Engineering, Economics, Structures and Innovations

Glenn Fain
Section Editor and Moderator

Evaluation of Composted Household Garbage as a Horticultural Substrate

Scott D. Croxton, Jeff L. Sibley, Wenliang Lu, and Milton Schaefer
Auburn University, Department of Horticulture, Auburn, AL 36849
Schaefer Nursery, Winchester, TN 37398
jsibley@acesag.auburn.edu

Index Words: manufactured soil mix, alternative media, potting soil

Significance to Industry: Municipal solid waste fluff compost (MSWFC) can be used as a partial substitute for pinebark (PB) or peat moss (PM) in container grown weeping figs. New Guinea impatiens can grow in blends with 40% MSWFC as good as in the three commercial blends compared in this study. Some bedding plants, like petunias, may not have good growth in 100% MSWFC, but MSWFC can be used to replace at least one third of the PB or PM as a substrate component for both petunias and dusty miller. Our studies suggest that a ratio of about one third MSWFC replacement can be effectively used to grow a wide variety of container plants or flowers.

Nature of Work Selection of substrates for horticultural use is often based on cost, availability, ease of handling, and reproducibility. Peat and pine or other types of bark are common substrate components for nursery growers in the United States. Availability and cost of peat and pine bark is greatly affected by the timber industry, transportation, and/or environmental conditions such that the supply can be inconsistent or unpredictable (1,2). Future supply of pine bark is predicted to be further constricted as papermills relocate outside of the United States or to regions of the country where freight costs will prohibit nursery use of the material. Additionally, pinebark use as a biofuel is increasing as EPA regulations requiring reduction in fossil fuels hit full stride early next year.

The phrase “One man’s waste is another man’s treasure” certainly applies to materials we find useful for various horticultural applications. Alternative products as substrate blending components for horticultural use in propagation and container production of landscape plants are evermore urgent. Factors such as transportation costs, consistency of product, disease and insect infestation, and availability of the various alternative materials have been the primary concerns for growers.

The objective of this study was to evaluate various blends of municipal solid waste fluff compost (MSWFC) as a horticultural substrate in (a) container growth of weeping figs (*Ficus benjamina*), and (b) growth of three bedding plant selections. MSWFC was obtained from the WastAway Sciences Co., in McMinnville, Tennessee following indoor windrowing for composting at the WastAway Processing Center in January 2004.

On February 19, 2004, four substrates were blended: 100% pine bark (PB), 50%:50% (v:v) PB:MSWFC, 75%:25% (v:v) PB:MSWFC, and 75%:25% (v:v) PB: peat (PM). Substrates were amended with 7.8 $kg{\cdot}m^{-3}$ (13.2 lbs/yd^3) Osmocote

18-6-12 (The Scotts Company, Marysville, OH) and 0.9 kg·m^{-3} (1.5 lbs/yd^3) Micromax (The Scotts Co.). Twelve weeping figs were transplanted from 3.8 L (#1) pots to 7.6 L (#2) pots in each substrate blend. Plants were grown in a double layer polyethylene-covered greenhouse at the Paterson Greenhouse Complex, Auburn University, AL for 12 weeks. Plants were arranged in a randomized complete block design with 4 treatments per block and four blocks.

Plant growth measurements were determined in terms of growth index (GI) (height + width at widest point + width perpendicular to width at widest point/3) measured initially and then 1, 6, 12 weeks after transplanting. At the end of the study on May 12, 2004, aboveground parts (shoots) of plants were harvested. Shoot fresh weights immediately after harvest and dry weights after drying at 70°C for 72 hr were recorded.

On March 17, 2004, plugs of New Guinea impatiens (*Impatiens* 'New Guinea'), were transplanted into 8 18-hole trays using one blend containing MSWFC and three commercial growing blends (Fafard 3B, Fafard 52, and ProMix), with 2 trays for each blend. The blend containing MSWFC was 2:2:1 MSWC:PM:Perlite (PLR) and was amended with the same rates of fertilizers as in the weeping fig study. Growth of impatiens was visually evaluated.

On March 17, 2004, plugs of dusty miller (*Senecio cineraria*) and petunias (*Petunia X hybrida*), were transplanted into 9 36-hole trays of three substrates with 3 trays for each species and substrate combination. Three blends were used: 100% MSWFC; 2:1 MSWC:PLR; and 1:1:1 PB:MSWFC:PLR. Initial leachates and final leachates at the end of the study were taken for determination of pH and electrical conductivity (EC). Leachates were collected weekly using the Virginia Tech Extraction Method (VTEM) (3). Leachates were analyzed using a Model 63 pH and conductivity meter (YSI Incorporated, Yellow Springs, Ohio).

Survival and growth of dusty miller and petunia were visually evaluated. At the end of the study, the shoots of dusty miller were harvested for determination of fresh and dry weights with the same procedure for weeping figs. All bedding plants were randomly placed under mist irrigation in a greenhouse at the Paterson Greenhouse Complex, Auburn University, AL for 2 months.

Results and Discussion: In the weeping fig study, plants in the 1:1 PB:MSWFC had a greater initial growth index (GI) than plants in 3:1 PB:PT. One week after transplanting, the GI of plants in 3:1 PB:MSWFC was greater than plants in 100% PB and 3:1 PB:PT (Table 1). Six weeks after transplanting, the GI of plants in 3:1 PB:MSWFC was greater than plants in 3:1 PB:PT. However, there were no significant differences on the final GI (12 weeks after transplant). Analysis also indicated a greater increase over initial GI of plants in 3:1 PB:MSWFC than plants in 3:1 PB:PT one week after transplanting. There was no difference on the increases over initial GI 6 or 12 weeks after transplanting. Fresh weights of weeping figs grown in 3:1 MSWFC:PB were greater than plants in 3:1 PB:PT, but there was no difference on the dry weights of plants across all four blends. The New Guinea impatiens grown in the blend containing MSWFC had the best growth and color development compared with the three commercial blends, which we attribute to the additional fertilizer included only in the MSWFC blends.

The survival of petunias in the 100% MSWFC was low (less than 20%), about 50% of the petunias survived and grew well in the 2:1 MSWC :PLR blend, almost all petunias on 1:1:1 PB : MSWFC : PLR survived and grew well. Dusty miller grew well in all three blends. Analysis of the harvest shoot weight indicated no significant differences in the fresh weights of dusty miller from different blends, but dusty miller in the 2:1 MSWFC:PB had a greater dry weight than those from 100% MSWFC. Leachate analysis of the blends indicated a very high initial EC reading in the 100% MSWFC (Table 2) which may have contributed greatly to the low survival of petunias in the 100% MSWFC.

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Table 1. Effect of substrate blends on weeping fig growth index (GI) and shoot weight.

Treatment[z]	GI				Increases over initial GI			Fresh weight	Dry weight
	Initial[x]	1 WAP[y]	6 WAP	12 WAP	1 WAP	6 WAP	12 WAP		
100% PB	26.53ab	27.47bc	35.47ab	58.86a	0.95b	8.94a	32.33a	163.63ab[y]	43.38a
3:1 PB:MSWFC	26.72ab	30.53a	36.55a	60.11a	3.81a	9.83a	33.39a	181.26a	47.52a
1:1 PB:MSWFC	27.42a	29.61ab	35.94ab	60.86a	2.19ab	8.53a	33.44a	163.77ab	42.75a
3:1 PB:PM	24.75b	25.78c	33.08b	57.22a	1.03b	8.34a	32.47a	143.94b	39.46a

[z]PB = pine bark, PM = peat moss, MSWFC = municipal solid waste fluff compost from household garbage.

[x]Means within columns followed by a different letter are different according to Duncan's Multiple Range Test ($p = 0.05$).

[y]WAP: weeks after planting.

Table 2. Leachate analysis and effect of substrate blends on growth of dusty miller.

Treatment[z]	Fresh weight[y]	Dry weight	Initial pH	Final pH	Initial EC[x]	Final EC[x]
100% MSWFC	12.29[w]	1.81b	7.06	6.85	14.08	0.31
1:1:1 PB:MSWFC:PLR	15.49	2.49ab	7.02	6.88	9.32	0.23
2:1 MSWC:PLR	15.24	2.68a	6.34	6.86	8.42	0.37

[z] PB = pine bark, MSWFC = municipal solid waste fluff compost from household garbage, and PLR = perlite.

[y] Fresh and dry weight measured in grams.

[x]Initial and final electrical conductivity measured in millisiemens per centimeter.

[w] Means within columns followed by a different letter are different according to Duncan's Multiple Range Test ($p = 0.05$).

Estimation of U.S. Bark Supply

Wenliang Lu[1], Jeff L. Sibley[1], Jim S. Bannon[2], Yaoqi Zhang[3], Charles H. Gilliam[1]
[1]Department of Horticulture, Auburn University, AL 36849
[2]Alabama Agriculture Experiment Station, Auburn University, AL 36849
[3]School of Forestry and Wildlife Sciences, Auburn University, AL 36849
jsibley@acesag.auburn.edu

Index Words: pine bark, woody residue, substrate, mulch, compost, softwood, hardwood

Significance to the Industry: The concern over the availability of bark for horticultural usage is not fiction. In the nursery industry, bark has been a resource instead of a waste since the 1970's. In recent years, with the continuous rise in energy prices, the demand for bark as a clean fuel resource continues to increase. This demand couples with the stable or slightly decreasing timber harvest since 1986; in the meantime, the horticulture industry has seen a rapid growth for the last two decades. With no significant decrease in current energy prices and only a minor increase in the long term bark output and expected horticulture industry growth, the market share of bark for horticultural usage will keep shrinking. This analysis indicates that the demand for alternative substrates will continue to gain momentum in the near future. Furthermore, regional shortages due to closing forest product mills will exacerbate potential bark shortage.

Nature of Work: In the horticultural industry, bark is the primary component in most container nursery substrates. In the eastern U.S., pine bark is often used as much as 75-90% (by volume) of the container substrate. In the western U.S., barks of douglas-fir, redwood, and western red cedar are widely used. However, there is a rising concern that the availability of bark for horticultural usage, especially for container use is limited or will be limited in some markets due to alternative demands (e.g. industrial fuel) and reduced timber production (1, 3). In the meantime, a variety of organic wastes have been evaluated for their usage in horticulture to replace bark and/or peat moss, either composted or uncomposted. An estimation of the U.S. bark supply and its projected availability to horticulture will confirm need of suitable alternatives or provide assurance of continued supply of bark. Estimating regional bark supply will also indicate future price.

This study evaluates the quantitative relationship of timber harvest and the generation of bark as a timber residue based on the most up-to-date sources. The disposal of bark is further analyzed, with emphasis on its usage in horticulture. The supply of bark is assessed up to 2050 based on the analysis of the future timber situation in the U.S.

Results and Discussion: Bark is a secondary product obtained when peeling trunks of trees and it has often been considered as a waste product to the forest industry. Since 1960's, bark, especially softwood bark, has been gradually used as a container growing substrate (2). Bark has also been used as industrial fuel and landscape mulch as a means of waste disposal. As a by-product of the timber industry, bark production is mainly determined by domestic timber harvest, its species and size structures (5).

An analysis of the U.S. timber situation found that between 1952 and 1997, total area of timberland decreased 1 percent, from 509 to 504 million acres (3). Over the next 50 years, a projected U.S. population increase of 126 million will result in a projected net loss of US timberland area of about 15 million acres. Between 1991 and 1997, timber harvest declined 1.5 billion cubic feet (bcf), or 8 percent, from 17.9 to 16.4 bcf (Table 1). Only the Southern Region experienced an increase in timber harvest during this period, 16 percent. It is projected that total timber harvest will increase from 17.9 bcf in 1991 to 23.1 bcf by 2050, or a 29 percent increase. However, the timber harvest has been relatively stable or slightly decreased since 1986 and this trend will continue for several years through the first decade of the 21st century (3, 6; Table 1). It is worth noting that the projected softwood harvest of 2020 (11.0 bcf) is still below the level of 1986 (11.3 bcf).

Johnson (4) reported national and regional timber removals, product output, and mill residue data compiled for the 1996 calendar year. It is estimated that 1.65 bcf of bark residue was generated in 1996 (Table 2). Softwood bark residue was 1.06 bcf, or 64 percent, and hardwood bark residue was 0.59 bcf, or 36 percent. More than 97 percent of bark residue was used as fuelwood, fiber products, or miscellaneous. The dominant use of bark was as fuelwood for various biomass energy systems, 1.29 bcf, or 78 percent. Miscellaneous use in 1996 was less than 19 percent or about 307 million cubic feet which includes container growing substrate and landscape mulch use. Analysis of the data concluded strong correlations between softwood and hardwood harvest and bark generation. If we assume that this correlation is valid up to the year of 2050, it is projected that the total bark output of 2050 will be 2.27 bcf. Softwood bark will be 1.41 bcf and hardwood bark will be 0.87 bcf (Table 3). Compared with 1996, total bark residue will increase 38 percent, or an annual increasing rate of 0.6 percent. Softwood and hardwood bark residue will increase 33 and 48 percent, respectively, or an annual increasing rate of 0.52 and 0.72 percent, respectively. Softwood bark will be below the level of 1996 (Table 2) until 2010; even until 2020, the projected softwood bark output will still be below that of 1986 (Table 1). In South, although the softwood harvest increased greatly from 1991 to 1997, this trend will reverse from 1997 to 2010, which results a reduced softwood bark output during this period.

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Table 1. Softwood and hardwood timber harvest in the U.S. by region, 1952-1997 with project to 2050 (*thousand cubic feet*)*.

Region	Species	Historical				Projections				
		1952	1986	1991	1997	2010	2020	2030	2040	2050
North	Soft.	596	908	940	825	817	786	790	806	818
	Hard.	1381	3190	3684	2713	3070	3341	3639	3869	4113
	All	1977	4098	4624	3538	3887	4127	4429	4675	4931
South	Soft.	3036	5317	5282	6157	5703	6743	7722	8299	8954
	Hard.	1933	2931	2914	3366	4588	4700	4700	4684	4650
	All	4969	8248	8196	9523	10291	11443	12422	12983	13604
Rocky Mountains	Soft.	497	876	996	612	781	825	864	902	912
	Hard.	10	30	14	44	92	98	103	110	113
	All	507	906	1010	656	873	923	967	1012	1025
Pacific Coast	Soft.	3393	4189	3765	2507	2548	2667	2633	2811	2991
	Hard.	37	145	264	172	525	491	460	436	425
	All	3430	4334	4029	2679	3073	3158	3093	3247	3416
U.S.	Soft.	7522	11289	10983	10101	9848	11021	12009	12818	13674
	Hard.	3361	6323	6875	6299	8346	8707	8985	9188	9393
	All	10883	17617	17858	16400	18194	19728	20994	22006	23067

Data may not add to totals because of rounding.

*Data were compiled from Haynes 2003 (3).

Table 2. Bark use by region and species type 1996 (*thousand cubic feet*)*.

	Bark use	Fiber byproducts	Fuelwood byproducts	Misc. byproducts	Not used	All byproducts
Northeast						
Bark type	Softwood	871	4692	9008	1898	16470
	Hardwood	2165	16472	38802	5344	62783
	total	3037	21164	47810	7242	79253
North Central						
Bark type	Softwood	104	32174	5321	1692	39290
	Hardwood	3639	118878	63323	6567	192407
	total	3742	151052	68645	8259	231697
South						
Bark type	Softwood	-	503654	95050	4905	603609
	Hardwood	534	257840	47919	5525	311818
	total	534	761494	142969	10430	915427
Rocky mountains						
Bark type	Softwood	-	101070	9180	11597	121847
	Hardwood	-	323	1203	348	1874
	total	-	101393	10382	11945	123721
Pacific coast						
Bark type	Softwood	1148	235833	33674	8560	279216
	Hardwood	43	14360	3773	127	18304
	total	1192	250193	37447	8687	297519
U.S.						
Bark type	Softwood	2124	877423	152233	28652	1060432
	Hardwood	6381	407873	155021	17911	587186
	total	8505	1285296	307253	46563	1647618

Data may not add to totals because of rounding.

A dash (-) indicates no sample for the cell.

*Data were compiled from Johnson 2001 (4).

Table 3. Projection of bark generation by region, species from 2010 to 2050 (*million cubic feet*).

Region	Species	2010	2020	2030	2040	2050
North	Softwoods	84	81	81	83	84
	Hardwoods	283	308	335	357	379
	All species	367	389	416	440	463
South	Softwoods	586	693	794	853	920
	Hardwoods	423	433	433	432	429
	All species	1009	1126	1227	1285	1349
Rocky Mountains	Softwoods	80	85	89	93	94
	Hardwoods	8	9	9	10	10
	All species	89	94	98	103	104
Pacific Coast	Softwoods	262	274	271	289	307
	Hardwoods	48	45	42	40	39
	All species	310	319	313	329	347
U.S.	Softwoods	1012	1133	1234	1317	1405
	Hardwoods	769	803	828	847	866
	All species	1781	1936	2062	2164	2271

Data may not add to totals because of rounding.

Socioeconomic Survey of Nursery Automation

B. Posadas, P. Knight, C. Coker, G. Fain, D. Veal, and R. Coker
Mississippi State University, Coastal Research and
Extension Center, 1815 Popps Ferry Road, Biloxi, MS 39532
benp@ext.msstate.edu

Index Words: socioeconomic survey, nursery automation, greenhouse and nursery

Significance to the Industry: The results of the survey will be used to evaluate the socioeconomic impact of automation currently used in container nursery production and greenhouse plant propagation on work force, nursery and greenhouse characteristics, and use of labor, capital, pesticides, chemicals and computers. The results of the survey will also show the differences in production levels and sales attributable to the differences in the levels of automation in the major tasks performed in nursery and greenhouse operations in the region. It is expected that with this information, growers can make informed decisions regarding nursery and greenhouse automation that would be beneficial to the nursery business and to its workforce.

Nature of Work: The major limitation to growth of the greenhouse nursery industry is the shortage of qualified labor for container-based handling of plants (1). A recent national survey of commercial nursery/landscape operations listed labor shortage as the number one limitation facing the industry at the end of 2001 (2), with 68.4% of the respondents citing labor as a critical issue for their business. Many of the jobs in the greenhouse nursery industry require large amounts of stooping, lifting of heavy containers, and exposure to chemicals, dust, and plant materials. Exposures to plant materials and pollen at flowering can also lead to increased risk of allergy and asthma. These jobs tend to be relatively low paying, making it difficult to compete for and retain workers in a tight labor market. Many commercial operations have turned to immigrant labor to meet their labor requirements; however, these workers are often relatively unskilled, not speaking English and many lack driver's license and needed certifications (2, 3, 9). There is a need to increase the skill level of workers in order to improve wage rates, recruitment, and retention of workers. The changing markets and evolving technologies are two major forces creating investment and employment opportunities, as well as adjustment problems, in the green industry (4). As the opportunities in the green industry grow, so does the need for better-educated and qualified employees in the industry. One of the main issues of concern for the green industry is the ability to find the right kind of trained workers. Universities can assist in training workers for the green industry through technology transfer and training. The socioeconomic (SEC) project is a part of a research program currently being undertaken by the Mississippi Agricultural and Forestry Experiment Station and the U.S. Department of Labor entitled "Enhancing Labor Performance of the Green Industry in the Gulf South". The overall goal of this SEC project is to develop a socioeconomic profile of horticulture workers and to evaluate the impact of automation technologies on their employment, earnings, safety, skill levels, recruitment and retention rates. Specifically, it aims to achieve the following objectives:

1. To develop socioeconomic profiles (NSEP) of horticulture workers in the region;
2. To formulate an index of automation for horticulture nurseries (NAI) in the region;
3. To evaluate the effects of automation on the socioeconomic characteristics (NSEM) of horticulture workers in the region; and
4. To create a socioeconomic database (NSED) for horticulture workers in the region.

Results and Discussion: The focus of the SEC project is the greenhouse and nursery industry of in the Northern Gulf of Mexico which includes Alabama, Mississippi and Louisiana. The region's population is 61-72% white, 26-37% African American, and 2-3% other racial groups (5). Those who had at least a bachelor's degree comprised 18% in Mississippi to 21 in Alabama and Louisiana, which were below the national average. Those who did not complete formal high school education ranged from 21% in Alabama to 25% in Mississippi, which were also higher than that of the national average. The percent of the population who spoke a language other than English at home ranged from 3% in Mississippi to 9% in Louisiana. The incidence of poverty in all the states covered was also higher than that reported for the entire nation, ranging from 17% in Alabama to 20% in Mississippi. The target populations are laborers indirectly through the operators of the greenhouse/nursery industry. The above demographic characteristics indicate that the region has a very low paid, relatively unskilled labor force from which the greenhouse nursery industry can recruit. As of July 2004, more than 50 interviews with nursery and greenhouse operators had been completed in Mississippi and Louisiana. Interviews with growers in Alabama will be completed in a couple of months. The results of this nursery survey are used to evaluate the socioeconomic impact of automation on greenhouse nursery workers. Major labor issues addressed include, among others, worker safety, skill levels, wage rates, and worker recruitment and retention rates. The number, employment and workers' earnings of nurseries by states are collected from both primary and secondary sources. Secondary sources include the U.S. Dept. of Agriculture (7, 8) and U.S. Census Bureau (5, 6). The Nursery Automation Index is a measure of the level of automation currently being practiced in each nursery included in the regional survey. It shows the extent by which nurseries have currently automated the various tasks involved in the production of horticulture products. A series of questions is asked to solicit the respondent's perceptions of the level, costs and labor requirements of every automation used in every nursery visited.

1. How would you describe the level of automation in <nursery task> in your nursery?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

where 100% = fully automated or mechanized and 0% = fully manually done.

2. If automated or mechanized, what type of automated system is used?
3. What was the cost of purchasing and installing the automation system?
4. How many workers are required to operate the equipment?

The Nursery Socioeconomic Models will estimate the relationships among the different parameters describing earnings, employment, working environment, and automation index. The Nursery Socioeconomic Database consists of variables linking labor, technical and economic information collected during the survey of horticulture nurseries in the region. Variables included are race, age, gender, formal education completed, marital status, household income, household size, nursery experience, percent of income from nursery, and level of satisfaction from current lifestyle.

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Climate Control Concepts for Retractable Roof Greenhouse

Gene A. Giacomelli[1], Armando Suárez-Romero[1], Jennifer Nelkin[2], Ursula Schuch[2], Merle Jensen[2], and Chieri Kubota[2]
Controlled Environment Agriculture Program (CEAC),
The University of Arizona,
1951 E. Roger Road, Tucson, Arizona 85719
[1]Agriculture & Biosystems Engineering Dept; [2]Plant Sciences Dept
giacomel@cals.arizona.edu

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Significance to Industry: Retractable roof greenhouses (RRGH) have become increasingly popular in the nursery industry. The benefits found for nursery crops include decreased time to finished product, improved crop quality and reduced labor for crop handling. Furthermore, unique environmental conditions resulting from positioning the walls and roof provide for microclimate manipulation and beneficial plant responses. Decreased operations and capital cost of RRGH compared to traditional greenhouses, has developed great interest for growers within the nursery industry, as well as, for field vegetable and herb growers. At the Controlled Environment Agriculture Center (CEAC) of the University of Arizona, container rose production, lemon grass, tomato, bell pepper, and basil production have been investigated under RRGH conditions.

Management of the roof and sidewalls to provide the desired environmental conditions requires appropriate control strategies. Traditional strategies utilizing time of day and/or air temperature have not been sufficient. Currently crop production strategies [not rooting cuttings, or over wintering] consist of exposing the crop to the maximum daily light radiation (stowing the roof) followed by protecting (deploying the roof) when stressful air temperature conditions (too high or low) exist. We have developed a black ball sensor that was successfully utilized as an inexpensive yet effective way to monitor plant microclimate and determine when appropriate to stow or deploy the roof to provide accelerated plant production conditions.

Nature of Work: Environmental control strategies for the RRGH consist in exposing the crop (tomato, peppers and basil) to the maximum light radiation while protecting it from excessively stressful conditions. Most of those stresses were induced by either air temperature (too hot, too cold), by solar radiation (too high), by wind (too fast, too dry), or a combination of all of them. The sensors required to monitor all these environmental parameters are expensive and require a complex control system. The use of a black ball sensor was found to be an inexpensive, effective and reliable way to indirectly monitor the combination of radiation, temperature and wind speed for control applications (3,4). The black surface in effect simulated the maximum potential temperature of a dry leaf at a given radiation level, surrounding air temperature and wind speed. It was possible to achieve a 42% increase in solar radiation for the plants, by controlling the roof position based on the surface temperature of the black ball sensor, as compared to using the traditional measurements of either outside air temperature and/or solar radiation.

The RRGH structure was described in detail by Suárez-Romero (3), and consisted of a retractable flat-roof greenhouse manufactured by Cravo Equipment, LTD, Branford, Ontario, Canada which was located at the campus agricultural center of The University of Arizona. It consisted of 6 connected bays oriented North-South. Each bay was 21m (60 ft) by 12.5m (30ft) providing a total growing area of 1315 m^2 (10800 ft^2). Each bay was equipped with a roof curtain and sidewall openings. The glazing material was woven mesh polyethylene. The roof curtains were moved by an electrical motor that stowed or deployed them in an accordion fashion by a cable drive system. The four sidewalls were raised/lowered by four independent motors which rolled them around a central shaft. All four walls and the roof could be deployed or stowed in daytime combinations that provided: (1) shading (roof deployed), (2) shading with side ventilation (roof deployed, sidewalls open), (3) full sun with maximum cooling (roof stowed, sidewalls open), (4) full sun with wind break protection (roof stowed, sidewalls closed), or (5) partial shading with wind break protection (roof partially deployed, sidewalls closed). At night roof and sidewalls were positioned to provide thermal protection to the crop.

Two black hemispherical copper globes were constructed to make the black ball sensor by soldering temperature sensors (thermocouples type K, gage 18, ±0.5°C) to the internal surface of the copper wall. The internal space was filled with insulation foam, and the surface was painted with black mat paint. One sensor was placed outside the RRGH on a platform mounted 5m (16 ft) above the ground. This location avoided any shading, and wind protection by the structure. The other sensor was placed on a similar platform adjacent to the crop. By comparing the temperature of the two sensors it was possible to determine when to reposition the roof or side walls. For example, if either black ball sensor was below 24°C (75°F) the greenhouse was completely enclosed (maximum protection), if between 24°C and 45°C (113°F) the roof was fully retracted (allowed full sun), and if beyond 45°C the roof is deployed (shading), and the walls are completely open (ventilation). Additionally, during wind conditions (32 kph, 20 mph) the decision to partially open the roof and sidewalls was based on the difference of temperature between inside and outside black ball sensors, and would allow high levels of ventilation while protecting the crop.

Results and Discussion:

RRGH Fruiting Vegetables production

Peppers and tomatoes were grown in a rock wool hydroponic drip fertigated system. Tomatoes in RRGH produced yields of 237, 178 and 188 Ton/Ha (23.7 kg/m^2 (4.8 lb/ft^2), 17.8 (3.6), and 18.8 (3.8)), respectively for the cultivars Rapsodie, Quest and Trust. These results are much higher than the 40 Ton/Ha (4 kg/m^2 (0.8 lb/ft^2)) commonly achieved in the field. However it is less than conventional greenhouses with soilless production systems where annual yields were measured as 371, 291 and 309 Ton/Ha (30000 plants/Ha (12000 plants/A)). The cost of the structure is approximately 25% of a glasshouse (43 US$/$m^2$ or 4 $/$ft^2$ compared to 161 US$/$m^2$ or 15 US$/$ft^2$). However, the greater availability of light in the RRGH, allowed subsequent tests at a higher plant density (45000 plant/Ha) resulting in a linear increase in yield (annualized 334 Ton/Ha (6.8 lb/ft^2) for Rapsodie). The result of the pepper yield of three cultivars (Fiesta, Enza Zaden 416319, and Triple Star) were 46, 82 and 76 Ton/Ha, respectively, which was significantly lower than the conventional greenhouse (143, 177 and 144 Ton/Ha), and an improvement on reported open field yields (15-20 Ton/Ha (1)).

RRGH Basil production
Basil production (cv. 'Purple Ruffles' and 'Genovese') in a RRGH under the semi-arid climate summer conditions of Arizona had increased productivity and quality compared to a field production. Both cultivars were grown within the RRGH under 35% and 50% shade, were fertigated via drip irrigation, and grown in either rockwool culture or in a peat-based media in containers. Rockwool resulted in significantly greater biomass, irrespective of shade, for both basil cultivars. Along with increased productivity under RRGH conditions, higher quality of basil was achieved for both cultivars compared to field production, including the absence of pest damage and greater leaf area. Summer production of 'Genovese' basil grown in rockwool produced 45% more than plants in containers, and 106% more than plants grown in the field, with 'Purple Ruffles' following this trend on a lesser scale. The cultivar 'Genovese' produced 91% more biomass as a cultivar than 'Purple Ruffles' (2). While shade percentage did not affect trends in yields, both RRGH environments proved to be more suitable growing environments compared to the field. Based on summer crop yields in the RRGH, the following projections can be estimated. 'Genovese' basil plants in the RRGH produced 4.3 kg/m^2 per crop (0.88 lb/ft^2) when grown in rockwool, 3.02 kg/m^2 (0.62 lb/ft^2) in containers and 2.12 kg/m^2 (0.43 lb/ft^2) under field conditions. 'Purple Ruffles' basil plants in the RRGH produced 2.27 kg/m^2 per crop (0.46 lb/ft^2) when grown in rockwool and 1.63 kg/m^2 (0.33 lb/ft^2) in containers, compared to 0.9 kg/m^2 (0.18 lb/ft^2) under field conditions. The production period included 4 months of full production with weekly harvests. Controlled environment agriculture of culinary herbs continues to increase as a viable market, and herbs such as basil have been found to benefit from RRGH structures which provide environmental control strategies with reduced operational costs compared to fully controlled greenhouse structures.

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Production of Bareroot *Ophiopogon japonicus* Using Calcined Clay as a Growth Substrate

Glenn B. Fain and Keri L. Paridon
Mississippi State University
Truck Crops Branch Experiment Station
Crystal Springs, MS 39059
gfain@msa-stoneville.ars.usda.gov

Index words: profile, mondo, bareroot, porous ceramic

Significance to the Nursery Industry: This study indicates that the use of calcined clay (Profile™ 24x48) in container production of bareroot *Ophiopogon japonicus* can increase the quality of bibbs produced and decrease the labor needed in the barerooting process.

Nature of Work: Many groundcover plants such as *Ophiopogon japonicus* are marketed and sold as bare root divisions. Dividing and barerooting these plants is a labor intensive process whether container grown or field grown. Profile™ (Profile products LLC, Buffalo Grove, IL) is a calcined clay product whose base minerals are illite clay and amorphous silica. The raw product is heated in a kiln at 1500+ ˚C, which permanently changes the base minerals to a stable calcined clay (also called porous ceramic) particle. The resulting particles have approximately 74% pore space with 1/2 capillary (water holding) and 1/2 non capillary (air and drainage) pores. The final product also has a cation exchange capacity of 33 meq/100g. These products have been used for many years as soil amendments in golf course greens to improve soil structure. There have been comprehensive reviews on these and other soil amendments in turfgrass (2,3). Past research has indicated an increase in bermudagrass (*Cynodon dactylon*) tissue when soil was amended with $\geq$ 40% profile (4). Rhododendron spp. have been shown to grow exceptionally well in media containing calcined clay at up to 50% by volume (1).

On February 23, 2003, 3 bare root single bibb divisions of *Ophiopogon japonicus* and *Ophiopogon japonicus* 'Nana' were potted into 8" wide by 5-1/8" tall containers (C-350 (small mum pan), Nursery Supplies Inc., Chambersburg, PA) using either 100% aged pinebark, 8:2 (v:v) pinebark:peatmoss, 100% perlite, 100% 24x48 Profile™ (P1) porous ceramic (Profile products LLC, Buffalo Grove, IL) , or 100% 5x50 ProfileTM (P2) porous ceramic. Hardware cloth was placed in the bottom of each container to prevent loss of substrate through container holes. Containers were place in a greenhouse and liquid fed at each irrigation with 15N-2.1P-12.3K (15-5-15 Cal-Mag, The Scotts Co., Marysville, OH). On June 18, 2003, the plants were moved to an outdoor shade structure covered 40% shade cloth, fertilized with 14g of 18N-2.5P-9.8K (18-6-12 The Scotts Co.) and overhead irrigated as needed. On September 24, 2003, four workers were randomly assigned two replications of *Ophiopogon japonicus* from each treatment and instructed to bareroot each container by washing the substrate from the root system using pressurized water. The time required to bareroot each container was recorded and this data was analyzed using proc mixed with worker as the random variable and substrate as the fixed (SAS v 8e, SAS Institute Inc., Cary, NC). Bibbs were subsequently divided and graded into #1, #2 and #3 grades based on density of foliage and roots. The *Ophiopogon japonicus* 'Nana' were overwintered under the shade structure and fertilized on March 12, 2004 with 18g 15N-1.7P-7.3K (15-4-9, Harrells, Sylacauga, AL), overhead irrigated as needed, and harvested as described above on July 14, 2004. The experimental design was a randomized complete block with 8 single plant replicates with each taxa a separate experiment.

Results and Discussion: At approximately 210 days after initial potting, the *Ophiopogon japonicus* were harvested as described. By nursery standards these containers would not have been considered full at the time of harvest. It took approximately 61% more time to bareroot plants grown in pinebark compared to those grown in P1 (Table 1). Plants grown in P1 yielded 52% more bibbs on average than any other substrate (Table 2). On March 12, 2004 the *Ophiopogon japonicus* 'Nana' were harvested. It took approximately 81% more time to harvest plants grown in pinebark than those grown in P1 (Table1). There was no difference in total bibb yield in plants grown in P1 compared to pinebark or pinebark:peat substrates (Table 2). Plants grown in P1 did yield 210% more #1 bibbs than pinebark:peat and 60% more #2 bibbs than pinebark. The results of this study indicate that *Ophiopogon japonicus* grown in P1 produce higher quality bibbs than those grown in more standard nursery substrates with a significant decrease in time to harvest for bareroot production.

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Table 1. Time required to bareroot container-grown *Ophipogon japonicus* (2003) and *Ophiopogon japonicus* 'Nana' (2004).

	Time to bareroot (sec)[z]		Time to bareroot per bibb (sec)	
Substrate	2003	2004	2003	2004
1 - Pinebark	57.1	135.5	5.92	1.44
2 - 80:20 pinebark:peat (v:v)	43.0	116.6	4.77	1.45
3 - Perlite	27.9	67.0	2.97	1.51
4 - Profile (24x48)	35.4	74.6	2.49	0.86
5 - Profile (5x50)	20.5	65.4	2.34	0.96
Contrasts[y]				
1 vs 2	*[x]	NS[w]	NS	NS
1 vs 3	*	***	**	NS
1 vs 4	NS	**	**	**
1 vs 5	**	***	**	*
2 vs 3	***	***	***	NS
2 vs 4	**	***	***	**
2 vs 5	***	***	***	*
3 vs 4	NS	NS	NS	**
3 vs 5	NS	NS	NS	*
4 vs 5	*	NS	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]*, **, and *** represent significance where $P \leq 0.05$, 0.01, and 0.001.

[w]NS represents a nonsignificant treatment response.

Table 2. Bareroot bibb production of container-grown *Ophipogon japonicus* (2003) and *Ophiopogon japonicus* 'Nana' (2004).

	2003 *Ophiopogon japonicus*			
Substrate	Total bibbs	# 1 bibbs	# 2 bibbs	# 3 bibbs
Pinebark	9.0 b[z]	2.0 b	3.8 ab	3.3 a
80:20 pinebark:peat (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 (24x48)	14.6 a	4.5 a	5.5 a	4.7 a
Profile (5x50)	9.8 b	2.8 ab	3.4 ab	3.6 a

	2004 *Ophiopogon japonicus* 'Nana'			
Substrate	Total bibbs	# 1 bibbs	# 2 bibbs	# 3 bibbs
Pinebark	82.6 ab	5.4 ab	11.6 b	65.6 ab
80:20 pinebark:peat (v:v)	96.1 a	2.6 b	14.5 ab	79.0 a
Perlite	45.6 c	2.6 b	10.0 b	33.0 c
Profile (24x48)	88.6 ab	8.1 a	18.6 a	61.9 ab
Profile (5x50)	70.5 b	4.1 ab	12.5 b	53.9 bc

[z]Means with different letters within columns are significantly different, separated by the Bonferroni method ($\alpha = 0.05$).

Tree Liner Production Using Retractable Roof Greenhouses

Alison A. Stoven, Hannah M. Mathers and Daniel K. Struve
Department of Horticulture and Crop Science,
The Ohio State University, Columbus, OH 43210
stoven.1@osu.edu

Index words: bare-root whip, container production, RRG

Significance to the Industry: Field-grown whips (or liners) are generally sold bare-root and lined out for caliper tree production; the process requires three or more years. Tree liners are a large commodity crop for many Midwest nursery growers. Ohio's nurseries annually buy $14 million of liners, or 930,000 trees (1). In our system, tree liner production began in February and used a retractable roof greenhouse (RRG). By October, 2 m (6.6 ft) tall tree liners were produced. Water and nitrogen-use efficiencies were higher under the RRG than tree liners produced outdoors. Environmental modification of a production environment can increase water and nitrogen use efficiencies, resulting in higher productivity without increasing fertilizer and irrigation application rates.

Nature of Work: The four objectives of this study were to monitor the environmental conditions outside and inside a retractable roof structure; to determine if environmental modification increases growth of four taxa; to determine the effects of fertilizer type; and to evaluate water and nitrogen-use efficiency. *Cercis canadensis* (Eastern redbud), *Quercus rubra* (red oak), *Acer x freemaniii* 'Jeffersred' (Autumn Blaze® maple) and *Malus* 'Prairifire' (Prairifire crabapple) were used for the study. The oak species were grown from seed; the one-year-old redbud seedlings, and the one-year-old maple and crabapple rooted cuttings were received in February. The plants were graded for size, root pruned to 5 cm (2 in.) length and 240 plants from each species were potted into Spinout® treated 250-XL containers (Nursery Supplies, Fairless Hills, PA) on 1 February 2003 using MetroMix 510 (O.M. Scott Company, Marysville, OH) substrate and placed in a heated glass greenhouse, temperatures set at 21/18°C (70/65°F) (day/night). Plants were watered as needed and fertilized once per week with 21N-3.1P-5.9K (21-7-7) water-soluable fertilizer (Peters, O.M. Scott Company, Marysville, OH) at 100 $mg \cdot L^{-1}$.

On 15 March 2003, half of the plants were moved to the unheated retractable-roof greenhouse, and placed on heat mats set at 21°C (70°F). The retractable roof greenhouse, built at The Ohio State University, Columbus, Ohio, is a peaked-roof structure, 30.5x9.5 m (97x30.5 ft), Cravo Equipment, Ltd. Brantford, Ontario, Canada. The walls and roof for the structure were operated by a MicroGrow system (MicroGrow Systems, Temecula, CA). The controller set points were based on outside air temperatures. The roof remained open when the temperature was between 12-30°C (55-85°F), and closed otherwise. The sidewalls of the structure were programmed to close when the outside air temperature was less than 21°C (70°F). Thus, in cold weather, the closed roof and sidewalls trapped solar heat. If temperatures warmed, the roof and sidewalls opened. At high air temperatures, the roof closed to shade plants, while the open sidewalls allowed for cross ventilation.

On 12 May 2003, 30 plants from each species and each environment (RRG and glass greenhouse) were harvested; an additional harvest occurred in October. Caliper, height and dry root and shoot weight of individual plants were recorded. On 15 May 2003, the remaining plants were transplanted into 11.4 L (3-gallon) classic Spinout® treated containers (Nursery Supplies, Inc., Fairless Hills, PA), filled with a 60% pine bark, 25% peat moss, 7% sludge (municipal sludge from the City of Akron, Ohio), 7% haydite and 1% sand substrate (by vol.). Plants from the heated greenhouse were moved to an outside gravel production area; plants from the retractable-roof greenhouse remained within the structure. Plants inside and outside were placed in rows by species on single-wire trellis lines, spaced 30.5 cm (1 ft) within row and 61 cm (2 ft) between rows.

Two fertilizers were used: the slow release, Osmocote®, (O.M. Scott Company, Marysville, OH) a nine-month formulation of 20% N, 2.2 % P and 6.6% K (20-5-8), was surface applied on 16 May at 45 g/pot; the Peter's 21% N, 3.1% P, 5.9% K (21-7-7) (O.M. Scott Company, Marysville, OH) was applied in 1.14 liters/day (0.3 gal/day) at 100 $mg \cdot L^{-1}$. All plants, regardless of environment, received 1.14 liters/day (0.3 gal/day) of irrigation water.

Two WatchDog® data loggers (Spectrum Technology, Plainfield, IL) were set up in each environment to monitor air and soil temperatures along with photosynthetic active radiation (PAR) on an hourly basis throughout the growing season. Hourly temperatures and PAR were averaged daily and used to compute monthly averages.

Results and Discussion: The environmental conditions inside the RRG were consistent due to the MicroGrow controller: air temperature was 27.1°C (80.8°F), container substrate temperature was 27.6°C (81.7°F) and PAR was 740.9 $\mu mol \cdot m\text{-}2 \cdot s^{-1}$. Outside air temperatures were similar as in the RRG, but container substrate temperature was 14.6% greater (31.6°C/89.0°F) and PAR was 53.8% greater (1139.2 µmol·m-2·s-1). Although direct statistical comparisons between environments cannot be made (environments were not replicated), liners grown in the RRG had greater height, caliper, nitrogen efficiency and water-use efficiency as opposed to those grown outside—18.3%, 6.0%, 33.2% and 12.5%, respectively (Table 1). Nitrogen efficiency, calculated by the total amount applied divided by the nitrogen content of the crop, was greatest for the maples. Nitrogen loading levels, the total amount of nitrogen applied, using the slow release fertilizer was nine g/pot (0.0198 lbs). Water use efficiency was determined by dividing the total amount of plant dry weight by the total volume of water applied from May to October (163.02 L/43.07 gal). These results demonstrate that modifying environmental conditions can increase production efficiency without increasing nitrogen and irrigation application rates.

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Table 1. Height, caliper, nitrogen efficiency and water use efficiency of four taxa grown in retractable-roof structure or outside from May to October, 2003; data taken from October 2003 harvest.

Species	Environment[w]	Fertilizer[x]	Height (cm)	Caliper[y] (mm)	Nitrogen Efficiency (%)	Water Use Efficiency (g dry wt·L^{-1})
Redbud	RRG	SR	225[z]	15.8	44.8	1.47
	Outside	SR	206	13.9	36.3	1.19
Red oak	RRG	SR	58	8.8	4.7	0.27
	Outside	SR	49	8.1	6.2	0.33
Autumn Blaze® maple	RRG	SR	222	16.3	61.7	1.91
	Outside	SR	218	16.9	54.9	2.02
Autumn Blaze® maple	RRG	SR	190	11.6	34.2	0.78
	Outside	SR	141	11.2	13.5	0.56

[w] Plants were grown in a retractable roof greenhouse (RRG) or outside production area from 15 May to 1 October 2003.

[x] Plants were fertilized with a slow release fertilizer (SR), Osmocote® 0.20N-0.022P-0.066K, 9-mo. release, top dressed at 45 g/pot (0.10 lbs/pot).

[y] Caliper was taken 10 cm (4 in.) above container substrate level.

[z] Each value is the mean of three single-plant subsamples from five replications.