 2).

Lagerstroemia x 'Natchez'. Across treatments there were no differences in rooting percentage (Table 2). Cuttings stuck in treatments containing H1:sandcombinations were the same in root quality, and root weight and were similar to 6:1 pine bark:sand. Cuttings rooted in 100% HydRocks® and 100% sand were the same in root quality and root weight and were similar to treatments containing H1:sand combinations. With shoot weight 1:1 H1:sand cuttings were the same as cuttings rooted in 6:1 pine bark:sand. No difference were seen in root:shoot ratio across treatments (Table 2).

Experiment 2

Physical Properties. Physical properties were determined using the North Carolina State Porometers (Table 3). Air space in H2 was higher and vermiculite and sand were lower than recommend ranges. Screened pine bark had the highest air space and sand had the lowest (Table 3). Fafard 3B (68.6 %) had the highest container capacity of all substrates and H2 (30.7 %) had the lowest container capacity. H2 and sand were lower and Fafard 3B higher than recommend ranges (Yeager et al., 2007). With the exception of sand all materials were in recommended ranges (50-86%) for total porosity. Fafard 3B had the highest total porosity (80.7 %) of all substrates. In bulk density, H2 (0.64 g/cm^{-3}) was almost three times heavier than screened pine bark (0.21 g/cm^{-3}) and almost three times lighter than sand (1.45 g/cm^{-3}) (Table 3).

Twenty weeks after sticking, no differences were found across treatments for each species in rooting percentages. Where different the tendency was for H2 to have better performance than perlite. Root quality varied slightly with treatment in species but where different, the greatest root quality overall was found with vermiculite (Table 4).

Elaeagnus x *ebbingei.* On a subjective scale, cuttings rooted in vermiculite and H2 were the same (3.8) and were similar to Fafard 3B (3.6) and perlite (3.6) (Table 4). No significance occurred in root weight across treatments. H2 was similar to all treatments in shoot weight. There were no differences in root:shoot ratio across treatments (Table 4).

Forsythia x *intermedia.* Superior root ratings occurred in *F.* x *intermedia* cuttings in pine bark, Fafard 3B, vermiculite and H2 which were similar in root quality, while sand and perlite were similar to each other the poorest root quality rating (Table 4). Fresh root weights of cuttings rooted in Fafard 3B (2.5 g) and vermiculite (2.1 g) were similar and had high root weights. Cuttings rooted in H2 were similar to pine bark, sand and perlite in root weight. Cuttings in Fafard 3B, pine bark and vermiculite were all similar in shoot weight. Fafard 3B and vermiculite had the highest root:shoot ratio of all treatments (Table 4). The high root and shoot weights of Fafard 3B treatments could be attributed to a starter fertilizer charge absent from all other treatments.

Ilex cornuta 'Burfordii Nana'. Cuttings rooted in pine bark, Fafard 3B, sand, and vermiculite were all similar in root quality (Table 4). Perlite had the lowest quality roots of any treatment. No differences occurred across treatments in root weights. H2 was similar to all treatments in shoot weight and root:shoot ratio (Table 4).

Illicium parviflorum. Cuttings rooted in pine bark, Fafard 3B, and vermiculite were all similar and had the highest root quality ratings and root weights (Table 4). Cuttings rooted in perlite were similar to sand and H2 in root weight. Excluding pine bark, H2 was similar to all other treatments in root weight. All treatments were similar in shoot weight and root:shoot ratio and rooting percentage (Table 4).

Lagerstroemia x 'Natchez'. Cuttings rooted in pine bark and vermiculite were the same and were both similar to Fafard 3B and all were high in root quality (Table 4). Perlite and sand had were both low in root quality. H2 was similar to all treatments in root weight. All treatments were the same in shoot weight. H2 was similar to all treatments in root:shoot ratio (Table 4).

HydRocks® performed as well as conventional substrates in most cases across species in these studies (Table 2 and Table 4). HydRocks® could have a higher utility as a propagation substrate over conventional substrates when ease of bare rooting is taken into account. There is potential for HydRocks® to be reused because it will not deteriorate like peat, perlite, vermiculite and other substrates. The well-drained, sterile nature, combined with high moisture retention makes HydRocks® an ideal propagation substrate. It was observed in both experiments during harvest across species that HydRocks® was easily dislodged from substrates. In the first experiment 100 % H1 was easily dislodged from roots. In some cases HydRocks® aggregates were fixed into callus tissue making removal somewhat difficult. Sand particles tended to stick to roots and in most cases would require washing with water. The 6:1 pine bark sand was difficult to remove in Experiment 1 where plants were tightly root bound. With the exception of 100% HydRocks®, all substrates required some water for substrate removal.

In the second study both organic substrates required water for the most part to remove particles from root systems. Vermiculite and sand were both easily dislodged from roots but still required some washing. HydRocks® aggregates do not have dust problems typically associated with vermiculite and perlite. Use of HydRocks® in propagation has some sustainability advantages. High pressure water generally used in bare root liner production is not needed with HydRocks®. Since HydRocks® does not degrade over time it could be potentially re-used for years. Results from the second study might have differed if fertilizer was applied to each treatment in the study. The results of these studies suggest that HydRocks® can be used as a successful rooting substrate. More work is needed to determine how fertilizer and water requirements might improve growth of cuttings rooted in HydRocks®.

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Table 1. Physical properties of HydRocks® and sand combinations compared to a conventional rooting substrate Experiment 1[Z].

Substrate	Air space[Y]	Container capicity[X]	Total porosity[W]	Bulk density (g/cm^3)[V]
6:1 Pinebark:sand	22.6 C[U]	43.0 A	65.7 A	0.34 F
100% HydRocks®[T]	44.2 A	19.8 C	64.0 A	0.56 E
3:1 HydRocks®:sand	32.0 B	22.6 C	54.6 B	0.78 D
1:1 HydRocks®:sand	2.8 E	32.9 B	35.7 D	1.34 B
1:3 HydRocks®:sand	6.4 D	39.7 A	46.1 C	1.1 C
100% Sand	1.3 E	33.0 B	34.3 D	1.45 A
Recommended range[S]	*10-30*	*46-65*	*50-85*	*0.19-0.17*

[Z]Analysis performed using the North Carolina State University porometer.

[Y]Air space is volume of water drained form the sample ÷ colume of the sample.

[X]Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[W]Total porosity is container capcity + air space.

[V]Bulk density after forced-air drying at 105°C (221.0°F) for 48 h; $1 g\cdot cm^{-3} = 62.4274\ lb/ft^{3}$.

[U]Means with different letters within columns are signifacntly different, separated by Duncan's Multiple Range Test ($p \leq 0.05$).

[T]All HydRocks® treatments were screened to ≈ 0.64 cm (0.25 in).

[S]Recommended ranges as reported in Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2007).

Table 2. Rooting response of *Elaeagnus* x *ebbingei* and *Lagerstroemia* x 'Natchez' rooted in HydRocks®, sand and pine bark combinations.

	Rooting %	Root rating[Z]	Root weight (g)[Y]	Shoot weight (g)[Y]	Root:Shoot[X]
			Elaeagnus x *ebbingei*		
6:1 Pine bark:sand	89% A[W]	3.2 BC[V]	0.88 AB	2.23 AB	0.39 A
100% HydRocks®[U]	97% A	3.4 AB	0.86 BC	2.48 AB	0.36 AB
3:1 HydRocks®:sand	97% A	3.9 A	1.12 A	2.88 A	0.39 A
1:1 HydRocks®:sand	94% A	3.3 ABC	0.85 BC	2.53 AB	0.35 AB
1:3 HydRocks®:sand	97% A	2.6 DC	0.60 DC	2.23 AB	0.27 B
100% Sand	94% A	2.3 D	0.54 D	1.98 B	0.28 B
			Lagerstroemia x 'Natchez'		
6:1 Pine bark:sand	87% A	3.8 A	1.67 A	2.54 A	0.82 A
100% HydRocks®	95% A	2.6 B	0.97 B	1.34 B	0.90 A
3:1 HydRocks®:sand	97% A	3.7 AB	1.35 AB	2.01 AB	0.80 A
1:1 HydRocks®:sand	97% A	3.2 AB	1.37 AB	2.36 A	0.68 A
1:3 HydRocks®:sand	97% A	3.0 AB	1.13 AB	1.85 AB	0.66 A
100% Sand	88% A	2.7 B	1.05 B	1.64 AB	1.67 A

[Z]1 = non-rooted and 5 = greatest root quality.

[Y]After air drying for 48 hours at room temperature.

[X]Root:shoot ratio = root weight ÷ shoot weight.

[W]Rooting Response caclulated Proc GLIMMIX binomial distribution and logit link function; means within column witl different letters are not similar.

[V]Comparison of least square means was carried out with multiple-comparisoin-adjusted significance level of 0.05 usinք simulation-stepdown method PROC GLIMMIX (June 2006 release)(SAS Version 9.1 SAS Institute, Cary NC).

[U] All HydRocks® treatments were screened to ≈ 0.64 cm (0.25 in)

Table 3. Physical properties of HydRocks® and five common rooting substrates Experiment 2[Z].

Substrate	Air space[Y]	Container capicity[X]	Total porosity[W]	Bulk density (g/cm^3)[V]
Screened pine bark	20.4 B[U]	50.2 C	70.8 B	0.21 C
Fafard 3B	12.1 D	68.6 A	80.7 A	0.12 E
Sand	1.3 F	32.9 E	34.3 F	1.45 A
Perlite	17.2 C	48.0 D	65.2 D	0.18 D
Vermiculite	8.7 E	59.8 B	68.5 C	0.19 D
HydRocks®[T]	31.7 A	30.7 F	62.0 E	0.64 B
Recommended range [S]	*10-30*	*46-65*	*50-85*	*0.19-0.17*

[Z] Analysis performed using the North Carolina State University porometer.

[Y] Air space is volume of water drained form the sample ÷ colume of the sample.

[X] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[W]Total porosity is container capcity + air space

[V]Bulk density after forced-air drying at 105°C (221.0°F) for 48 h; $1 g \cdot cm^{-3} = 62.4274\ lb/ft^{3}$.

[U]Means with different letters within columns are signifacntly different, separated by Duncan's Multiple Range Test ($p \leq 0.05$).

[T]Screened to ≈0.47cm(0.19 in.).

[S]Recommended ranges as reported in Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2007).

Table 4. Rooting response of five woody species rooted in six different substrates.

	Roting %	Root quality rating[Z]	Root (g)[Y]	Shoot (g)[Y]	Root:Shoot[X]
		Elaeagnus x *ebbingei*			
Pine bark	89% A[W]	2.7 C[V]	0.60 A	1.83 B	0.61 A
Fafard 3B	97% A	3.6 AB	0.69 A	2.01 AB	0.34 A
Sand	97% A	3.0 BC	0.60 A	2.20 A	0.28 A
Perlite	94% A	3.6 AB	0.63 A	2.17 AB	0.29 A
Vermiculite	97% A	3.8 A	0.64 A	1.88 AB	0.39 A
HydRocks®[U]	94% A	3.9 A	0.85 A	2.14 AB	0.39 A
		Forsythia x *intermedia*			
Pine bark	100% A	3.9 A	1.85 BC	1.5 ABC	0.35 B
Fafard 3B	100% A	4..1 A	2.48 A	1.72 A	0.76 A
Sand	100% A	3.0 B	1.61 C	1.24 C	0.37 B
Perlite	100% A	2.4 B	1.74 BC	1.31 BC	0.42 B
Vermiculite	100% A	4.1 A	2.13 AB	1.66 AB	0.60 A
HydRocks®	100% A	4.0 A	1.59 C	1.32 BC	0.31 B
		Ilex cornuta 'Burfordii Nana'			
Pine bark	97% A	3.7 AB	0.51 A	2.61 AB	0.20 AB
Fafard 3B	97% A	4.1 AB	0.54 A	2.52 AB	0.22 AB
Sand	97% A	3.6 AB	0.51 A	2.82 A	0.18 AB
Perlite	84% A	1.9 C	0.41 A	2.72 AB	0.16 B
Vermiculite	97% A	4.4 A	0.53 A	2.31 B	0.23 A
HydRocks®	95% A	3.3 B	0.56 A	2.45 AB	0.23 A
		Illicium parviflorum			
Pine bark	99% A	4.0 A	1.95 A	2.92 A	0.68 A
Fafard 3B	97% A	4.3 A	1.73 AB	2.75 A	0.67 A
Sand	97% A	3.1 BC	1.35 BC	2.65 A	0.57 A
Perlite	99% A	2.6 C	1.17 C	2.39 A	0.51 A
Vermiculite	99% A	4.3 A	1.69 AB	2.58 A	0.67 A
HydRocks®	99% A	3.3 B	1.45 BC	2.80 A	0.53 A
		Lagerstroemia x 'Natchez'			
Pine bark	92% A	4.3 A	1.04 AB	1.77 A	0.65 AB
Fafard 3B	94% A	4.1 AB	0.85 AB	1.63 A	0.57 AB
Sand	95% A	3.1 CD	0.75 B	1.56 A	0.52 B
Perlite	86% A	2.7 D	0.89 AB	1.32 A	0.73 AB
Vermiculite	97% A	4.4 A	1.15 A	1.53 A	0.80 A
HydRocks®	97% A	3.5 BC	0.85 AB	1.46 A	0.63 AB

[Z] 1 = non-rooted and 5 = greatest root quality.

[Y] Root and shoot fresh weight.

[X] Root:shoot ratio = root weight ÷ shoot weight.

[W] Rooting Response caclulated Proc GLIMMIX binomial distribution and logit link function; means within column with different letters are not similar.

[V] Comparison of least square means was carried out with multiple-comparisoin-adjusted significance. level of 0.05 using simulation-stepdown method PROC GLIMMIX (June 2006 release) (SAS Version 9.1 SAS Institute, Cary, NC).

[U] Screened to ≈0.47cm(0.19 in).

Table 5. Particle size distribution of coarse HydRocks® and sand combinations compared to a conventional rooting substrate Experiment 1.

US standard sieve #	Sieve opening (mm)	6:1 Pine bark:sand	100% HydRocks®[Y]	3:1 Hyd:sand	1:1 Hyd:sand	1:3 Hyd:sand	Sand
1/2	12.50	0.0[X]A[W]	0.00 A	0.00 A	0.00 A	0.00 A	0.00 A
3/8	9.50	0.73 A	0.10 B	0.03 B	0.00 A	0.00 B	0.00 B
1/4	6.30	10.90 BC	18.40 A	12.47 B	7.10 C	2.80 D	0.00 D
6	3.35	27.87 C	69.00 A	45.0 B	26.00 C	14.03 D	4.40 E
8	2.36	13.53 A	6.93 BC	7.07 B	6.13 BC	5.83 BC	4.90 C
10	2.00	5.80 A	1.50 C	2.43 B	2.63 B	2.80 B	2.77 B
14	1.40	11.03 A	1.97 D	4.90 C	6.40 B	7.47 B	7.36 B
18	1.00	8.60 BC	0.83 E	5.10 D	8.37 C	9.53 AB	10.23 A
35	0.50	13.13 D	0.57 E	13.80 D	26.66 C	32.00 B	38.47 A
60	0.25	5.30 D	0.33 E	7.73 D	15.20 C	21.13 B	26.83 A
140	0.11	2.67 BC	0.33 D	1.23 DC	1.40 DC	3.50 AB	4.47 A
270	0.05	0.33 BC	0.03 C	0.23 C	0.20 C	0.77 A	0.57 AB
Pan	0.00	0.00 A	0.00 A	0.00A	0.00 A	0.00 A	0.00 A

[Z]Substrates were air dried at ambient room temperature under normal conditions.

[Y]All HydRocks® treatments were screened to ≈ 0.64 cm (0.25 in)

[X]Mean percent weight of material retained on each screen using Camsizer® (Restsch® Technology, Haan Germany) for seperation.

[W]Means within row with different letters are different based on LSD mean separation (α=0.05, n=3).

Tabe 6. Particle size distribution of six different rooting substrates Experiment 2.

US standard sieve #	Sieve opening (mm)	Screened Pinebark	Fafard 3B	Sand	Perlite	Vermiculite	HydRocks®[Y]
1/2	12.50	0.00[X] A[W]	0.10 A	0.00 A	0.00 A	0.00 A	0.00 A
3/8	9.50	0.00 B	1.73 A	0.00 A	0.00 B	0.00 B	0.00 B
1/4	6.30	0.20 A	7.90 A	0.00 A	0.00 A	0.00 A	0.00 B
6	3.35	12.80 ABC	21.37 A	4.40 BC	4.40 BC	0.90 C	6.10 A
8	2.36	13.13 BC	12.47 BC	4.90 C	4.90 C	4.67 C	24.77 A
10	2.00	6.63 BC	5.27 BC	2.77 C	2.77 C	5.53 BC	27.77 A
14	1.40	16.23 AB	10.93 BC	7.37 C	7.37 C	22.37 A	17.67 AB
18	1.00	12.20 B	10.13 B	10.23 B	10.23 B	28.63 A	16.23 AB
35	0.50	18.60 C	18.47 C	38.47 A	38.47 A	38.47 A	5.20 C
60	0.25	10.80 BC	8.40 CD	26.83 A	26.83 A	6.30 D	1.53 E
140	0.11	9.90 A	3.03 C	4.47 BC	4.47 BC	3.27 C	0.27 E
270	0.05	1.20 A	0.20 A	0.57 A	0.57 A	0.60 A	0.33 C
Pan	0.00	0.00 A	0.00 A	0.00 A	0.00 A	0.00 A	0.13 A

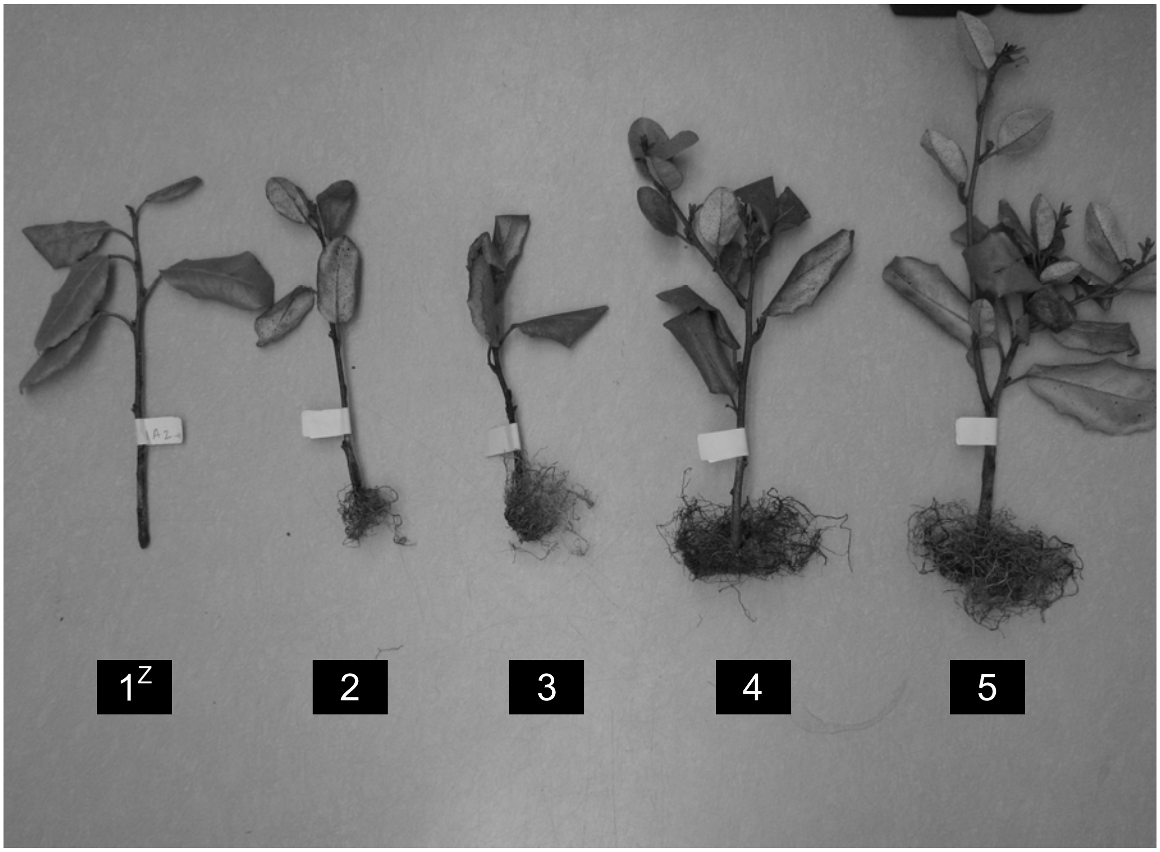
[Z]Substrates were air dried at ambient room temperature under normal conditions.

[Y]Screened to ≈0.47cm(0.19 in.).

[X]Mean percent weight of material retained on each screen using Camsizer® (Restsch® Technology, Haan Germany) for seperation.

[W]Means within row with different letters are different based on LSD mean separation (α=0.05, n=3).

Figure 1. Example of visual rating scale used for root quality of harvested *Elaeagnus* x *ebbingei* cuttings.



[Z] Rating scale based on quality of cuttings relative to the entire population of species harvested (1 = non-rooted cuttings and 5 = greatest quality cuttings).

V. FINAL CONCLUSIONS

Lightweight expanded clay aggregates (LECA) as a weed barrier

Results from our study evaluating LECA as a weed barrier in container grown plants indicates that HydRocks® applied as a surface mulch at 2.54 cm (1.0 in) provided successful control of oxalis when seeds were already present in the substrate but only limited control of oxalis when seeds were applied on top of mulch. Only two mulch depths were used in this study and only one weed species. Both studies were conducted in full sun.

Additional research related to using light weight clay aggregates as weed barriers is needed in order to answer further questions regarding effectiveness: What other weed species might be controlled by using clay aggregates as a weed barrier? In large containers, would deeper mulch depths provide better effectiveness? How long would a light weight aggregate weed barrier be effective? How could combinations of mulch and chemical pre-emergent herbicides increase effectiveness? What equipment would be needed for LECA to be applied mechanically at potting? How does LECA affect container temperature and moisture levels?

Larger containers and planters common in container shade tree production might have more potential for a light weight aggregate weed barrier. Container shade tree production requires extended production times and large space allocations between containers. Deeper mulching depths possible in these larger containers could provide greater control of weeds. It is common for container grown shade trees to be drip irrigated. Drip irrigation concentrates water in localized surface areas and would allow mulch to maintain a dryer state throughout production that is not as practical in smaller container production under overhead irrigation. Drip irrigation could be applied under mulch allowing the mulch to maintain a dry state further increasing effectiveness of weed control. Further evaluations along this line are warranted.

Combinations of mulch and chemical pre-emergent herbicides have shown to increase the longevity of weed control when compared to mulch only or pre-emergent only. Pine bark nuggets applied as surface mulch in combination with a single pre-emergent application was shown to provide excellent weed suppression 180 days after treatment (Richardson et al., 2005) Using a combination of mulch and herbicide might allow the herbicide to control weeds not controlled by the mulch and reduce the seed bank of already present weed seeds.

Lightweight expanded clay can be manufactured in a number of particle sizes. More work is needed to determine the most effective particle size of light weight clay aggregates. The particles in our mulch study were screened at 0.25 inch leaving many smaller aggregates of various sizes. The environment for seed germination would become more hostile if these finer particles were removed leaving the mulch more porous and able to dry out faster. Shade also might play a role in the effectiveness of HydRocks® as a weed barrier. In a separate study conducted under shade HydRocks® outperformed a single application of Snapshot 28 weeks after application but the number of weeds not controlled was too many to be considered acceptable. It is possible that when HydRocks® is used in the shade it is not allowed to dry out as readily as if it were used in the full sun making the environment less hostile for weed germination (Table 1).

Evaluation of LECA in perennial offshoot production

Results from this study indicate that clay materials such as HydRocks® and Profile™, when compared to conventional substrates can provide suitable yields while also decreasing labor cost by decreasing time to bare-root. EC and pH were not monitored during this experiment. Only two cultivars of the same species were used in this study (*Ophiopogon japonicus* and *Ophiopogon japonicus* 'Nana'). Plants were grown in containers in this study and in most cases perennial offshoot are grown in in-ground beds.

Additional research is needed to answer questions regarding clay product effectiveness as a bare rooting substrate: How effective would these products be on other dividing perennial species? If these materials were used in in-ground beds how would their physical properties (porosity, air space and container capacity) change and influence yield? How would increased fertilizer rates effect yield when using these clay products? How does the difference in cation exchange capacity (CEC) affect salt levels when comparing Profile™ to HydRocks®? How does shortening or extending production time effect time to bare root and yields of these materials?

The HydRocks® material in this study was only screened at 0.19 inches. Finer aggregates could aid in increased water holding capacity and potentially improve CEC by providing particles with greater surface area.

These materials could be effectively re-used after harvest for many years. Further research on the incidence of soil born pathogens with the re-use of clay products is needed. More research is needed to evaluate pesticide retention). If materials were re-used would a build up of pesticides influence yield. Also chemical pesticides might behave different when applied to these clay products. Profile™ has a high CEC and is considered to mimic soil but, HydRocks® has a low CEC that could affect some chemical pesticides that need to bind to soil/substrate colloids. Many pre-emergent herbicides rely on binding to the soil and if they were not allowed to bind soil/substrate structures they would become ineffective.

Lightweight aggregates a rooting substrate

In both experiments shoot growth, root growth, and ease of dislodging substrate particles were compared to conventional methods of producing bare root liners. The results of these studies suggest that HydRocks® can be used as a successful rooting substrate. The results of cutting quality vary depending on species. In the second experiment no fertilizer was added to any treatment. Mist was applied evenly to all treatments throughout the test. Further research might answer additional questions that might improve root quality and rooting percentage for cuttings rooted in Hydrocks™. What influence does mist application have on rooting percentage and rooting quality for cuttings rooted in HydRocks®? How do fertilizer applications influence cutting quality and percentage? How do combinations of different HydRocks® particle sizes influence physical properties (total porosity, container capacity and air space)? How physical properties might be changed if HydRocks® was used in in-ground beds? How effective are chemical pesticides such as fungicides and herbicides when applied to HydRocks® substrates? How well do HydRocks® grown plants transplant when compared to other treatments?

The nursery industry differs from traditional agricultural industries, in that; there is a tremendous amount of room for innovation and improvement. The nursery industry requires growers to not only be experts in producing thousands of different plant species but to also require growers to be able to handle plant diseases, insect pest, weed control, propagation, irrigation, and shipping. This leaves a tremendous amount of room for innovation and improvement, some would argue more than any other agricultural industry.

With an ever-changing economy and increasingly stringent environmental policies new production methods and techniques that were once not cost effective have potential to one day become more practical. Expanded clay aggregates have potential to be re-used, most of common substrates are made from organic materials that are can only be used for a single growing. As the price of pine bark and peat continue to rise along with transportation cost bare root liner beds filled with HydRocks® may be provide a more sustainable production approach. As pesticide regulations continue to increase and the market for organically grown agriculture products continues to grow, HydRocks® could find a good deal of utility in large container production or retail garden centers where chemical applications are difficult.

Literature Cited:

Richardson B.M., C.H. Gilliam, G.R. Wehtje, and G.B. Fain. 2005. A non-chemical alternative for weed control in container nursery crops. South. Nurs. Assoc. Res. Conf. Proc. 50: 449-451.

Table 1. Comparison of HydRocks® to Snapshot™ in control of volunteer *Oxalis stricta*

	Oxalis Fresh Weights		
	Wide Brim[Z]	T-Rex[Y]	Pooled[X]
No weed control	4.13 a[V]	4.46 a	4.26 a
Snapshot™[W]	3.85 a	4.56 a	4.20 a
Hydrocks™	1.16 b	1.40 b	1.26 b

[Z] *Hosta* 'Wide Brim'.

[Y] *Hosta* 'T-Rex'.

[X] Pooled data from 'Wide Brim' and 'T-Rex' Hosta.

[W] Snapshot™ applied at a rate of 150 lbs per acre.

[V] Means within column followed by the same letter are not significantly different (Waller-Duncan K-ratio t test $p \leq 0.05$).

APPENDIX A:

USE OF LIGHT EXPANDED CLAY AGGREGATES AS CHEMICAL CARRIERS IN THE NURSERY INDUSTRY

Using LECA as a chemical carrier

LECA has the ability to absorb water when submerged and through filling of the interconnected network of cells and cavities. Physical properties of the lightweight aggregate HydRocks® reveals that the material has the capacity to absorb 54%-83% of its on weight in water (Table A1). The absorptive properties of HydRocks® suggests possible use as a chemical carrier in the nursery industry.

The following studies were conducted to evaluate HydRocks® use as a hormone carrier in propagation, a herbicide carrier in container production, and a fertilizer carrier in container nursery substrates.

HydRocks® as a hormone carrier. Auxin application to stem cuttings has traditionally been applied in the form of a basal quick dip or a talc powder. Labor involved with quick dip and powder applications requires only a few seconds for a bundle of cuttings, but a few seconds adds up when considering application to thousands of cuttings. Recently, newer methods of application, such as foliar sprays and auxin saturated substrate, have been explored in an effort to improve automation and decrease human contact with auxin-based chemicals (Blythe et al., 2004). EPA worker protection standards require the use of personal protective equipment when handling agriculture chemicals. Protective equipment typically is cumbersome and uncomfortable in a propagation environment. Decreased human contact with auxins may reduce the need for protective equipment. Employees using agricultural chemicals are concerned about toxicity for even the safest chemicals. Employees may develop a safer outlook of their job if the constant handling involved with quick-dip applications of hormones could be eliminated.

Low concentration of auxin incorporated into rooting substrates has been proven successful on several species (Blythe et al., 2004). Auxin in an ethanol solution has been shown to be absorbed throughout the epidermis as well as the cut surface at the base of the stem (Geneve, 2000). Blythe et al. (2004) reported that incorporating auxin into a rooting substrate provided equal to or a higher quality cutting when compared to the traditional quick dip. Blythe et al. (2004) also stated that cuttings inserted into auxin-incorporated substrate demonstrated higher rooting percentages, root number, and root length when compared to conventional basal quick-dip techniques. Lower concentrations of auxin are required because prolonged exposure to ethanol and sodium carriers results in a phytotoxic response exhibited through abscission of foliage and complete death of cuttings.

On December 20, 2005 medial cuttings were collected off greenhouse grown *Ficus benjamini* 'Variegata.' Cuttings were prepared with an average length of 10.2 cm (4 in) with three leaves per cutting and sequentially stuck into the appropriate treatments in 72 cell inserts (50 ml per cell). Treatments included three HydRocks® (a light weight expanded clay aggregate marketed for the horticulture industry) materials (3/16, 1/8, and crusher fines) which were evaluated alone or with lime and/or hormone combinations. Hormone treatments included three different concentrations, 10 ppm, 100 ppm, and 1000 ppm IBA of indole-3-butryic acid from the formulation of Dip N' Grow®, (Dip 'N Grow®, Inc., Clackamas, OR). Treatments with a quick dip of 100 ppm and 1000 ppm IBA with Fafard 3B as a substrate were used for controls for comparison with HydRocks® treatments. HydRocks® materials were oven dried at 71°C (160°F) for 48 hours prior to soaking. HydRocks® treatments were soaked in appropriate hormone concentrations for 72 hours in sealed containers at room temperature and standard room air pressure. This study was conducted in a constant 25.5°C (72°F) greenhouse at Paterson Greenhouse Complex, Auburn University. Cuttings were placed under intermittent mist in a randomized complete block design with a total of 3 blocks. Each block contained a row of 6 cuttings per treatment. In total, 20 treatments with 18 cuttings per treatment were evaluated in this study (Table A2).

On February 20, 2006, two months after the initiation, the study was terminated. Data collected included rooting percent and a root quality rating based on a scale of 1 to 5. The root quality rating was based on structure and development of roots for each cutting, awarding #1 to cuttings with no roots and #5 for the best overall root system.

All 6 treatments containing concentrations of 1000 ppm IBA, regardless of particle size or presence of lime were considered failures with rooting percentages ranging from 0 to 28% (Table A2). These treatments became chlorotic and buds appeared scorched. Treatments without lime at the 1000 ppm concentration did not exhibit any scorched symptoms. The burning is likely do to high alcohol concentration in the hormone suggesting that the lime treatments might have held the hormone better than treatments without lime. Generally no differences were observed between Fafard 3B control treatments containing 100 ppm and 1000 ppm IBA. HydRocks® treatments presoaked in 10 ppm and 100 ppm had the highest rooting percent and scored higher on the root quality rating than the Fafard 3B treatments (Table A2). Fafard 3B treatments exhibited root development only at base of cutting, whereas, the HydRocks® treatments exhibited root development along the entire shaft of the cutting. HydRocks® treatments predominantly developed roots at the surface of the substrate and continued down the shaft of the cutting forming an upside down Christmas tree shape or a sporadic round shape in some cases. HydRocks® treatments did not form roots at the basal end of the cuttings like the Fafard 3B treatments. Despite the lack of roots at the bottom of the cutting, HydRocks® treatments with 10 ppm and 100 ppm had a much higher number of root tips when compared to Fafard 3B treatments. The higher number of root tips in HydRocks® treatments could be attributed to the constant contact of hormone along the entire shaft of the cutting and the abrasive nature of the HydRocks® aggregate. Successful HydRocks® treatments resembled the type root systems formed when air root-pruning pots are used in container production and did not exhibit any visible circling of roots. Fafard 3B treatments, however, had longer roots that did start circling the root ball after reaching the walls of the cell.

HydRocks® as a herbicide carrier. Two sizes of HydRocks® (3/16 in. and 1/8 in.) were soaked in two pounds of pendimethalin and applied to the surface of containers over seeded with *Digitaria sanguinalis* (crabgrass) to evaluate HydRocks® as a herbicide carrier. This study was deemed a failure, based on several factors. The quality of the crabgrass seed we used was questionable (i.e. poor germination even in untreated/control pots). Rates at which pre-soaked HydRocks® aggregates were applied to the surface of each container was based on the Pendulum 2g rates (with a much lower bulk density than HydRocks®). Even at the highest rate, HydRocks® would not adequately provide the needed coverage for good weed control. More work is warranted to determine an ideal particle size of HydRocks® and the amount of herbicide soaked HydRocks® to apply to a container surface to provide sufficient coverage. After the size and the amount of HydRocks® is determined then concentration of herbicide solution to soak HydRocks® in could be determined. Subsequently, the effectiveness of HydRocks® could be determined. Other confounding factors would need to be addressed such as the rate at which HydRocks® would release an absorbed herbicide. It is possible that the interior of HydRocks® aggregates might have a higher CEC than the outer surface because of increased surface area. A higher CEC in the inside of the aggregate could cause the herbicide to bind to the inside of the aggregate rendering the herbicide less effective.

HydRocks® as a fertilizer carrier. HydRocks® charged with fertilizer could give it a competitive advantage over conventional bagged substrates sold to retailers. On 03/30/04, *Lycopersicum esculentum* 'Better Boy' transplants were potted half way up the stem into 2 gal nursery pots (12.8 L) filled with one of two substrates (HydRocks® and Pine bark) and four fertilizer concentrations (1000, 500, 100 and 0 ppm Nitrogen (Peters 20-10-20)) (Table A3). HydRocks® and pine bark substrates were oven dried for 24 hours before being soaked in different concentrations of 20-10-20 fertilizer. Substrates were soaked for 12 hours in appropriate fertilizer concentrations. Treatments with no fertilizer concentration were soaked in water for 12 hours. All treatments were amended with 10 lbs of pulverized lime (SRM Aggregates, Opelika, AL). Containers were placed in a double polyurethane greenhouse where each plant received 600 ml of water daily from drip irrigation. Stem diameter and plant height were taken weekly. All data was analyzed using the GLM procedure with mean separation by Waller-Duncan K-ratio test (SAS Version 9.1 SAS Institute, Cary, NC).

After seven weeks of growth 500 and 1000 ppm N pine bark treatments had the greatest growth difference in height and caliper (Table A3 and Table A4). HydRocks® soaked with 500 ppm and 1000 ppm N were the similar in height growth difference to 0 ppm and 100 ppm N of both substrates (Table A3). This study suggest that HydRocks® charged with fertilizer is unable to retain nutrients long enough to sustain plant growth even at the highest rates when compared to organic based substrates (Table A3 and A4, Figure A1 and A2). HydRocks® inability to retain nutrients suggests it could be used as a hydroponic media where retention of nutrients is unfavorable, or as a substrate in other aquaculture systems.

Literature Cited

Blythe, E.K., J.L. Sibley, K.M. Tilt, and J.M. Ruter. 2004. Auxin application to stem cuttings of selected woody landscape plants by incorporation into a stabilized organic rooting substrate. J. Environ. Hort. 22:63-70.

Geneve, R.L. 2000. Root formation in relationship to auxin uptake in cuttings treated by the dilute soak, quick dip, and talc methods. J. Environ. Hort 18: 409-412.

Table A1. Adsorption capacity for 3 sizes of HydRocks®[Z].

Aggregate Screen Size	Bulk density[Y]	Fully saturated[X]	Adsorption capacity[W]
HydRocks® 3/16 inch	0.69 / 43.1	97	0.545
HydRocks® 1/8 inch	0.68 / 42.5	105.3	0.835
HydRocks® Crusher Fines	0.78 / 48.7	103.4	0.72

[Z](Big River Industries, Alpharetta, GA).

[Y] g/cm^3 and pounds per cubic foot.

[X]Aggregates were soaked for 12 hours after being oven dried.

[W]Adsorption capacity of aggregates was calculated as the difference between saturated weight and oven dried weight.

Table A2. Root quality rating[Z] and rooting percent for *Ficus benjamina* 'Variegata' cuttings using HydRocks®.

	Treatment	Average rating	Rooting percentage
1	900ml 3/16 HydRocks® + 300ml Lime + 1000ppm D&G[Y]	1	0%
2	900ml 3/16 HydRocks® + 300ml Lime + 100ppm D & G	3.7	72%
3	900ml 3/16 HydRocks® + 0ml Lime + 10ppm D &G	4	78%
4	900ml 3/16 HydRocks® + 0ml Lime + 1000ppm D & G	1	11%
5	900ml 3/16 HydRocks® + 0ml Lime + 100ppm D&G	4	78%
6	Fafard 3B + 0 ml Lime + Dip and Stick D &G 1000ppm	3	78%
7	300ml 3/16 HydRocks® + 100ml Lime + 10ppm D&G	3	33%
8	Fafard 3B + 0 ml Lime + Dip and Stick D &G 100ppm	3	78%
9	900ml 1/8 HydRocks® + 300ml Lime + 1000ppm D & G	1	11%
10	900ml 1/8 HydRocks® + 300ml Lime + 100ppm D & G	3.3	89%
11	900ml 1/8 HydRocks® + 0ml Lime + 10ppm D & G	3.3	94%
12	900ml 1/8 HydRocks® + 0ml Lime + 1000ppm D & G	1.3	28%
13	900ml 1/8 HydRocks® + 0ml Lime + 100ppm D &G	2	67%
14	250 ml 1/8 HydRocks® + 83 ml Lime + 10ppm	2	17%
15	900ml Cr[X] HydRocks® + 300ml Lime + 1000ppm D & G	1	0%
16	900ml Cr HydRocks® + 300ml Lime + 100ppm D & G	5	94%
17	300ml Cr HydRocks® + 0ml Lime + 10ppm D & G	3	83%
18	300ml Cr HydRocks® + 100ml Lime + 10ppm D & G	3	100%
19	900ml Cr HydRocks® + 0ml Lime + 1000ppm D & G	1	0%
20	900ml Cr HydRocks® + 0ml Lime + 100ppm D &G	4.7	78%

[Z] Rating scale is 1 = poor or no roots up to 5 = best root system.

[X] Dip'N Grow® (Dip'N Grow® Inc., Clackamas OR)

[Y] CR = crusher fines

Table A3. Height difference of tomato plants grown in fertilizer soaked substrate.

Substrate	ppm N	Week 2		Week 3		Week 4		Week 5		Week 6		Week 7	
HydRocks®[Z]	1000	7.56[Y]	bc[Y]	12.56	b	19.22	b	17.90	bc	20.33	b	16.44	bc
HydRocks®	500	6.44	cd	10.44	bc	16.00	b	13.90	cd	13.56	bc	13.89	bc
HydRocks®	100	3.11	ed	5.00	d	8.33	c	8.11	de	8.44	cd	2.22	c
HydRocks®	0	1.77	e	1.67	d	2.68	c	2.56	e	1.33	d	0.00	c
Pine bark	1000	10.67	ab	22.11	a	30.00	a	33.66	a	32.00	a	33.90	a
Pine bark	500	13.33	a	21.77	a	27.77	a	23.89	b	32.77	a	32.10	a
Pine bark	100	4.00	cde	6.11	cd	6.33	c	2.89	e	3.89	d	3.78	c
Pine bark	0	3.00	de	4.11	d	6.00	c	3.11	e	3.22	d	4.33	c

[Z]≈ 0.46 (3/16 in) HydRocks® (Big River Inudstries, Alpharetta, GA)

[Y]Difference in height from week one (presented in cm).

[X]Means within column followed by the same letter are not significantly different (Waller-Duncan K-ratio t test $p \leq 0.05$).

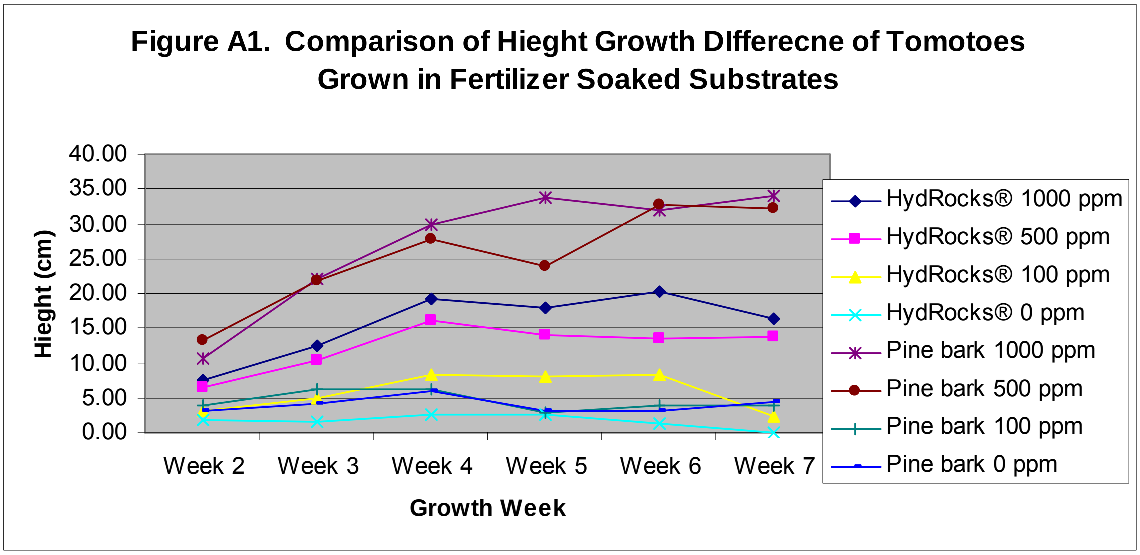
Table A4. Caliper of tomato plants grown in fertilizer soaked substrate.

Substrate	ppm N	Week 2		Week 3		Week 4		Week 5		Week 6		Week 7	
HydRocks®[Z]	1000	0.31[Z]	b[Y]	0.62	bc	1.44	b	1.47	b	1.54	b	2.17	b
HydRocks®	500	0.45	ab	0.76	bc	0.97	b	1.28	b	1.64	b	1.54	bc
HydRocks®	100	0.49	ab	0.85	bc	1.37	b	1.85	b	1.80	b	1.80	bc
HydRocks®	0	0.44	b	0.35	bc	0.88	b	0.88	b	0.85	b	0.91	c
Pine bark	1000	1.57	ab	2.08	a	3.80	a	4.29	a	4.69	a	4.43	a
Pine bark	500	1.05	ab	1.63	ab	3.51	a	4.66	a	4.56	a	4.41	a
Pine bark	100	0.47	ab	0.97	bc	0.88	b	1.05	b	1.11	b	1.10	c
Pine bark	0	0.49	ab	1.44	ab	1.63	b	1.80	b	1.85	b	1.77	bc

[Z]≈ 0.46 (3/16 in) HydRocks® (Big River Inudstries, Alpharetta, GA)

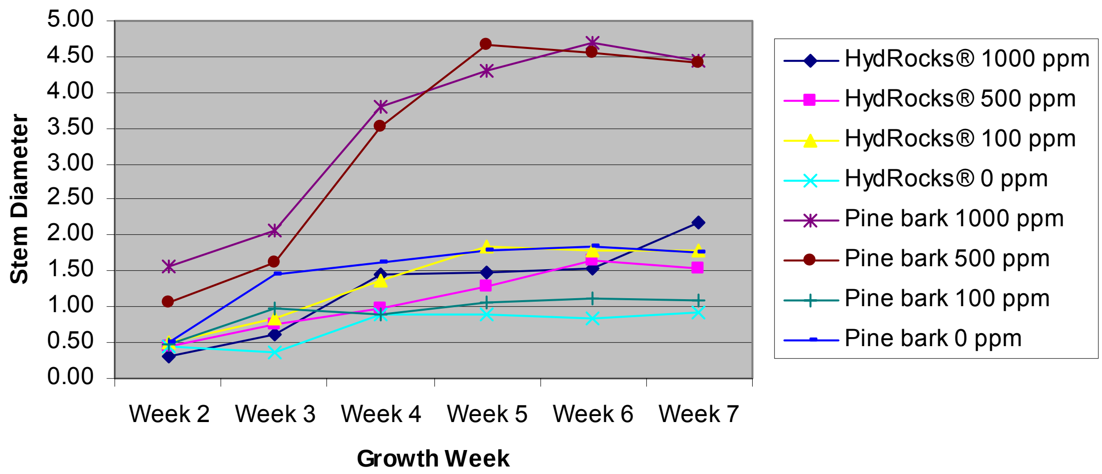
[Y] Difference in caliper from week one (presented in cm).

[X]Means within column followed by the same letter are not significantly different (Waller-Duncan K-ratio t test $p \leq 0.05$).



[Z]Mean growth difference in height from initial measurement at planting analyzed using the GLM procedure in the SAS System (SAS Version 9.1 SAS Institute, Cary, NC).

Figure A2. Comparisons of Tomato Caliper Grown in Fertilizer Soaked Substrates



[Z]Mean growth difference in caliper from initial measurement at planting analyzed using the GLM procedure in the SAS System (SAS Version 9.1 SAS Institute, Cary, NC).

APPENDIX B

LIGHT EXPANDED CLAY AGGREGATES AS A BARE ROOTING SUBSTRATE FOR BULB AND TUBER PRODUCTION

Most bulbs and tuber crops are traditionally field grown and are mechanically harvested. Preliminary studies have shown HydRocks® to be easily dislodged from roots. Because of the potential for HydRocks® to provide a suitable substrate for bare rooting bulb and tuber crops for home gardeners and small growers, HydRocks® and sand were combined and compared to conventional substrates as a bare rooting substrate for bulbs.

On April 17, 2007 single bare root bulbs of *Polianthes tube*rosa (tuberose) were potted into 6 inch azalea pots in the following substrates: pine bark, 8:2 pine bark:peat moss (v:v), 6:1 pine bark:sand (v:v), 3/16 HydRocks®, sand, 1:1 HydRocks®:sand (v:v), 3:1 HydRocks®:sand(v:v) , and 6:1 HydRocks®:sand (v:v) (Table B1). Containers were placed in sleeve pots containing screening to prevent the loss of substrate. The objective of this study was to evaluate HydRocks® as a bare rooting substrate in the production of *Polianthes tuberosa*.

On October 2, 2007 plants were harvested with shoot fresh and dry weights recorded, as well as total bulb number per container and the diameter of the largest bulb. Bulbs were subsequently divided into size grades 1-5 (#1 bulb ≥ 25 mm, #2 bulb = 19-23 mm, #3 bulb = 15-18 mm, #4 bulb = 10-14mm, and # 5 bulb ≤ 9 mm). All data was analyzed using the GLM procedure with mean separation by Waller-Duncan K-ratio test (SAS Version 9.1 SAS Institute, Cary, NC).

Plants grown in 100% pine bark and 6:1 pine bark:sand had high shoot dry weights and were both were similar to 8:2 pine bark:peat moss (Table B1) All HydRocks® treatments were similar to pine bark in total number of bulbs per container. No differences across treatments were observed for diameter of the largest bulb within each treatment (Table B1). No differences across treatments in the number of #1 bulbs (Table B2). Pine bark, 6:1 pine bark:sand, 8:2 pine bark:peat moss , and 3:1 HydRocks®:sand were all similar in number of #2 bulbs. No differences were observed across treatments in the number of #3 bulbs. HydRocks® and 3:1 HydRocks®:sand had high numbers of #4 bulbs per container and all bark treatments had significanlty fewer. No differences were observed across treatments in # 5 bulbs (Table B2). While HydRocks® treatments had similar total bulbs per container as most bark treatments, HydRocks® treatments had fewer large bulbs than bark treatments (Table B1).

We observed that generally as air space was reduced total bulb number had a tendency to increase, suggesting that HydRocks® might have produced larger bulbs and higher yield if container capacity was increased and/or irrigation frequency or duration was increased. Also, further research is warranted to determine if increasing fertilizer concentrations might increase yield in HydRocks® treatments.

In a separate study using caladiums, HydRocks® was compared to conventional substrates. Treatments were evaluated with or without 10 lbs of pulverized lime (SRM Aggregates, Opelika, AL. Throughout this study HydRocks® performed as well as bark and peat based substrates based on visual observations. Visually no differences were observed between treatments containing lime and treatments without lime. HydRocks® treatments performed as well as conventional substrates with regard to total number of leaves emerging from the pots, over all height of leaves, and total leaf area (data not shown).

Table B1. Yield evaluation of HydRocks® and sand combinations compared to pine bark based substrates in the production of *Polianthes tuberosa.*

	Fresh weight (g)	Dry weight (g)	Total bulbs	Diameter of of largest bulb (mm)
100% Pine bark	202.5 a[Z]	19.5 a	21.0 ab	48.9 a
100%HydRocks®[Y]	108.3 d	10.8 de	18.0 b	44.9 a
100% Sand	106.3 d	10.6 e	23.8 a	45.9 a
8:2 Pinebark:peat (v:v)	173.8 ab	16.7 ab	21.7 ab	52.5 a
1:1 HydRocks®: Sand (v:v)	156.9 bc	15.7 bc	24.0 a	49.7 a
3:1 HydRocks®: Sand (v:v)	149.8 bc	14.5 cde	23.2 a	47.9 a
6:1 HydRocks®: Sand (v:v)	130.3 cd	12.7 cde	20.2 ab	47.3 a
6:1 Pinebark: Sand (v:v)	206.9 a	19.9 a	23.2 a	50.8 a

[Z]Means within column followed by the same letter are not significantly different (Waller-Duncan K-ratio t test $p \leq 0.05$).

[Y]≈0.46 cm (0.18 in) HydRocks® (Big River Industries, Alpharetta, GA).

Table B2. Bulb quality evaluation of HydRocks® and sand combinations compared to pine bark based substrates in the production of *Polianthes tuberosa*.

	#1 Bulb[Z]	#2 Bulb[Y]	#3 Bulb[X]	#4 Bulb[W]	#5 Bulb[V]
100% Pine bark	6.3 a[U]	37.2 a	28.7 ab	23.3 d	4.3 a
100% HydRocks®	0.8 a	5.1 c	16.3 b	63.0 a	14.7 a
100% Sand	1.3 a	15.7 bc	31.5 ab	36.5 cd	15.1 a
8:2 Pinebark:peat (v:v)	3.7 a	24.1 ab	36.3 ab	28.2 cd	7.8 a
1:1 HydRocks®: Sand (v:v)	0.8 a	13.8 bc	30.8 ab	49.0 ab	5.7 a
3:1 HydRocks®: Sand (v:v)	2.7 a	23.1 ab	46.8 ab	25.6 d	1.8 a
6:1 HydRocks®: Sand (v:v)	2.3 a	11.1 bc	41.0 ab	42.5 bc	3.1 a
6:1 Pinebark: Sand (v:v)	7.7 a	22.1 ab	34.5 ab	28.7 cd	7.3 a

[Z]#1 bulb ≥ 25 mm.

[Y]#2 bulb = 19-23 mm.

[X]#3 bulb = 15-18 mm.

[W]#4 bulb = 10-14 mm.

[V]#5 bulb ≤ mm.

[W]Means within column followed by the same letter are not significantly different (Waller-Duncan K-ratio t test $p \leq 0.05$).