UTILIZATION OF MUNICIPAL SOLID WASTE COMPOST IN HORTICULTURE

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Wenliang Lu

Certificate of Approval:

James S. Bannon
Director, Outlying Units
Alabama Agricultural Experiment Station

Jeff L. Sibley, Chair
Alumni Professor
Horticulture

Charles H. Gilliam
Professor
Horticulture

Yaoqi Zhang
Assistant Professor
Forestry and Wildlife Sciences

Joe F. Pittman
Interim Dean
Graduate School

UTILIZATION OF MUNICIPAL SOLID WASTE COMPOST IN HORTICULTURE

Wenliang Lu

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Wenliang Lu

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Signature of Author

____
Date of Graduation

DISSERTATION ABSTRACT

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Wenliang Lu

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Composting of municipal solid waste (MSW) has long been considered an attractive waste management tool for effective reduction of waste volume and beneficial utilization of MSW compost (MSWC) can eventually turn waste into a resource. Horticultural applications are regarded as a high-end market of MSWC because the industry is in frequent need for high quality organic materials and is able to pay premium prices for various compost products.

The historical, current, and future bark availability for horticultural use was quantitatively evaluated. With expected horticulture industry growth, increased demand of bark for other uses, and only a minor increase in the long term bark output, the total amount and share of bark to the horticulture market will likely decrease. This analysis indicates strong incentives to develop alternative substrate components, such as various organic waste composts.

Utilization of a mixed MSWC as a substrate component in greenhouse and container nursery production was evaluated using 19 ornamental crops. Plant growth responded differently to substrates containing MSWC. In outdoor container production, 4 of 10 crops in substrates with 100% MSWC (in volume) grew equally to plants in non-amended pine bark (PB)-based substrates. Most plants (9 of 12) had similar growth in substrates with 75% MSWC than in the non-amended PB control. No plant growth was negatively affected by amendment of PB with MSWC at lower ratios (25% and 50% MSWC) and several species had better growth in substrates with 25% MSWC than in 100% PB and/or 100% MSWC. In greenhouse production, three of five ornamental crops had similar growth in MSWC-amended substrates than in PB alone. Growth responses to different irrigation levels and fertilization rates were not significantly affected by substrate amendment with MSWC. Under recommended fertilization rates, any growth contribution from nutrients in MSWC was likely minimal and occurred in a short period after potting.

The effect of amending soil with the mixed MSWC on yield and heavy metal concentrations in edible parts of okra (*Abelmoschus esculentus*) and watermelon (*Citrullus lanatus*) were investigated. Addition of MSWC increased okra yield and watermelon weights over non-amended plots. There were no differences among all treatments in heavy metal concentrations in okra pods, watermelon pulp, or watermelon juice.

Overall, our studies indicate current use of MSWC by ongoing research to integrate MSWC into horticultural production systems is warranted.

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This whole page won't be enough even I limit to a few words of thanks for each of my family members, but it's perfectly fine even I say nothing. Here is one BECAUSE: I started to understand my father when it was too late, but he won't blame me anything in his permanent peace.

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TABLE OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

I. LITERATURE REVIEW

Introduction

A majority of horticulture crops are produced in commercially available container substrates. In general, growers want substrates that are consistent, reproducible, available, easy to handle and mix, cost effective, and have the appropriate physical and chemical properties for the crop they are growing (Klock-Moore et al., 2000; Wang and Blessington, 1990). Widely used substrate components include peat moss, pine bark, perlite, vermiculite, sand, etc.

Peat moss is a major component in container substrates used in the greenhouse and nursery industries. This resource is becoming less plentiful while the production of potted plants has increased. Furthermore, environmental damage caused by large scale peat extraction is of concern. Pine bark is one of the most widely used substrate components in the nursery industry. However, concerns over erratic and highly variable supplies of pine bark have produced a need to evaluate alternative materials for use in organic container substrates. Composting of biosolids and other organic municipal and industrial wastes is becoming increasingly popular in the U.S. (Goldstein, 1987).

Utilization of compost in container substrates therefore could decrease the demand for sphagnum peat moss and also enhance recycling of solid waste through composting. In field nursery production, one major reason for nurseries to apply compost would be to mitigate topsoil loss and effectively extend the usefulness of their land (Maynard, 1998). Municipal solid waste compost (MSWC)as a horticultural substrate has attracted much attention as current substrates have become less available and/or more expensive. Studies using MSWC have been conducted to substitute the peat or pine bark fractions or to amend the soil as a mulch and soil conditioner (Klock-Moore et al., 2000; Ozores-Hampton et al., 2001). However, extensive studies are still needed before MSWC can be used widely as a horticultural substrate, mulch, or soil conditioner.

Literature Review

MSW Generation and MSW Composting

MSW Generation

Municipal solid waste (MSW) is the nonliquid, nonhazardous waste from households, institutions (e.g. schools, universities), and commercial establishments. MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, and batteries. Not included are materials that also may be disposed in landfills, but are not generally considered MSW, such as construction and demolition debris, municipal wastewater treatment sludges, and non-hazardous industrial wastes.

In the United States, about 229.2 million tons of MSW were generated in 2001 -- a decrease of 2.8 million tons (or 1.2 percent) from 2000 (US EPA, 2003). In 2003, the tonnage of MSW was 236.2 million tons (US EPA, 2005). While individual MSW generation rate has remained relatively constant since 1990s, the total annual generation has maintained an increasing trend. In 2001, about 65% of the municipal waste stream was organic matter (paper and paperboard, yard trimmings, food scraps, and wood). About 55.7% of the MSW was landfilled; 14.7% was combusted, primarily in trash-to-energy plants; and 29.6% (68.0 million tons) was recycled. Within the 29.6% of MSW that was recycled, about 5.8% was non-organic matter like glass, metals, plastics, rubber and leather, etc. A total of 54.5 million tons (23.8% of total MSW) of recycled MSW was organic matter. Within the recovered organic matter, recycling of paper and wood was 38 million tons, while the remaining 16.6 million tons (7.2% of total MSW) was yard trimmings, food scraps and other MSW organic materials. Overall, 63% of organic material still remained in the waste stream after recovery and recycling efforts (US EPA, 2003).

Commercial Composting Process

Composting is a biological process through which microorganisms convert organic materials into a reduced form. Composting is predominantly an aerobic or oxygen-requiring process. Many biological transformations and products occur in the composting process, mediated by a variety of microorganisms, inhabiting diverse microenvironments (Epstein, 1997). Oxygen is provided to the composting materials via aeration, but part of decomposition also occurs anaerobically. In addition to oxygen, the organisms need moisture, a balance of nutrients, and favorable temperatures and pH. The ideal balance of moisture generally falls in the range of 50 to 60% (wet basis) (Rynk and Richard, 2001). Ordinarily, nutrients are managed by providing balanced proportions of two primary nutrients, C and N. An ideal C:N ratio of a final compost product is considered to be in range of 25:1 to 30:1 (Epstein, 1997). Temperature is the primary factor affecting microbial activity in composting and it indicates the performance and stage of the composting process (Epstein, 1997; Golueke, 1972). Based on microbial activity, the composting process can be divided into four different stages: mesophilic, thermophilic, cooling, and curing or maturation stages.

According to whether or not the composting materials are physically contained, two categories of composting methods are typically used: (1) “open” methods that provide little or no containment and (2) “in-vessel” methods that contain composting materials in a reactor or vessel. However, the distinction between open and in-vessel composting is not precise as several methods can be considered in either category. Main open methods include turned windrows, passively aerated static piles, static piles and windrows with assisted passive aeration, aerated static piles and bins, aerated and turned piles, windrows, and bins. In-vessel methods include aerated containers, horizontal agitated beds, aerated-agitated containers, silo or tower reactors, and rotating drums (Rynk and Richard, 2001).

Municipal Solid Waste Composting

A report released by US EPA (1999) identified seven composting strategies of: (1) grasscycling, (2) backyard composting, (3) yard trimmings composting, (4) onsite institutional composting, (5) commercial composting, (6) mixed waste composting, and (7) residential source-separated composting. Using existing strategies and technologies, 36% of the US waste stream (about 75 million tons) was available for composting in 1997. A total of 83% was suitable for composting at a net benefit to society (i.e. savings over traditional disposal methods) through the first five strategies. Composting the remaining 17% (13 million tons in 1997) of the applicable organic waste stream could be accomplished through more costly mixed waste composting or source-separated composting once this strategy becomes better established in the United States. The 6^{th} strategy, mixed waste composting, refers to a centralized processing system that accepts mixed MSW and separates materials into component parts for composting, recycling, and refuse disposal. In theory, mixed waste composting could divert all organic waste that is currently targeted for composting. All organic materials might never be composted this way due to the cost and problems with marketing the end-product. Technically, however, this method of composting is capable of handling 100 percent of the currently discarded organic materials stream.

The following part of this section addresses composting of the waste stream by centralized processing system, which processes either mixed MSW or residential source-separated feedstock.

Serious US studies on composting of MSW as an engineering process began in the 1950s with only a few composting plants (Hickman, 2003). Between 1951 and 1969, 18 plants were funded and built. The last of the plants built between 1951 and 1969 closed in the mid-1980s. Many reasons can be cited for the closures, including odor complaints, poor product quality, lack of markets, and poor economics.

A resurgence in MSW composting begun in the 1980s due to a number of factors, including closure of substandard landfills in rural areas; rising tipping fees in some regions as well as perceived decreases in landfill capacity; minimal development of waste to energy facilities; a perceived natural fit with the growing interest in recycling; the existence of technologies; flow control restrictions that could enable projects to direct MSW to their facilities; and potential revenue stream from tip fees and product sales (Goldstein, 2001).

During the 1980s, MSW composting in the US emerged on two tracks. The mixed waste approach involves bringing unseparated loads of trash and doing all separation at the facility. The source separated approach relies on residents and other generators to separate out recyclables, compostables, and trash.

In the late 1980s, many in the solid waste field felt there would be a landfill crisis in some regions of the country, prompting a surge of interest in alternative management options. However, the expected landfill crisis never really materialized. The number of municipal solid waste landfills has decreased substantially over the years, from nearly 8,000 in 1988 to 1,767 in 2002 - while average landfill size increased (US EPA 2003, 2005). At the national level, capacity does not appear to be a problem, although regional constrictions sometimes occur.

Solid waste composting projects were also negatively impacted by a 1994 US Supreme Court decision that struck down a flow control law that helped facilities "guarantee" a flow of waste (Goldstein and Steuteville, 1994). That set off a trend which continues today – to haul MSW long distances to cheaper landfills. Other factors slowing the development of MSW composting in the US include generation of odors, inadequate capitalization to fix problems relating to odors; production of a marginal compost product; and significant skepticism about the technology due to previous project failures (Goldstein, 2001). Despite all factors affecting the development of MSW composting, the number of total operational composting facilities has remained relatively stable since 1991 (Table 1).

In 2001, a total of 16 MSW operating facilities were reported, with 11 of them using mixed MSW, and five of them using source separated MSW (Satkofsky, 2001). Nine of the 16 operating facilities used some type of in-vessel technology. Of the nine, seven used rotating drums, one an operated agitated bay system, and one used aerated containers. All but the agitated bay system had a second phase of composting in windrows, aerated windrows, or aerated static piles. The remaining seven facilities used enclosed aerated static piles -1; Windrows – 5; aerated static piles -1. Actual throughput ranged from 4 tons per day (tpd) to 300 tpd (Satkofsky, 2001). Compared with 2001, a new site was added in 2002 to the operational composting facilities, while one was temporarily closed, and one site closed permanently. In the update of MSW composting facilities published by *BioCycle*, the total number of projects was 28, of which 16 using mixed MSW and 12 projects using residential source separated organics (Goldstein, 2005a, b).

The total throughput of MSW processed by these facilities was about 0.64 million tons in 2001 and about the same in 2002. Compared with the amount recovered by composting of yard trimmings (15.8 million tons), this number is non-significant, an indication that there is a long way to go for MSW composting by centralized processing systems.

MSWC Quality Requirement for Horticultural Applications

With greenhouse or nursery crops, the most critical compost quality factors are plant growth response, pH and soluble salts, man-made inerts, maturity and biological stability, and particle size (Sullivan and Miller, 2001). In suggested compost quality guidelines for horticultural applications developed by the US Composting Council, quality parameters including nutrient content, water holding capacity, bulk density, and organic matter content must be reported; compost must pass germination and growth screen tests; must exceed EPA's Part 503 limits for trace element concentrations; moisture content should be 35-55%, and pH from 5.5 to 8.0 (US Composting Council, 1996). As container substrates, compost requires high stability, soluble salts with a maximum of 3 dS m^{-1} in mixed substrates, and particle size of no larger than 13 mm. However, most horticultural professionals considered the guidelines too general to apply to their specific situations. These guidelines are best used by compost producers as a minimum quality standard (E & A Environmental Consultants and Stenn, 1996). Specification should be established based upon reliable and readily interpretable test procedures.

Craul and Switzenbaum (1996) described a set of criteria developed to insure consistency of product for a large urban construction project in which a quantity of "constructed topsoil" was needed. Their parameters included specific targets for C:N ratio, stability of product, odor, particle size, pH, cation exchange capacity, and nutrient content. As a transplant substrate component, compost that is inexpensive, is readily available in adequate quantities, meets state and federal safety guidelines, and is consistently uniform in stability and maturity could be an asset in this highly competitive industry (Sterrett, 2001). The challenge to the compost industry is to develop the guidelines to insure the consistent production, management, and storage of high-quality compost products.

Utilization of MSWC in Field Nursery Production

The horticulture industry is regarded as a high-end market as horticulture is a more intensive culture type than general agriculture. Horticultural markets are more specialized, diverse and smaller, but the value of the crops is greater, especially, landscape ornamentals. Among the horticultural compost markets, the potential market for sod production, landscapers, nurseries, residential retail, delivered topsoil is estimated at 20, 2, 0.9, 8, and 3.7 million cubic yards per year, respectively (US EPA, 1999).

Because of a high potential material volume needed, many compost marketers prefer to sell their production to field nurseries. Field nurseries are the traditional production method of ornamental trees, shrubs, fruit trees, and perennial flowers. Field production often results in significant topsoil removal when nursery stocks are harvested using balled and burlapped method (B&B), which is the main harvesting method for stocks of three years or older. The topsoil has to be replenished and maintained up to a certain level of soil quality for sustainable crop production. Application of compost is a common option when the material is available.

While field nursery production is still common in some areas, container production has become increasingly dominant in commercial plant nurseries in the past 50 years (Davidson et al. 1999). Because the growing substrate is sold with the crop at the end of one production cycle, growers of container crops must acquire new substrate supplies at the beginning of each new production cycle. Numerous articles describe horticultural application of compost products derived from biosolids, yard trimmings, waxed corrugated cardboard, and food or agricultural residues such as spent mushroom, crab offal, and poultry wastes (Cole and Sibley, 2004; Rosen et al., 1993; Shiralipour, 1992). Literature covering application of commercially available MSW composts, defined as one including residential waste that arrives at the composting plant as mixed waste or source separated fractions (Satkofsky, 2001), are less common.

Although emphasis on MSWC utilization studies has been on nursery container production, some publications have detailed uses of MSWC as amendments in field nursery soil (Chong, 1999a; Fitzpatrick, 2001; Maynard, 1998).

Experiments evaluating the suitability of mixed compost from MSW, biosolids, and yard trimmings as a soil amendment or a mulch to suppress weeds were conducted in the production of field-grown nursery stock on four tree species for three growing seasons (Maynard, 1998). With increasing compost amounts, first year mortality of transplanted seedlings decreased in two species, increased in one species, with all seedlings of one species surviving regardless of treatment. While the decreased mortality was attributed to increased water holding capacity of the compost amended soil, the increased mortality with increasing amounts of compost could be due to either the high conductivity or the high ammonium concentration of the compost, which was most likely due to the immaturity of the compost. Weed control with two inches of MSWC mulch was slightly less effective compared to herbicide treated plots, but provided adequate weed control in the first year. Three of four tree species had a positive response to MSWC in one or more growth parameters (Maynard, 1998).

Effects of MSWC on soil properties and nutrient status have attracted much interest in a broad range of agricultural crops (Bugbee, 1996; Chong, 1999a; Crecchio et al., 2001; Iglesiasjimenez and Alvarez, 1993; Soumaré et al., 2003), and a few ornamental crops (Albiach et al., 2001; Fitzpatrick, 2001; Kahtz and Gawel, 2004). Albiach et al. (2001) analyzed organic matter components and aggregate stability after application of MSWC and four other organic amendments to a horticulture soil (in Spain) four and five years after experiment initiation. With application rates of 24 t ha^{-1} yr^{-1}, plots treated with MSWC had the highest increases in contents of organic matter, total humified substances, humic acids, carbohydrates and microbial gums, and the structural stability of aggregates. Organic matter and carbohydrates appeared to be the parameters most closely related to soil aggregate stability.

Compared with those few publications on field nursery crops, relatively abundant publications addressing compost use are available on other agricultural crops like ryegrass, barley, wheat, corn, and fruit crops (Mamo et al., 1999; Ozores-Hampton et al., 2001; Roe, 1998; Soumaré et al., 2003; Sterrett, 2001).

Utilization of Composts from Various Organic Wastes as Container Substrate components in Production of Ornamental Crops

With MSWC included, this section is a comprehensive review of recent research findings on different types of composts as container substrate components for production of various ornamental plants, either in greenhouses or in container nurseries.

Introduction

Composts made from various organic wastes have been tested as major components of container substrates since the very early stage of modern container production of nursery crops about 60 years ago (Bunt, 1987; Matkin et al., 1957; Poole et al., 1981). Even though various composts have been recommended to be good components by different researchers and while a few of them have been used by commercial growers to a certain extent, none of any single type of compost has gained the status of being used as extensively as peat or tree bark (Bunt, 1987; Davidson et al., 2000; Poole et al., 1981). Poole et al. (1981) identified many factors influencing selection of substrate components and classified these factors into three categories: economic, chemical, and physical. Economic factors include cost, availability, reproducibility, and ease of mixing. Chemical factors include cation exchange capacity (CEC), nutrient level, pH, and soluble salts. Physical factors include aeration, water-holding capacity (WHC), particle size, density, and uniformity.

Depending on parent materials and composting technologies, as well as plant types grown in containers, different concerns have been associated with most composted materials to be used as container substrates (Chong, 2005; Fitzpatrick et al., 1998; Rosen et al., 1993; Sanderson, 1980; Shiralipour et al., 1992). In the meantime, numerous research studies have been conducted on a wide variety of ornamental plants grown in substrates containing all kinds of organic wastes, either composted or not composted, with mixing ratios ranging from 4% (by volume and hereafter if not specified) to as much as 100% in the container substrate (Chong, 2005; Fitzpatrick, 2001; Fitzpatrick et al., 1998; Keener et al., 2001; Moore, 2005; Pudelski, 1987; Shiralipour et al., 1992). Over the years, literature reviews and review type papers have been published addressing different aspects of compost, or different types of composts as container substrate components. A book edited by Stoffella and Kahn (2001) provided a comprehensive review on the utilization of compost in horticultural cropping systems, in which Fitzpatrick (2001) addressed compost used as container substrate component, while Sullivan and Miller (2001) addressed issues related to compost quality. Pudelski (1987) and Shiralipour et al. (1992) reviewed compost utilization in both agricultural crops and horticultural crops, both with coverage of composts as substrate components for growth of ornamental plants. In a book on composting by Epstein (1997), a section on utilization of compost in horticulture was included, which mostly reviewed container studies. Similarly, several papers (Gouin, 1982, 1993; Raviv, 2005; Rosen et al., 1993) reviewed different aspects of compost utilization in horticulture, with container usage included. In addition, several general reviews summarized many previous studies on container-grown ornamental plants (Chong, 1999b, 2005; Fitzpatrick et al., 1998; Moore, 2005; Sanderson, 1980). Sanderson (1980) reported greenhouse and woody nursery plants could be successfully grown in substrates amended with sewage-refuse compost. Fitzpatrick et al. (1998) summarized important issues pertaining to compost use in ornamentals, while Chong (1999b, 2005) reviewed different types of organic wastes and composts as nursery substrates mainly based on the author’s own research experiences. Moore (2005) defined five basic plant response patterns to increasing percentages of organic waste composts in the substrates: 1) no response, 2) plateau, 3) linear increase, 4) bell curve, or 5) decrease.

Production of organic waste composts to be used in containers has to take care of important factors identified by Poole et al. (1981). A caveat to Poole et al.'s classification of these factors is that chemical and physical properties of substrates can be very different from its composting components. The challenge is that besides assuring good quality of composts before mixing it, every time a new substrate is mixed, important chemical and physical properties of the new-formed substrate have to be tested. The opportunity is that many quality requirements of an individual component do not have to be at equal level required of the final substrate, as it is possible to tune up important properties, such as bulk density, particle size distribution, WHC, pH, CEC etc., to suitable ranges by mixing different proportions of different components.

Types of organic waste composts used as container substrates

Biosolids or sewage sludge compost, municipal solid waste (MSW) compost, green waste compost, animal waste composts (dairy manures, poultry litter, fish waste, etc.), and composts of agricultural crop residual (sugar cane bagasse, rice hulls, and cotton gin compost, etc.) are among the most frequently studied and used composts in container production systems, largely due to their availability, physical and chemical properties, costs of handling, and environmental regulations (Barker, 1997; Cole and Sibley, 2004; Chong, 1999b; Pudelski, 1987; Sibley et al., 2005). Various tree barks, once regarded as wastes, have become widely accepted as a standard component of container substrates (Lu et al., 2006). Bark may be used as fresh or aged, such as pine bark, or has to be composted, such as hardwood bark. Due to long established acceptance, this paper treats various barks, along with peat, as conventional or industry standard components, to which organic composts are often compared with. Also, since coconut coir or coir dust has triggered great interest due to its similarity to peat, its acceptance has also become well established (Hernandez-Apaolaza, 2005; Wilson et al., 2001a) and therefore is not reviewed in this manuscript.

According to organic waste sources, composting technologies and important compost characteristics related to their utilization as container substrate components, various composts were grouped into six major types: 1) Biosolids-based compost, 2) MSW-based compost, 3) green waste-based compost, 4) animal waste-based compost, 5) agricultural crop waste compost, and 6) others.

i). biosolids-based compost

Biosolids are the organic materials resulting from the treatment of sewage sludge. Raw sewage sludge is often composted with wood chips, sawdust, or ground yard trimmings as the commonly used bulking agents (Goldstein, 2001). Due to environmental regulations, sewage sludge is being converted to compost by many municipalities as a disposal alternative (Gouin, 1993; Sanderson, 1980). In some cases, wastewater treatment plant operators joined forces with public work forces to create co-composting of biosolids and yard trimmings, with the later as the bulking agent (Goldstein, 2001). Sewage sludge compost is regarded as an ideal material for ornamental production, and it has been successfully used as container substrates in many early studies (Gouin, 1993; Sanderson, 1980; Shanks and Gouin, 1984). However, due to the huge amount generated each year (6.9 million dry tons in the U.S. in 1998, US EPA, 1999), composts or co-

composts of biosolids are continuously tested as substrate components under different settings for nursery crop production.

ii). MSW-based compost

Similar to municipal sewage sludge, municipal solid wastes are ubiquitous and readily availability. Composting of MSW in the U.S. started in the 1950s as a MSW management method and since then MSW compost has been evaluated for various ways of utilization (Hickman, 2003; Shiralipour et al., 1992).

iii). green waste-based compost

Again, green wastes are everywhere. Green wastes loosely include various wastes of plant materials that relate to landscape maintenance, such as tree trimmings, leaves, weeds, and lawn grass. With many states imposing bans on disposal of green wastes at landfills and incinerators (Goldstein, 2001), composting of green wastes or co-composting green wastes with biosolids or other materials is a major management strategy.

iv). animal waste-based compost

Modern industrialized fishery, poultry, and animal production and processing often result large amount of wastes in a single location, such wastes include poultry litter, livestock manure, stable waste, fishery waste, etc. Animal wastes often have high nutrients, such as high phosphorus and nitrogen contents in poultry litter, high nitrogen in manures. One major concern related to animal waste compost is pathogens in composts as potential human health threat.

v). agricultural crop waste compost

Agricultural crops produce large quantities of plant originated wastes, such as rice hulls, sugar cane bagasse, corn stalks, and cotton gin trash etc. Composting of agricultural crop wastes is an accelerated way to the natural decomposing process of returning organic wastes back to the nutrient cycle of any ecosystem. Composting is documented as early as agriculture itself (Fitzpatrick et al., 1998) and often started handily with agricultural wastes (Gasser, 1984). With large amount of wastes being produced by industrialized agriculture, composting of crop wastes alone or co-composting with other wastes is under continuous effort to form quality products which may be accepted by different end users. As sustrate components, such composts are only considered suitable when better chemical and physical properties are present in the final compost than were present in the starting stock.

vi). others

Many different organic wastes have been composted for possible use in the production of container ornamental plants. It's not practical if not impossible to separate all kinds of organic wastes into different lists and therefore all those relatively less reported composts were classified as into "others". However, due to the dynamics of technologies, social, and economic development, and other unseen factors, some of the "others" have the potential to become major compost products in the future.

Properties of container substrates derived from composts and plant growth responses

i).Biosolids or biosolids-yard trimming co-composts

Sewage sludge composts or biosolids have long been studied in container ornamental production (Bugbee and Frink, 1989; Chaney et al., 1980; Gouin, 1993; Sanderson, 1980; Shanks and Gouin, 1984; Wootton et al., 1981). However, changes in composting technologies, raw material composition, and various co-composting of biosolids with other materials, such as municipal solid wastes and yard trimmings have continuously attracted researcher's attention. An increasing number of nursery and greenhouse crops have been studied under a variety of experimental settings (Table 2).

Many studies were conducted in greenhouses on production of bedding plants, floriculture crops, or foliage plants, which often have relatively short production periods. Many plants grew equally or better in substrates with low ratios of compost than in standard or conventional substrates as controls, and then growth was reduced with high amounts of compost in the substrate (Klock, 1997a; Klock-Moore, 2000, 2001; Moore, 2004; Wilson et al., 2001b; Zubillaga and Lavado, 2001). Klock-Moore (2000) mixed substrates with 0, 30, 60, and 100% co-compost of biosolids and yard trimmings and reported that annual salvia (*Salvia* sp.) shoot dry mass and flower number increased as the rate of compost increased from 0 to 60% but decreased at 100%. Analysis of the substrates indicated that initial EC, N, P and K concentrations increased linearly as rate of compost in the substrate increased and higher nutrient concentrations probably contributed to greater growth. However, very high initial soluble salt concentrations (measured as electrical conductivity, EC) in substrates containing 100% compost (EC value: 2.17 dS m^{-1}) were attributed to the reduced growth of salvia, which was similar to the growth responses of dianthus (*Dianthus* sp.), impatiens (*Impatiens walleriana* Hook.), and petunia (*Petunia* × *hybrida* Hort.) under the same experimental setting (Klock, 1997a; Moore, 2004). Zubillaga and Lavado (2001) also reported that substrates with 25 to 75% composts resulted better growth of petunia and vinca (*Vinca* sp.) than in 100% compost substrate. Water availability, soluble salt concentrations or pH were reported to be the main factors attributing to the growth differences. Apparently, the benefit of higher nutrient concentrations in substrate containing 100% compost was at least partially offset by its higher soluble salt concentrations (Klock-Moore, 2001). Other studies (Klock, 1997b, 1998; Klock-Moore, 1999; Table 1) reported that when initial soluble salts were only 0.83 dS m^{-1} in 100% compost substrate, salt-sensitive plants impatiens and snapdragon (*Antirrhinum majus* L.) had a linear increase in shoot dry mass, size, and height with increasing compost in the substrate up to 100%. Besides factors due to substrate, plant provenance has been reported to be important in some cases. For example, four hammock species native to Florida grew better in substrates with 40% compost or 100% compost than in peat-based substrate (Wilson et al., 2004), while under the same research protocol, seven out of 10 non-native perennial species had reduced shoot weight in substrates with more than 50% compost (Wilson et al., 2001d).

However, hazardous effects of compost can appear in substrates containing much lower rate than 100% compost (Ku et al., 1998; Wilson et al., 2001a, 2001c, 2001d; Wilson et al., 2002; Verdrame and Moore, 2005). When two biosolids composts were used to grow poinsettia (*Euphorbia pulcherrima*), branch number, plant height and width, and plant grade were all reduced at all three levels of compost (25, 33, and 50%) compared with those in two commercial substrates, except with no difference in branch number in 25% of one compost (Ku et al., 1998). High pH or EC levels were considered as possible causes to the reduced growth, while possible contribution from different physical properties was not determined by the study. Contrary to the positively linear plant growth in impatiens and snapdragon observed by Klock (1997b), both growth indexes and shoot dry weight of Mexican heather (*Cuphea hyssopifolia*) decreased either quadratically or linearly with increasing compost to replace peat or coir in substrates from 0 to 100% in volume (Wilson et al., 2001a), although plants grown with 50% or less compost had a similar appearance than plants grown in two controls. Increasing levels of EC and bulk density or reducing levels of percent moisture were possible causes of decreasing growth in substrates of high compost levels. When the same compost was used to grow 10 perennials, similar results were reported, generally with reduced shoot dry weight even from substrates with only 25% compost (Wilson et al., 2001d, 2002). Wilson et al. (2003) also reported that regardless of irrigation methods (ebb-and-flow, drip, or manual irrigation), three perennial salvias in containers filled without or with 50%, or 100% biosolid-yard waste compost generally grew slightly less (stem weight, leaf weight, and stem length) than those grown in peat-based substrates.

Biosolids had also been used for rooting of plant cuttings (Chen et al., 2003). A standard 1:1 pine bark:peat rooting substrate was replaced with 20, 50, or 80% of each of two composts derived from biosolids and MSW or yard trimmings. Cuttings of three foliage plant species had shorter total root length after rooting for 21 days in 50% and 80%

of biosolids and yard trimmings co-compost than in the control or substrate with 20% co-compost. However, the root-ball coverage ratings at 45 days after sticking were only reduced in substrates with 80% compost. The reduced root length and root-ball ratings were attributed to less air space, higher initial EC readings, and higher pH in substrates of higher compost levels (Table 1).

In an outdoor container study, a commercially available composted municipal sewage sludge was used to replace the peat or coir part of a 3:1 pine bark:peat or bark:coir substrate. Nine tree species generally grew equally in all substrates (Struve, 2002), regardless of N fertilizer treatments.

Besides high soluble salt levels, other substrate properties may be more important in different conditions. Bugbee (1996) reported that pH affected plant growth more than the percent compost. In another container study with a total of 24 species, including flowering annuals, herbaceous perennials, and woody ornamentals, Bugbee (2002) reported that, after adjusting substrate pH to between 5.0 and 6.0, most plants grew positively linear or quadratic to increasing compost in substrates (0, 25, 50, 100%), with no plants growing significantly less than in the control. Plants growing in substrates high in compost were often somewhat stunted and chlorotic for several weeks after planting, probably due to higher levels of salinity and ammonium nitrogen in the substrate. However, by the middle of the growing season these plants had recovered and at season's end, they were often superior to plants grown in substrates with less compost. Bugbee (1999) also reported that replacing 10 to 30% of perlite with fresh sawdust greatly increased the C:N ratio but failed to reduce leaching of NH_4^+ from biosolids compost-based substrates.

Although heavy metal toxicity was often reported to be problem in the utilization of composted wastes as container substrates, a study showed that several sewage sludge composts from different sources caused severe manganese (Mn) deficiency in queen palms (*Syagrus romanzoffiana*) by tying up Mn in composts (Broschat, 1991). However, the explanation of Mn binding in sewage sludge composts was not clearly documented. Chaney et al. (1980) suggested that substrates with high organic matter content and neutral to basic pH in compost can restrict heavy metal availability to plants.

ii). MSW composts

Early studies on MSW had been summarized by Rosen et al. (1993) and Shiralipour et al. (1992). Some of the early studies reported both negative and positive growth responses of plants to MSW compost substrates (Conover and Joiner, 1966; Gogue and Sanderson, 1975; Sanderson and Martin, 1974; Poole, 1969; Siminis and Manios, 1990). Higher pH and soluble salt levels, or phytotoxicity caused by high trace element concentrations like boron were all reported as possible causes to reduced plant growth. Beneficial effects often came from suitable physical properties for plant growth in containers and higher nutrient levels in composts than other commonly used material like pine bark, peat or mineral soil (Rosen et al., 1993; Shiralipour et al., 1992). Recent studies continued to test MSW compost often up to 100% in the container substrate using all kinds of plant material, from floriculture and foliage plants, bedding plants, landscape shrubs, to woody ornamentals (Table 3).

In a study on the effects of three different composts used as substrates for impatiens, mass of plants grown in MSW compost decreased as the rate of compost in the medium increased (Klock and Fitzpatrick, 1997). Such a negative effect could be attributed to the high levels of soluble salts and less maturity in the MSW compost, with a C:N ratio of 29:1. Similarly, poinsettias had less height, width, or grade in substrates with all three levels of MSW compost from 25% to 50% than in two commercial substrates (Ku et al., 1998). Plant widths with 25% compost treatments were greater than those in 50% compost treatments.

MSW compost (MSWC) potential as a fertilizer was evaluated in greenhouse production of potted geranium (*Pelargonium* sp.) (Ribeiro et al., 2000). MSWC was mixed with a peat-based substrate at rates of 0, 10, 20, 30, 40 and 50%. With no additional fertilization, 10% and 20% MSWC promoted the highest plant growth in 90 days. The yield was lowest at 0% MSWC, caused by a low level of available nutrients in the substrate. Application rates of MSWC >20% reduced plant growth as a consequence of the high level of salts. Tissue analysis indicated that MSWC provided only a part of the required N and P for plant needs in 10 and 20% MSWC substrate, while an adequate supply of K, Ca, Mg, Fe, Zn, Mn, and Cu was obtained from the compost in the substrate.

In a study comparing the production and interior performance of three tropical ornamental foliage plants grown in container substrates amended with composts derived from different sources, co-compost of MSW and biosolids and two other composts was mixed with sphagnum peat or pine bark to obtain 6 different substrates containing 12 to 80% MSW-biosolids co-compost (Chen et al., 2002). Physical properties of the substrates were generally within the recommended range for production of foliage plants and other ornamental plants. The pH, electrical conductivity (EC), and CEC increased with more compost in the substrate (Table 2) and three of the six substrates had EC readings higher than 3.0 dS m^{-1}, the upper limit for most foliage plant production. Two of the three species had better or comparable growth in substrates with 20% and 50% co-compost of MSW and biosolids than in the control of 1:1 sphagnum peat:pine bark.

In an outdoor container study, Kahtz and Gawel (2004) used noncomposted recycled household waste to grow barberry (*Berberis thunbergii* var. atropurpurea) liners and reported that plants had less shoot dry weight in substrates amended with all four levels of waste (25, 50, 75, 100%) than plants in nontreated control substrates; however, the differences were only statistically significant for plants in 50 and 75% waste amended substrates. Elevated salt levels were regarded as the attributing factor to the reduced growth. In another outdoor container study, Hicklenton et al. (2001) reported that in source-separated MSWC as components of container substrates, growth of rooted cuttings of a evergreen shrub *Cotoneaster dammeri* cv. 'Coral Beauty' was strong at ratios from 25% to 75% of MSWC, and all were comparable with growth in substrates with the same rate of pine bark. Soluble salt content was initially high in substrates containing MSWC (4.5 dS m^{-1}, Table 2), but declined to <1 dS m^{-1} within one month of potting. Besides rapid leaching of soluble salts under normal nursery practice, the highly organic nature of the medium was believed to provide a high salt-buffering capacity and protection for root systems.

MSWC had also been tested as a greenhouse rooting substrate of stem cuttings of nine evergreen landscape shrubs (Chong, 2000a). Containers were filled with 100% sphagnum peat or 100% perlite, or peat or perlite mixed with 15, 30, 45, 60 or 75% by volume of MSWC. The EC levels were positively correlated with levels of MSW. Depending on taxa, increasing salt levels had various degrees of diminutive, neutral, and enhancing effects on rooting response, expressed in terms of percent rooting, root number per cutting, and root length (longest root per cutting). Four taxa were tolerant of the salt levels tested (positively influenced or unaffected). Five other taxa were intolerant (adversely affected). Similar results were obtained in rooting of terminal stem cuttings of seven deciduous woody taxa with MSWC (Chong, 1999a).

He et al. (1995) documented substantial variabilities in both chemical and physical properties among the MSW composts generated in different facilities. Even though such variabilities may not necessarily result in different plant growth (Hicklenton et al., 2001), efforts should always be taken to reveal such potential different responses and gather useful information for future research and application.

iii). green waste composts

Studies utilizing green waste composts (GWC) as container substrates were conducted with greenhouse grown herbaceous plants, bedding plants, or floriculture crops (Hartz et al, 1996; Vendrame and Moore, 2005) or seed germination and seedling development, rooted cuttings (Burger et al., 1997), as well as on outdoor container nursery crops (Beeson, 1996; Benito et al., 2005; Calkins et al., 1997; Fitzpatrick and Verkade, 1991; Table 4).

Different responses from different greenhouse grown ornamentals to GWC in the substrate were expected (Garcia-Gomez et al., 2002; Vendrame and Moore, 2005). For example, Vendrame and Moore (2005) reported that shoot dry weights in one of four herbaceous ornamentals decreased in all three compost levels (30, 60, and 100%) than in a peat-based control, and three other species had similar shoot dry weights. Using three bedding plants, one flower crop, and three shrubs, Burger et al. (1997) observed that as a group, germinating seeds of bedding plant species were most adversely affected by GWC in substrates while the outdoor grown woody plants were the least affected. Also, as plants grew and were transplanted into larger containers, they were better able to grow in substrates with higher GWC content.

In general, outdoor container grown plants often responded well even in very high compost levels substrates. Two ornamental plants were grown in outdoor containers filled with standard peat and bark based substrate or amended with 20 to 80% composted yard wastes for over a year (Beeson, 1996). Both species had similar or better shoot growth in compost substrates than in control. Different types of ornamental crops (three coniferous, three deciduous, and one herbaceous perennial) were container grown for two years under overhead irrigation in a standard nursery production environment (Calkins et al., 1997). All seven species grew similarly or better in substrates with 50 or 100% of the peat replaced by one of four municipal composts substrates than in a 3:2:1 woodchips:peat:sand control. Similarly, three perennial species in containers with 10 to 100% of a common substrate replaced by a compost made from municipal leaves, digested sewage sludge, and street sand compost grew at least equally than plants in non-amended substrate (Bugbee et al., 1991).

Limited nutritional benefits of GWC were observed when marigold (*Tagetes erecta* L.) and tomato (*Lycopersicon esculentum* Mill.) were grown in a substrate of 50% CGW and 50% perlite after the substrate was thoroughly leached to remove soluble salts (Hartz et al., 1996). Growth of marigold and tomato seedlings in a GWC/perlite substrate was equivalent or superior to that in peat/perlite. Substantially higher macronutrient content of plants in the GWC/perlite substrate than plants in peat/perlite indicated GWC supplied certain N, P, and K for plant uptake. However, such benefit was mostly unobserved when fertilizer was applied to both GWC/perlite and peat/perlite treatments, a phenomenon also reported by Bugbee et al. (1991). Similarly, Eklind et al. (1998) reported a considerable amount of the plant nutrients needed in the substrate for the initial six weeks of plant growth was supplied by a herbage compost.

Besides expected different responses from different crops or from different production conditions, chemical and physical properties of substrates *per se* are often variable. Benito et al. (2006) reported that among 12 pruning waste compost samples taken in three different seasons over a period of 18 months, there were no significant differences in chemical properties, while water retention characteristics were affected by seasonal changes in components entering the facility. Hartz and Giannini (1998) observed that at least 9 to 12 weeks of composting were required to minimize the undesirable characteristics of immature yard waste compost, such as viable weed seeds, plant pathogens, high C:N ratio, N immobilization, or phytotoxicity as an overall maturity index. Chong (2000b) reported that high soluble salt concentrations of municipal leaf and yard waste compost was primarily due to elevated levels of Cl, K, and Na, which can be easily leached; however, pH values of compost-based substrates changed little or not at all with or without leaching.

iv). Animal waste based composts

Composting of animal wastes, especially manures, are often through a special process called vermicomposting, which is a biological process that involves the use of earthworms for breaking down and stabilizing organic wastes. Besides manures, other raw materials of vermicomposting include food wastes, crop residues, industrial refuse, and sewage sludge etc. (Atiyeh et al., 2000b, 2002). Vermicompost, the end product of vermicomposting, is estimated to have considerable commercial potential in the horticultural industry as container substrate component (Atiyeh et al., 2002).

As substrate components, vermicomposts had been studied in greenhouse production of many ornamentals and vegetables (Atiyeh et al., 2000a, 2000b, 2001, 2002; Hidalgo and Harkess, 2002; Hidalgo et al., 2006; Subler et al., 1998; Table 5). In general, the addition of relatively small amounts of vermicompost has resulted in improvements in plant growth, while higher proportions of vermicompost did not always improve plant growth (Atiyeh et al., 2002; Subler et al., 1998). For example, the greatest vegetative growth of marigold resulted from 30% and 40% substitution of a standard commercial greenhouse substrate with pig manure vermicompost, while substrates with 90% or 100% vermicompost produced the smallest plants, as well as smallest and fewest flowers (Atiyeh et al., 2002). Similarly, germination and growth of marigold and tomato seedlings was enhanced in 10% or 20% of a commercial container substrate substituted by either pig manure or food waste vermicompost (Atiyeh et al., 2000b), while raspberry grew equally in mineral soil with 20% vermicompst without fertilizer than in mineral soil with fertilizer. In contrast to the reduced plant growth in substrate with high vermicompost (Atiyeh et al., 2000b, 2002), replacement of pine bark and peat moss with 25 to 100% cow manure-derived earthworm castings all resulted increased plant growth index, stem diameter, root growth, dry weight, and flower number of marigolds (Hidalgo et al., 2006). With no additional fertilizer applied to any treatments, such improvement was associated with increasing amount of nutrients with more earthworm castings in the substrates. Incorporation of earthworm castings into pine bark based substrates generally resulted in better water holding capacity and increased but still acceptable pH values (Table 4). Also, the low EC value (0.90 mS m^{-1}) in 100% earthworm castings posed no risk even to salt-sensitive plants.

However, not all vermicompsts are created equal, as found with growth of chrysanthemum (*Chrysanthemum* sp.) which was most positively affected by sheep manure vermicompost than vermicomposts from other sources (Hidalgo and Harkess, 2002). Besides enhanced nutrient values and physical properties than conventional greenhouse substrate components, vermicomposts possibly had some other undetermined benefits, such as enhanced microbial activity, plant growth regulators, etc. (Atiyeh et al. 2000b, 2001; Subler et al., 1998).

Other than vermicomposts, recent investigation of animal manure-based composts used in substrates included composts from swine manure and wood shavings, chicken manure or poultry/turkey litter, dairy cattle solid biomass, and pig slurry etc. (Barker and Bryson, 2006; Carr et al., 1998; Chong, 2001; Freeman and Cawthon 1999; Jensen et al., 2002; Keener et al., 2001; Raviv et al., 2005). Beneficial effects from manure composts are often observed at low rates (usually less than 50%), while suppression or toxic effects were found more often with higher rates. Barker and Bryson (2006) assessed the nutritional benefits of two composts derived composted chicken manure and reported that optimum growth of tomato occurred in substrates in which compost did not exceed 25% of the volume. Raviv et al. (2005) reported that high nitrogen compost of separated cow manure provided enough nitrogen for growth of cherry tomato (*Lycopersicon esculantum* Mill.) for at least 4 months. In contrast, Keener et al. (2001) reported that incorporation of the compost made from swine manure and wood shavings at a 4% amendment rate into a standard pine bark container medium significantly increased growth of two woody plant species, while toxic effects started to appear in compost amendment rates of 8% to some plants due to high initial NH_4^+ concentrations in the substrate.

While beneficial effects of animal manure-based composts were often identified as coming from enhanced nutrient levels, phytotoxic effects were often more variable, such as excessive potassium supply and accumulation (Barker and Bryson, 2006), high initial NH_4^+ concentrations, high EC values or superoptimal nutrient levels (Freeman and Cawthon, 1999; Jensen et al., 2002).

While greenhouse-grown ornamentals often responded negatively to high compost levels in substrates, Chong (2001) found three container grown nursery woody species responded positively to substrates amended with 25 to 100% turkey litter composts. Potentially damaging high soluble salt concentration (5.9 dS m^{-1} in 100% compost) was rapidly reduced to about 1.9 dS m^{-1} after the first irrigation and to nontoxic levels (≤ 0.9 dS m^{-1}) within days. Similarly, marigold and geranium had at least the same quality up to 7 weeks after transplant in 100% fishwaste compost substrate compared with plants in 100% bark substrate receiving N liquid fertilizer (Hummel et al., 2000). However, under standard container nursery overhead irrigation regimes, such nutritional benefits were short-lived (2-3 weeks) due to excessive N leaching and denitrification (Kuo et al., 1997). Compared with the rapid leaching of N, easily soluble P leached out within first two weeks, but fishwaste amended substrate sustained high P concentration in leachate at least 10 weeks after potting (Kuo et al., 1999).

Recent studies also evaluated less commonly used animal wastes such as ground bovine bone (Evans, 2004a) and processed poultry feather fiber (Evans, 2004b). Ground bovine bone was found to be inadequate as a feasible alternative to perlite in greenhouse production of three common floriculture crops (Evans, 2004a), but the same three crops had similar growth in sphagnum and perlite-based substrates replaced by up to 30 to 50% feather fiber than in an unamended control (Evans, 2004b).

v). agricultural crop waste-based composts

Earlier studies evaluated a variety of agricultural wastes, such as rice hulls, bagasse, corn residue, and peanut hulls (Bilderback et al., 1982; Einert, 1972; Guttay, 1982; Poole et al., 1981). Recent studies continued work on waste composts from major agricultural crops as nursery crop growing substrates (Table 6).

Composts made from cotton or cotton gin trash have been evaluated as substrate components for ornamental plant propagation, development and growth in both greenhouses and container nurseries (Cole et al., 2002, 2005; Jackson et al., 2005; Papafotiou et al., 2001a, 2001b; Wang, 1991; Wang and Blessington, 1990). Four ornamentals had different growth responses to substitution of 50 and 60% of the peat in a 1:1 peat:perlite control with cotton gin trash compost (CGC) for 6 to 10 months of greenhouse production (Papafotiou et al., 2001b). One species grew equally in CGC-amended than non-amended substrates in plant height, leaf number, foliage fresh weight and root dry weight, while two species grew less in at least one of the growth measurement and the last one had better plant height and foliage fresh weight in substrates of 60% replacement of peat with CGC. Similar species dependent responses were observed in growth of four floriculture crops in similar settings (Papafotiou et al., 2001a) or in two tropical foliage plants when levels of cotton waste compost in substrates did not exceed 50% (Wang, 1991). However, both tropical foliage plants responded negatively once there was more than 50% cotton compost. In contrast, poinsettia had less plant height, width, and dry weight in all compost replacement levels from 25% to 75% (Wang and Blessington, 1990).

Cole et al. (2002) evaluated CGC as a substitute of peat in greenhouse plant propagation and reported that cuttings of three ornamental species rooted equal or better in substrates of 50% CGC and 50% perlite than in standard 50% peat and 50% perlite substrates in all categories of root evaluation.

Under commercial container nursery settings, growth of four ornamental crops had equal or greater growth in substrates with 25 to 75% of pine bark replaced by CGC than in the control of pine bark and sand over one growing season (Jackson et al., 2005). While early growth in two crops was somewhat negatively affected by high ratios of CGC in the substrates, such effects disappeared in late growth period, a phenomenon also observed other studies under container nursery settings (Bugbee, 2002).

Besides cotton waste composts, a variety of other agricultural material derived composts have been evaluated as container growing components in recent studies (Table 5): bagasse (Stoffella et al., 1996), rice hulls (Evans and Gachukia, 2004; Papafoutiou et al., 2001a), olive-mill waste (Papafotiou et al., 2004, 2005), and *Miscanthus* straw (Jensen et al., 2001).

Stoffella et al. (1996) used bagasse compost to grow two *Citrus* rootstocks from seeds and found that seeds had similar total percent emergence, mean days to emergence and root weights, but taller seedlings with heavier shoots than the control in 25 to 75% bagasse compost. Leaf N, Ca and Zn contents were higher for seedlings produced in compost amended substrates than in 100% control.

Five ornamental species grew as well in substrates that included composted bagasse as those grown in peat moss or pine bark (Trochoulias et al., 1990). African violets (*Saintpaulia* sp.) produced greater root dry matter in a substrate containing a high proportion of composted bagasse. However, when fresh bagasse was used in the substrate, plants of most species had reduced growth rates and the substrate shrank excessively.

Fresh parboiled rice hulls were used to substitute 10 to 40% of perlite in peat-based substrates and four greenhouse crops grew equally to the equivalent perlite-containing substrates, with the exception of less dry shoot weights of tomato or pansy (*Viola* × *wittrockiana* Gams) in substrates with 20 to 40% or 15 to 20% of the rice hull, respectively (Evans and Gachukia, 2004). Non-treated rice hulls were used by Papafotiou et al. (2001a) to replace half of the perlite in a 1:1 peat:perlite substrate found to yield satisfactory growth in greenhouse production of five flowers tested.

In a study conducted in two commercial nurseries, replacement of 50% of peat in a standard 1:1 peat:grape marc with seven different combinations of sewage sludge, MSW compost, rice hull, or pine bark was used to grow three ornamentals (Ingelmo et al., 1998). One species had reduced height with all seven new substrates while the other two had either equal or less growth depending on different substratees.

Without any further amendment, compost made from *Miscanthus* straw and ammonium sulfate or urea as additional N source (Jensen et al., 2001) generally produced less growth (shoot length and dry matter) of *Hedera helix* from cuttings, either four or 12 months after sticking, or five months following cut back.

Composted olive-mill waste (OWC) was evaluated as a peat substitute in production of foliage potted plants (Papafotiou et al., 2005). Similar to the responses of CGC (Papafotiou et al., 2001b), greenhouse grown ornamental crops responded differently, as some had satisfactory growth with up to 75% of peat replaced by OWC, while growth of poinsettia from rooted cuttings showed that at least one of the growth measurements was significantly reduced even when 25% of peat was replaced.

While high soluble salt concentrations are often concern for many composts, it has been reported that soluble salts leached out rapidly after potting and are often within an acceptable EC range in a short period (Carrión et al, 2005; Chong, 2002, 2005; Kerr and Hanan, 1985; Kuo et al., 1999; Sawhney et al., 1994). Carrión et al (2005) studied the leaching of salt and mineral elements from composts prepared from residual vegetable crop biomass and found that after pouring 8 container capacities of water, the leaching efficiency of the salts was 84%, 89% and 77% for melon, pepper and zucchini-based composts, respectively. However, mineral elements differed in their ability to be removed from the composts; available N (NH_4^+ and NO_3^-), K^+, Na^+, Cl^-, and S were leached readily, whereas P, Ca^{2+}, and Mg^{2+} were not easily removed due to chemical binding or adsorption. Besides types of ions, other factors, such as substrate properties, fertilizer concentration, type and delivery method can also determine leachate compositions (Frost et al., 2003; Kerr and Hanan, 1985; Marconi and Nelson, 1984; Marfà et al., 2002; Yelanich and Biernbaum, 1994).

vi). others

Other than the five groups summarized above, many other types of organic wastes have been evaluated to grow ornamental crops in containers (Table 7). Among those materials, paper mill sludge composts and spent mushroom compost have been used extensively under different experimental settings (Chong et al., 1991, 1998; Chong and Cline, 1993; Evanylo and Daniels, 1999; Young et al., 2002). Other less reported materials include recycled paper (Craig and Cole, 2000), waxed corrugated cardboard

(Raymond et al., 1998), sawdust (Gariglio et al., 2004), river waste (Di Benedetto et al., 2004),and slag (Holcomb and Walker, 1995), etc.

Bellamy et al. (1995) and Chong (2005) summarized the utilization of paper mill sludge as nursery substrates. Based on their experience and reviews, overall, no more than one-third of the substrate as sludge is recommended (Bellamy et al., 1995; Chong and Purvis, 2004), although in some cases up to two-thirds of the substrate can be sludge (Chong, 2003). Paper mill sludge was successfully used at a rate of 25% for pot-in-pot shade tree production (Chong and Lumis, 2000).

Raw paper mill sludge has also been evaluated as rooting substrates (Chong and Hamersma, 1996; Chong et al., 1998). Using stem cuttings of seven deciduous landscape shrubs, a few shrubs rooted in substrates with up to 60% sludge, but most species grew equally well or better at low rates (10 to 30%). Similarly, most greenhouse vegetables and one ornamental did not grow well in substrate of 100% composted paper mill sludge (Evanylo and Daniels, 1999).

Chong (2005) summarized studies on spent mush compost (SMC) and concluded that SMC usually is rich in certain nutrients and has physical properties, such as aeration porosity and water retention capacity, comparable to or better than those of bark. Among phytotoxic effects of high ratios of SMC in substrate, high soluble salt level is a major concern (Chong, 2005; Chong et al., 1994; Lohr and Coffery, 1987; Young et al., 2002). In container culture, some shrubs responded positively with increasing levels of SMC up to 100%, whether it was unweathered, weathered, or unweathered compost leached with water, while the reverse relationship can occur in other species (Chong et al., 1991). It was noticed that any injury to roots caused by high salt levels likely occurred during a relatively short, critical period (days) after planting. Besides high EC, toxicity of ammonium (Lohr and Coffery, 1987; Lohr et al., 1984), decreased air pore space (Young et al., 2002), and high pH (when acid-requiring plants are grown) were some other cited phytotoxic effects from SMC.

In other less evaluated material, four containerized deciduous ornamental shrubs were grown using immature (non-aged) composts derived from waxed corrugated cardboard (WCC) (Raymond et al., 1998). Depending on plant species, substrate of 25 or 50% WCC mixed with SMC and/or wood wastes had more, similar, or less growth than that in a 80:15:5 PB:Peat:top soil nursery substrate (Raymond et al., 1998). Using recycled paper to replace partial or all pine bark, Craig and Cole (2000) reported that reasonable growth of *Spiraea japonica* occurred only in substrates containing less than or equal to 50% recycled paper, although N leaching decreased as substrate paper concentration increased.

Slag can replace about 50% of peat to produce similar chrysanthemums and poinsettia plants (Holcomb and Walker, 1995), but plant growth was reduced in slag alone substrate. Plants grown in slag or slag substrates generally were low in P and Mn and high in B, which indicated that the slag substrates seem to remove P and Mn from the substrate solution while releasing B and to some extent Ca to the substrate solution.

Composted willow (*Salix* sp.) sawdust (WS) can replace all the peat of a 3:1 peat:perlite substrate and resulted in similar growth of *Calendula officinalis*, while non-composted willow sawdust resulted in reductions of total dry matter, dry matter partition to flowers, plant height, flower diameter, and flower buds per plant from 43 to 82% (Gariglio et al., 2004). Increasing the proportion of N-enriched composted WS in perlite from 25% to 75%, flower diameter decreased in calendula and marigold when the N-enriched composted WS exceeded 50%, but with no effect on total dry matter, plant height, or flower number per plant.

Future research areas for improvement of compost quality

The golden rule of substrate selection is that no single substrate can fit all purposes. There is no exception when it comes to incorporation of composts into container substrate. In fact, composts are so varied that differences are mostly expected and there is no universal rate of compost can be applied to all situations (Klock-Moore et al., 2000). However, despite the variability in composts and plant responses, several general trends can be summarized from results reviewed in this paper (while there are always exceptions):

1). Composts often have higher pH than commonly recommended values (5.0-6.5; Ingram et al., 2003; Yeager et al., 2007) for ideal substrates and are more likely to be basic than acidic (Table 1 through 6). While high pH value in certain composts like biosolids are due to addition of lime in processing, relatively high pH values are a natural property of most composts.

2). Compost EC values are generally high. Damage induced by high soluble salt concentrations was one of the most cited causes in reduced plant growth in compost based substrates. However, leaching can reduce high EC levels in a very short period. It has also been argued that any injury to roots caused by high salt levels likely occurred during the first few days after planting (Chong et al., 1991).

3). Ornamental crops often respond differently to exactly the same substrate, which is no surprise since plants have generally been selected from many different native environmental conditions and such response characteristics are largely inherent and stable.

4). Crops grown in greenhouses tend to respond more negatively to compost in the substrate than in outdoor container nurseries. Possible causes are a). different species compositions, as herbaceous or floriculture greenhouse crops are often likely to be grown for a short period of production, while in outdoor production, woody species are more often used; b). differences in cultural practices, such as irrigation or fertilization. For example, water in outdoor production is often delivered through overhead irrigation and a single heavy rain event can deliver excessive water to containers in a very short period (hours).

5). In outdoor container production, less plant growth in compost-based substrates is less obvious in late growth stages than in early stages, which was documented by several studies with periodic growth measurements (Bugbee, 2002; Jackson et al., 2005). However, growth variation in time scale apparently needs more experiments to document.

6). Nutrient benefits were mostly detectable in a short period after potting; relatively, long-term nutrient benefits are less documented, either due to difficulty to detect such benefits or actual lack of such benefits.

With above general trends in mind, the intrinsic variability in composts is tractable. As conventional potting materials are becoming less available and more expensive, alternatives derived from organic wastes continue to be evaluated for their utilization in container substrates. Current research on composts regularly documents physical and chemical properties, plant growth responses, and plant quality. Many research projects also routinely report results of tissue analysis and substrate nutrients as well as trace elements. With affordable modern equipment and technology and research development in related fields, compost research has the potential to reach a new frontier, which may require some drastic changes in experimental design, methods used, as well as objectives to be addressed, and evaluation of research results. some facets of this new frontier were tentatively proposed:

1). Utilization of compost is more closely related to water and nutrient utilization in research. Availability and consumption of groundwater or public surface waters are in rapid decline for greenhouse and nursery production (Beeson et al., 2004). Substrate properties have been shown to be important factors in determinations of water use efficiency and therefore, research is needed to determine if change of substrate composition affects the crop water relationship. In the meantime, while nutritional value has been demonstrated in many composts, such value must be linked to fertilizer application and quantified to increase overall nutrient use efficiency.

2) While composting and utilization of composts are often hailed as effective ways to reduce environmental damage from organic wastes, compost utilization in container ornamental production *per se* is not immune from potential environmental problems. Common environmental concern includes heavy metal contamination and other water pollutants from discharge of irrigation runoff. Public concern on pollutants

from agricultural activities will certainly exert more pressure on allowable pollutant concentrations and quantities from nursery runoff in the future. While collection ponds are becoming more common in nursery operations as an effective way to increase water use efficiency and reduce pollutant discharge into public water bodies, the water quality through collection ponds is likely to be a concern when compost becomes a significant proportion of the overall substrate compositions.

3) More interactions between horticulturists and compost users (nurserymen) and up-end compost producers and researchers. While there is no magic substrate that can grow all plants, there is no compost that is simultaneously good for its various usage, such as in container, organic fertilizer, landscape or garden mulch, or as soil conditioner in agricultural land, as soil amendment for land reclamation, erosion control, etc. Composts have to satisfy different requirements for different purposes. Closer interaction and cooperation between horticulturists and composting researchers, compost users (nurserymen) and compost producers will surely benefit all parties involved.

4) While a general goal of ornamental production is to grow plants bigger and quicker with certain quality, it’s not the sole objective. Postharvest or field performance after transplanting is an important part of crop quality. Without exception, any change in the containers has potential effects on the plant grown in it. Therefore, besides measurements on height and/or growth index, weight, quality rating etc. in the process of growth or at the end of growth, post harvest physiology and performance need more attention once new substrate become a part of production systems.

5) Development of best management practices for compost utilization based on research results. Overall, large scale use of compost in containers is a new practice for the majority of greenhouse and nursery producers. Although pressures to use more alternative materials to grow ornamental crops are obvious, the industry won't use large amount of composts when there are significant uncertainties from introduction of composts into the production system. As discussed earlier, changes in containers may possibly require changes in other parts of production. The much touted best management practices may no longer be best in new situations. Research will be needed to determine best management practices relative to use of new substrates which incorporate various composts.

Summary

In theory, mixed waste composting could divert all organic waste that is currently targeted for composting. Mixed solid waste was predicted to be transformed into high-quality products with no modification to waste collection systems while vastly decreasing our dependence on landfills. But since the 1950s until now, composting the MSW organic component is still a very good idea that has never really caught on. Currently, operating composting facilities only handle less than 0.7 million tons of feedstock annually (Goldstein, 2001). The marketing remain the essential barrier to composting MSW. Typically, compost producers initially aim for high-end markets like horticulture. Such markets have the greatest potential for utilizing and paying a higher price for composts. However, the horticultural market for waste compost is difficult to penetrate, as only the highest quality composts are acceptable. With the advance of technology, the quality of finished compost will be improved. But this improvement of technology will also substantially increase the cost of mixed waste composting (US EPA, 1999). New facilities with state-of-the-art equipment will be increasingly expensive to build. In most areas of the country, tipping fees at mixed waste composting facilities are higher than landfill tipping fees. In correspondence with the low volume of MSWC sold to horticultural markets, there is a huge knowledge gap on how to effectively use more and more of it in horticultural crop production systems. With the lack of comprehensive information and knowledge on use of waste compost in modern horticultural growing systems, there is little opportunity for MSWC to be fully accepted and used in routine growing practices.

Significance

Given that about 80 percent of all marketed containerized ornamental plants are grown in substrates comprised of 75 to 80 percent organic matter, this industry could be a huge potential market for compost. Use of compost to improve topsoil in field production of horticultural crops is also important. For example, harvesting one acre of balled and burlapped trees and shrubs is estimated to remove more than 200 tons of soil; and therefore compost can be used to create new topsoil to keep such operations sustainable (Gouin, 1995). Research on application of MSWC in major nursery crop production systems will contribute to the much needed knowledge pool for using of MSWC in the horticulture industry. As a waste product, environmental and health concerns are important issues with the utilization of MSWC, such as high concentrations of heavy metals, inclusion of plastics, pathogens, etc. Studies properly addressing health concern will greatly benefit the human welfare while the benefits of MSWC utilization are maintained.

Objectives

The studies presented in the following chapters seek to evaluate the utilization of MSWC in greenhouse, container nursery, and field production of horticultural crops. Specific objectives were to:

1). estimate U.S. bark generation and implications to the horticultural industries, with the evaluation of historical, current, and projected supply of bark;

2). evaluate the suitability of MSWC as a substrate component in container production of ornamental crops. Plant growth, substrate chemical and physical properties will be compared with those of a standard pine bark based substrate;

3). evaluate the performance of MSWC as a substrate component in greenhouse production of ornamental crop production. Crops respond to MSWC substrates ranging from 0% to 100% and the interaction of fertilization rate with MSWC amendment were evaluated;

4). quantify effects of different irrigation and fertilizer levels on growth responses of ornamental crops to different MSWC mixing levels in the substrates, and

5). determine the effect of filed amendment of MSWC on yield and heavy metal accumulation on okra and watermelon production.

Literature Cited

Albiach, R., R. Canet, F. Pomares, and F. Ingelmo. 2001. Organic matter components and aggregate stability after the application of different amendments to a horticultural soil. Biores. Technol. 76:125-129.

Atiyeh, R.M., N.Q. Arancon, C.A. Edwards, and J.D. Metzger. 2002. The influence of earthworm-processed pig manure on the growth and productivity of marigolds. Bioresour. Technol. 81:103-108.

Atiyeh, R.M., C.A. Edwards, S. Subler, and J.D. Metzger. 2000a. Earthworm-processed organic wastes as components of horticultural potting media for growing marigold and vegetable seedlings. Compost Sci. Util. 8:215-223.

Atiyeh, R.M., C.A. Edwards, S. Subler, and J.D. Metzger. 2001. Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth. Bioresour. Technol. 78:11-20.

Atiyeh, R.M., S. Subler, C.A. Edwards, G. Bachman, J.D. Metzger, and W. Shuster. 2000b. Effects of vermicomposts and composts on plant growth in horticultural container media and soil. Pedobiologia 44:579-590.

Barker, A.V. 1997. Composition and uses of compost. In. Rechcigal, J.E. and H.C. MacKinnin (Eds.) Agricultural uses of by-products and wastes. ACS Symposium Series 668, Washtington, DC: American Chemical Society. pp. 140-162.

Barker, A.V. and G.M. Bryson. 2006. Comparisons of composts with low or high nutrient status for growth of plants in containers Commun. Soil Sci. Plant Anal. 37:1303-1319.

Beeson, R.C., Jr. 1996. Composted yard waste as a component of container substrates. J. Environ. Hort. 14:115-121.

Beeson, R.C. Jr., M.A. Arnold, T.E. Bilderback, B. Bolusky, S. Chandler, H.M. Gramling, J.D. Lea-Cox, J.R. Harris, P.J. Klinger, H.M. Mathers, J.M. Ruters, and T.H. Yeager. 2004. Strategic vision of container nursery irrigation in the next 10 years. J. Environ. Hort. 22:113-115.

Bellamy, K.L., C. Chong, and R.A. Cline. 1995. Paper sludge utilization in agriculture and container nursery culture. Sci. Hort. 24:1074-1082.

Benito, M., A. Masaguer, R. De Antonio, and A. Moliner. 2005. Use of pruning waste compost as a component in soilless growing media. Bioresour. Technol. 96:597-603.

Benito, M., A. Masaguer, A. Moliner, and R. De Antonia. 2006. Chemical and physical properties of pruning waste compost and their seasonal variability. Bioresour. Technol. 97:2071-2076.

Bilderback, T.E., W.C. Fonteno, and D.R. Hohnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peatmoss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

Broschat, T.K. 1991. Manganese binding by municipal waste composts used as potting media. J. Environ. Hort. 1991:97-100.

Bugbee, G.J. 1996. Growth of Rhodedendron, Rudbeckia and Thuja and the leaching of nitrates as affected by the pH of potting media amended with biosolids compost. Compost Sci. Util. 4(1):53-59.

Bugbee, G.J. 1999. Effects of hardwood sawdust in potting media containing biosolids compost on plant growth, fertilizer needs, and nitrogen leaching. Commun. Soil Sci. Plant Anal. 30:689-698.

Bugbee, G.J. 2002. Growth of ornamental plants in container media amended with biosolids compost. Compost Sci. Util. 10:92-98.

Bugbee, G.J. and C.R. Frink. 1989. Composted waste as a peat substitute in peat-lite media. HortScience 24:625-627.

Bugbee, G.J., C.R. Frink, and D. Migneault. 1991. Growth of perennials and leaching of heavy metals in media amended with a municipal leaf, sewage sludge and street sand compost. J. Environ. Hort. 9:47-50.

Bunt, A.C. 1987. Media and Mixes for Container-grown Plants. Unwin Hyman, London.

Burger, D.W., T.K. Hartz, and G.W. Forister. 1997. Composted waste as a container medium amendment for the production of ornamental plants. HortScience 32:57-60.

Calkins, J.B., B.R. Jarvis, and B.T. Swanson. 1997. Compost and rubber tire chips as peat substitutes in nursery container media: growth effects. J. Environ. Hort. 15:88-94.

Carr, L.E., H.L. Brodie, J.C. Bouwkamp, and C.S.M. Ku. 1998. Poultry residual composts: materials balance and crop response. Compost Sci. Util. 6(2):36-43.

Carrión, C., M. Abad, A. Maquieira, R. Puchades, F. Fornes, and V. Noguera. 2005. Leaching of composts from agricultural wastes to prepare nursery potting media. Acta Hort. 697:117-124.

Chaney, R.L., J.B. Munns, and H.M. Cathey. 1980. Effectiveness of digested sewage sludge compost in supplying nutrients for soilless potting media. J. Amer. Soc. Hort. Sci. 105:485-492.

Chen, J., D.B. McConnell, C.A. Robinson, R.D. Caldwell, and Y. Huang. 2002. Production and interior performances of tropical ornamental foliage plants grown in container substrates amended with composts. Compost Sci. Util. 10:217-225.

Chen, J., D.B. McConnell, C.A. Robinson, R.D. Caldwell, and Y. Huang. 2003. Rooting foliage plant cuttings in compost-formulated substrates. HortTechnology 13:110-114.

Chong, C. 1999a. Rooting of deciduous woody stem cuttings in peat- and perlite-amended MSW compost media. Compost Sci. Util. 7(4):6-14

Chong, C. 1999b. Experiences with the utilization of wastes in nursery potting mixes and as field soil amendments. Can. J. Plant Sci. 79:139-148.

Chong, C. 2000a. Relationship of soluble salts content in MSW compost media and rooting of evergreen cuttings. Compost Sci. Util. 8:29-35.

Chong, C. 2000b. Can I use municipal waste compost in my propagation media? Comb. Proc. Intl. Plant Prop. Soc. 50:290-295.

Chong, C. 2001. Using turkey litter compost in growing media. Comb. Proc. Intl. Plant Prop. Soc. 51:390-394.

Chong, C. 2002. Use of waste and compost in propagation: challenges and constraints. Comb. Proc. Intl. Plant Prop. Soc. 52:410-414.

Chong, C. 2003. Paper mill waste mixed with compost and other ingredients as container nursery substrates. Compost Sci. Util.11:16-26.

Chong, C. 2005. Experience with wastes and composts in nursery substrates. HortTechnology 15:739-747.

Chong, C. and R.A. Cline. 1993. Response of four ornamental shrubs to container substrate amended with 2 sources of raw paper-mill sludge. HortScience 28:807-809.

Chong, C, R.A. Cline, and D.L. Rinker. 1994. Bark-amended and pet-amended spent mushroom compost for containerized culture of shrubs. HortScience 29:781-784.

Chong, C.V., R.A. Cline, D.L. Rinker, and O.B. Allen. 1991. Growth and mineral nutrient status of containerized woody species in media amended with spent mushroom compost. J. Ameri. Soc. Hort. Sci. 116:242-247.

Chong, C. and B. Hamersma. 1996. Raw paper mill sludge in a rooting medium for deciduous woody cuttings. HortScience 31:869-871.

Chong, C., B. Hamersma, and K.L. Bellamy. 1998. Comparative rooting of deciduous landscape shrub cuttings in media amended with paper mill biosolids from four different sources. Can. J. Plant Sci. 78:519-526.

Chong, C. and G.P. Lumis. 2000. Mixtures of paper mill sludge, wood chips, bark, and peat in substrates for pot-in-pot shade tree production. Can. J. Plant Sci. 80:669-675.

Chong, C. and P. Purvis. 2004. Nursery crop response to substrates amended with raw paper mill sludge, composted paper mill sludge and composted municipal waste. Can. J. Plant Sci. 84:1127-1134.

Cole, D.M., J.L. Sibley, E.K. Blythe, D.J. Eakes, and K.M. Tilt. 2002. Cotton gin compost as an alternative substrate for propagation. Comb. Proc. Intl. Plant Prop. Soc. 52:388-392.

Cole, D.M. and J.L. Sibley. 2004. Waste not, want not. Amer. Nurseryman 200(9):44-47.

Cole, D. M., J. L. Sibley, E.K. Blythe, D.J. Eakes, and K.M. Tilt. 2005. Effect of cotton gin compost on substrate properties and growth of azalea under differing irrigation regimes in a greenhouse setting. HortTechnology 15:145-148.

Conover, C.A. and J.N. Joiner. 1966. Garbage compost as a potential soil component in production of Chrysanthemum morifolium ‘Yellow Delaware’ and ‘Oregon’. Proc. Florida State Hort. Soc. 79:424-426.

Craig, P.B. and J.C. Cole. 2000. Recycled paper as a growth substrate for container Spirea production. HortScience 35:1253-1257.

Craul, P.J. and M.S. Switzenbaum. 1996. Developing biosolids compost specification. BioCycle 37(12):44-47.

Crecchio, C., M. Curci, R. Mininni, P. Ricciuti, and P. Ruggiero. 2001. Short-term effects of municipal solid waste compost amendments on soil carbon and nitrogen content, some enzyme activities and genetic diversity. Biol. Fert. Soils 34:311-318.

Davidson, H., R. Mecklenburg, and C. Peterson. 2000. Nursery Management; Administration and Culture. 4th ed. Upper Saddle River, NJ, Prentice-Hall.

Di Benedetto A.H., R. Klasman, and C. Boschi. 2004. Use of river waste in growing media for ornamental herbaceous perennials. J. Hort. Sci. Biotech. 79:119-124.

E & A Environmental Consultants and H. Stenn. 1996. Compost End-Use Guidelines Development Project. Report CM-96-1. Clean Washington Center, Department of Trade and Economic Development., Seattle, WA.Eklind, Y., L. Salomonsson, M. Wivstad, and B. Ramert. 1998. Use of herbage compost as horticultural substrate and source of plant nutrients. Biol. Agric. Hort. 16:269-290.

Einert, A.E. 1972. Performance of rice hulls as a growing media for pot lilies under three forcing systems. HortScience 7:60-61.

Epstein, E. 1997. The Science of Composting. Lancaster, PA: Technomic Publishing Company, Inc.

Evans, M.R. 2004a. Ground bovine bone as a perlite alternative in horticultural substrates. HortTechnology 14:171-175.

Evans, M.R. 2004b. Processed poultry feather fiber as an alternative to peat in greenhouse crops substrates. HortTechnology 14:176-179.

Evans, M.R. and M. Gachukia. 2004. Fresh parboiled rice hulls serve as an alternative to perlite in greenhouse crop substrates. HortScience 39:232-235.

Evanylo, G.K. and W.L. Daniels. 1999. Paper mill sludge composting and compost utilization. Compost Sci. Util. 7(2):30-39.

Fitzpatrick, G.E. 1989. Solid waste composts as growing media. BioCycle 30(9):62-64.

Fitzpatrick, G.E. 2001. Compost utilization in ornamental and nursery crop production systems. In: Stoffella, P.J. and B.A. Kahn (Eds.). Compost Utilization in Horticultural Cropping Systems. Boca Raton, FL: Lewis Publishers. Pp.135-150.

Fitzpatrick, G.E., E.R. Duke, and K.A. Klock-Moore. 1998. Use of compost products for ornamental crop production: research and grower experiences. HortScience 33:941-944.

Fitzpatrick, G.E. and S.D. Verkade. 1991. Substrate influence on compost efficacy as a nursery growing medium. Proc. Florida State Hort. Soc.104:308-310.

Freeman, T.M. and D.L. Cawthon. 1999. Use of composted dairy cattle solid biomass, poultry litter and municipal biosolids as greenhouse growth media. Compost Sci. Util. 7(3):66-71.

Frost, M.D., J.C. Cole, and J.M. Dole. 2003. Fertilizer source affects iron, manganese, and zinc leaching, nutrient distribution, and geranium growth. J. Plant Nutr. 26:315-329.

Garcia-Gomez, A., M.P. Bernal, and A. Roig. 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bioresour. Technol. 83:81-87.

Gasser, J.K.R. 1984. Composting of Agricultural and Other Wastes. New York, NY: Elsevier.

Gariglio, N.F., M.A. Buyatti, C.A. Bouzo, M.E. Weber, and R.A. Pilatti. 2004. Use of willow (Salix sp.) sawdust as a potting medium for calendula (Calendula officinalis) and marigold (Tagetes erecta) plant production. N. Z. J. Crop Hort. Sci. 32:147-151.

Gogue, G.J. and K.C. Sanderson. 1975. Municipal compost as a media amendment for chrysanthemum culture. J. Amer. Soc. Hort. Sci. 100:213-216.

Goldstein, N. 1987. Sewage sludge composting maintains momentum. BioCycle 28:24-29.

Goldstein, N. 2001. The composting industry in the United States: past, present and future. In:Stoffella, P.J. and B.A. Kahn (eds.). Compost Utilization in Horticlutural Cropping System. Boca Raton, FL:Lewis Publishers.

Goldstein, N. 2005a. Mixed MSW composting facilities in the US. BioCycle 46(11):19-28.

Goldstein, N. 2005b. Source separated MSW composting in the US. BioCycle 46(12):20-26.

Goldstein, N. and R. Steuteville. 1994. Solid waste composting seeks its niche. BioCycle 35(11):30-35.

Golueke, C.G. 1972. Composting: a Study of the Process and its Principles. Rodale Press, Emmaus, PA. 110p.

Gouin, F.R. 1982. Using composted waste for growing horticultural crops. BioCycle 23(1):45-47.

Gouin, F.R. 1993. Utilization of sewage sludge compost in horticulture. HortTechnology 3:161-163.

Gouin, R.R. 1995. Market strength in horticultural industries. BioCycle 26(8): 68-70.

Hicklenton, P.R., V. Rodd, and P.R. Warman. 2001. The effectiveness and consistency of source-separated municipal solid waste and bark composts as components of container growing media. Scientia Horticulturae 91:365-378.

Guerrero, F., J.M. Gasco, and L. Hernandez-Apaolaza. 2002. Use of pine bark and sewage sludge compost as components of substrates for Pinus pinea and Cupressus arizonica production. J. Plant Nutr. 25:129-141.

Guttay, A.J. 1982. The growth of three woody plant species and the development of their mycorrhizae in three different plant composts. J. Amer. Soc. Hort. Sci. 107:324-327.

Hartz, T.K., F.J. Costa, and W.L. Schrader. 1996. Suitability of composted green waste for horticultural uses. HortScience 31:961-964.

Hartz, T.K. and C. Giannini. 1998. Duration of composting of yard wastes affects both physical and chemical characteristics of compost and plant growth. HortScience 33:1192-1196.

He, X.T., T.J. Logan, and S.J. Traina. 1995. Physical and chemical characteristics of selected US municipal solid-waste composts. Sci. Hort. 24:543-552.

Hernandez-Apaolaza, L., A.M. Gasco, J.M. Gasco, and F. Guerrero. 2005. Reuse of waste material as growing media for ornamental plants. Bioresour. Technol. 96:125-131.

Hicklenton, P.R., V. Rodd, and P.R. Warman. 2001. The effectiveness and consistency of source-separated municipal solid waste and bark composts as components of container growing media. Sci. Hort. 91:365-378.

Hickman, Jr., H.L. 2003. American alchemy: the history of solid waste management in the United States. Santa Barbara, CA: Forester Press.

Hidalgo, P.R. and R.L. Harkess. 2002. Earthworm castings as a substrate amendment for chrysanthemum production. HortScience 37:1035-1039.

Hidalgo, P.R., F.B. Matta, and R.L. Harkess. 2006. Physical and chemical properties of substrates containing earthworm castings and effects on marigold growth. HortScience 41:1474-1476.

Holcomb, E.J. and P.N. Walker. 1995. Chrysanthemum and poinsettia growth in coal gasification slag amended media. Commun. Soil Sci. Plant Anal. 26:2497-2510.

Hummel, R.L., S. Kuo, D. Winters, and E.J. Jellum. 2000. Fishwaste compost medium improve growth and quality of container-grown marigolds and geraniums without leaching. J. Environ. Hort. 18:93-98.

Ingelmo, F., R. Canet R, M.A. Ibanez, F. Pomares, and J. Garcia. 1998. Use of MSW compost, dried sewage sludge and other wastes as partial substitutes for peat and soil. Bioresour. Technol. 63:123-129.

Iglesiasjimenez, E. and C.E. Alvarez. 1993. Apparent availability of nitrogen in composted municipal refuse. Biol. Fertility Soils 16:313-318.

Ingram, D.L., R.W. Henley, and T.H. Yeager. 2003. Growth media for container grown ornamental plants. BUL241, the Environmental Horticulture Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. pp. 18.

Jackson, B.E., A.N. Wright, D.M. Cole, and J.L. Sibley. 2005. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Jensen, H.E.K., M. Leth, and J.J.L. Iversen. 2001. Growth of Hedera helix L. container plants in compost substrates made with Miscanthus ogiformis Honda straw and various N-sources. Compost Sci. Util. 9:206-214.

Jensen, H.E.K., M. Leth, and J.J.L. Iversen. 2002. Effect of compost age and concentration of pig slurry on plant growth. Compost Sci. Util. 10:129-141.

Kahtz, A. W. and N. J. Gawel. 2004. Growth of barberry liners in media amended with noncomposted recycled waste. HortTechnology 14:192-195.

Keener, H.M., D.L. Elwell, K. Ekinci, and H.A.J. Hoitink. 2001. Composting and value-added utilization of manure from a swine finishing facility. Compost Sci. Util. 9:312-321.

Kerr, G.P. and J.J. Hanan. 1985. Leaching of container media. J. Amer. Soc. Hort. Sci. 110:474-480.

Klock, K.A. 1997a. Growth of dianthus and petunia in media amended with composted urban waste. J. Environ. Hort. 15:135-137.

Klock, K.A. 1997b. Growth of salt sensitive bedding plants in media amended with composted urban waste. Compost Sci. Util. 5 (3):55-59.

Klock, K.A. 1998. Influence of urban waste compost media and paclobutrazol drenches on impatiens growth. HortScience 33:277-278.

Klock, K.A. and G.E. Fitzpatrick. 1997. Growth of impatiens 'Accent Red' in three compost products. Compost Sci. Util. 5 (4):26-30

Klock-Moore, K.A. 1999. Bedding plant growth in greenhouse waste and biosolid compost. HortTechnology 9:210-213.

Klock-Moore, K.A. 2000. Comparison of salvia growth in seaweed compost and biosolids compost. Compost Sci. Util. 8:24-28.

Klock-Moore, K.A. 2001. Effect of controlled-release fertilizer application rates on bedding plant growth in substrates containing compost. Compost Sci. Util. 9:215-220.

Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. BioCycle 41(11):58-60.

Ku C.S.M., J.C. Bouwkamp, and F.R. Gouin. 1998. Effects of compost source and timing of fertigation initiation on growth of potted poinsettia. Compost Sci. Util. 6 (4):57-66

Kuo, S., R.L. Hummel, E.L. Jellum, and D. Privett. 1997. Fishwaste compost effects on rhododendron growth and nitrogen leaching and transformation. Sci. Hort. 6:733-739.

Kuo, S., R.L. Hummel, E.J. Jellum, and D.Winters. 1999. Solubility and leachability of fishwaste compost phosphorus in soilless growing media. J. Environ. Qual. 28:164-169.

Lohr, V.I. and D.L. Coffey. 1987. Growth responses of seedlings to varying rates of fresh and aged spent mushroom compost. HortScience 22:913-915.

Lohr, V.I., R.G. O'Brien, and D.L. Coffey. 1984. Spent mushroom compost in soilless media and its effects on the yield and quality of transplants. J. Amer. Soc. Hort. Sci. 109:693-697.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Mamo, M., J.A.E. Molina, C.J. Rosen, and T.R. Halbach. 1999. Nitrogen and carbon mineralization in soil amended with municipal solid waste compost. Can. J. Soil Sci. 79:535-542.

Marconi, D.J. and P.V. Nelson. 1984. Leaching of applied phosphorus in container media. Sci. Hort. 22:275-285.

Marfà, O., F. Lemair, R. Cáceres, F. Giuffrida, and V. Guérin. 2002. Relationships between growing media fertility, percolate composition and fertigation strategy in peat-substitute substrates used for growing ornamental shrubs. Sci. Hort. 94:309-321.

Matkin, O.A., P.A. Chandler, and K.F. Baker. 1957. Components and development of mixes. In:K.F. Baker (ed.) The U.C. System for Production Healthy Container-Grown Plants. University of California, Division of Agricultural Sciences, Agricultural Experiment Station, Extension Service.

Maynard, A.A. 1998. Utilization of MSW compost in nursery stock production. Compost Sci. Util. 6(4):38-44.

Moore, K. K. 2004. Growth of bedding plants in substrates amended with compost and fertilized with three different release rates of a control led-release fertilizer product. HortTechnology 14:474-478.

Moore, K.K. 2005. Uses of compost in potting mixes. HortTechnology 15:58-60.

Ozores-Hampton, M., T.A. Obreza, P.J. Stoffella. 2001. Mulching with composted MSW for biological control of weeds in vegetable crops. Compost Sci. Util. 9:352-360.

Papafotiou, M., V. Asimakopoulou, P. Kouvari, I. Kovaeou, M. Phsyhalou, I. Lytra, and G. Kargas. 2001a. Cotton gin trash compost as growing medium ingredient for the production of pot ornamentals. Gartenbauwissenschaft 66:S.229–232.

Papafotiou, M., J. Chronopoulos, G. Kargas, M. Voreakou, N. Leodaritis, O. Lagogiani, and S. Gazi. 2001b. Cotton gin trash compost and rice hulls as growing medium components for ornamentals. J. Hort. Sci. Biotech. 76:431-435.

Papafotiou, M, G. Kargas, and I. Lytra. 2005. Olive-mill waste compost as a growth medium component for foliage potted plants. HortScience 40:1746-1750.

Papafotiou, M., M. Phsyhalou, G. Kargas, I. Chatzipavlidis, and J. Chronopoulos. 2004. Olive-mill wastes compost as growing medium component for the production of poinsettia. Sci. Hort. 102:167-175.

Poole, R.T. 1969. Rooting response of four ornamental species propagated in various media. Proc. Florida State Hort. Soc.82:393-397.

Poole, R.T., C.A. Conover, and J.N. Joiner. 1981. Soils and potting mixtures, p. 179-202. In:J.N. Joiner (ed.). Foliage Plant Production. Prentice Hall, Englewood Cliffs, N.J.

Pudelski, T. 1987. Horticultural use of compost. p. 20-29. In: De Bertoldi, M, M.P. Ferranti, P. L'Hermite, and F. Zucconi (eds.). Compost: Production, Quality and Use. Elsevier, New York, NY.

Raviv, M. 2005. Production of high-quality composts for horticultural purposes:a mini-review. HortTechnology 15:52-57.

Raviv, M., Y. O., J. Katan, Y. Hadar, A. Yogev, S. Medina, A. Krasnovsky, and H. Ziadna. 2005. High-nitrogen compost as a medium for organic container-grown crops. Bioresour. Technol. 96:419-427.

Raymond, D.A., C. Chong, and R.P. Voroney. 1998. Response of four container grown woody ornamentals to immature composted media derived from waxed corrugated cardboard. Compost Sci. Util. 6 (2):67-74

Ribeiro, H.M., E. Vasconcelos, and J.Q. dos Santos. 2000. Fertilization of potted geranium with a municipal solid waste compost. Bioresour. Technol. 73:247-249.

Rodd, A.V., P.R. Warman, P. Hicklenton, K. Webb. 2002. Comparison of N fertilizer, source-separated solid waste compost and semi-solid beef manure on the nutrient concentration in boot-stage barley and wheat tissue. Can. J Soil Sci. 82:33-43.

Roe, N.E. 1998. Compost utilization for vegetable and fruit crops. HortScience 33:934-937.

Rosen, C.J., T.R. Halbach, and B.T. Swanson. 1993. Horticultural uses of municipal solid waste composts. HortTechnology 3:167-173.

Rynk, R. and T.L. Richard. 2001. Commercial compost production systems. p. 51-93. In: Stoffella, P.J. and B.A. Kahn (Eds). Compost Utilization in Horticultural Cropping Systems. Lewis Publishers, Boca Raton, FL.

Sanderson, K.C. 1980. Use of sewage-refuge compost in the production of ornamental plants. HortScience 15:173-178.

Sanderson, K.C. and W.C. Martin, Jr. 1974. Performance of woody ornamentals in municipal compost medium under nine fertilizer regimes. HortScience 9:242-243.

Sawhney, B.L., G.J. Bugbee, and D.E. Stilwell. 1994. Leachability of heavy-metals from growth media containing source-separated municipal solid-waste compost. Sci. Hort. 23:718-722.

Satkofsky, A. 2001. 2001 BioCycle National Survey: MSW composting developments in the US. BioCycle 42(12):58-64.

Shanks, J.B. and F.R. Gouin. 1984. Compost suitability for greenhouse ornamental plants. BioCycle 25(1):42-45.

Shiralipour, A., D.B. McConnell, and W.H. Smith. 1992. Uses and benefits of MSW compost: a review and an assessment. Biomass Bioenerg. 3:267-279.

Shiralipour, A., D.B. McConnell, and W.H. Smith. 1993. Applying compost to crops. BioCycle 34(6):70-72.

Sibley, J.L., D.N. Cole, and W. Lu. 2005. Waste is a terrible thing to mind. Comb. Proc. Intl. Plant Prop. Soc. 54:596-603.

Siminis, H.I. and V.I. Manios. 1990. Mixing peat with MSW compost. BioCycle 31(11):60-61.

Soumaré, M., F.M.G. Tack, and M.G. Verloo. 2003. Ryegrass response to mineral fertilization and organic amendment with municipal solid waste compost in two tropical agricultural soils of Mali. J. Plant Nutr. 26:1169-1188.

Sterrett, S.B. 2001. Composts as horticultural substrates for vegetable transplant production. p. 227-240. In: Stoffella, P.J. and B.A. Kahn (Eds). Compost Utilization in Horticultural Cropping Systems. Lewis Publishers, Boca Raton, FL.

Stoffella, P.J. and B.A. Kahn. 2001. Compost Utilization in Horticultural Cropping Systems. Boca Raton, FL: Lewis Publishers.

Stoffella, P.J., Y.C. Li, D.V. Calvert, and D.A. Graetz. 1996. Soilless growing media amended with sugarcane filtercake compost for citrus rootstock production. Compost Sci. Util. 4 (2):21-25.

Struve, D.K. 2002. Growth of several tree spp. in containers in responses to N loading, fertilizer type and substrate. J. Environ. Hort. 20:133-137.

Subler, S., C. Edwards, and J. Metzger. 1998. Comparing vermicomposts and composts. BioCycle 39(7):63-65.

Sullivan, D.M. and R.O. Miller. 2001. Compost quality attributes, measurements, and variability. p. 95-120. In: Stoffella, P.J. and B.A. Kahn (Eds). Compost Utilization in Horticultural Cropping Systems. Lewis Publishers, Boca Raton, Florida.

Trochoulias, T., A.J. Rochoulias, and E. White. 1990. The use of bagasse as a potting medium for ornamentals. Sci. Hort. 42:161-167.

Vendrame, W. and K.K. Moore. 2005. Comparison of herbaceous perennial plant growth in seaweed compost and biosolids compost. Compost Sci. Util. 13:122-126.

US Composting Council. 1996. Field Guide to Compost Use. US Composting Council, Amherst, OH.

US Environmental Protection Agency (EPA), 1999. Biosolids generation, use, and disposal in The United States. EPA530-R99-009.

US Environmental Protection Agency (US EPA). 2003. Municipal Solid Wastes in the United States: 2001 Facts and Figures. Report No. EPA530-S-03-011. Office of Solid Waste and Emergency Response, USEPA, Washington, DC.

US Environmental Protection Agency (US EPA). 2005. Municipal Solid Wastes in the United States: Facts and Figures for 2003. Report No. EPA530-F-05-003. Office of Solid Waste and Emergency Response, USEPA, Washington, DC.

Wang, Y.T. 1991. Evaluation of media consisting of a cotton waste for the production of tropical foliage species. J. Environ. Hort. 9:112-115.

Wang, Y.T. and T.M. Blessington. 1990. Growth and interior performance of poinsettia in media containing composted cotton burrs. HortScience 25:407-408.

Wilson, S. B., P. J. Stoffella, and D.A. Graetz. 2001a. Compost-amended media for growth and development of mexican heather. Compost Sci. Util. 9:60-64.

Wilson, S. B., P. J. Stoffella, and D.A. Graetz. 2001b. Evaluation of compost as an amendment to commercial mixes used for container-grown golden shrimp plant production. HortTechnology 11:31-35.

Wilson, S.B., P.J. Stoffella, and D.A. Graetz. 2001c. Use of compost as a media amendment for container production of two subtropical perennials. J. Environ. Hort. 19:37-42.

Wilson, S.B., P.J. Stoffella, and L.A. Krumfolz. 2001d. Containerized perennials make good use of compost. BioCycle. 42(8):59-61.

Wilson, S.B., P.J. Stoffella, and D.A. Graetz. 2002. Development of compost-based media for containerized perennials. Sci. Hort. 93:311-320.

Wilson, S.B., P.J. Stoffella, and D.A. Graetz. 2003. Compost amended media and irrigation system influence containerized perennial Salvia. J. Amer. Soc. Hort. Sci. 128:260-268.

Wilson, S.B., L.K. Mecca, P.J. Stoffella, and D.A. Graetz. 2004. Using compost for container production of hammock species native to Florida. Nativ. Plants J. 5:186-194.

Wilson, S.B., L.K. Mecca, H.E. Danielson, D.A. Graetz, and P.J. Stoffella. 2006. Container and field evaluation of three native shrubs grown in compost-based media. Compost Sci. Util. 14:178-183.

Wootton, R.D., F.R. Gouin, and F.C. Stark. 1981. Composted, digested sludge as a medium for growing flowering annuals. J. Amer. Soc. Hort. Sci. 106:46-49.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops. 2nd Edition. 103 pages. Southern Nursery Assoc., 1827 Powers Ferry Road, Atlanta, GA.

Yelanich, M.V. and J.A. Biernbaum. 1994. Fertilizer concentration and leaching affect nitrate-nitrogen leaching from potted poinsettia. HortScience 29:874-875.

Young, J. R., E. J. Holcomb, and C.W. Heuser. 2002. Greenhouse growth of marigolds in three leached sources of spent mushroom compost over a 3-year period. HortTechnology 12:701-705.

Zubillaga, M.S. and R. S. Lavado. 2001. Biosolids compost as component of potting media for bedding plants. Gartenbauwissenschaft 66:304–309.

Table 1. Number of municipal solid waste (MSW) composting projects in the US since 1985 as reported by *BioCycle*'s Annual MSW composting survey.

Year	Operational	Total
1985	1	1
1986	1	6
1987	3	18
1988	6	42
1989	7	75
1990	9	89
1991	18	n/a
1992	21	82
1993	17	n/a
1994	17	51
1995	17	44
1996	15	41
1997	14	39
1998	18	33
1999	19	25
2000	16	23
2001	16	23
2002	15	25
2003/4	-	28
2005	28	28
2006	26	26

Sources: Goldstein, 2001 and *Biocycle* Annual MSW Composting Surveys: 1985-2006.

Table 2. Selected chemical and physical properties of substrates derived from biosolids-based compost and plant responses.

Components	pH[a]	EC[b] $dS \cdot m^{-1}$	WHC[b] %	Air space %	Plant species	Plant response	Study duration	Reference
BS-YT[b]: 0, 25, 50, 75, 100%[c]	adjusted to 5.0, 6.0, 7.0	n/a	65, 66, 64, 62, 61	17, 17, 22, 23, 25	*Rhododendron* sp., *Rudbeckia* sp., *Thujia* sp.	affected by pH more than by the percent compost	18mo.	Bugbee, 1996
BS-YT: 0, 30, 60, 100%	4.7, 4.6, 6.4, 6.5	0.03, 0.34, 0.50, 0.83	71.7, 39.1, 43.5, 25.0	21.7, 39.1, 17.4, 27.2	impatiens, snapdragon	linear increase in shoot dry mass, size, and ht[b] with percent compost	n/a	Klock, 1997b
2 BS: 0, 25, 33, 50%	25-50% BS: 7.2-7.5; 5.8-6.2; est.[b]	25-50% BS: <2.0; 3.5-5.8 est.	n/a	n/a	4 poinsettia cultivars	less in plant ht, width, and grade than two controls	16wk.	Ku et al., 1998
BS-YT, seaweed-YT: 0, 30, 60, 100%	5.8, 6.4, 7.1, 6.9; 5.8, 6.9, 7.6, 7.8	0.07, 0.59, 0.97, 2.17; 0.08, 0.35, 0.78, 1.48	52, 36, 32, 21; 56, 50, 55 52	39, 24, 22, 24; 40, 38, 14, 17	salvia	increased shoot dry wt[b], flower number 0 - 60%; then equal or less	1- 2mo.	Klock-Moore, 2000
BS-YT: 0, 30, 60, 100%	5.5, 6.5, 6.8, 6.9	0.11, 0.83, 1.20, 1.31	59, 37, 36, 22	28, 29, 20, 25	impatiens, salvia	equal or higher shoot dry wt	35-42d.	Klock-Moore, 2001
peat or coir with BS-YT: 0, 25, 50, 75, 100%	5.4, 6.2, 6.4, 6.6, 6.9; 6.5, 6.3, 6.7, 6.9, 7.1	0.13, 0.14, 0.17, 0.21, 0.24; 0.04, 0.09, 0.13, 0.16, 0.20	n/a	n/a	*Cuphea hyssopifolia*	less growth index, shoot dry wt with more compost	8wk.	Wilson et al., 2001a
BS: 0, 25, 50, 75, 100%	5.4 -6.0	0.1-0.4	n/a	n/a	*Petunia hybrida, Vinca* sp.	*P.*: 25, 75% better than control and 100% in ht; *V.*: all positive	*P.:* 6d *V.*: 7d	Zubillaga and Lavado, 2001
BS: 0, 25, 50, 100%	adjusted to 5.0 - 6.0	0.6, 0.9, 2.5, 3.3	38, 40, 38, 40	47, 39, 39, 38	7 annuals, 9 perennials, 8 woody/field	equal or better	5-6mo. or 1.5yr.	Bugbee, 2002
BS: 0, 15%	4.9, 6.0	4.6, 8.1	n/a	40, 34	2 conifers	same or better in shoot dry wt	2yr.	Guerrero et al., 2002
BS-YT: 0, 25, 50, 75, 100%	6.1, 7.0, 6.8, 6.8, 6.9	1.5, 1.8, 2.6, 4.5, 5.4	n/a	air filled porosity %: 4.3, 6.4, 7.0, 4.8, 4.4	*Gloxinia sylvatica*, *Justicia carnea*, *Lysimachia congestiflora*	reduced or same in stem length or growth index, shoot dry weight	10wk.	Wilson et al., 2002

Components	pH[a]	EC[b] $dS \cdot m^{-1}$	WHC[b] %	Air space %	Plant species	Plant response	Study duration	Reference
BS-MSW, YT, BS-YT: 20, 50, 80%; all three: 36, 60, 84%	4.6, 6.0, 6.9; 4.7, 5.1, 6.2; 5.0, 6.0, 6.6; 4.6, 5.8, 6.4; control: 3.8	1.5, 6.0, 10.5; 1.4, 2.9, 6.2; 2.1, 5.7, 9.6; 2.3, 6.5, 12.4; control: 0.3	44.5-60.8; control: 48.4	14.7, 10.0, 4.5; 12.9, 10.2, 5.5; 11.5, 10.4, 8.4; 13.8, 11.2, 10.8; control: 18.2	3 foliage plant cuttings	equal in root numbers, equal or less in root length, root ball coverage ratings	42d.	Chen et al., 2003
BS-YT: 0, 50, 100%	6.5, 6.8, 7.0	1.2, 5.0, 7.6		8.0, 7.7, 8.4	3 perennial *Salvia*	equal or less	6wk.	Wilson et al., 2003
BS+PB[b] or coconut fiber: 15, 30%	BS+PB: 7.2, 7.6; BS+fiber: 7.1, 7.0	BS+PB: 6.2, 8,2; BS+fiber: 5.3, 9.4		BS+PB: 44, 31; BS+fiber: 45, 41	3 conifers	equal or increased ht, shoot wt, few decreased in 30%	6, 12mo.	Hernandez-Apaolaza et al., 2005
BS-YT: 0, 40, 100%	6.58, 5.97, 6.53	1.63, 5.7, 6.5	43, 38, 44	n/a	three native shrubs to Florida	similar plant ht and shoot dry wt; better GI in 100% compost in one sp.	18wk.	Wilson et al., 2006

[a] All substrate chemical and physical properties were measurements of initial conditions.

[b] EC: electrical conductivity; WHC: water holding capacity; ht: height; wt: weight; est.: indicates estimated number(s) from graph; BS: biosolids; YT: yard trimmings; MSW: municipal solid waste; PB: pine bark.

[c] Compost or co-compost as the percentage of substrate in volume.

Table 3. Selected chemical and physical properties of substrates derived from municipal solid waste compost and plant responses.

Components	pH[a]	EC[b] $dS \cdot m^{-1}$	WHC[b] %	Air space %	Plant species	Plant response	Study duration	Reference
MSW[b], MSW-BS[b]: 100%[c]	7.7; 7.4	1.95; 3.52	87.13; 66.72	6.80; 23.21	3 tropical crops	increased ht[b] and dry wt[b] in one species	6, 12mo.	Fitzpatrick, 1989
MSW: 0, 30, 60, 100%	4.4, 5.8, 7.2, 7.6	0.09, 0.87, 1.97, 2.76	n/a	n/a	impatiens	linearly decreased shoot dry wt with increasing MSW	40d.	Klock and Fitzpatrick, 1997
MSW: 0, 25, 33, 50%	6.0-6.5 est.[b]	<2 est.	n/a	n/a	4 poinsettia cultivars	equal or less in ht, width, and grade than 2 controls	16wk.	Ku et al., 1998
MSW: 15, 30, 45, 60, 75%	4.0-9.0 est.	0.10-0.70 est.	40-70 est.	10-30 est.	7 deciduous ornamentals for rooting test	equal, increase or decrease in percent rooting, root number and length, taxa dependent	3mo.	Chong, 1999a
MSW: 15, 30, 45, 60, 75%	4.0-9.0 est.	0.10-1.20 est.	n/a	n/a	9 evergreen landscape shrubs	equal, increase or decrease in percent rooting, root number and length, taxa dependent	3mo.	Chong, 2000a
MSW: 0, 10, 20, 30, 40, 50%	n/a	linearly increased; 1.4- 12	reduced by MSWC	n/a	geranium	highest shoot dry wt in 10, 20%; lowest in 0% control; reduced in >20%		Ribeiro et al., 2000
MSW: 25, 50, 75, 100%; 1996, 1997	6.0-7.5 for 25 - 75%; est.	1.5-4.5 for 25-75%; est.	59.1, 62.2, 57.3, 51.3; 55.0, 53.2, 51.2, 44.8	14.2, 17.9, 19.2, 22.0; 15.3, 18.1, 20.2, 24.0	*Cotoneaster dammeri* cv. 'Coral Beauty'	equal to or greater than in bark-based substrates; least growth in 100% MSW and 100% bark	4mo.	Hicklenton et al., 2001
MSW-BS: 20, 50, 80%; MSW-various: 36, 60, 84%	3.8, 6.7, 7.9; 4.6, 5.9, 7.2; control: 3.7	0.8, 2.7, 5.3; 1.4, 3.5, 4.9; control: 0.2	n/a	n/a	3 tropical foliage plants	equal GI and fresh wt in 20% or 36%; equal or less GI and fresh wt in other ratios	n/a	Chen et al., 2002
MSW: 0, 25, 50, 75, 100%	5.3, 6.5, 6.6, 6.5, 7.1[d]	0.43, 0.89, 1.20, 1.60, 2.40[d]	n/a	n/a	barberry	equal shoot dry wt in 25, 75%; reduced shoot dry wt in 50, 100% composts	142d.	Kahtz and Gawl, 2004

[a] All substrate chemical and physical properties were measurements of initial conditions.
[b] EC: electrical conductivity; WHC: water holding capacity; ht: height; wt: weight; est.: indicates estimated number(s) from graph; MSW: municipal solid waste; BS: biosolids; DAT: date after transplanting.
[c] Compost or co-compost as the percentage of substrate in volume.
[d] Measurements of pH and EC were taken 7 days after transplanting.

Table 4. Selected chemical and physical properties of substrates derived from green waste compost and plant responses.

Components	pH	EC[b] $dS \cdot m^{-1}$	WHC[b] %	Air space %	Plant species	Plant response	Study duration	Reference
GW[b] & others: 0, 10, 30, 60, 80, 100%[c]	100%: 6.6	100%: 3.1	59, 58, 52, 43, 48, 50	11, 15, 15, 20, 25, 27	3 perennials	equal or better	4mo.	Bugbee et al., 1991
YW[b]: 0, 20, 40, 60, 80%	100%: 7.3	100%: 0.66	52, 33, 42, 48, 54	15, 29, 23, 14, 12	*Rhododendron* sp. *Pittosporum* sp.	similar or better shoot growth	1yr.	Beeson, Jr., 1996
50% GW+ 50% perlite	n/a	thoroughly leached	n/a	n/a	tomato, marigold	increased plant ht[b] and dry wt in non-fertilized trt[b]	1.5-2mo.	Hartz et al.,1996
GW: 0, 25, 50, 75, 100%	n/a	100%: 5.8-12.8	100%: 0.45-0.48	100%: 6.1-9.3	3 bedding plants, 1 flower, 3 shrubs	for most plants, no more than 75% GW can be used for adequate growth	4-6wks to 6-8mo.	Burger et al., 1997
50% GW with varied compost-ing periods	finished compost: 7.5-8.0	finished compost: 3.6-16.9	n/a	n/a	fescue, vinca	minimal 9-12 wks for mature compost	varied	Hartz and Giannini, 1998
2 composts: 25, 50, 75%	5.01-7.51	0.46-4.95	37-55	37-51	*calendula* sp., *calceolaria* sp.	calendula: equal/ better than peat, equal or less than CS[b]; calceolaria: 25% equal /better, 50, 75% equal/less	3mo.	Garcia-Gomez et al., 2002
12 PW[b] composts in 18 mo.	8.2-8.9; mean: 8.6	0.33-0.51; mean: 0.42	WBC[b]: 1.1-5.3	34-55; mean: 44	n/a	n/a	n/a	Benito et al., 2006
YT[b]-Seaweed, YT-BS: 0, 30, 60, 100	5.5, 7.0, 7.7, 7.6; 5.5, 6.5, 6.5, 6.8	0.14, 0.31, 1.01, 0.87; 0.14, 1.06, 1.62, 1.45	56, 50, 55, 52; 52, 36, 32, 21	40, 38, 14, 17; 39, 34, 22, 24	4 herbaceous perennials	equal shoot dry wt[b] in 2 sp.; interaction in shoot dry wt b/t other 2 sp. and 2 mix	38d.	Verdrame and Moore, 2005

[a] All substrate chemical and physical properties were measurements of initial conditions.
[b] EC: electrical conductivity; WHC: water holding capacity; ht: height; wt: weight; GW: green waste; YW: yard waste; PW: pruning waste; YT: yard trimming; trt: treatment; WBC: water buffering capacity; CS: commercial substrate.
[c] Compost or co-compost as the percentage of substrate in volume.

Table 5. Selected chemical and physical properties of substrates derived from animal waste compost and plant responses.

Components	pH[a]	EC[b] dS·m^{-1}	WHC[b] %	Air space %	Plant species	Plant response	Study duration	Reference
2 VMs[b]: 10, 20%[c] or 20% only	100% VM: 5.3, 7.3	100% VM: 4.80, 3.30	n/a	n/a	tomato, marigold, raspberry	t: increased in 10% of one VM; m: died in 20% of one VM; r: same shoot dry wt[b] fertilized control in one VM	t & m: 2d r: 4mo.	Atiyeh et al., 2000b
FWC[b]: 0, 50, 100%	n/a	1.98, 2.11, 1.06	n/a	n/a	marigold, geranium	better shoot growth index, dry wt, quality in 50, 100% than in control	7-9wk.	Hummel et al., 2000
manure: 0, 4, 8, 12, 16%	100% compost: 8.37	100% compost: 22	n/a	n/a	juniper, taxus, deutzia	equal in juniper and taxus; deutizia: increased in 4%, decreased in others	6wk.	Keener et al., 2001
VM: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100%	100% VM: 5.30	100% VM: 11.76	n/a	n/a	French marigold *Tagetes patula*	shoot wt of 28 days/121 days: - increased in 40%/30, 40%; decreased in 100%/90, 100%; ht of 28 days: decreased in 70, 90, 100%	12d.	Atiyeh et al., 2002
4 straw + pig slurry: 100% 3, 6, 9, 12, 15 mo.	5.3-6.4	high in straw +30, 100% pig slurry	n/a	n/a	*Hedera helix*	less in compost of straw, or straw-3%, 100% slurry; little effect of compost age on growth	2.5mo.	Jensen et al., 2002
poultry fiber: 0, 10, 20, 30, 40, 50, 60%	5.5, 5.1, 5.3, 5.7 for 0, 10, 20, 30%	n/a	n/a	n/a	geranium, vinca, coleus, tomato, cucumber	same dry shoot wt in geranium and vinca (0-30%); less dry shoot wt of coleus and cucumber in 60% and tomato in 40-60%	4, 6, 8wk.	Evans, 2004b
earthworm castings (C): 25, 33, 50, 100%; 3 CM[b]	100% C: 7.59; C mix: 6.1-6.8; CM: 5.7-6.6	100% C: 0.90; C mix: 0.34-0.55; CM: 0.10-0.42	100% C: 60; C mix: 41-72; CM: 39-53	100% C: 22; C mix: 3-13; CM: 6-36	marigold	increased growth index, stem diameter, root growth, dry wt, and flower number		Hidalgo et al., 2006

[a] All substrate chemical and physical properties were measurements of initial conditions.
[b] EC: electrical conductivity; WHC: water holding capacity; wt: weight; VM: vermicompost; FWC: fishwaste compost; CM: conventional mix
[c] Compost or co-compost as the percentage of substrate in volume.

Table 6. Selected chemical and physical properties of substrates derived from agricultural waste compost and plant responses.

Components	pH[a]	EC[b] dS·m^{-1}	WHC[b] %	Air space%	Plant species	Plant response	Study duration	Reference
bagasse: 0, 25, 50, 100%[c]	100% compost: 7.2	0.8	n/a	n/a	2 *Citrus* sp.	similar or better in 25-75%; less or similar in 100% compost	86d.	Stoffela et al., 1996
3 straw composts; 2 peat mix	straw: 4.1-6; peat: 6.1, 4.2	straw:1.8-5.8; peat: 3.2, 1	n/a	n/a	*Hedera helix*	less or equal in shoot length, less in shoot wt[b] in than unfertilized peat mix	5-12mo.	Jensen et al., 2001
CGC[b]: 25, 30%[c]; RH[b]: 25, 50% CGC+RH: 25+50%, 30+50%	control: 6.0; CGC: 6.5, 6.9; RH: 6.0, 6.0; CGC+ RH: 6.2, 6.8	control: 0.6; CGC: 7.7, 10.1; RH: 0.7, 1.0; CGC+ RH: 6.1, 10.0	EAW[b]: control: 19; CGC: 15, 14; RH: 18, 13; CGC-RH: 13, 10	n/a	2 mums, geranium, oleander, *Lantana camara*	CGC: equal in ht[b] in 2 crops, less in others; more flower # in 3 crops; more or equal in lateral shoots; RH: mostly equal or less; CGC+ RH: varied	4-5mo.	Papafotiou et al., 2001a
RH: 10, 15, 20, 25, 30, 35, 40%	n/a	n/a	n/a	n/a	tomato and 5 annuals	decreased shoot dry wt of tomato in 20 - 40%; equal shoot dry wt in all other ratio and species	5, 8wk.	Evans and Gachukia, 2004
OMW[b]: 0, 12.5, 25, 37.5%	5.5, 5.5, 6.0, 6.6; 100%: 7.6	0.6, 1.6, 3.5, 5.2; 100%: 8.5	EAW: water: 19, 18, 8, 8	n/a	poinsettia	decrease of plant ht, brat number, node number with increasing compost	8mo.	Papafotiou et al., 2004
CGC: 0, 25, 50%	3.88, 5.68, 6.14	0.96, 1.92, 1.94	77, 79, 76	41, 33, 20	azalea	equal in GI[b] and visual root rating change, except less in root rating in 50%	120d.	Cole et al., 2005
CGC: 0, 25, 50, 75%	5.4, 5.5, 5.7, 5.6	2.2, 6.2, 6.9, 9.1	33, 42, 53, 57	41, 32, 24, 13	Azalea, *Buxus* sp., *Nandina* sp.	similar or greater growth index than control0	2 seasons	Jackson et al., 2005
OMW: 0, 12.5, 25, 37.5%	5.3-6.3; 0, 12.5%: lime adjusted	0.5, 1.8, 3.2, 5.0 est.[b]	EAW: 19, 18, 8, 8 est.	n/a	*Codiaeum variegatum*, *Syngonium podophyllum*; *Ficus benjamina*	*C.*: reduced stem length and foliage wt in 37.5%; *F.*: reduced foliage wt; *S.*: same or less in stem length, foliage wt in 25, 37.5%	5, 10mo.	Papafotiou et al., 2005

[a] All substrate chemical and physical properties were measurements of initial conditions.
[b] EC: electrical conductivity; WHC: water holding capacity; ht: height; wt: weight; BS: biosolids. CGC: cotton gin compost; RH: rice hull; EAW: easily available water; OMW: olive mill waste; GI: growth index; est.: estimated from graph.
[c] Compost or co-compost as the percentage of substrate in volume.

Table 7. Selected chemical and physical properties of substrates derived from other compost and plant responses.

Components	pH	EC[b] (dS m^{-1})	WHC[b] (%)	Air space (%)	Plant species	Plant response	Study duration	Reference
SMC[b]: 0, 12.5, 25, 37.5, 50%[c], fresh/aged	fresh: 5.7, 6.2, 6.3, 6.2, 6.4; aged: 5.7, 6.2, 6.1, 6.2, 6.3	fresh: 0.9, 4.6, 6.4, 9.9, 11.6; aged: 0.9, 4.4, 6.7, 11.0, 13.6	n/a	n/a	marigold and three vegetables	quadratic responses in dry wt[b], ht[b], quality rating with increasing SMC rates; better growth in aged than fresh SMC	6 wk.	Lohr and Coffey, 1987
3 SMC: 33, 67, 100%; weathered-w; unweathered-u	6.7. 7.1, 7.4; 7.0, 7.4, 7.3; 7.4, 7.5, 7.5; PB: 6.1	2.2, 3.7, 5.5; 3.9, 6.3, 8.7; 0.4, 0.5, 0.8	w. SMC: 23; u. SMC: 20	w. SMC: 23; u. SMC: 61	8 deciduous ornamental shrubs	most equal or better in shoot dry wt, ht than in 100% PB	5 mo.	Chong et al., 1991
2 SMC, each 25 or 50% to form 6 mix	7.4-7.9	1.3-4.6; 1.2-4.0	n/a	10-31; 9-29 est.	4 deciduous ornamental shrubs	equal or increased shoot dry wt, ht, compaction than control; very few differences in two sources of SMC	4 mo.	Chong et al., 1994
2 composts of various urban wastes: 0, 30, 60, 100	4.3, 6.5, 7.0, 6.9; 4.2, 6.3, 6.6, 6.8	0.08, 0.17, 0.28, 0.50; 0.09, 0.21, 0.58, 0.61	n/a	n/a	impatiens in shade house	shoot dry mass, plant size, and number linearly increased in one compost, flower number increased in the 2[nd] compost with increasing compost levels	40d.	Klock and Fitzpatrick, 1997
4 raw paper mill biosolids: 0, 15, 30, 45, 60%	100% biosolids: 6.9-7.8	100% biosolids: 0.2-0.7	23-28	34-40	6 deciduous landscape shrub cuttings	more, equal or less according to biosolids sources, species and ratios in the mix	1 mo.	Chong et al., 1998
3 compost mix from SMC, cardboard, wood wastes	7.8-8.0	5.2, 5.3, 6.4	30, 31, 30	30, 27, 26	4 deciduous ornamental shrubs	increased shoot dry wt than 100% PB mix	2 season	Raymond et al., 1998
PMS[a]: 100% into 3 particle sizes; 50% PMS with/no	100% PMS: 6.73	100% PMS: 1.49	n/a	n/a	marigold; 3 vegetables	marigold leaf biomass, pedicel length, flower number decreased, with the exception of same pedicel	n/a	Evanylo and Daniels, 1999

Components	pH	EC[b] (dS m^{-1})	WHC[b] (%)	Air space (%)	Plant species	Plant response	Study duration	Reference
N						length in <2 mm compost		
WC[b]: 0, 25, 50% + 25% peat or PMS; other: PB[b]	n/a	0.1-0.4	20-57	16-43	green ash, Japanese birch, silver maple	less trunk diameter in PB+ WC+PMS, others equal or more; ht: same for maple; equal or less for ash and maple;	2 seasons	Chong and Lumis, 2000
3 SMCs: 0, 25, 50, 75, 100%	100%: 8.1-8.3	100%: 16-26; 100% 1[st] leaching 3.4-4.7	65-67; 56-66; 62-69	11-17; 12-26; 13-20	marigold	highest fresh and dry wt at SMC percentages of 25 to 75%; significant effect of the source of SMC	7 trials in 2.5yr	Young et al., 2002
raw PMS sludge/ 4 composts 20, 40, 60%	all: 7.3-8.2; PB: 6.0	0.31-0.36; 0.34-0.37; 0.46-0.99; 0.85-1.72; 0.39-0.86	WRC[b]: 16-22; 21-25; 21-26; 16-19; 10-18	25-27; 21-23; 21-23; 25-30; 23-50	silverleaf dogwood, forsythia, weigela	more, equal, or less in aboveground dry wt according to species and composts	5mo.	Chong and Purvis, 2004
river waste: 50, 100%	5.2, 5.0	0.71, 71.5	20, 64	17.33, 22.80	19 herbaceous perennials	equal or higher dry wt accumulation in about half species in 50% than in control	n/a	Di Benedetto et al., 2004

[a] All substrate chemical and physical properties were measurements of initial conditions.

[b] EC: electrical conductivity; WHC: water holding capacity; ht: height; wt: weight; SMC: spent mushroom compost; PMS: paper mill sludge; WC: wood chip; PB: pine bark; WRC: water retention capacity

[c] Compost or co-compost as the percentage of substrate in volume.

II. ESTIMATION OF U.S. BARK GENERATION AND IMPLICATIONS TO THE HORTICULTURAL INDUSTRIES

Abstract

The historical, current, and projected supply of bark was evaluated. Since the 1980's more than 95 percent of the U.S. bark supply has been utilized in some way. Industrial fuel consumes the largest share of the market for bark, absorbing about 83 percent of softwood bark and 66 to 71 percent of hardwood bark. Current market share of bark for horticulture use (categorized in the miscellaneous group), is about 15 percent of softwood bark supply and about 30 percent of hardwood bark supply. In recent years, domestic timber harvest has been relatively stable or has slightly decreased. During the same time period, there has been an increasing demand for bark as an energy resource. Based on historical data, linear models were fitted between U.S. timber harvest and bark generation at the regional level. With those fitted models, projected bark generation was estimated based on the timber harvest data of the fifth Renewable Resources Planning Act (RPA) timber assessment. It is estimated that only a minor increase in the long term bark output will occur. For softwood bark which has the greatest demand, projected supply will be below the level of 2001 until about 2020. With expected horticulture industry growth, increased value of bark as a readily available energy source for wood processing mills, and a shift in pulp generation from domestic paper mills to international sources, the total amount and share of bark to the horticulture market will likely decrease.

Index words: wood residue; substrate; mulch; compost; softwood.

Significance to the Nursery Industry

The concern over the availability of bark for horticultural use is not merely speculative. In the nursery industry, bark has been considered a resource instead of a waste since the 1970's. In recent years, with the continuous rise in energy prices, demand for bark as a clean fuel resource continues to increase. This increased demand for bark has coincided 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 declining. Furthermore, regional shortages due to the closing of forest product mills will exacerbate the potential bark shortage. This analysis indicates that the demand for alternative substrates will continue to gain momentum in the near future.

Introduction

Bark, especially softwood bark, is widely used in horticulture as the primary component in most nursery and greenhouse substrates. In the eastern U.S., pine bark often comprises as much as 75 to 100 percent (by volume) of container substrates. In the western U.S., barks of Douglas fir, redwood, and western red cedar are widely used. In addition, softwood bark is one of the most commonly used landscape mulches in the U.S.

However, there is a rising concern that the availability of bark for use in the nursery, greenhouse, and landscape industries will be limited in some markets due to alternative demands (e.g. industrial fuel), reduced timber production, and closing or relocation of primary timber processing mills to other regions or abroad (Cole et al., 2002; Haynes, 2003; Penick, 1980). In the late 1970's, the horticultural industry began to realize the pressure of limited bark supplies as bark for fuel began to gain momentum in response to the energy crisis and other factors (Penick, 1980). In recent years, rising energy prices has led to decreased bark availability because of the roles of price in two directions: higher energy prices makes bark more attractive as an economical fuel (Saeman, 1975); and, bark transported out of its generation location becomes more expensive. Furthermore, the relocation of primary timber processing mills to other regions or abroad further constricts bark supplies within some regions.

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. Bark disposal is further analyzed, with emphasis on horticultural usage. Bark supply is assessed up to 2050 based on the projection of the future timber situation in the U.S. Our focus is on the handling of the large quantity of bark as a by-product, residue or waste of the forest industry.

Bark utilization market Bark is a by-product of the forest industry products sector, obtained when peeling trunks of trees. Bark can make up 6 to 22 percent of the bulk of the trunk (Vaucher, 2003). As the economic value of bark has been both quantitatively and qualitatively much less than that of wood, it was considered as a worthless waste product to the forest industry for many years. Often bark was given away for free or at a minimal price. As a main product, on a small scale, bark is harvested for a variety of special purposes such as tannins and dyes, spices and incense, medicine or phytotherapy, cork, and construction material, etc. (Vaucher, 2003). Beneficial uses of bark relative to agriculture such as soil amendments and animal bedding have been known.

With the rapid economic development after World War II, bark developed into a profitable segment known as the "horticulture bark industry" (4) and was used mostly for landscaping. In the meantime, bark was tested extensively in many agricultural labs and research stations as a component of container substrates with the development of container production in ornamental horticulture demanding large quantities of soilless "media" or substrates (Joiner and Conover, 1967; Pokorny, 1979; Self et al., 1967).

In the process of bark gaining the status of the "standard" component of container substrates, the forest industry itself looked for various methods for better utilization of bark and wood residues other than burning and dumping into landfills. Bark is primarily used as industrial fuel. Due to the energy crisis of the 1970's and environmental restrictions research focused on bark and wood residues as energy resources (Penick, 1980; Saeman, 1975).

The Clean Air Act Amendments of 1970 and other environmental regulations and policies since then have shaped the methods by which the forest products industry has made its products and generated and consumed energy (Bowyer et al., 2003; Mayes, 2003). Ingram et al. (1993) reported that during the late 1960's about 20 percent of Florida's sawmills and most of the pulpmills utilized pine bark for fuel but that by the 1990's almost all operations generating large quantities of pine bark utilized at least part of it for fuel. The result is that the forest products industry now generates about 50% of its own energy needs by making use of its wood residues and byproducts. The forest products industry consumes about 14% of domestic manufacturing energy use, making it the third largest industrial consumer of energy, behind only petroleum and chemicals (Energy Information Administration, 2002). Besides its use in horticulture, bark has only minor usages in other areas, including fiber, building insulation, animal bedding, absorption and filtering, and chemical feedstocks (Bowyer et al., 2003; Vaucher, 2003).

Factors affecting bark production Bark production is affected by many factors, which range from the influence of the tree itself; to the structure of harvested timbers; to those factors such as harvest technology and methods, regional trade, and long-term macroeconomic activity. Accurate measurement of bark production is the basis for any further estimation of bark volume and quantity. For a single tree, the bark volume relative to wood is calculated by stem diameter and bark thickness. Those two factors are mainly decided by species, age, height in a stem, and silviculture management (Bowyer et al., 2003). Regression equations between bark thickness and diameter have been formed for many species. Because most bark contains numerous fissures and voids, bark volume percentages should be adjusted downward to allow for this factor. Unfortunately, void volumes have been calculated for relatively few species and thus estimation of this factor may be necessary (Bowyer et al., 2003). Silvicultural practices such as fertilizing, weeding, and thinning can affect the volume of bark relative to wood, although quantification of this effect largely remains to be done.

Debarking technology has a direct effect on how much bark is peeled from the log. Sawmills use either ring debarkers or Rosserhead debarkers, while most wood-panel and pulp and paper mills debark their roundwood in drum debarkers. Debarking is never totally effective and different end products have different tolerances to the amount of unremoved bark. For example, a requirement in most pulping processes is generally no bark, while larger quantities of bark can be incorporated deliberately into the central layer of a three-layered particleboard (Walker et al., 1993). The result is that primary wood processors can generate different volumes of bark from exactly the same feedstock if there are different debarking methods and end product structures.

Besides the mainstream central debarking, logs are debarked at the harvest site in certain situations. In such cases, the bark is discarded back to the forest land and no bark byproduct is generated.

From the regional level, trade of wood products can shift the balance of bark generation. Some logs are traded with bark on and this results in different locations of wood harvest and bark generation. Other forest products, such as chips, debarked roundwood and sawmill slabs, are traded without debarking. The result is a mixture of self- or local-supplied feedstock and outside-supplied feedstock with or without bark for some primary wood processors.

Over time, the demand side of the forest products market guides the direction of products structure. The demand is largely based on dynamics of macroeconomic activity and population. In the long term, species structure, management intensity, rotation of plantation stand, harvest technology and methods can be gradually shifted or fluctuated. The consequence is that the generation of bark will be subtly affected.

Materials and Methods

Data collection and statistics Statistical data of forest resources, timber product output and use, forest products market, and wood and wood waste as energy resources are reported and updated frequently by both state- and federal-level agencies. As for natural resources, the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) requires the Secretary of Agriculture to conduct an assessment of the Nation's renewable resources every 10 years (Haynes, 2003; Smith et al., 2003). The national RPA timber assessment has been conducted five times with the latest report as a technical document supporting the 2000 USDA Forest Service RPA Assessment. This report analyzed historical timber removals, harvest, growth, and inventory data in the U.S. as well as a bioeconomic modeling framework for the timber projections up to 2050 (Haynes, 2003). This framework has evolved over more than two decades and by far provides the most reliable projection on future timber situation. However, this report has not included any projection component on wood waste production. Consequently, the future generation of bark can only be estimated based on historical correlations.

We collected historical data of bark generation as a base for the analysis of the correlation between bark production and timber harvest. Beginning from 1986, bark generation and its utilization were reported every five years at regional level for the following seven regions: Northeast, North Central, Southeast, South Central, Pacific Northwest, Pacific Southwest, and Rocky Mountain (Powell et al., 1993; Smith et al., 2001, 2003; Waddell et al., 1987) indicating that the value of bark can no longer be ignored. However, while timber products output and use are reported to the county level with detailed species groups through a 100-percent canvass of all primary wood processing mills in a state, bark and other residue (shavings, sawdust, coarse residue) are reported as a total number of the whole state. Thus, currently there is no data available to analyze the relation between bark generation and single tree species and only regional level relationships can be evaluated. The use of bark is currently reported as fiber, fuelwood, miscellaneous, and not used. Fiber is incorporated into such products as particleboard. Fuelwood is believed to be used as industrial fuel onsite, with other kinds of fuel negligible. Miscellaneous is an ambiguous word and this could include any use of bark other than fuel and fiber. While no further details are available for this grouping our assessment is that this grouping is mainly directed to various horticultural uses.

We included the bark data of 1986, 1991, 1996, and 2001 for the analysis. Linear relations between timber harvest and corresponding bark generation were developed at the regional level for softwood and hardwood, respectively. Simple linear models were developed with the timber harvest as an independent variable, and bark generation as the dependent variable:

$$Y_i = \beta_1 X_i + \varepsilon_i$$

Where: Y_i is the historical, regional bark generation, in unit of thousand dry tons; β_1 is a parameter (the slope); X_i is the historical, regional timber production, in unit of million cubic feet; ε_i is a random error term with independent $N(0, \sigma^2)$.

The intercept of the simple linear regression model has no meaning as bark is a timber byproduct; therefore the correlation was regressed through the origin (with no β_1 term). The analysis was conducted using SAS (SAS 9.1, 2003, Cary, NC). The developed models were used to calculate future bark generation for different regions by using the projected timber harvest (Haynes, 2003) for the independent variable X_i.

Results and Discussion

Analysis of historical forest products data indicated that between 1952 and 2002, total area of U.S. timberland decreased 1 percent, from 509 to 504 million acres (Powell et al., 1993; Smith et al., 2001, 2003; Waddel et al., 1987; Table 1). Over the next 50 years, a projected U.S. population increase of 126 million will result in a projected net loss of U.S. timberland area of about 15 million acres, or a loss of about 3 percent between 1997 and 2050 (4; Table 1). Between 1991 and 2001, U.S. timber harvest declined 2206 million cubic feet (mcf), or 12 percent, from 17889 to 15683 mcf (Table 2). Only the Southern Region experienced an increase in timber harvest during this period (6 percent). It is projected that total timber harvest will increase from 17889 mcf in 1991 to 23067 mcf by 2050, or a 29 percent increase.

Overall, 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 (Haynes, 2003; Smith et al., 2001, 2003; Table 2). It is worth noting that the projected softwood harvest of 2020 (11021 mcf) is still below the level of 1986 (11345 mcf). Softwood bark generation in the Southeast was steady from 1986 through 1996 (Table 3), but dropped about 40% by 2001. Transportation cost is a major limitation in bark distribution and can have a significant impact on bark availability out of a local area. Similar trends occurred in the Pacific Northwest and Southwest.

Overall, the bark utilization rate increased from about 95% for 1986 to more than 97% for 1996 and 2001 (Fig. 1). For both softwood and hardwood bark, the largest share was fuelwood. Except a slight dip in 1991, about 82 to 83 percent of total softwood bark was used as fuelwood. The next group was miscellaneous, a category that stabilized at about 15% in recent years. Hardwood had a relatively lower fuelwood usage and higher rate of miscellaneous. Bark used as fiber has remained at a very low level (Fig. 1). The Southeast and South Central subregions continue to produce the largest amount of bark, followed by Pacific Northwest (Table 3). It has to be noted that these bark data were obtained through canvass of primary wood-using mills according to USDA Forest Service Forest Inventory and Analysis. Therefore, the accuracy of these data is limited by the canvass responses, which themselves are often estimated by mills.

Linear regression models were fitted for softwood and hardwood harvest and bark generation for seven subregions (Table 4). Only Northeast softwood bark and Pacific Southwest hardwood bark had no significant linear relation with their timber harvest; there is a weak linear relation for Northeast hardwood bark and timber harvest (R^2=0.732, P=0.065). Examination of the data indicates that the Northeast had abnormally higher hardwood and softwood bark weights in 1991 compared with the consequent timber harvests. While the Northeast had similar softwood timber harvests for each year (678, 651, 545, and 545 mcf for 1986, 1991, 1996, and 2001, respectively), the corresponding softwood bark weight was 212, 1667, 247, and 246 thousand dry tons. The same is true with the hardwood bark. However, the accuracy of these high numbers of bark in 1991 for the Northeast subregion is difficult to verify. The reported low hardwood bark quantities in the Pacific Southwest (Table 3) is largely because fuelwood was the only major type of roundwood harvested in this area (there is no bark generated as byproduct for fuelwood production). Different slopes of Table 4 also indicate regional and subregional differences in bark generation due to various factors as described earlier.

With the above variance and contributing factors in consideration, we fitted parameters to predict future bark generation based on the timber harvest provided by Haynes (2003) for four regions (North, South, Pacific Coast, and Rocky Mountains) from 2010 to 2050. It is projected that the total bark output of 2050 will be 32,644 thousand dry tons, with softwood bark at 20,236 thousand dry tons and hardwood bark at 12,408 thousand dry tons (Table 5). Compared with 1996, total bark residue will increase 33 percent (0.5 percent annually). Softwood and hardwood bark residue will increase 28 and 43 percent, respectively (0.5 and 0.7 percent increase annually, respectively). Softwood bark harvest will be above the level of 1996 (Table 2) until about 2020.

Several important implications can be made from this analysis and projection of bark generation. First, most bark is used by the timber industry as fuelwood. Secondly, with the predicted slow increase in timber harvest, overall bark generation will have a modest increase over the next fifty years. Thirdly, major variations exist among regions and subregions for the bark generation rate as reflected in Table 4 and Table 5. While the overall market will reflect the national bark generation trend, the availability of bark for the horticulture industry is expected to be greatly affected by local wood industry production structures and development. Costs of available bark is expected to increase in response to increasing freight costs and increased demand. Finally, as an overall trend, there will be less availability and affordability of bark for the horticulture industry with current and predicted economic conditions.

Literature Cited

Bowyer, J.L., R. Shmulsky, and J.G. Haygreen. 2003. Forest Products and Wood Science: an Introduction, 4th edition. Iowa State Press, Ames, IO.

Cole, D.M, J.L. Sibley, E.K. Blythe, D.J. Eakes, and K.M. Tilt. 2002. Evaluation of cotton gin compost as a horticultural substrate. Proc. SNA Res. Con. 47:274-277.

Energy Information Administration. 2002. Manufacturing Energy Consumption Survey 2002. Publication by Energy Information Administration, U.S. Department of Energy, last accessed on April 11, 2005 through http://www.eia.doe.gov/emeu/mecs/contents.html.

Haynes, R.W., tech. coord. 2003. An analysis of the timber situation in the United States: 1952-2050. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-560, pp. 254.

Ingram, D.L., R.W. Henley, and T.H. Yeager. 1993. Growth media for container grown ornamental plants. Florida Cooperative Extension Service, IFAS, University of Florida, Bul. 241, pp. 16.

Joiner, J.N. and C.A. Conover. 1967. Comparative properties of shredded pine bark and peat as soil amendments for container-grown Pittosporum at different nutrient levels. Proc. Amer. Soc. Hort. Sci. 90: 447-453.

Mayes, F. 2003. A view of the forest products industry from a wood energy perspective. Last accessed on April, 2008 through http://www.eia.doe.gov/cneaf/solar.renewables/at_a_glance/wood/contents.htm.

Penick, E.B., Jr. 1980. Future of the horticultural bark industry in the United States. p. 2-3. *In* R.C. Allison (editor). Organic and Fuel Uses for Bark and Wood Residues. Proceedings No. P-80-27, Forest Products Research Society, Madison, WI.

Pokorny, F.A. 1979. Pine bark container media – an overview. Proc. Plant Prop. Soc. 29: 484-495.

Powell, D.S., J.L. Faulkner, D.R. Darr, Z. Zhu, and D.W. McCleery. 1993. Forest Resources of the United States, 1992. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Gen. Tech. Rep. RM-234, pp. 132 [Revised, June 1994].

Saeman, J.F. (Editor). 1975. Wood Residue as an Energy Source. Proceedings No. P-75-13, Forest Products Research Society, Madison, WI.

Self, R.L., J.I. Wear, R.D. Rouse, and H.P. Orr. 1967. Potting mixtures and fertilization practices for container grown ornamental plants. Ala. Agr. Expt. St. Cir. 157, pp. 10.

Smith, W. B., J.S. Vissage, D.R. Darr, and R.M. Sheffield. 2001. Forest Resources of the United States, 1997. USDA Forest Service, North Central Research Station, Gen. Tech. Rep. NC-219, pp. 190.

Smith, W. B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2003. Forest Resources of the United States, 2002. USDA Forest Service, North Central Research Station, Gen. Tech. Rep. NC-241, pp. 137.

Vaucher, H., translated and edited by J.E. Eckenwalder. 2003. Tree bark: a Color Guide. Timber Press, Inc., Portland, OR.

Waddell, K.L., D.D. Oswald, and D.S. Powell. 1987. Forest statistics of the United States. USDA Forest Service, Pacific Northwest Research Station, Resour. Bull. PNW-RB-168, pp.106.

Walker, J.C.F., B.G. Butterfiled, T.A.G. Langrish, J.M. Harris, and J.M. Uprichard. 1993. Primary Wood Processing: Principles and Practice. Chapman & Hall, London, UK.

Table 1. Area of timberland in the U.S. by region, 1952-97 with projections to 2050[z] (*million acres*).

Region	Historical						Projections				
	1952	1962	1977	1987	1997	2002	2010	2020	2030	2040	2050
North	154.3	156.6	153.4	154.4	159.4	158.7	159.4	157.9	155.6	153.1	151.0
South	204.5	208.7	199.6	197.3	201.1	202.7	200.3	199.6	199.3	198.6	197.8
Rocky Mountains	66.6	66.9	60.2	61.1	71.0	70.6	71.4	71.3	71.2	71.0	70.9
Pacific Coast	83.4	82.9	79.1	73.5	72.2	71.5	71.0	70.3	69.9	69.6	69.3
Total[y]	508.9	515.1	492.4	486.3	503.8	503.5	502.1	499.2	496.0	492.2	489.0

[z] Data were compiled from Haynes (2003), Powell et al. (1993), Smith et al. (2001), Smith et al. (2003), and Waddell et al. (1987).

[y] Data may not add to totals because of rounding.

Table 2. Softwood and hardwood timber harvest in the U.S. by region, 1952-2001 with projection to 2050[z] (*million cubic feet*).

Region	Species	Historical					Projections				
		1952	1986	1991	1996	2001	2010	2020	2030	2040	2050
North	Softwood	596	901	907	816	787	817	786	790	806	818
	Hardwood	1381	3178	3233	2693	2559	3070	3341	3639	3869	4113
	All[y]	1977	4079	4140	3509	3346	3887	4127	4429	4675	4931
South	Softwood	3036	5302	5505	6155	6234	5703	6743	7722	8299	8954
	Hardwood	1933	2777	3108	3438	2863	4588	4700	4700	4684	4650
	All	4969	8079	8613	9593	9097	10291	11443	12422	12983	13604
Rocky Mountains	Softwood	497	853	845	594	565	781	825	864	902	912
	Hardwood	10	95	93	94	69	92	98	103	110	113
	All	507	948	938	688	634	873	923	967	1012	1025
Pacific Coast	Softwood	3393	4289	3924	2472	2434	2548	2667	2633	2811	2991
	Hardwood	37	197	274	170	172	525	491	460	436	425
	All	3430	4486	4198	2642	2606	3073	3158	3093	3247	3416
U.S.	Softwood	7522	11345	11181	10036	10020	9848	11021	12009	12818	13674
	Hardwood	3361	6248	6708	6395	5662	8346	8707	8985	9188	9393
	All	10883	17593	17889	16430	15683	18194	19728	20994	22006	23067

[z] Data were compiled from Haynes (2003), Powell et al. (1993), Smith et al. (2001), Smith et al. (2003), and Waddell et al. (1987).

[y] Data may not add to totals because of rounding.

Table 3. Bark generation by species type from 1986 to 2001 in seven subregions of the U.S.[z] (*thousand dry tons*).

Region	Bark type	1986	1991	1996	2001
Northeast	Softwood	212	1667	247	246
	Hardwood	402	2520	942	941
	Total[y]	614	4187	1189	1189
North Central	Softwood	394	336	466	417
	Hardwood	1919	2238	2329	2335
	Total	2313	2574	2795	2752
Southeast	Softwood	4174	4092	4567	2552
	Hardwood	1800	1687	2012	1324
	Total	5974	5779	6579	3876
South Central	Softwood	3864	6027	5452	5585
	Hardwood	2333	3715	3157	2991
	Total	6197	9742	8609	8576
Rocky Mountains	Softwood	1297	1393	1521	1402
	Hardwood	30	30	22	3
	Total	1327	1423	1544	1405
Pacific Northwest	Softwood	4217	3501	2624	2620
	Hardwood	99	100	198	199
	Total	4316	3601	2822	2819
Pacific Southwest	Softwood	1418	1395	991	991
	Hardwood	0	13	1	1
	Total	1418	1408	992	992
U.S.	Softwood	15576	18411	15868	13813
	Hardwood	6583	10303	8661	7794
	Total	22159	28714	24530	21609

[z] Data were compiled from Powell et al. (1993), Smith et al. (2001), Smith et al. (2003), and Waddell et al. (1987).

[y] Data may not add to totals because of rounding.

Table 4. Fitted linear model[z] between bark generation and timber harvest in seven subregions of the U.S. [y]

Region	Type	Parameter (slope)	R^2	Two-sided P-value
Northeast	hardwood	0.89	0.732	0.0646
	softwood	1.01	0.516	0.1719
North Central	hardwood	1.42	0.976	0.0016
	softwood	1.62	0.987	0.0006
Southeast	hardwood	1.38	0.992	0.0003
	softwood	1.44	0.956	0.004
South Central	hardwood	1.69	0.984	0.0008
	softwood	1.67	0.983	0.0009
Rocky Mountains	hardwood	0.25	0.875	0.0194
	softwood	1.88	0.948	0.0051
Pacific Northwest	hardwood	0.99	0.782	0.0465
	softwood	1.29	0.994	0.0002
Pacific Southwest	hardwood	0.07	0.494	0.1853
	softwood	1.52	0.996	0.0001

[z] Analysis by linear regression through the origin (intercept set to be zero).

[y] Linear models were developed based on bark generation and timber harvest data compiled from Powell et al. (1993), Smith et al. (2001), Smith et al. (2003), and Waddell et al. (1987); (see also Table 2 and Table 3 of this paper).

Table 5. Projection of bark generation by region and species type from 2010 to 2050[z] (*thousand dry tons*).

Region	Species	2010	2020	2030	2040	2050
North	Softwood	515	495	498	508	515
	Hardwood	3408	3709	4039	4295	4565
	Total[y]	3922	4204	4537	4802	5081
South	Softwood	8954	10587	12124	13029	14058
	Hardwood	7295	7473	7473	7448	7394
	Total	16249	18060	19597	20477	21451
Rocky Mountains	Softwood	1468	1551	1624	1696	1715
	Hardwood	23	25	26	28	28
	Total	1491	1576	1650	1723	1743
Pacific Coast	Softwood	3363	3520	3476	3711	3948
	Hardwood	520	486	455	432	421
	Total	3883	4007	3931	4142	4369
U.S.	Softwood	14300	16153	17721	18943	20236
	Hardwood	11245	11692	11993	12201	12408
	Total	25545	27845	29715	31145	32644

[z] Projection based on combination of parameters developed from linear regression models presented in Table 4 and projection data by Haynes (2003).

[y] Data may not add to totals because of rounding.

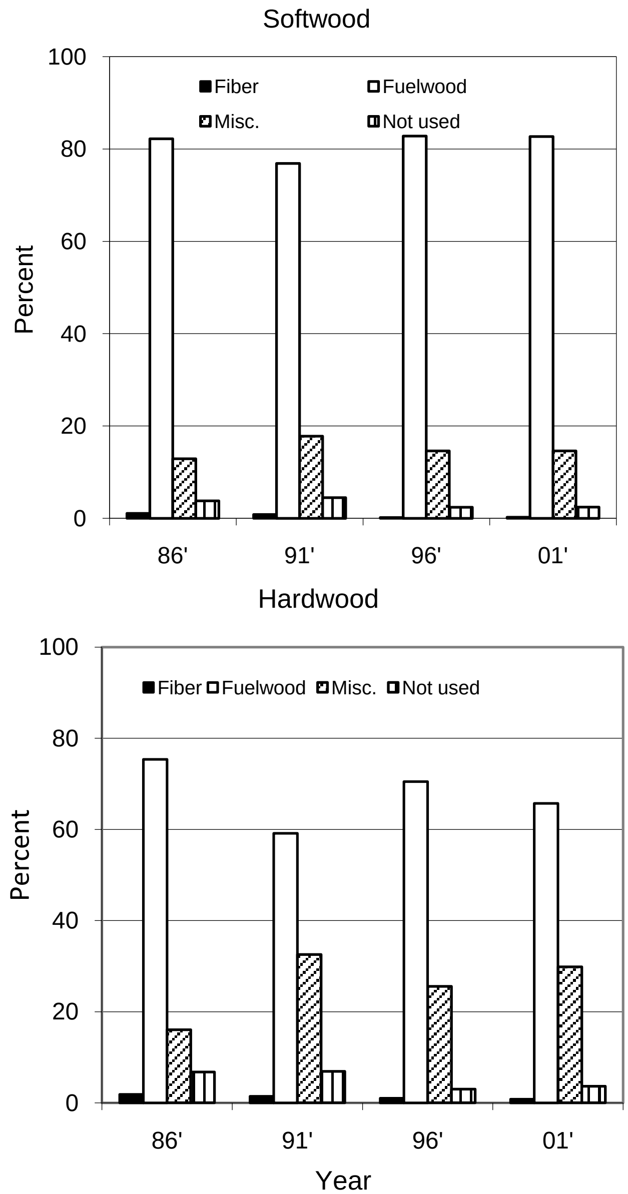

Figure 1. Historical usage of bark from 1986 to 2001 in the U.S. Data compiled from different sources (Powell et al., 1993, Smith et al., 2001, Smith et al., 2003, Waddell et al., 1987) were used to construct this figure.

III. EVALUATION OF MIXED MUNICIPAL SOLID WASTE COMPOST AS PINE BARK AMENDMENT IN CONTAINER NURSERY PLANT PRODUCTION

ADDITIONAL INDEX WORDS. azalea, compacta holly, *Nandina domestica*, dwarf yaupon holly, *Ternstroemia gymnanthera*, common flowering quince, common sweetshrub, Indian hawthorn, wax leaf ligustrum

Abstract

Compost derived from mixed municipal solid waste (MSW) was evaluated as a substitute to the commonly used pine bark (PB) for container substrate to grow ornamental crops. A total of eleven woody ornamentals were grown in three locations in either 2003 to 2004 or 2005 to 2006 in outdoor container nursery settings with overhead irrigation. Addition of the MSW compost (MSWC) generally increased substrate water holding capacity, while air space was still within acceptable ranges. Initially, high soluble salt levels in leachates were detected; however, leaching effectively reduced soluble salt levels in a very short period (10 to 20 days). As expected, plant growth responded differently to substrates containing MSWC. Nandina in 100% MSWC in the 2003-2004 Auburn University experiment grew equally to plants in non-amended pine bark-based substrates. In the meantime, most plants had similar growth in substrates with up to 75% MSWC and no species had less growth in 50 or 25% MSWC than in the standard pine bark control. In

the 2003-2004 experiment at Greene Hill Nursery, Waverly, AL, growth of common flowering quince and common sweetshrub was increased in substrate with 25% MSWC. Based on results of this study, the evaluated MSWC can safely replace up to about half of pine bark without detrimental effects on growth of container-grown ornamentals.

Pine bark (PB) is widely used in horticulture as a component in nursery and greenhouse substrates. In the southeast U.S., pine bark has been a dominant material used in container growing mixtures for several decades. Pine bark is lightweight, resistant to decomposition, with particle size distribution easy to manipulate through hammer-milling and sieving, and is generally lacking phytotoxicity. Pine bark has satisfactory cation exchange and water holding capacities for container-grown plants (Poole et al., 1981) and yet maintains adequate pore space even when receiving excessive water after heavy rain events. Historically, pine bark has been readily available at comparatively low prices as a by-product of the huge harvest of southern pines, in which the southern U.S. accounts for about 60% of the nation’s harvest (Haynes, 2003). However, the availability of inexpensive bark to nursery, greenhouse and landscape industries is a rising concern due to alternative demands (e.g. industrial fuel), reduced timber production, and closing or relocation of primary timber processing mills to other regions or abroad (Lu et al., 2006). Based on timber harvest projection for the next 50 years (Haynes, 2003), the decline of total amount and share of bark to the horticulture market is a long-term trend. Alternatives to pine bark as major substrate components are needed.

An attractive substrate alternative is compost derived from municipal solid waste (MSW), commonly known as household garbage or trash (Hicklenton et al., 2001; Kahtz and Gawel, 2004; Ribeiro et al., 2000). Approximately two thirds of MSW in the U.S. is organic matter, and composting is regarded as an effective means to turn MSW that would otherwise be sent to landfills or incinerators into valuable resources (U.S. E.P.A., 2003). From the aspect of compost utilization in container ornamental crop production, MSW is always available and practically unlimited, as every community generates trash continuously year around and every person in the U.S., on average, produces more than 1,600 pounds of trash each year (U.S. E.P.A., 2003).

Compost of MSW or co-compost of MSW with other materials has been tested as a substrate component for ornamental plant production in both greenhouse and outdoor container nursery conditions with mixed results (Chen et al., 2003; Hicklenton et al., 2001; Klock and Fitzpatrick, 1997; Ribeiro et al., 2000). Among many factors contributing to the various plant growth responses, variations from compost itself, different cultural conditions, and plant species are most obvious. While composting of source-separated MSW generally produces a more uniform product with less undesirable materials, such as metals, glass, or rubber, composting of mixed MSW requires no efforts from individual households and therefore is more economical and easier to implement.

This paper reports outdoor container study results from a larger research project on replacement of pine bark in container substrate with compost from mixed MSW on a variety of ornamental crops in different locations in the southeast U.S. The overall objective was to evaluate the utilization of mixed MSWC as a soilless container potting component in outdoor ornamental crop production. Plant growth, and substrate chemical and physical properties were compared with those of a standard pine bark based substrate.

Materials and Methods

The MSWC evaluated in all experiments reported in this paper was derived from mixed household wastes without any presorting (WastAway Services, LLC, McMinnville, TN). After being processed by a system of grinders, shredders and pressurized heat, the material was further composted with an indoor, turned windrow method. Before mixing, the compost was sifted through a 1 in. screen to remove any large particles.

Experiment 1

This experiment was conducted on an outdoor container pad in the Paterson Greenhouse Complex, Auburn University, AL (32° 36'N × 85° 29'W, USDA Hardiness Zone 8a). In late September of 2003, five substrate blends were mixed (by vol.) 6 pine bark (PB) : 1 sand (S), 6 municipal solid waste compost (MSWC) : 1 S, 4.5 MSWC : 1.5 PB : 1 S, 3 MSWC : 3 PB: 1 S, and 1.5 MSWC : 4.5 PB: 1 S. The conventional 6 PB : 1 S container substrate blend served as the control. Each substrate blend was amended with 11 $lbs{\cdot}yd^{-3}$ Osmocote 18-6-12 (18N-2.6P-10K; The Scotts Company, Marysville, OH), 1.5 $lbs{\cdot}yd^{-3}$ Micromax (The Scotts Company, Marysville, OH), and 5 $lbs{\cdot}yd^{-3}$ dolomitic limestone. Three ornamental species used in this experiment were: azalea (*Rhododendron indica* 'Renee Mitchell'), compacta holly (*Ilex crenata* 'Compacta'), and *Nandina domestica* 'Atropurpurea Nana'. For each species, 45 plants were transplanted from 3.8-L (1-gallon) containers into 11.4-L (3-gallon) containers and randomly assigned to five substrate blends. Plants were arranged using a randomized complete block design with three blocks. Each block had a total of 45 plants, as 15 plants were from each species, which represented three subsamples of each substrate and species combination within a block. Plants were supplemented with two daily cycles of overhead irrigation totaling 0.5 in. of water.

Physical properties of three representative samples from each of five substrate blends were determined using the North Carolina State University Porometer (NCSU-P, Fonteno et al, 1981). The four physical properties determined by NCSU-P method were: air space (AS), water holding capacity (WHC), total porosity (TP), and bulk density (BD).

Similarly, initial leachates were collected from three representative samples for each of five substrate blends using the nondestructive Virginia Tech Extraction Method (Yeager et al., 2007). Leachates were then analyzed for pH and electrical conductivity (EC) using a Model 63 pH and conductivity meter (YSI Incorporated, Yellow Springs, OH). After the initial leachate analysis, leachates were collected for determination of pH and EC one week after transplant (WAT), two WAT, and thereafter every four weeks from one randomly selected block. Final leachates were collected in June, 2004.

Plant growth was measured using growth index (GI), which was calculated as the average of plant height, widest plant width, and plant width perpendicular to widest width. The initial GI was determined at potting; and then every two months for each plant in all blocks. Final measurements were made in June 2004.

Experiment 2

This experiment was conducted at the Center for Applied Nursery Research (CANR), Dearing, GA (33° 22'N × 82° 24'W, USDA Hardiness Zone 8a).

Similar to Experiment 1, five substrate blends were prepared by using the same MSWC to replace 0 to 100% (by vol.) pine bark of a standard pine bark based substrate.

Five substrate blends were mixed (by vol.) 6 pine bark (PB) : 1 sand (S), 6 municipal solid waste compost (MSWC) : 1 S, 4.5 MSWC : 1.5 PB : 1 S, 3 MSWC : 3 PB: 1 S, and 1.5 MSWC : 4.5 PB: 1 S. The conventional 6 PB : 1 S container substrate blend served as the control. Nutricote 18-6-8 (18N-2.6P-6.6K) type 270 controlled-release fertilizer including micronutrients (Chisso-Asahi Fertilizer Co. Ltd., Tokyo, Japan) was incorporated into each substrate blend at a rate of 12.5 $lbs \cdot yd^{-3}$. Three species used in this experiment were: ‘Pink Ruffle’ azalea (*Rhododendron* × ‘Pink Ruffle’), dwarf yaupon holly (*Ilex vomitoria* ‘Nana’), and *Ternstroemia gymnanthera*. For each species, a total of 75 plants were randomly assigned to five substrates; therefore, there were 15 replications for each combination of substrate and species. All plants were transplanted from 3.8-L (1-gallon) containers into 11.4-L (3-gallon) containers in Mar. 2004. Plants were arranged using a completely randomized design in an outdoor container pad at the research facility of CANR.

After one growing season under standard commercial nursery production, plant GI was determined using the same method as in Experiment 1. At the end of the experiment, leaf tissues were collected for plant tissue analysis. One compound sample was collected from 10 to 30 full mature leaves from different plants for each blend and species combination. Tissue analysis was conducted by the Auburn University Soil Testing Lab.

Experiment 3

This experiment was conducted at Greene Hill Nursery, Waverly, AL (33°45'N × 85°30'W, USDA Hardiness Zone 8a).

In this experiment, 25% of the PB in a standard pine bark-based container potting mixture was replaced by MSWC and compared to a non-amended substrate of 6 PB : 1 S. Three species were used to evaluate the substrates: common flowering quince (*Chaenomeles speciosa* ‘Cameo’), common sweetshrub (*Calycanthus floridus*), and Indian hawthorn (*Rhaphiolepis* ‘Snow White’). Each substrate blend was amended with 12 $lbs \cdot yd^{-3}$ Osmocote 19-6-12 (19N-2.6P-10K) and 5 $lbs \cdot yd^{-3}$ dolomitic limestone.

Plants were potted in Sept. 2003 from 3.8-L (1-gallon) containers to 11.4-L (3-gallon) and grown on a container pad with standard commercial nursery production practices. After one growing season GI was determined for all three species using the method described in Experiment 1.

Experiment 4

This experiment was conducted in the same location of Experiment 2, i.e. CANR, Dearing, GA following the same experimental procedures.

Five substrate blends were prepared using MSWC to replace 0, 25, 50, 75, and 100% of pine bark in a standard pine bark-based container potting mixture. Four species used in this study were: Gumpo azalea (*Rhododendron* × ‘Pink Gumpo’), compacta holly, *Ternstroemia gymnanthera*, and wax leaf ligustrum (*Ligustrum japonicum*). With the same experimental design as in Experiment 1, a total of 75 plants for each species were randomly assigned to five substrates and plants were arranged using a completely randomized design. All plants were potted in Sept. 2005 from 3.8-L (1-gallon) containers to 11.4-L (3-gallon) plastic containers.

Starting in Jan. 2006, container leachates were collected monthly using the Virginia Tech Extraction Method and analyzed for pH and EC values until September, 2006. The study was concluded after one year and plant GI was determined in September, 2006. Data were analyzed according to experimental designs for each experiment. Any statistical test with $P \leq 0.05$ was considered significant and reported as such where appropriate. Multiple comparisons between means (mean separation) were conducted using Tukey's studentized range test (HSD). All statistical analyses were conducted using SAS for Windows v.9.1 (SAS Institute Inc., Cary, NC).

Results and Discussion

Experiment 1

Physical properties of substrates containing MSWC were generally within recommended ranges (Table 1; Yeager, et al., 2007). Total porosity (TP, the sum of WHC and AS) was in a narrow range of 67% in 6 MSWC : 1 S to 78% in 6 PB : 1 S, compared with the suggested range of 50 to 85% in a best management practice guide by Yeager et al. (2007). Substrate WHC was increased from 38% in the control to 39, 44, 48, and 49%, respectively when 25 to 100% of PB was replaced by MSWC. While the WHC in the control blend was slightly lower than the recommended value (45%), such an increase in WHC was an improvement over the control. A similar study showed that a 6:1 PB:S blend had an initial WHC of 33%, but the final WHC of the same blend increased 44 to 49%, after 40 weeks with three ornamental species (Jackson et al., 2005). Similar results occurred with this study as PB breaks down continuously (although slowly) after potting due to both biological and abiotic factors, as the PB degrades, a higher proportion of smaller particle size components in the blend exist, resulting in higher WHC. Amendment with MSWC had the reverse effect as AS decreased after potting (Table 1). These results are similar to those of previous research (Jackson et al., 2005). One concern with the 6 MSWC : 1 S was its already low AS (18%) that could decrease below recommended levels (10%). The BDs observed in this study (Table 1) were high compared with results of other compost research (such as Chen et al., 2003). This is explained by the inclusion of sand in the substrate. A major benefit of sand in a substrate blend is to increase both water retention and bulk density. In this study, MSWC apparently had a similar effect to sand in increasing both AS and BD (Table 1). Therefore, when plant growth is not negatively affected by use of MSWC, sand can be partially or completely removed from the mixture. Overall, our studies indicate that amendment of traditional PB-based substrates with MSWC can improve a substrate's physical properties.

Leachate pH and EC were greatly affected by addition of MSWC (Table 2). The MSWC had a pH value of 7.86 (Table 3), which, as expected for most kinds of composts, was higher than neutral level. As a result, a pH greater than 7 occurred in all mixtures containing more MSWC than PB (Table 2) throughout the experiment. While pH was generally stable through the growing season, the initial high soluble salt concentrations declined within a few weeks, a trend noted in other outdoor container studies (Chong, 2005). In this experiment, initial EC values were greater than 2 $dS \cdot m^{-1}$ for mixtures containing more MSWC than PB. Two weeks after transplanting, all leachate EC values were within acceptable ranges, even for salt sensitive plants (Chong, 2002).

With few exceptions, plant growth was similar amongl substrate blends (Fig. 1). No growth differences (GI) existed early in the season for azalea or compacta holly. However, azalea in 4.5 MSWC : 1.5 PB : 1 S (Fig. 1A) and compacta holly in 6 MSWC :1 S (Fig. 1B) had a smaller GI compared to plants in 6 PB : 1 S. The initial plant size for dwarf nandina in 6 MSWC : 1 S blend was the smallest, but no differences existed in April, 2004 and GI were similar by the conclusion of the study (Fig. 1C).

Experiments 2-4

In Experiment 2, all plant species had a smaller GI in blends of 100% MSWC (Table 4), while growth of plants in blends with lower rates of MSWC (25% to 75%) was greater than or similar to that of other blends. Plants in 100% compost were often visually smaller and slightly chlorotic. Leaf tissue analysis results (Table 5) did not immediately explain the stunted growth, suggesting symptoms were not due to element toxicity or deficiency. Elemental analysis of MSWC did not reveal presence of elements that would be phytotoxic (Table 3). With the very high EC values determined in Experiment 1 (Table 2), salt damage, along with excessive water holding capacity and reduced air space probably caused the off-color and reduced plant growth in the 100% MSWC substrates for experiment 2.

In Experiment 3, the replacement of 25% PB with MSWC resulted in a nearly 10% increase of GI in common flowering quince and common sweetshrub compared with the non-amended 100% PB substrate (Table 4). Such increased growth with the relatively low ratio of PB replacement was also a common response observed in studies with many other types of compost (Chong, 2005; Fitzpatrick, 1989; Ribeiro et al., 2000). The increased growth can be explained by improved water holding capacity (WHC) and physical properties with only slightly increased soluble salt level. The third species, Indian hawthorn had similar growth regardless of MSWC amendment.

Experiment 4 had similar results to that of Experiment 2, with all four species having a smaller GI (where different) in the 100% compost-based substrate (Table 4) than with other blends. In addition, azalea and compacta holly in 3 MSWC : 1 PB had lower GI than plants in the 100% PB or two substrates with less MSWC. Leachate analysis indicated that 100% PB substrates were acidic and all MSWC amended substrates had higher pH values (Table 6), however, pH levels did not appear to be a growth limiting factor in this experiment.

Our multi-year, multi-site, multi-species/cultivar study on MSWC as a substrate component with PB had very encouraging results. Overall, replacement of PB up to 50% with MSWC resulted in the same or better plant growth (GI) than plants in non-amended PB control. In 75% PB replaced substrates, most species/cultivars (seven out of 10) grew equally or better than in standard PB:S blends. In contrast, most species/cultivars (eight out of 10) did not grow well in the 100% MSWC-based substrates. This study also identified some important advantages and disadvantages of MSWC as an alternative to PB. Major advantages include: 1). relative to PB, MSWC has a higher water-holding capacity; 2). MSWC has a high bulk density relative to such common substrate components as PB or peat moss. These two properties suggest MSWC can at least partly replace the sand that is usually added to PB-based substrates. The biggest disadvantage of MSWC appears to be an initially high soluble salt concentration. While leaching with large quantities of water is recommended to reduce salt damage, caution should be used with a high ratio of MSWC (> 50%) with salt-sensitive species. The usually high pH value of MSWC is a property that can be carefully used when mixing with PB. Our results suggest that no lime amendment is needed when the mixture consists of 50% or more MSWC.

Literature Cited

Chen, J., D.B. McConnell, C.A. Robinson, R.D. Caldwell, and Y. Huang. 2003. Rooting foliage plant cuttings in compost-formulated substrates. HortTechnology 13:110-114.

Chong, C. 2002. Use of waste and compost in propagation: challenges and constraints. Comb. Proc. Intl. Plant Prop. Soc. 52:410-414.

Chong, C. 2005. Experience with wastes and composts in nursery substrates. HortTechnology 15:739-747.

Fitzpatrick, G.E. 1989. Solid waste composts as growing media. BioCycle 30(9):62-64.

Fonteno, W.C., D.K. Cassel, and R.A. Larson. 1981. Physical properties of three container media and their effect on poinsettia growth. J. Amer. Soc. Hort. Sci. 106:736–741.

Haynes, R.W. 2003. An analysis of the timber situation in the United States: 1952-2050. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-560, pp. 254.

Hicklenton, P.R., V. Rodd, and P.R. Warman. 2001. The effectiveness and consistency of source-separated municipal solid waste and bark composts as components of container growing media. Sci. Hort. 91:365-378.

Jackson, B.E., A.N. Wright, D.M. Cole, and J.L. Sibley. 2005. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Kahtz, A.W. and N.J. Gawel. 2004. Growth of barberry liners in media amended with noncomposted recycled waste. HortTechnology 14:192-195.

Klock, K.A. and G.E. Fitzpatrick. 1997. Growth of Impatiens 'Accent Red' in three compost products. Compost Sci. Util. 5 (4):26-30.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Poole, R.T., C.A. Conover, and J.N. Joiner. 1981. Soils and potting mixtures, p. 179-202. In: J.N. Joiner (ed.). Foliage Plant Production. Prentice GHall, Englewood Cliffs, N.J.

Ribeiro, H.M., E. Vasconcelos, and J.Q. dos Santos. 2000. Fertilization of potted geranium with a municipal solid waste compost. Bioresour. Technol. 73:247-249.

US Environmental Protection Agency (US E.P.A.). 2003. Municipal Solid Wastes in the United States: 2001 Facts and Figures. Report No. EPA530-S-03-011. Office of Solid Waste and Emergency Response, USEPA, Washington, DC.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best Management Practices: Guide for

Producing Nursery Crops. 2nd Edition. 103 pages. Southern Nursery Assoc., 1827
Powers Ferry Road, Atlanta, GA.

Table 1. Initial physical properties of five substrate blends in Experiment 1, Auburn University, AL.

Blends [z]	TP (%) [y]	WHC (%) [y]	AS (%) [y]	BD (g·cm-3) [y]
6 PB : 1 S	78	38	40	0.27
6 MSWC : 1 S	67	49	18	0.48
4.5 MSWC : 1.5 PB : 1 S	75	48	27	0.44
3 MSWC : 3 PB : 1 S	73	44	29	0.39
1.5 MSWC : 4.5 PB : 1 S	76	39	37	0.32
Desirable Range [x]	50-85	45-65	10-30	0.19-0.70

[z] PB: Pine bark; S: sand; MSWC: municipal solid waste compost.

[y] TP: total porosity; WHC: Water holding capacity; AS: air space; BD: bulk density.

[x] Recommended ranges for substrates used in general nursery production (Yeager et al., 2007)

Table 2. Leachate pH and electrical conductivity of five container potting blends in Experiement 1, Auburn University, AL.

Species	Blends	---------- pH -----------		----------------------- Electric conductivity ($dS \cdot m^{-1}$) -------------------------				
		Initial [y]	Final	Initial	1 WAT [w]	2 WAT	6 WAT	Final
Azalea ‘Pink Ruffle’	6 PB : 1 S [z]	5.83 b [x]	6.54 c	0.67 c	0.42 b	0.31 b	0.38 b	0.24
	6 MSWC : 1 S	7.16 a	7.37 a	7.31 a	3.35 a	1.21 a	0.95 a	0.52
	4.5 MSWC : 1.5 PB : 1 S	7.40 a	7.32 a	4.38 b	1.38 ab	0.67 ab	0.65 ab	0.59
	3 MSWC : 3 PB : 1 S	7.30 a	7.28 a	2.64 bc	2.50 ab	0.72 ab	0.56 ab	0.38
	1.5 MSWC : 4.5 PB : 1 S	7.00 a	6.84 b	0.91 c	0.71 b	0.48 ab	0.32 b	0.27
Compacta holly	6 PB : 1 S	6.54 c	5.86 c	0.35 a	0.38 b	0.21	0.20	0.30
	6 MSWC : 1 S	7.37 a	7.54 a	3.40 a	2.15 a	0.77	0.75	0.55
	4.5 MSWC : 1.5 PB : 1 S	7.32 a	7.42 a	2.14 a	0.84 ab	0.52	0.48	0.57
	3 MSWC : 3 PB : 1 S	7.28 a	7.34 a	2.67 a	1.68 ab	0.60	0.68	0.35
	1.5:4.5:1 MSWC:PB:S	6.84 b	6.86 b	0.83 a	0.79 ab	0.45	0.27	0.25
Nandina domestica ‘Atropurpurea Nana’	6 PB : 1 S	5.78 c	5.83 c	0.48 b	0.55	0.34 b	0.27	0.38
	6 MSWC : 1 S	7.43 a	7.27 a	7.90 a	2.58	1.22 a	1.05	0.45
	4.5 MSWC : 1.5 PB : 1 S	7.34 a	7.24 a	4.44 ab	1.59	0.68 ab	0.95	1.07
	3:3:1 MSWC:PB:S	7.27 a	7.28 a	3.99 ab	1.63	0.67 ab	0.55	0.64
	1.5 MSWC : 4.5 PB : 1 S	6.83 b	6.47 b	1.09 b	0.76	0.66 ab	0.31	0.58

[z] PB: pine bark; MSWC: municipal solid waste compost.

[y] Initial leachate was collected for pH and electrical conductivity analysis after container receiving full drench after transplanting. Final leachate was collected on 8 months after transplanting.

[x] Means within columns for same species followed by different letters are significantly different according to Tukey’s studentized range (HSD) test (p-value ≤ 0.05).

[w] WA T: week(s) after transplanting.

Table 3. Element and soil analysis of municipal solid waste compost (MSWC) passing through a one-in. screen.[z]

Ca	K	Mg	P	Al	B	Ba	Cd	Co	Cr	Cu	Fe	Mn
ppm												
88.9	580.9	18.4	9.2	7.5	3.8	0.1	<0.1	<0.1	0.6	20.9	15.4	0.8

Na	Ni	Pb	Zn	NO_3-N	EC [y]	SS [y]	pH	S	N	C	C:N ratio
ppm					$dS \cdot m^{-1}$	ppm		%	%	%	
1154.3	0.7	0.9	4.1	38.7	9.5	6650	7.86	0.29	1.22	31.55	26:1

[z] Analysis was conducted by Auburn University Soil Testing Laboratory using the saturated paste extract method, February, 2004.

[y] EC: electrical conductivity; SS: soluble salts.

Table 4. Growth index[z] of container plants in blends of composted municipal solid waste (MSWC) and pine bark (PB) at Center for Applied Nursery Research (CANR), Dearing, GA in 2004 and 2006 and at Greene Hill Nursery, Waverly, AL in 2004.

Experiment	Species	100% MSWC [y]	3 MWSC : 1 PB[y]	1 MSWC : 1 PB	1 MSWC : 3 PB	100% PB
CANR, 2004	'Pink Ruffle' azalea	17.9 b [x]	20.9 a	19.6 ab	21.1 a	21.4 a
	Dwarf Yaupon holly	14.8 b	19.5 a	17.7 ab	17.7 ab	18.0 ab
	Cleyera	24.1 b	30.2 a	26.4 ab	30.2 a	31.0 a
Greene Hill Nursery, 2004	Common flowering quince	n/a [w]	n/a	n/a	63.3 a	57.6 b
	Common sweetshrub	n/a	n/a	n/a	54.2 a	49.5 b
	Indian hawthorn	n/a	n/a	n/a	39.5 a	40.4 a
CANR, 2006	Azalea 'Pink Gumpo'	13.7 b	15.1 b	15.7 ab	16.1 ab	17.8 a
	Compacta holly	22.1 b	22.1 b	24.4 ab	26.2 ab	27.7 a
	Ternstroemia gymnanthera	26.1 b	28.5 ab	31.0 a	30.3 a	27.9 ab
	Wax leaf ligustrum	27.4 b	34.1 ab	35.1 a	36.6 a	36.8 a

[z] Growth index determined by (height + width at widest point + width perpendicular to width at widest point)/3.

[y] MSWC: municipal solid waste compost; PB: pine bark.

[x] Means within rows followed by different letters are significantly different according to Tukey's studentized range (HSD) test (p-value ≤ 0.05).

[w] n/a: not available.

Table 5. Tissue Analysis Result of azalea, yaupon holly, Ternstroemia gymnanthera leaves grown in each of five substrate blends of Experiment 2, 2004, at the Center for Applied Nursery Research, Dearing, GA[z].

Species	Blends	Ca	K	Mg	P	N	S	Al	B	Cu	Fe	Mn	Na	Zn
		------ % [x] ------						------ ppm ------						
Azalea 'Pink Ruffle'	100% PB [y]	2.00	0.49	0.29	0.09	1.15	0.167	133.3	92.8	32.2	40.5	194.1	512.0	48.5
	100% MSWC	2.18	0.37	0.31	0.12	1.13	0.149	125.0	64.8	10.7	35.8	281.4	306.9	54.8
	75% MSWC : 25% PB	2.33	0.44	0.23	0.12	1.07	0.157	141.9	103.4	12.8	36.9	104.4	353.5	47.7
	50% MSWC :50% PB	1.93	0.42	0.28	0.11	1.17	0.115	133.0	73.9	8.9	37.0	268.4	436.5	46.3
	25% MSWC :75% PB	1.69	0.41	0.30	0.15	1.12	0.142	138.0	60.8	8.7	35.1	287.9	491.2	55.0
Dwarf yaupon holly	100% PB	1.62	0.49	0.26	0.13	0.71	0.212	167.9	49.8	6.3	32.4	29.0	2354.1	10.3
	100% MSWC	1.69	0.45	0.40	0.18	0.84	0.140	163.5	39.8	6.4	24.3	30.1	938.0	10.4
	75% MSWC : 25% PB	1.67	0.55	0.36	0.16	0.78	0.142	144.0	44.9	7.7	22.6	23.2	928.1	7.8
	50% MSWC :50% PB	1.39	0.50	0.32	0.15	0.77	0.114	117.3	37.3	8.4	21.4	15.5	950.9	7.9
	25% MSWC :75% PB	1.22	0.69	0.29	0.18	0.80	0.117	196.2	32.4	11.9	36.6	22.4	1018.5	9.0
Tern-stroemia gymnan-thera	100% PB	0.64	0.40	0.44	0.10	1.48	0.148	119.1	89.9	20.8	37.1	446.8	261.3	278.8
	100% MSWC	0.70	0.47	0.56	0.15	1.52	0.150	123.3	92.9	41.8	55.0	704.0	430.2	417.5
	75% MSWC : 25% PB	0.78	0.35	0.52	0.09	1.33	0.125	135.9	121.7	15.4	31.8	541.7	217.2	342.2
	50% MSWC :50% PB	0.59	0.44	0.46	0.10	1.35	0.137	100.8	105.4	48.3	35.8	593.1	447.4	353.1
	25% MSWC :75% PB	0.63	0.38	0.48	0.13	1.40	0.130	110.5	81.1	9.7	32.0	758.7	199.4	302.4

[z] Analysis was conducted by Auburn University Soil Testing Laboratory.

[y] PB: pine bark; MSWC: municipal solid waste compost.

Table 6. Leachate analysis of container plants in blends of municipal solid waste compost (MSWC) and pine bark (PB) of Experiment 4, 2006, at the Center for Applied Nursery Research, Dearing, GA.

Species	Blends	pH					Electric conductivity($dS \cdot m^{-1}$)				
		Jan.	Mar.	May	Jul.	Sep.	Jan.	Mar.	May	Jul.	Sep.
Azalea	100% PB [z]	4.40	4.10	4.20	3.90	3.80	0.59	0.57	0.17	0.19	0.45
	100% MSWC	6.30	6.20	6.50	6.10	6.40	0.10	0.09	0.10	0.10	0.21
	75% MSWC : 25% PB	6.30	6.00	6.20	5.90	6.30	0.14	0.09	0.11	0.11	0.22
	50% MSWC :50% PB	6.50	5.80	6.40	6.00	6.30	0.16	0.20	0.11	0.11	0.11
	25% MSWC :75% PB	5.80	5.40	5.60	5.10	5.30	0.41	0.28	0.15	0.26	0.48
Compacta holly	100% PB	4.30	4.50	3.60	3.50	3.80	0.45	0.25	0.49	0.13	0.13
	100% MSWC	6.20	6.50	6.40	5.60	6.50	0.06	0.09	0.08	0.06	0.27
	75% MSWC : 25% PB	6.10	6.30	6.10	5.40	6.40	0.18	0.10	0.06	0.05	0.10
	50% MSWC :50% PB	6.00	6.20	5.60	5.10	6.00	0.20	0.18	0.24	0.05	0.18
	25% MSWC :75% PB	5.30	5.90	5.60	4.70	5.40	0.66	0.32	0.26	0.08	0.19
Ternstroemia gymnanthera	100% PB	4.20	4.40	4.10	3.70	3.50	0.48	0.62	0.19	0.15	0.25
	100% MSWC	6.30	6.40	6.10	5.80	6.50	0.08	0.07	0.06	0.07	0.26
	75% MSWC : 25% PB	6.00	6.20	5.80	5.40	6.10	0.19	0.11	0.07	0.05	0.35
	50% MSWC :50% PB	6.00	6.10	5.80	5.20	6.00	0.21	0.10	0.07	0.04	0.20
	25% MSWC :75% PB	5.80	6.00	5.50	4.60	4.90	0.47	0.11	0.11	0.27	0.29
Ligustrum	100% PB	5.10	4.60	3.70	3.60	3.90	0.28	0.26	0.52	0.20	0.25
	100% MSWC	6.90	6.40	6.10	5.40	6.40	0.05	0.07	0.05	0.07	0.09
	75% MSWC : 25% PB	6.60	6.10	5.80	5.20	6.30	0.08	0.06	0.07	0.04	0.12
	50% MSWC :50% PB	6.00	5.90	5.80	5.10	6.00	0.07	0.07	0.07	0.04	0.12
	25% MSWC :75% PB	5.40	5.70	5.20	4.60	5.40	0.18	0.07	0.13	0.08	0.16

[z] PB: pine bark; MSWC: municipal solid waste compost.

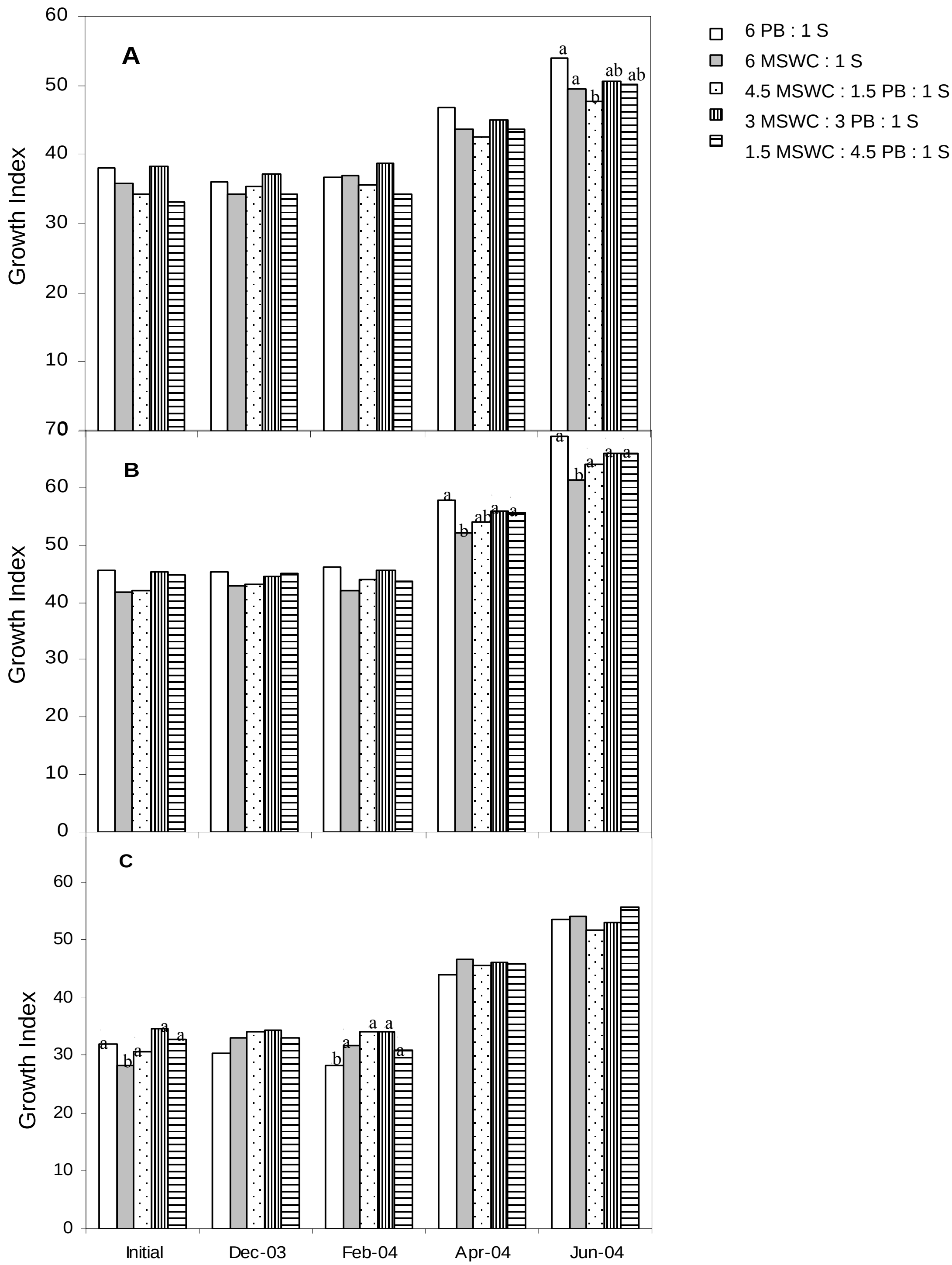

Figure 1. Growth index ((height + width at the widest point + width perpendicular to the widest point)/3) of (A) 'Renee Mitchell' azalea, B) Compacta holly, and (C) Nandina in each of five blends of Municipal Solid Waste Compost (MSWC) and pinebark (PB) of Experiment 1, 2004, at Auburn University, AL. Within same date, different letters indicate significant difference using Tukey's studentized range (HSD) test (*p*-value ≤ 0.05).

IV. UTILIZATION OF MIXED MUNICIPAL SOLID WASTE COMPOST AS SOILLESS POTTING COMPONENT IN GREENHOUSE PRODUCTION OF FOUR FLORICULTURAL CROPS

Abstract

Mixed municipal solid waste compost (MSWC) was evaluated as a soilless potting mix component for greenhouse production using four floricultural crops: dusty miller (*Senecio cineraria*), hybrid petunia (*Petunia× hybrida*), Japanese holly fern (*Cyrtomium falcatum*), and begonia (*Begonia × semperflorens-cultorum*). Dusty miller and petunia plugs were transplanted into 36-cell trays filled with MSWC based substrates and grown for two months. Petunia only grew well in the blend with the lowest MSWC ratio (33%), while dusty miller grew well in all MSWC blends. Japanese holly fern and begonia liners were transplanted into 15-cm (6-in) azalea pots and grown for 12 weeks in five substrates: 100% pine bark (PB), 3:1 PB:MSWC, 1:1 PB:MSWC, 1:3 PB:MSWC, and commercially available Fafard 3B Mix. In addition to substrate, a controlled-release fertilizer was applied at two rates to form a two-way factorial completely randomized design. Replacement of PB with MSWC resulted at least equal plant quality and growth of begonia in the aspects of growth index, leaf greenness (SPAD value), flower number, visual rating, and shoot fresh and dry weight. For Japanese holly fern, replacement of PB with MSWC

resulted in a lower visual rating, but without other negative responses in plant. For the four greenhouse crops tested, plant growth and quality were seldom negatively affected at low ratios of MSWC (25% to 33%). However, our studies indicate the impact of blending traditional pine bark with higher than 50% MSWC is species specific.

Index words: container substrate, pine bark, bedding plants.

Species used in this stuy: dusty miller (*Senecio cineraria*), hybrid petunia (*Petunia* × *hybrida*), Japanese holly fern (*Cyrtomium falcatum*), begonia (*Begonia* × *semperflorens-cultorum*).

Significance to the Nursery Industry

Various organic waste composts have long been regarded as alternative substrate components. As an organic waste, municipal solid waste (MSW) or household garbage, is always locally available and composting is encouraged as an effective pathway to reduce volumes of MSW. However, growers in the nursery industry have often been skeptical about the quality of municipal solid waste compost (MSWC) and are also reluctant to shift to substrates other than pine bark (PB) unless absolutely necessary. The results of two experiments using four popular floriculture crops grown in 0% to 100% MSWC based substrates reported here provides useful information for both sides of a emerging market for compost utilization. Replacement of PB with MSWC at a low ratio (30% or less) often increased plant growth. At a higher ratio (up to 75% MSWC in the substrate), plants often grew equally well as in 100% PB. Results suggest that MSWC can be a viable alternative to pine bark for container grown floricultural crops.

Introduction

Selection of substrates for horticultural use is often based on cost, availability, ease of handling, function and reproducibility. Peat and pine, or other types of bark, are the most common substrate components for nursery and greenhouse growers in the United States. However, horticultural crop growers have been under increasing pressure to find consistent and affordable supplies of peat and pine bark. Increased transportation costs, limited natural resources of peat, and related environmental regulations for peat mining have posed limitations for peat supply. Likewise, in recent years, nursery growers have had increased difficulty maintaining reliable pine bark supplies (Jackson et al., 2003; Lu et al., 2006). The availability of inexpensive bark is a rising concern due to alternative demands (e.g., industrial fuel), reduced timber production, and closing or relocation of primary timber processing mills to other regions or abroad (Lu et al., 2006). The needs for alternative substrate components 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.

An attractive substrate alternative is MSWC. Major advantages of MSWC include: 1) local availability; 2) practically unlimited resources, as every community generates trash continuously year around; 3) about 2/3's of MSW in the U.S. is organic matter which makes it easy to compost (US E.P.A.); and 4) like other composts, high quality MSWC can suppress certain diseases and pathogens (Hointink and Fahy, 1986).

Compost of MSW or co-compost of MSW with other materials has been tested as a potting mixture component for ornamental plant production in both greenhouse and nursery crops with mixed results (Chong, 2002; Hicklenton and Warman, 2001; Klock and Fitzpatrick, 1997). In general, results have shown that while a low MSW or MSWC ratio in the blend often promotes better plant growth than in non-amended blends, at higher ratios (50% or more) such benefits often disappear or even cause reduced growth compared with conventional container mixtures. Among the many factors contributing to the various plant growth responses, variations from the compost itself, different cultural conditions, and plant species are most obvious. While composting of source-separated MSW generally produces a more uniform product with less undesirable materials, such as metals, glass, or rubber, composting of mixed MSW requires no efforts from individual households and therefore is more economical and easier to implement.

This paper reports greenhouse production of four popular floricultural crops using MSWC produced from a mixed MSW stream. The overall objective was to evaluate the general performance of mixed MSWC as a soilless potting component in greenhouse ornamental crop production. Specifically objectives were to determine: 1) How crops respond to MSWC blends ranging from 0% to 100%; 2) Causes of different plant growth responses in MSWC blends; 3) How crops respond to different fertilizer rates incorporated with MSWC; 4) Effect on plant quality and marketability from different MSWC blends and fertilizer rates; and 5) directions for future research of alternative organic waste composts.

Materials and Methods

The MSWC in all experiments reported in this paper was derived from mixed household wastes without any presorting (WastAway Services, LLC, McMinnville, TN). Arriving waste feedstock had about 60% to 70% organic matter (by volume), such as yard wastes, food scraps, and paper products, etc. Aluminum and ferrous metals were removed with remaining MSW processed by a system of grinders, shredders and pressurized heat, after which the material was further composted with an indoor, turned windrow method. Before mixing, the compost was sifted through a 25.4 mm (1 in) screen to remove any large particles. Besides organic components, the compost had inert components ground to small particles (majority < 12.7 mm or 0.5 in), such as glass, plastics, rubbers, etc. The compost had above neutral pH (7-8), high soluble salt concentration (electrical conductivity: 4 - 8 $dS \cdot m^{-1}$ with saturated media extract method), and C:N ratio of 20 to 30. Besides high pH and EC reading, other physical and chemical properties were within recommended range for nursery crops (Sibley et al., 2005; Yadava, 1986).

Experiment 1. Three substrates were blended (by volume): 100% MSWC, 2:1 MSWC:Perlite (PRL), and 1:1:1 pine bark (PB):MSWC:PRL. Our previous studies on nine ornamental crops and commercial grower's field trial on multiple greenhouse and nursery crops found that replacement of PB with 1/3 or less MSWC had very few adverse effect on plant growth (Sibley et al., 2005) and thus the 1:1:1 PB:MSWC:PRL was treated as our baseline substrate. Each substrate blend was amended with 6.6 kg m^{-3} (11 $lbs \cdot yd^{-3}$) Osmocote 18-6-12 (18N-2.6P-10K, 8-9 mo.; The Scotts Company, Marysville, OH), 0.9 kg

m^{-3} (1.5 $lbs \cdot yd^{-3}$) Micromax (The Scotts Company, Marysville, OH), and 3.0 kg m^{-3} (5 $lbs \cdot yd^{-3}$) dolomitic limestone. On March 17, 2004, plugs of dusty miller (*Senecio cineraria*) and petunias (*Petunia* × *hybrida*), were transplanted into 36-cell trays with 3 trays for each species and substrate combination.

All trays of bedding plants were placed under overhead irrigation in a double layer polyethylene-covered greenhouse at the Paterson Greenhouse Complex, Auburn University, AL (32° 36'N × 85° 29'W, USDA Hardiness Zone 8a) for 2 months. A completely randomized design was utilized, with each tray regarded as an experiment unit and each plant in each tray regarded as subsamples.

Initial leachates, leachates at one week after transplant (WAT), two WAT, and final leachates at the end of the study were taken for determination of pH and electrical conductivity (EC). Leachates were collected using the nondestructive Virginia Tech Extraction Method (VTEM) (Wright, 1984) and 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, shoots of dusty miller were harvested for determination of fresh weights and then dry weights were determined after oven-drying at 70C (158F) for 72 hr.

Experiment 2. Five substrates were blended (by volume): 100% PB, 3:1 PB:MSWC, 1:1 PB:MSWC, 1:3 PB:MSWC, and commercially available Fafard 3B Mix (Conrad Fafard, Inc., Agawam, MA, a blend of peat, perlite, vermiculite, and pine bark) served as the control blend. All blends were amended with 0.9 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) Micromax (The Scotts Company, Marysville, OH), and 3.0 $kg \cdot m^{-3}$ (5 $lbs \cdot yd^{-3}$) dolomitic limestone. All substrate blends were then further amended (pre-plant incorporated) with one of two rates of a controlled-release fertilizer (CRF): Polyon NPK 19-6-12 6-month (19N-2.6P-10K; Pursell Technologies Inc., Sylacauga, AL) at 4.7 kg·m^{-3} (7.9 lbs·yd^{-3}, low rate) or 9.4 kg m^{-3} (15.8 lbs·yd^{-3}, high rate).

Liners of begonia (*Begonia* × *semperflorens-cultorum*) and Japanese holly fern (*Cyrtomium falcatum*) were transplanted into 15-cm (6-in.) azalea pots on September 13, 2006 and grown in a double-layer, polyethylene-covered greenhouse at the same Greenhouse Complex of Expt. 1 for 12 weeks. Each treatment combination (a species, fertilizer and substrate combination, total of 20) had 10 pots as repetitions and all plants were placed with a completely randomized design. Plants were hand-watered as needed.

Initial leachates were collected from three representative samples for each of five substrate blends using the VTEM. Leachates were then analyzed for pH and EC as in Expt. 1. After the initial leachate analysis, leachates were collected two WAT, and final leachate (at 12 WAT) for pH and EC determination.

Leaf chlorophyll values (greenness) were nondestructively measured on three of the youngest, fully developed leaves for all plants with a portable chlorophyll meter (SPAD-502) (Minolta Camera Co., Japan) (Yadava, 1986) at 12 WAT. Readings are expressed in SPAD values, which are technically unit-less and crop specific.

At 12 WAT, plant growth was measured using a growth index (GI), calculated as the average of plant height plus widest plant width plus plant width perpendicular to widest width/3. Also at 12 WAT, numbers of fully blooming flowers for each begonia plant were counted. The quality of begonia and Japanese holly fern was visually estimated by grouping plants with similar quality together: 5 – best quality, with no obvious visual defect in aspects of color, morphology, overall health, and/or blooming; 4 – very good, but with minor defect; 3 – good, with 2-3 defect; 2 – fair, obvious visual defect; 1 – poor, overall quality undesirable, marketability very low. Quality similarity was based on agreement by estimation of two research assistants. At the termination of the experiment at 12 WAT, aboveground parts of plants (shoot) were harvested. Shoot fresh and dry weights were determined as in Expt. 1.

Analysis of variance (ANOVA) was performed on data of both experiments where appropriate. Any statistical test with p-value < 0.05 was considered as significant and reported as such. For Experiment II, the main effects of fertilizer and substrate blend and their interaction were analyzed using two-way factorial ANOVA. All statistical analyses were conducted using SAS for Windows v.9.1 (SAS Institute Inc., Cary, NC).

Results and Discussion

Experiment 1. Survival of petunias in the 100% MSWC was low (less than 20%), about 50% of the petunias survived and grew well (without obvious visual defect, such as discoloring, margin burning, small or stunt leaves) in the 2:1 MSWC:PRL blend, and almost all petunias grown in 1:1:1 PB : MSWC : PRL survived and grew well. Dusty miller grew well in all three blends (100% survival). There were no significant differences in the fresh weights of dusty miller from different blends, but shoot dry weight for plants grown in 2:1 MSWC:PB were higher than that found in 100% MSWC (Table 1). Initial leachate EC readings of the blends, especially the 100% MSWC, were very high and may have contributed to the low survival of petunias; however, EC readings were within or close to intermediate salt levels (1.0-2.5 dS· m^{-1}, Chong, 2002) by 2 WAT. Similar studies concluded that salts leach quickly, especially in shallow flats or plugs and a few days' leaching under mist will lower soluble salts of waste-derived substrates to acceptable levels (Chong, 2001, 2002, 2005; Kuo et al., 1999). Even where EC values were higher than recommended (Yeager et al., 2007) two weeks after transplanting (Table 1), effects of high EC levels on dusty miller's growth were mostly minimal. The highly organic nature of waste-based substrates was believed to provide a high salt-buffering capacity and protection for root systems (Hicklenton et al., 2001).

Experiment 2. Similar to Expt. 1, initial EC readings were high (data not shown) but by two WAT, EC readings were well within recommended ranges (Table 2). Compared with results of Expt. 1 (Table 1), leachate soluble salts decreased faster with minimal, if any visible damage from initially high EC levels. This observation agreed with results from similar studies (Chong, 2001). The much lower EC values in Expt. 2 (0.45 – 0.80 dS·m^{-1}) than in Expt. 1 (1.37 – 2.18 dS·m^{-1}) at two WAT in substrate with similar MSWC proportion was due to a much higher irrigation amount received from the hand-watering in September than from mist irrigating in March. The commercial Fafard 3B mix and 100% PB mix had lower pH levels than blends with 50% and 75% MSWC, a difference of about 0.7 to 1 pH unit.

Both substrate blend and fertilizer rate affected some aspects of plant growth (Tables 3-5). Begonias grown in Fafard 3B had statistically higher fresh shoot weight than plants in 100% PB and 25% to 75% MSWC replaced blends (Table 3). There was no statistical difference among substrate blends for leaf greenness (SPAD values), growth index, quality rating, or flower number. However, the plant marketability or quality based on visual evaluation was obvious from plants in 100% PB (average rating 3.33) to plants in the Fafard 3B (average rating 4.33). Overall, replacement of 25% to 75% PB with MSWC did not have any negative effect on begonia growth and quality. Interestingly, CRF rate had a similar effect on begonia growth: shoot fresh and dry weights were increased by more CRF in containers, while all other indicators were not statistically affected by CRF rate. However, there were marginal interactions between substrate blends and CRF rates on begonia SPAD values and visual quality rating (Table 3). Separation of CRF effect from blends indicates that high fertilizer rates increased SPAD values (*p*-value = .009) from 49.5 in low CRF to 56.0 in high CRF) and also marginally increased SPAD values of plants grown in 100% PB (*p*-value = .096; Table 5). Visual rating of begonias was also marginally increased when grown in 100% PB or 1:1 PB:MSWC (both with *p*-value = .054). The actual increase in rating was rather impressive: from 2.67 to 4.0 in 100% PB, an improvement from mostly fair to very good and from 3.33 to 4.67 in 1:1 PB:MSWC, an improvement from mostly good to mostly best quality.

The effect of MSWC replacement on Japanese holly fern growth was different from other species (Table 4) in many aspects. Plant height, growth index as overall canopy volume indicator, and shoot fresh weight and dry weight were all similar among five substrates. Japanese holly fern had higher SPAD values in 1:1 PB:MSWC mix than in 100% PB mix. The handheld SPAD meter measures the greenness of leaves as reflected by the chlorophyll content and N status. The relationship between leaf greenness and N sufficiency is well documented (Sibley et al., 1996; Yadava, 1986). However, higher greenness was no guarantee of plant quality, as the quality rating between plants in 100% PB was higher than in 1:1 PB:MSWC blend, a completely reverse relationship. Based on visual rating, the marketability and quality of Japanese holly fern was adversely affected by the increased MSWC fraction (1:3 PB:MSWC), although such decrease in quality was not observed in other aspects. Other than increased SPAD values of ferns grown in the high CRF rate, fertilizer had negligible effects on other plant growth and quality indicators. Marginally significant interaction between blend and CRF on fern dry weight was evident and further analysis indicated that plants with high CRF rate in the 25% PB replaced blend (3:1 PB:MSWC) had higher shoot dry weight, but there was no effect on plants in other blends (Table 5). Other than sufficient supply of N and other nutrients, other properties of substrates, such as pH, drainage (air space), moisture (water holding capacity) can be more important and may have contributed to our results.

Overall, replacement of 25% to 75% PB with MSWC mostly improved begonia's growth, while growth of Japanese holly fern was negatively affected in visual quality. Expt. 2 indicates different responses between two greenhouse crops. Such varied effects on different species are mostly expected based on previous work that has shown that no universal percentage of any compost can be applied to all situations (Klock-Moore et al., 2000).

For the four greenhouse crops we tested, plant growth and quality were seldom negatively affected at low ratios of MSWC (25% to 33%). At higher level, however, replacement of the traditional pine bark with MSWC can either benefit or limit plant growth, which is often species specific. In our study, rapid leaching in Expt. 2 is believed to have reduced potential damage from high soluble salt concentrations in the MSWC we used. Similar to experiences with pine bark, some species can grow well even in 100% compost based substrates, while some other species may be negatively affected with less than 50% compost in the mix. However, unlike pine bark, MWSC, and probably most other composts, has chemical and physical properties that are often beyond the commonly recommended range (Yeager et al., 2007) and thus always need careful attention on a crop by crop basis under varying horticultural crop production methods. Also vital to both researchers and industry, is the vast variation among different types of compost made from different raw material, regions of the country, composting methods, and maturity level, etc.

Our studies indicate that actual compost materials must be carefully evaluated before large scale use, but with careful attention should be considered viable blending components for nursery and greenhouse crops.

Literature Cited

Chong, C. 2001. Using turkey litter compost in growing media. Proc. Intl. Plant Prop. Soc. 51:390-394.

Chong, C. 2002. Use of waste and compost in propagation: challenges and constraints. Proc. Intl. Plant Prop. Soc. 52:410-414.

Chong, C. 2005. Experience with wastes and composts in nursery substrates. HortTechnology 15:739-747.

Hicklenton, P.R., V. Rodd, and P.R. Warman. 2001. The effectiveness and consistency of source-separated municipal solid waste and bark composts as components of container growing media. Sci. Hort. 91:365-378.

Hointink, H.A.J. and P.C. Fahy. 1986. Basis for the control of soilborne plant pathogens with composts. Ann. Rev. Phytopathol. 24:93-114.

Jackson, B.E., A.N. Wright, D.M. Cole, and J.L. Sibley. 2005. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Klock, K.A. and G.E. Fitzpatrick. 1997. Growth of Impatiens 'Accent Red' in three compost products. Compost Sci. Util. 5 (4):26-30.

Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. BioCycle 41(11):58-60.

Kuo, S., R.L. Hummel, E.J. Jellum, and D.Winters. 1999. Solubility and leachability of fishwaste compost phosphorus in soilless growing media. J. Environ. Qual. 28:164-169.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Sibley, J.L., D.N. Cole, and W. Lu. 2005. Waste is a terrible thing to mind. Proc. Intl. Plant Prop. Soc. 54:596-603.

Sibley, J.L., D.J. Eakes , C.H. Gilliam, G.J. Keever, W.A. Dozier , Jr., and D.G. Himelrick. 1996. Foliar SPAD-502 meter values, nitrogen levels, and extractable chlorophyll for red maple selections. HortScience 31:468–470.

US Environmental Protection Agency (US E.P.A.). 2003. Municipal Solid Wastes in the United States: 2001 Facts and Figures. Report No. EPA530-S-03-011. Office of Solid Waste and Emergency Response, USEPA, Washington, DC.

Wright, R.D. 1984. The pour-through method: a quick and easy way to determine a medium’s nutrient availability. Amer. Nurseryman. 160(3):109-111.

Yadava, U.L. 1986. A rapid and nondestructive method to determine chlorophyll in intact leaves. HortScience 21:1449-1450.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best Management Practices: Guide for

Producing Nursery Crops. 2^{nd} Edition. 103 pages. Southern Nursery Assoc., 1827 Powers Ferry Road, Atlanta, GA.

Table 1. Leachate analysis and effect of substrate blends on growth of dusty miller (Expt. 1).

Blends[z]	pH				Electric conductivity (EC, dS m^{-1})				Fresh weight (g)	Dry weight (g)
	initial	1 WAT[y]	2 WAT	final	initial	1 WAT	2 WAT	Final		
100% MSWC	7.06	6.89	7.05	6.85	14.08	5.32	2.76	0.31	12.29	1.81b[x]
1:1:1 PB:MSWC:PRL	7.02	7.16	7.10	6.88	9.32	2.43	1.37	0.30	15.49	2.49ab
2:1 MSWC:PRL	6.34	6.72	6.81	6.86	8.42	4.12	2.18	0.37	15.24	2.68a

[z] MSWC = municipal solid waste compost; PB = pine bark; PRL = perlite.

[y] WAT: week(s) after transplant.

[x] Means within columns followed by a different letter are different according to Tukey's studentized range (HSD) test (p-value < 0.05).

Table 2. Leachate analysis at two weeks after transplant for begonia and Japanese holly fern (Expt. 2).

Species	Treatment[z]	pH[y]	Electric conductivity (EC, $dS \cdot m^{-1}$)
Begonia	*Blend*		
	100% PB	6.01 ab	0.57
	3:1 PB:MSWC	6.13 ab	0.45
	1:1 PB:MSWC	6.64 a	0.80
	1:3 PB:MSWC	6.59 a	0.70
	Fafard 3B Mix	5.61 b	0.83
	Fertilizer		
	Low rate	6.20	0.67
	High rate	6.19	0.66
Japanese holly fern	*Blend*		
	100% PB	5.75 b	0.58
	3:1 PB:MSWC	6.16 ab	0.63
	1:1 PB:MSWC	6.80 a	0.67
	1:3 PB:MSWC	6.44 a	0.66
	Fafard 3B Mix	5.76 b	0.75
	Fertilizer		
	Low rate	6.25	0.63
	High rate	6.11	0.68

[z] PB = pine bark; MSWC = municipal solid waste compost.

[y] Means within rows followed by different letters are significantly different according to Tukey's studentized range (HSD) test (p-value < 0.05).

Table 3. Effects of substrate blends and fertilizer levels on SPAD reading (greenness), growth index (GI), quality rating, flower number, shoot fresh weight, and dry weight of begonia (Expt. 2).

Treatment[z]	SPAD value[y]	GI	Quality rating	Flower number	Fresh weight (g)	Dry weight (g)
Blend						
100% PB	51.71	25.39	3.33	15.17	110.37 b	4.55 c
3:1 PB:MSWC	51.03	27.61	4.17	16.33	136.51 b	5.61 bc
1:1 PB:MSWC	52.91	27.06	4.00	15.50	131.13 b	5.68 bc
1:3 PB:MSWC	52.30	26.50	4.00	14.50	147.07 b	6.72 ab
Fafard 3B Mix	52.76	29.11	4.33	19.83	193.63 a	8.12 a
Fertilizer						
Low rate	51.42	26.91	3.87	15.40	131.05 b	5.37 b
High rate	52.87	27.36	4.07	17.13	156.43 a	6.91 a
P value						
Main effect						
Blend	0.7831	0.2270	0.2802	0.2308	<0.0001	<0.0001
Fertilizer	0.1767	0.6585	0.4992	0.2668	0.0135	0.0004
Interaction	0.0621	0.5015	0.0688	0.6997	0.1662	0.2327

[z] PB = pine bark; MSWC = municipal solid waste compost.

[y] Means within rows followed by different letters are significantly different according to Tukey's studentized range (HSD) test (p-value < 0.05).

Table 4. Effects of substrate blends and fertilizer levels on SPAD reading (greenness), growth index (GI), quality rating, shoot fresh weight, and dry weight of Japanese holly fern (Expt. 2).

Treatment[a]	SPAD value[y]	Height (cm)	GI	Quality rating	Fresh weight (g)	Dry weight (g)
Blend						
100% PB	38.45 b	21.33	29.17	4.50 a	23.11	4.60
3:1 PB:MSWC	41.02 ab	20.00	28.22	3.67 abc	21.15	4.34
1:1 PB:MSWC	45.77 a	19.83	27.06	3.17 c	18.58	3.74
1:3 PB:MSWC	42.83 ab	19.17	26.22	3.33 bc	20.36	4.03
Fafard 3B Mix	40.68 ab	24.17	30.72	4.67 a	22.86	4.60
Fertilizer						
Low rate	39.44 b	20.27	27.91	3.73	20.51	4.13
High rate	44.06 a	21.53	28.64	4.00	21.91	4.37
P value						
Main effect						
Blend	0.0719	0.2334	0.1130	0.0035	0.1569	0.1626
Fertilizer	0.0062	0.3897	0.5047	0.3140	0.2738	0.3324
Interaction	0.4186	0.7211	0.1844	0.4825	0.3073	0.0966

[z] PB = pine bark; MSWC = municipal solid waste compost.

[y] Means within rows followed by different letters are significantly different according to Tukey's studentized range (HSD) test (p-value < 0.05).

Table 5. Effects of fertilizer on SPAD value and visual rating of begonia, on dry weight of Japanese holly fern for different substrate blends (Expt. 2)[z].

Blend	SPAD value, begonia			Quality rating, begonia			Dry weight, fern		
	Low[x]	high	*P*	low	high	*P*	low	high	*P*
100% PB[y]	49.70	53.72	.096	2.67	4.00	.054	4.52	4.69	.759
3:1 PB:MSWC	51.36	50.70	.791	4.00	4.33	.614	3.61	5.07	.012
1:1 PB:MSWC	54.18	51.64	.288	3.33	4.67	.054	3.83	3.65	.743
1:3 PB:MSWC	52.32	52.28	.987	3.67	4.33	.317	3.80	4.25	.421
Fafard 3B Mix	49.52	56.00	.009	4.00	4.67	.317	4.88	4.20	.220

[z] Effects reported in this table are where there are marginally significant interactions between substrate blend and fertilizer rate based on Table 3 and Table 4.

[y] PB = pine bark; MSWC = municipal solid waste compost.

[x] Low: low fertilizer rate; high: high fertilizer rate.

V. IRRIGATION AND FERTILIZATION RATES ON GROWTH RESPONSE OF ORNAMENTAL CROPS TO MUNICIPAL SOLID WASTE COMPOST SUBSTRATES

Additional index words. Weeping fig (*Ficus benjamina*), 'Harbor Dwarf' nandina (*Nandina domestica* 'Harbor Dwarf'), *Elaeagnus* × *ebbingei*, controlled-release fertilizer, container production

Abstract

Mixed municipal solid waste compost (MSWC) was evaluated as a substrate component using weeping fig (*Ficus benjamina* L.), 'Harbor Dwarf' nandina (*Nandina domestica* Thunb. 'Harbor Dwarf'), and *Elaeagnus* × *ebbingei* Boom. Weeping figs were grown in a greenhouse in four substrates: pine bark (PB), 3 PB : 1 peat (PT), 3 PB: 1 MSWC, or 1 PB : 1 MSWC and drip irrigated with one of three irrigation rates for 12 weeks. Growth of weeping fig was at least equally well in the two PB : MSWC substrates as in the PB or PB : PT substrates. In an outdoor experiment, *Nandina* and *Elaeagnus* were grown in 100% PB or in substrates of 25%, 50%, and 75% MSWC with PB for 16 weeks. Controlled-release fertilizer (CRF) was blended into the substrate at one of three rates: 7.9, 5.3, and 2.6 $kg{\cdot}m^{-3}$. *Nandina* in 25% compost was about 18% larger than in 100% PB and 75% MSWC substrates and *Elaeagnus* was marginally larger in the two

substrates with highest MSWC than in the other two. Growth index (GI) of each species was similar among four substrates. The CRF rates had a minimal effect on height of *Elaeagnus* and GI of *Nandina*, with less growth in the lowest CRF rate than in the higher rates. Further, any contribution from nutrients in the MSWC was likely minimal and occurred in a short period after potting.

In North America, a majority of nursery and greenhouse ornamental crops are grown in containers with soilless substrates. Peat, especially sphagnum peat, and pine or other types of bark are the most common substrate components. However, due to limited natural resources, environmental concerns in peat mining and competitive usage of pine bark for other purposes, growers have been under increasing pressure to find comparative and affordable substitutes for peat and pine bark (Bilderback et al., 1982; Lu et al., 2006; Wilson et al., 2003).

Compost derived from municipal solid waste (MSW) has been tested in various configurations to grow ornamental plants. Studies on MSW compost (MSWC) have reported both negative and positive growth responses (Chen et al., 2002; Chong, 2005; Fitzpatrick, 1989; Gogue and Sanderson, 1975; Hicklenton et al., 2001; Kahtz and Gawel, 2004; Ribeiro et al., 2000; Rosen et al., 1993). Higher pH and soluble salt levels, or phytotoxicity caused by high trace element concentrations like boron were all reported as possible causes to reduced plant growth (Chen et al., 2002; Gouge and Sanderson, 1975; Kahtz and Gawel, 2004; Rosen et al., 1993). Beneficial effects often came from suitable physical properties for plant growth in containers and higher nutrient levels in composts than other commonly used material like pine bark, peat or mineral soil (Fitzpatrick, 2001; Hicklenton et al., 2001; Ribeiro et al., 2000; Rosen et al., 1993).

He et al. (1995) documented substantial variability in both chemical and physical properties among the MSWC generated in different facilities. Variability may not necessarily result in different plant growth (Hicklenton et al., 2001), but efforts should always be taken to reveal such potential different responses and gather useful information for future research and application. Studies on co-compost of MSW with other waste materials such as biosolids or yard trimmings have been widely reported, but much less on composts of mixed MSW produced in large commercial scale (Ozores-Hampton et al., 1994). In container production of ornamental crops, besides substrate, fertilization and irrigation are the most fundamental cultural practices affecting plant growth. MSWC has different physical and chemical properties from either pine bark or peat. Like other composts, extra nutrients from MSWC were often cited to promote its utilization (Ribeiro et al., 2000; Rosen et al., 1993). Interaction between substrate and irrigation and fertilization has to be addressed.

In this study, we tested the suitability of a mixed MSWC to replace pine bark in both greenhouse and outdoor container production conditions. In the greenhouse experiment, we used three levels of drip irrigation to determine effects of MSWC on the irrigation requirement of weeping figs (*Ficus benjamina*). In the outdoor container experiment, we used three controlled-release fertilizer (CRF) levels to test the interaction between fertilizer and substrate blends on growth of *Nandina* (*Nandina domestica* 'Harbor Dwarf') and *Elaeagnus* (*Elaeagnus* × *ebbingei*).

Materials and Methods

The MSWC evaluated in this paper was derived from mixed household wastes without any presorting (WastAway Services, LLC, McMinnville, TN). Aluminum and ferrous metals were removed with remaining MSW processed by a system of grinders, shredders and pressurized heat, after which the material was further composted with an indoor, turned windrow method. Before mixing, the compost was sifted through a 2.54 cm screen to remove any large particles. The MSWC had above neutral pH (7-8), high soluble salt concentration (8 – 15 $dS \cdot m^{-1}$), and C:N ratio of 20 to 30.

Expt. 1: Growth of a greenhouse foliage plant in substrates amended with MSWC and three irrigation rates. On 19 Feb. 2004, four substrates were blended: pine bark (PB), 1 PB : 1 MSWC (by volume), 3 PB : 1 MSWC, and 3 PB :1 peat (PT). Substrates were amended with 3.0 $kg \cdot m^{-3}$ dolomitic limestone, 7.8 $kg \cdot m^{-3}$ controlled-release fertilizer 18N-2.6P-10K (Osmocote NPK 18-6-12, 8-9 mo.; The Scotts Co., Marysville, Ohio), and 0.9 $kg \cdot m^{-3}$ Micromax (The Scotts Co.), which is a mix of micronutrients including Fe, B, Zn, Cu, Mo, etc and several macronutrients including Ca, Mg, and S. Twelve weeping figs were transplanted from 3.8 L containers into 7.6 L containers for each substrate blend. Each substrate treatment was drip irrigated under one of three irrigation regimes using one, two, or three emitters per container using a split application (three equal applications daily at 0800, 1100, and 1500 HR) for a total of 600, 1200, or 1800 $mL \cdot d^{-1}$ municipal tap water (See Appendix for water analysis results). Plants were arranged in a randomized complete block design with four substrate treatments and three irrigation regimes per block and four blocks. Plants were grown in a double-layer polyethylene-covered greenhouse at the Paterson Greenhouse Complex, Auburn University, AL (lat. 32°36′ N, long. 85°29′W) for 12 weeks. Greenhouse air temperatures were maintained between 19 ± 6 and 29 ± 6 °C and the maximum photosynthetically active radiation in the greenhouse was 600 $\mu mol \cdot s^{-1} \cdot m^{-2}$.

Physical properties of three representative samples from each of four substrate blends were determined using the North Carolina State University Porometer (NCSU-P, Fonteno et al., 1981). Replacement of one fourth to one half pine bark with MSWC resulted in overall improved physical properties with increased water holding capacity and acceptable air space.

Initial leachates were collected from three representative samples for each of four substrate blends using the nondestructive Virginia Tech Extraction Method (VTEM) or pour-through method (Yeager et al., 1983). Leachates were then analyzed for pH and electrical conductivity (EC) using a Model 63 pH and conductivity meter (YSI Incorporated, Yellow Springs, Ohio). After the initial leachate analysis, leachates were collected for determination of pH and EC weekly after potting until the end of the experiment (12 weeks after potting (WAP)).

Plant growth was measured using a growth index (GI), calculated as the average of plant height, greatest width, and width perpendicular to greatest width. The initial plant growth was determined immediately after potting; and then at one, six, and 12 WAP (final). At the end of the study (12 WAP), aboveground parts (shoots) of plants were harvested and shoot fresh weight and dry weights (70^{0}C for 72 hr) were recorded.

Expt. 2: Growth of two ornamental plants in outdoor container production in substrates amended with MSWC and three fertilizer rates. On 18 Aug. 2006, 48 liners of *Nandina* and *Elaeagnus* were transplanted from 3.8 L containers to 11.4 L containers. Four soilless growing substrates were blended: PB only, 3 PB : 1 MSWC (by volume), 1 PB : 1 MSWC, and 1 PB : 3 MSWC. Sand was added to each blend at one part of sand to every six parts of bark or bark and MSWC to increase substrate bulk density and to improve physical properties. Each substrate was amended with 0.9 $kg \cdot m^{-3}$ Micromax and 3 $kg \cdot m^{-3}$ dolomitic limestone. Within each substrate blend, a controlled-release fertilizer (CRF) 19N-2.6P-10K (Polyon NPK 19-6-12 6-Month; Pursell Technologies Inc., Sylacauga, Ala.) was incorporated at one of three rates: 1) 7.9 $kg \cdot m^{-3}$ as the baseline level, which is the recommended application rate, 2) 5.3 $kg \cdot m^{-3}$ (two thirds of the baseline level), and 3) 2.6 $kg \cdot m^{-3}$ (one third of the baseline level). Four substrate blends and three CRF rates resulted in 12 treatment combinations and 48 plants of each species were arranged in a randomized complete block design with 12 plants (corresponding to 12 treatment combinations) in each of four blocks. Plants were grown on an outdoor container pad at the Paterson Greenhouse Complex, Auburn University, AL for 16 weeks. All plants were irrigated as needed with an overhead irrigation system.

Initial leachates were collected for pH and EC analysis as described in Expt.1. Leachate was then collected weekly for 4 weeks and once every 4 weeks until the termination of experiment (16 WAP). Plant growth (height and GI as described for Expt. 1) was collected with the same frequency as leachates.

At 16 WAP, leaf greenness (chlorophyll content) of *Nandina* and *Elaeagus* were nondestructively measured on the youngest, fully developed leaves with a portable chlorophyll meter (SPAD-502) (Minolta Camera Co., Japan) (Yadava, 1986). Three replicate measurements from leaves in the canopy of each plant were averaged and expressed in SPAD units.

Statistical analyses. Even with best efforts to use uniformly grown liners and with randomized assignment of plants to treatments, plant growth measurements can still be confounded by uncontrollable factors. We first used analysis of variance (ANOVA) to examine the existence of difference among treatments in growth (height and GI) immediately after potting, i.e. the initial height and GI. Analysis of Covariance (ANCOVA) was conducted with the initial height and GI as continuous covariates where initial difference was determined. Interaction between treatment groups and covariate was included in the model to test the heterogeneity of treatment groups (Littell et al., 2002). The adjusted treatment means (least-squares means) were compared using Tukey's multiple comparison method (SAS, 2004). Leachate pH and EC and leaf greenness (SPAD reading) were analyzed using ANOVA. All statistical analyses were conducted using SAS for Windows v.9.1 (SAS Institute Inc., Cary, NC).

Results and Discussion

Expt. 1. After adjusted for the initial difference in height, weeping fig height was similar among the four substrates and the three irrigation rates throughout the experiment (Table 1). No interaction between substrates and irrigation rates was observed for height. The plants also had similar GI and shoot fresh and dry weight among the four substrates except greater GI of plants in the substrate with the lower ratio of MSWC (25%) than plants in 100% PB and 3 PB : 1 PT substrates at one WAP. However, the difference later disappeared. No interaction between substrates and irrigation rates were observed for GI. Irrigation only had effect on GI at 6 WAP as plants receiving 600 $mL \cdot d^{-1}$ water had higher GI than plants receiving 1200 and 1800 $mL \cdot d^{-1}$ water and slightly lower GI (*p*-value = 0.0598) with the highest irrigation rate; but again, difference evened out by 12 WAP. Higher irrigation levels in this experiment were apparently unnecessary. In contrast, early growth of weeping fig was improved when PB-based substrate was amended with MSWC. Consistent growth across various in substrate blends and irrigation levels indicates that a crop like weeping fig is a good candidate for alternative substrate components such as various organic waste composts.

The initial soluble salt concentrations (EC values) of leachates were high (Table 2). While the initial soluble salt content was beyond ideal levels (Chong, 2002; Yeager et al., 2007), flushing with water after potting for a few minutes leached salts to safe levels. Soluble salts of MSWC leached readily with mean EC values of all substrate treatments below 2 $dS \cdot m^{-1}$ at 1 WAP. In contrast, irrigation rate had a more effect on EC values (Table 2) as leachates collected from pots with the lowest 600 $mL \cdot d^{-1}$ irrigation was about twice that of those in the first half of experiment period (2.29 $dS \cdot m^{-1}$ vs. 1.16 and 1.07 $dS \cdot m^{-1}$ at 3 WAP; 1.59 $dS \cdot m^{-1}$ vs. 0.79 and 0.83 $dS \cdot m^{-1}$ at 6 WAP).

Overall, the initial substrate pH was increased by addition of MSWC and declined slightly afterward (Table 2). All pH readings were within or close to the commonly recommended range for nursery crops (Yeager et al., 2007) with the difference between highest and lowest pH about half unit, which would not be expected to have a noticeable effect on plant growth response (Chong et al., 2004). Throughout the experiment, pH did not to change differently in response to irrigation rate.

At the end of the study, weeping fig growth was similar in substrates with 25% and 50% MSWC as in the traditional pine bark substrate. Plant growth was not affected by irrigation indicating irrigation could be reduced without any negative effect on growth or plant quality with the substrates evaluated in this study. Similar growth responses to substrate and irrigation treatments were observed in 'Formosa' azalea (*Rhododendron indicum*) when testing the suitability of cotton gin compost as a substrate in the same greenhouse setup (Cole et al., 2005).

Expt. 2. Height of *Nandina* and *Elaeagus* in the early growth period (3 WAP) was similar across the four substrate blends and three fertilizer rates (Table 3). At the end of the study after 16 weeks, *Nandina* in the substrate with 25% compost was about 18% larger than in non-amended 100% PB and 75% : 25% MSWC:PB. In the meantime, *Elaeagnus* was slightly larger (p-value = 0.0537) in the two substrates with highest MSWC than in the other two. Interestingly, *Elaeagnus* grew marginally taller (*p-value* = 0.0683) in the middle fertilizer level (5.3 $kg{\cdot}m^{-3}$) than in the lowest fertilizer level (2.6 $kg{\cdot}m^{-3}$). There was no substrate × CRF interaction in height growth in both species. GI was similar for both *Nandina* and *Elaeagnus* except the final GI of *Nandina* in the highest fertilizer rate (7.9 $kg{\cdot}m^{-3}$) was marginally greater (p = 0.0936) than plants that received less fertilizer.

Initial pH values had a similar increase as in Expt. 1 when pine bark was replaced by MSWC (Table 3). However, the EC values decreased rapidly in this outdoor container production with overhead irrigation such that by 3 WAP, all EC values were below 1 $dS \cdot m^{-1}$, a similar result to other outdoor container studies using MSWC (Hicklenton et al., 2001; Kahtz and Gawel, 2004). As a measurement of total soluble salts concentration, EC value also indicates the total nutrient charge in the soil solution. Extra nutrients from various composts were often cited as a benefit to promote their utilization (Hummel et al., 2000; Ribeiro et al., 2000); however, the small and non-significant difference in EC between four substrates did not provide strong evidence of MSWC's nutrient value. Nutrient contribution from compost to overall plant growth is perhaps minimal and occurs primarily during a relative brief period after potting (Chong et al., 2004; Ribeiro et al., 2000; Wilson et al., 2003). This postulation was verified by the experiment of Hummel et al. (2000) on utilization of fishwaste compost to grow marigolds and geranium. With a relatively low salt content that required no leaching to prevent salt injury to the plants, a substrate of 100% fishwaste compost provided sufficient inorganic N for marigold and geraniums up to 7 weeks after transplant. Similarly, at 6 weeks, three perennial *Salvia* species had higher leaf P, K, and Mn content grown in substrate with 50% or 100% biosolid-yard waste compost than plants in 100% peat-based substrate (Wilson et al., 2003). However, plants grown in the compost amended substrate were either similar or smaller than plants in a peat-based substrate. In the Wilson et al. (2003) study, all substrate treatments received same amount of CRF and might thus have masked particular nutrient benefits from compost.

In our study, as expected, the higher fertilizer rate resulted in higher EC values and the difference was significant in leachates extracted from *Elaeagus* at 3 WAP (Table 4). Our study provides further evidence that nutrient values of compost diminish after just a few weeks in outdoor container production with overhead irrigation and strong rainfall events.

There were differences in pH values among substrate groups and CRF groups, but the range of pH was about 0.7 unit among four substrates and 0.2 unit among CRF groups. However, this level of variation in pH seldom affects growth of most species.

Leaf greenness (SPAD-502) at 16 WAP (end of experiment) was similar among plants in all four substrate groups; but *Nandina* had lower SPAD values when receiving only one-third of the baseline CRF rate than plants in the two higher CRF groups (Fig. 1). SPAD values closely reflect leaf chlorophyll concentration (Yadava, 1986) and the lower SPAD values of *Nandina* growing in the lowest fertilizer rate corresponded to a marginally lower GI (Table 3). *Elaeagnus*, a fast-growing species, increased more than 80% in both height and GI over 16 weeks across all treatment groups; in contrast, *Nandina* increased less than 15%. We postulate that the fast-growing *Elaeagnus* had a very high nutrient uptake rate and likely a very high nutrient utilization efficiency and therefore displayed no apparent lack of nutrients even in the lowest fertilizer rate.

Overall, growth of weeping fig, *Nandina*, and *Elaeagus* in substrates with MSWC fractions of 25% to 75% by volume grew equally well or better than in PB or PB and peat moss-based substrates when measured by plant height, growth index, or shoot weight. Irrigation rates we employed had little to no effect on growth of weeping fig in a greenhouse, while higher CRF rates only produced marginally larger *Elaeagus* or *Nandina* with marginally greater GI. Any growth contribution from nutrients of the compost was likely minimal and occurred in a short period after potting.

Literature Cited

Bilderback, T.E., W.C. Fonteno, and D.R. Hohnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peatmoss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

Chen, J., D.B. McConnell, C.A. Robinson, R.D. Caldwell, and Y. Huang. 2002. Production and interior performances of tropical ornamental foliage plants grown in container substrates amended with composts. Compost Sci. Util. 10:217-225.

Chong, C. 2002. Use of waste and compost in propagation: challenges and constraints. Comb. Proc. Intl. Plant Prop. Soc. 52:410-414.

Chong, C. 2005. Experience with wastes and composts in nursery substrates. HortTechnology 15:739-747.

Chong, C., G. Lumis, and P. Pervis. 2004. Growth and nutrient status of six species of nursery stock grown in a compost-based medium with recycled nutrients. HortScience 39:60-64.

Cole, D. M., J. L. Sibley, E.K. Blythe, D.J. Eakes, and K.M. Tilt. 2005. Effect of cotton gin compost on substrate properties and growth of azalea under differing irrigation regimes in a greenhouse setting. HortTechnology 15:145-148.

Fitzpatrick, G.E. 1989. Solid waste composts as growing media. BioCycle 30(9):62-64.

Fitzpatrick, G.E. 2001. Compost utilization in ornamental and nursery crop production systems, p.135-150. In: Stoffella, P.J. and B.A. Kahn (eds.). Compost utilization in horticultural cropping systems. Lewis Publ., Boca Raton, FL.

Fonteno, W.C., D.K. Cassel, and R.A. Larson. 1981. Physical properties of three container media and their effect on poinsettia growth. J. Amer. Soc. Hort. Sci. 106:736–741.

Gogue, G.J. and K.C. Sanderson. 1975. Municipal compost as a media amendment for chrysanthemum culture. J. Amer. Soc. Hort. Sci. 100:213-216.

He, X.T., T.J. Logan, and S.J. Traina. 1995. Physical and chemical characteristics of selected US municipal solid-waste composts. J. Environ. Qual. Hort. 24:543-552.

Hicklenton, P.R., V. Rodd, and P.R. Warman. 2001. The effectiveness and consistency of source-separated municipal solid waste and bark composts as components of container growing media. Sci. Hort. 91:365-378.

Hummel, R.L., S. Kuo, D. Winters, and E.J. Jellum. 2000. Fishwaste compost medium improve growth and quality of container-grown marigolds and geraniums without leaching. J. Environ. Hort. 18:93-98.

Kahtz, A. W. and N. J. Gawel. 2004. Growth of barberry liners in media amended with noncomposted recycled waste. HortTechnology 14:192-195.

Littell, R.C., W.W. Stroup, and R.J. Freund. 2002. SAS for linear models. 4th ed. SAS Institute Inc., Cary, N.C.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Ozores-Hampton, M., B. Schaffer, and H.H. Bryan. 1994. Nutrient concentrations, groth, and yield of tomato and squash in municipal solid-waste-amended soil. HortScience. 29:785-788.

Ribeiro, H.M., E. Vasconcelos, and J.Q. dos Santos. 2000. Fertilization of potted geranium with a municipal solid waste compost. Bioresour. Technol. 73:247-249.

Rosen, C.J., T.R. Halbach, and B.T. Swanson. 1993. Horticultural uses of municipal solid waste composts. HortTechnology 3:167-173.

SAS Institute Inc. (SAS). 2004. SAS/STAT® 9.1 User's Guide. Cary, NC: SAS Institute Inc.

Wilson, S.B., P.J. Stoffella, and D.A. Graetz. 2003. Compost amended media and irrigation system influence containerized perennial Salvia. J. Amer. Soc. Hort. Sci. 128:260-268.

Yadava, U.L. 1986. A rapid and nondestructive method to determine chlorophyll in intact leaves. HortScience 21:1449-1450.

Yeager, T.H., R.D. Wright, and S.J. Donohue. 1983. Comparison of pour-through and saturated pine bark extract N, P, K, and pH levels. J. Amer. Soc. Hort. Sci. 108:112-114.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops. 2nd Edition. 103 pages. Southern Nursery Assoc., 1827 Powers Ferry Road, Atlanta, GA.

Table 1. Effect of four substrate blends and three irrigation rates on plant height, growth index (GI) and shoot weight of weeping fig (*Ficus benjamina*) grown for 12 weeks in 7.6-L containers under greenhouse conditions (Expt. 1).

Treatment	------------Ht (cm) -----------			--------------- GI[z] --------------			Shoot wt (g)	
	1WAP[y]	6WAP	12WAP	1WAP	6WAP	12WAP	fresh	dry
Substrate[x]								
100% PB	29.27[w]	34.62	47.96	27.35b[v]	35.43	58.77	163.46	43.35
3 PB : 1 MSWC	31.34	35.80	49.30	30.28a	36.46	59.91	180.90	47.44
1 PB : 1 MSWC	29.04	33.69	48.99	28.88ab	35.66	60.28	162.71	42.51
3 PB : 1 PT	28.92	32.97	44.59	26.88b	33.51	58.11	145.57	39.83
Irrigation ($mL \cdot d^{-1}$)								
600	29.91	35.19	49.16	28.98	37.25a	59.30	177.70	45.79
1200	30.04	33.78	46.90	28.96	34.24b	59.85	157.93	42.04
1800	28.99	33.84	47.07	27.10	34.31b	58.64	153.82	42.00
Statistical test: P value								
Main effect								
Substrate	0.0967	0.1836	0.1207	0.0103	0.2835	0.6614	0.0725	0.2168
Irrigation	0.4553	0.3989	0.3536	0.0598	0.0365	0.7473	0.1996	0.2101
Interaction	0.3106	0.2079	0.2516	0.0912	0.0989	0.1251	0.8184	0.6101

[z] GI = (height + greatest width + width perpendicular to greatest width)/3.

[y] WAP = weeks after potting.

[x] PB = pine bark; MSWC = municipal solid waste compost; PT = peat moss.

[w] Height and GI were adjusted means (least-squares means) using the initial height and GI as covariates in the statistical analysis.

[v] Least-squares means within rows of substrate or irrigation followed by different letters are significantly different using Tukey's multiple comparison adjustment (*p*-value $\leq$ 0.05).

Table 2. Effect of four substrate blends and three irrigation rates on electrical conductivity and pH of leachate collected from weeping fig (*Ficus benjamina*) grown for 12 weeks in 7.6-L containers under greenhouse conditions (Expt. 1).

Treatment	---- Electrical conductivity ($dS \cdot m^{-1}$) ----					------------------------ pH ------------------------				
	Initial[z]	WAP[y]				Initial	WAP			
		3	6	9	12		3	6	9	12
Substrate[x]										
100% PB	5.68b[w]	1.06	1.12	0.48	0.51	6.62ab	6.42a	5.43b	5.51b	5.53ab
3 PB : 1 MSWC	7.66ab	1.97	1.09	0.44	0.41	6.69a	6.52a	5.99a	6.04a	5.92ab
1 PB : 1 MSWC	10.91a	1.96	1.26	0.78	0.62	7.01a	6.62a	5.96a	6.05a	6.11a
3 PB : 1 PT	5.23b	1.04	0.80	0.45	0.38	6.25b	6.10b	5.49b	5.39b	5.42b
Irrigation ($mL \cdot d^{-1}$)										
600	-	2.29a	1.59a	0.85	0.69	-	6.42	5.68	5.90	5.77
1200	-	1.16b	0.79b	0.48	0.41	-	6.40	5.71	5.79	5.82
1800	-	1.07b	0.83b	0.28	0.33	-	6.43	5.76	5.90	5.67

[z] Initial electrical conductivity (EC) and pH were measured from leachate extracted immediately after potting and therefore there was no data for EC and pH under three irrigation rates.

[y] WAP = Weeks after potting.

[x] PB = pine bark; MSWC = municipal solid waste compost; PT = peat moss.

[w] Means within rows of substrate or irrigation followed by different letters are significantly different using Tukey's studentized range (HSD) test (p-value ≤ 0.05.

Table 3. Effect of four substrate blends and three controlled-release fertilizer rates on electrical conductivity and pH of leachate collected three weeks after potting from nandina (*Nandina domestica* 'Harbor Dwarf') and *Elaeagnus* × *ebbingei* grown in 11.4-L containers in an outdoor container pad under overhead irrigation (Expt. 2).

Treatment	Electrical conductivity ($dS \cdot m^{-1}$)		pH	
	Nandina	*Elaeagnus*	Nandina	*Elaeagnus*
Substrate[z]				
100% PB	0.67	0.48	6.29c	6.21c
3 PB : 1 MSWC	0.60	0.56	7.06a	6.94a
1 PB : 1 MSWC	0.75	0.63	6.85a	6.86a
1 PB : 3 MSWC	0.60	0.60	6.59b	6.54b
Fertilizer[z]				
7.9 $kg \cdot m^{-3}$	0.63	0.69a[y]	6.57b	6.53b
5.3 $kg \cdot m^{-3}$	0.79	0.59a	6.74a	6.67ab
2.6 $kg \cdot m^{-3}$	0.50	0.42b	6.79a	6.72a

[z] PB = pine bark; MSWC = municipal solid waste compost. Fertilizer rates of 19N-2.6P-10k (Polynon NPK 19-6-12).

[y] Means within rows of substrate or fertilizer followed by different letters are significantly different according to Tukey's studentized range (HSD) test (p-value $\leq$ 0.05).

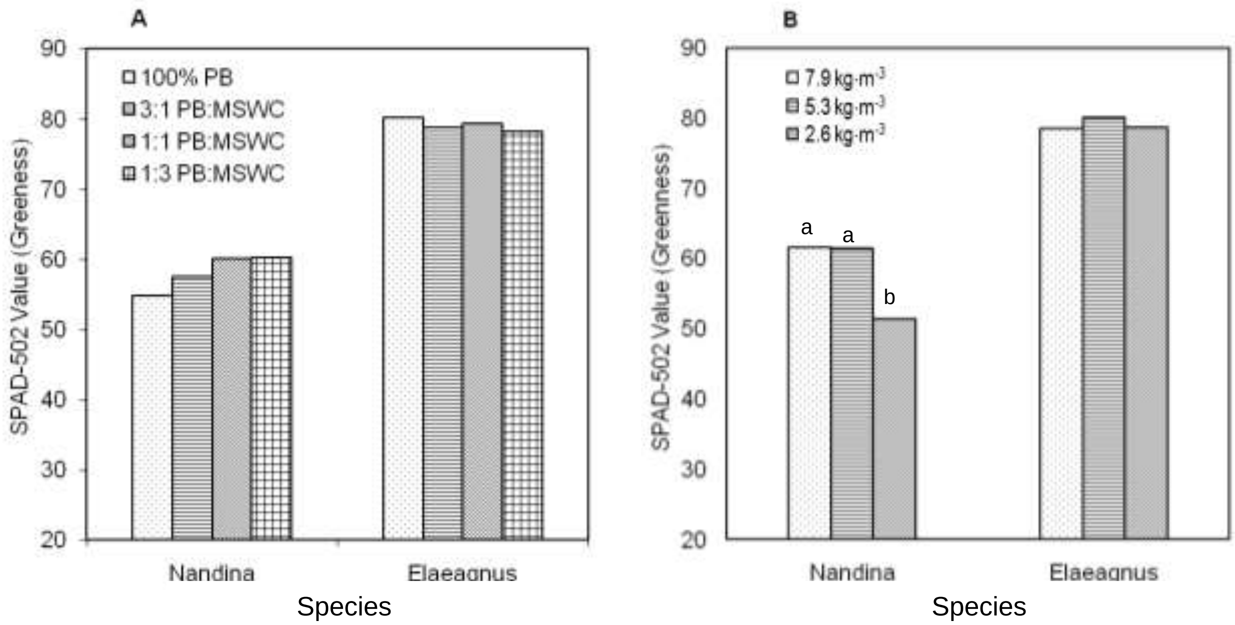

Fig. 1. Effect of four substrate blends (A) and three controlled-release fertilizer rates (B) on leaf greenness (SPAD-502 value) of nandina (*Nandina domestica* 'Harbor Dwarf') and *Elaeagnus* × *ebbingei* grown in 11.4-L containers on an outdoor container pad for 16 weeks under overhead irrigation (Expt. 2). Within same species, different letters indicate significant difference using Tukey's studentized range (HSD) test (p-value ≤ 0.05) (Expt. 2). A: PB = pine bark; MSWC = municipal solid waste compost. B: fertilizer rate of 19N-2.6P-10K (Polynon NPK 19-6-12).

Table 4. Effect of four substrate blends and three controlled-release fertilizer rates on plant height and growth index (GI) of nandina (Nandina domestica 'Harbor Dwarf') and Elaeagnus × ebbingei grown in 11.4-L containers on an outdoor container pad for three weeks after potting (WAP) and 16 weeks after potting (final) under overhead irrigation (Expt. 2).

Treatment	Height (cm)				Growth index[x]			
	Nandina		*Elaeagnus*		Nandina		*Elaeagnus*	
	3 WAP	Final	3 WAP	Final[y]	3 WAP	Final	3 WAP	Final
Substrate[z]								
100% PB	18.18[w]	18.91b[v]	37.43	58.63	33.40	36.76	33.22	51.52
3 PB : 1 MSWC	20.74	22.23a	38.51	59.29	34.46	38.02	32.89	50.73
1 PB : 1 MSWC	18.93	19.60ab	40.88	65.80	33.80	36.12	34.03	53.83
1 PB : 3 MSWC	18.73	18.68b	38.18	63.44	33.12	35.91	33.06	53.72
Fertilizer								
7.9 $kg \cdot m^{-3}$	19.94	20.04	37.60	61.29	34.03	38.17	32.50	52.65
5.3 $kg \cdot m^{-3}$	18.50	19.64	40.76	65.06	33.27	36.13	33.62	53.63
2.6 $kg \cdot m^{-3}$	19.00	19.88	37.90	59.02	33.78	35.80	33.78	51.07
Statistical test: P value								
Main effect								
Substrate	0.2554	0.0215	0.2837	0.0537	0.5255	0.4320	0.8076	0.2144
Fertilizer	0.2595	0.8820	0.1015	0.0683	0.5521	0.0936	0.4029	0.2129
Interaction	0.9604	0.9110	0.6762	0.1207	0.2909	0.8691	0.7439	0.3804

[z] PB = pine bark; MSWC = municipal solid waste compost.

[y] Final growth measurement was taken at 16 WAP.

[x] GI = (height + greatest width + width perpendicular to greatest width)/3.

[w] Height and GI were adjusted means (least-squares means) using the initial height and GI as covariates in the statistical analysis.

[v] Least-squares means within rows of substrate or fertilizer followed by different letters are significantly different using Tukey's multiple comparison adjustment (p-value ≤ 0.05).

VI. MIXED MUNICIPAL SOLID WASTE COMPOST AS A SOIL AMENDMENT ON YIELD AND HEAVY METAL ACCUMULATION IN OKRA AND WATERMELON

Abstract

Application of compost in horticultural crops has the potential to provide many benefits and yet there are concerns regarding the accumulation of heavy metals in the crop, and human health. Effects of amending soil with compost made from mixed municipal solid waste (MSW) on yield of okra (*Abelmoschus esculentus* L.) and watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai); and on heavy metal concentrations (Cd, Cu, Cr, Ni, Pb, and Zn) in pods of okra and pulp and juice of watermelon were investigated. Four MSW compost rates were applied: 25, 50, 75, and 100 $Mg \cdot ha^{-1}$, and compared to an un-amended control with no compost application. Addition of MSWC increased yield of okra and weight of watermelons over the control. There were no differences among treatments in heavy metal concentrations in okra pods, watermelon pulp or juice.

KEYWORDS. *Abelmoschus esculentus*, *Citrullus lanatus*, heavy metal juice, and pulp.

Introduction

Besides landfill and incineration, composting of municipal solid waste (MSW) is considered as a waste management tool, as composting can effectively reduce the waste volume and beneficial utilization of compost can eventually turn waste material into a resource. Benefits of soil application of compost have been attributed to improvement of physical properties, i.e., increased water infiltration, water-holding capacity, aeration and permeability, reduction of disease incidence, weed control, or improvement of soil fertility (Barker, 1997; Gallardo-Lara and Nogales, 1987; Mkhabela and Warman, 2005; Ozores-Hampton et al., 1994; Parr and Hornick, 1992; Rosen et al., 1993).

Amending soil with organic compost has been reported to increase yields of vegetable crops, such as pepper (*Capsicum* spp.), carrot (*Daucus carota* L.), tomato (*Lycopersicon esculentum* Mill.), broccoli (*Brassica oleracea* L.), okra (*Abelmoschus esculentus* L.), cucumber (*Cucumis sativus* L.), squash (*Cucurbita maxima* Duch. Ex Lam.), blackeye peas (*Pisum sativum* L.), and eggplant (*Solanum melongena*) (Clark et al., 2000; Maynard, 2005; Moral et al., 2006; Ozores-Hampton et al., 1998, 2000; Roe, 1998, 2001).

Mixed or unsorted MSW composting does not require sorting of household waste into compostables, recyclables, and trash. Mixed MSW composting can be handled in medium-to-large scale industrial facilities, and is more likely to provide an affordable, steady, high-quality product. However, development of mixed MSW composting has not received much endorsement for the last decade (Spencer and Goldstein, 2006). One important factor is market acceptance of the final MSW compost (MSWC) product. Use of mixed MSWC in horticultural crops has some special concerns, mainly the presence of heavy metal compounds; foreign and un-degradable particles, such as glass, rubber, or chemical fibers; and ttoxic organic compounds (Ozores-Hampton et al., 1994; Rosen et al., 1993).

Because of human consumption of vegetables there has been a reluctance to use MSWC in their production (Rosen et al., 1993). Heavy metals posing the greatest threat to human health are cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn), which may be taken up and accumulated by plants in edible parts (Shiralipour et al., 1992). Regional variation in MSWC has to be carefully weighed when comparing results from different locations. Even with the same type of MSWC, research results cannot be comfortably extrapolated from one region to another, as soil properties, including soil type, pH, cation exchange capacity, soil microbial community, soil flora and fauna, precipitation, temperature, cultural methods and tillage history, can vary and result in different responses in soil and crops grown on it.

Therefore the objectives of this study was to evaluate the effect of MSWC application on yield and heavy metal accumulation in edible portions of okra pods and watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] pulp and juice.

Materials and Methods

The study was conducted at the North Alabama Horticulture Research Center, Cullman, Alabama (34^{o}11'N × 86^{o}48'W) in a Hartselle fine sandy loam soil with a pH of 6.1.

On 1 June 2006, five parallel, raised beds were prepared. Beds were 2.44 m wide with a 2.44 m of non-bedded alley between each bed as a buffer area. Two beds were divided into four equally sized blocks for okra and three beds were divided into four equally sized blocks for watermelon. For okra, each block was 22.86 m long and equally divided into five treatment plots, with each treatment 3.05 m long and a space of 1.52 m between treatments as a buffer. The area of one treatment plot for okra was 7.44 m^2 (3.05 × 2.44 m). For watermelon, each block had a total length of 60.96 m and was equally divided into five treatment plots, with each treatment being 9.14 m long and a space of 3.05 m between treatments as a buffer. The area of one treatment plot for watermelon was 22.30 m^2 (9.14 × 2.44 m). The study was arranged in a randomized complete block design (RCBD) with each of five treatments randomly assigned and appearing once in each block. The MSWC evaluated in this study was derived from household wastes without any presorting (WastAway Services, LLC, McMinnville, TN). Aluminum and ferrous metals were removed with remaining MSW processed by a system of grinders, shredders and pressurized heat, after which the material was further composted with a turned windrow method. Before incorporating into the soil, the compost was piled outdoors at the testing site for about two months. The MSWC had above neutral pH of 7.8, an initial high soluble salt concentration of 4.0 $dS \cdot m^{-1}$, and a C:N ratio of 27:1.

On 5 June 2006, MSWC was spread evenly on the bed surface and incorporated into the top 30 cm of soil using five amendment rates which were: non-amended [0 $Mg \cdot ha^{-1}$ MSWC (control)], 25, 50, 75, and 100 $Mg \cdot ha^{-1}$ MSWC. On 6 June 2006, preplant fertilizer 13N-5.7P-10.8K (Super Rainbow NPK 13-13-1; Agrium, Inc., Calgary, Alberta, Canada) was incorporated into the soil at 445 kg·ha^{-1} with the same manner of compost application. Preplant fertilizer provided about 50% of the total fertilizer requirement for okra and watermelon. On 6 June 2007 white plastic mulch (1.25 mil or 0.032 mm) was applied along with drip tape buried 30–40 mm deep for drip irrigation. On 7 June 2006 okra, cv. Clemson Spinless, and watermelon, cv. Jubilation, were seeded underneath the plastic mulch by punching holes through the mulch to a depth of 3 cm. For okra, 4-5 seeds were used for each spot on the center of the raised bed every 61 cm. For watermelon, 2-3 seeds were used for each spot every 183 cm. From the third week, N was applied in the form of $CaNO_3$ through the drip system at 5.56 kg·ha^{-1} per week. One month after seeding, okra and watermelon for each spot were thinned to one plant. Depending on weather conditions, crops were irrigated through the drip irrigation tape every other day for 2–3 hrs after seeding.

On 28 June 2006, the vegetative growth of watermelon was measured using the length of the main vine and total length of all vines for each watermelon plant. On 26 July 2006, leaf chlorophyll readings of okra and watermelon were nondestructively measured on the youngest, fully developed leaves with a portable chlorophyll meter (SPAD-502, Minolta Camera Co., Japan).

Starting on 14 Aug. 2006, okra was harvested three times a week, until 22 Sept. for a total of 18 harvests. Fresh weight of marketable okra pods was determined immediately after harvest. Watermelons were harvested on 23 Aug. 2006. After harvest total number of watermelons were determined and all were weighed.

From the last harvest, three okra pods from every treatment of each block were randomly selected for elemental analysis. Okra was washed with deionized water and then oven-dried in paper bags at 72^{o}C until dry weight stabilized. For watermelon, one melon was randomly selected from every treatment of each block. The watermelon flesh was separated into pulp and juice following maceration by hand with a kitchen knife and squeezing through a standard cheese cloth and analyzed separately. The pulp and juice were cleared of any seeds. The pulp was oven-dried in 250 mL glass beakers in the same way of drying okra pods. The juice was filtered through #42 ashless filter paper (Whatman International Limited, Maidstone, KY) and kept in a cooler at 2-4^{o}C for later elemental analysis. Samples of okra pods and watermelon juice and pulp, 20 samples of each, were dry-ashed and extracted by solution of HNO_3 and HCl and analyzed using an inductively coupled argon plasma (ICAP) spectrometer (Jarrell-Ash ICAP 9000, Jarrell-Ash, Franklin, MA). Levels of the elements (Al, B, Cd, Ca, Cu, Cr, Fe, Pb, Mg, Mn, Ni, K, P, Na, Zn) were determined. One composite sample of MSWC was randomly collected from five locations of the compost pile prior to field application and the same 15 elements from the saturated media extract of the compost were analyzed using ICAP. Elemental analysis was conducted by the Soil Testing Laboratory of Auburn University, AL.

Statistics. Okra yield was analyzed for three harvest periods: early, middle, and last, and total. Analysis of variance (ANOVA) was carried out according to the RCBD. Multiple comparison of treatment means was with Tukey's studentized range test (HSD). When elemental concentrations were below the detection limit (BDL, <0.1 µg·g^{-1}), the data points were regarded as missing and when more than 50% of the data were missing in any of treatments, no statistical test was conducted due to excessive missing data. All statistical analyses were conducted using SAS for Windows v.9.1 (SAS Institute Inc., Cary, NC).

Results and Discussion

Early vegetative growth. At 3 weeks after seeding, watermelon plants grew equally in both height of main vine and total vine length for all five compost amendment levels (average height: 28.97 cm; average vine length: 41.04 cm). Similarly, there was no difference in SPAD values of either okra (average SPAD value: 41.20) or watermelon (average SPAD value: 53.78) between treatments. SPAD values have been shown to have a strong correlation with leaf chlorophyll content and can be used for rapid diagnosis of leaf N supply status (Yadava, 1986). As all plants received the recommended application rate and frequency of mineral fertilizers which included N, no plants had symptoms of N deficiency. Any nutrient benefit of N derived from the compost was not evident in the leaf N content indicated by SPAD values.

Okra yield. All amended treatment plots had similar or greater harvest weights than non-amended plots (control) (Table 2). For the first six harvests (early period), yield from the non-amended treatment was significantly less (6.27 kg) than from plants amended with 50 $Mg \cdot ha^{-1}$ MSWC (9.08 kg; a 45% increase). Yield was similar in the middle period harvest: non-amended plots had a total of 12.8 kg, while the 50 $Mg \cdot ha^{-1}$ MSWC treatment was 16.0 kg, an increase of 35%. Statistically there was no difference in the late period for okra yield due to treatment. The total yield was increased from 26.0

kg for the control to 34.5 kg in the 50 Mg·ha^{-1} MSWC treatment, an increase of 33%. The increase was 11, 21, and 16% for treatment 2 (25 Mg·ha^{-1} MSWC), 4 (75 Mg·ha^{-1} MSWC), and 5 (100 Mg·ha^{-1} MSWC), respectively, but the increase was not statistically significant.

Watermelon yield. Plants treated with 100 Mg·ha^{-1} MSWC had significantly greater yields than the controls; 249.6 kg vs. 203.3 kg, an increase of 23% (Table 3). The other treatments were intermediate between the extremes. There were no differences in number of fruit due to treatment, average about 25.

Heavy metal accumulation. There were only a few treatment differences in the concentrations of non-heavy metals (Al, B, Ca, Fe, Mg, Mn, Na, K, and P) in okra pods (data not shown). Among heavy metals, treatment did not affect concentrations of Cu, Ni or Zn in okra (Table 4). Concentrations of Cd and Pb were all BDL. Chromium was detected in one of four in the control; one sample of the 50 Mg·ha-1 MSWC treatment, and two samples of the 100 Mg·ha-1 MSWC treatment, with all other samples BDL. The Cr concentrations in samples from the 50 and 100 Mg·ha-1 MSWC treatments were either similar to, or lower than, concentrations in the sample from the non-amended control (Table 4). Overall, heavy metal concentrations of Cd, Cu, Cr, Pb, Ni, and Zn in okra were not affected in plants amended with MSWC compared with non-amended control plots.

Concentrations of non-heavy metals were mostly similar among treatments for both watermelon pulp and juice (data not shown). In the watermelon pulp, there was no difference in the Ni and Zn concentrations and concentrations of Cr and Pb of all treatments were BDL (Table 4). Concentrations of Cu were higher in the 100 Mg·ha^{-1}

MSWC treatment than in the non-amended control and the 75 $Mg \cdot ha^{-1}$ MSWC treatment in watermelon pulp. Chromium was detected in three of four samples from the 100 $Mg \cdot ha^{-1}$ MSWC treatment, and one sample each from the 25, 50 and 75 $Mg \cdot ha^{-1}$ MSWC treatments in watermelon pulp. Chromium was detected in higher frequency (3/4 of samples) from the 100 $Mg \cdot ha^{-1}$ MSWC treatment and the concentrations were relatively high in two of the three samples, while all samples from the control plots were BDL, which suggests that the amendment levels in the 100 $Mg \cdot ha^{-1}$ MSWC treatment were high enough to significantly increase Cr levels in watermelon pulp. However, considering that the U.S. EPA drinking water standard for Cr concentration is 0.1 $\mu g \cdot g^{-1}$ and dry weight of pulp is less than 10% of the total watermelon weight, the amount of Cr in the tissue is not expected to be detrimental to human health at normal consumption rate.

For watermelon juice, concentrations of Cd, Ni and Pb were BDL. Zinc was detected in 11 of 20 samples, but in very low levels, and Zn concentrations were not linearly affected by MSWC amendment. For most of the juice samples, Cu was BDL. When Cu was detected, it appeared to be randomly distributed among the five treatment levels, i.e., concentrations were not systematically affected by MSWC amendments. Chromium was detected in one watermelon juice sample of the 25 and 50 $Mg \cdot ha^{-1}$ MSWC treatments, with Cr in all other samples being BDL.

Overall, amendment of MSWC caused no increases in heavy metal concentrations in edible parts of okra and watermelon, except in Cu, but is not detrimental to human health. Use of the MSWC appears suitable for producing okra and watermelon for human consumption.

Literature Cited

Barker, A.V. 1997. Composition and uses of compost, pp. 140-162. In. J.E. Rechcigal and H.C. MacKinnin (eds.) Agricultural uses of by-products and wastes. ACS Symposium Series 668, American Chemical Society, Washington, DC.

Clark, G. A., C. D. Stanley, and D. N. Maynard. 2000. Municipal solid waste compost (MSWC) as a soil amendment in irrigation vegetable production. Trans. ASAE. 43:847-853.

Gallardo-Lara, F. and R. Nogales. 1987. Effect of the application of town refuse compost on the soil-plant system: a review. Biol. Wastes 19:35-62.

Maynard, A. A. 2005. Low rates of compost increase vegetable yields. BioCycle 46(11):46-48.

Mkhabela, M. S. and P. R. Warman. 2005. The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash dandy loam soil in Nova Scotia. Agr. Ecosys. Environ. 106:57-67.

Moral, R., J. Moreno-Caselles, M. D. Perez-Murcia, C. Paredes, and Agullo, E. 2006. Micronutrient concentration in horticultural crops grown on a soil amendment with the solid phase of pig slurry. Commun. Soil Sci. Plant Anal. 37:2595-2603.

Ozores-Hampton, M., T. A. Obreza, and P. J. Stoffella. 2000. Residual effect of municipal solid waste and biosolid compost on snap beans production, pp. 19-29. In: C.S.

Coker (Ed.). Proceedings of the 2000 Y2K Composting in the Southeast Conference, October 9-11, 2000. Charlottesville, VA.

Ozores-Hampton, M., B. Schaffer, H. H. Bryan, and E. A. Hanlon. 1994. Nutrient concentrations, growth and yield of tomato and squash in municipal solid waste amended soil. HortScience 29:785-788.

Ozores-Hampton, M., T. A. Obreza, and G. Hochmuth. 1998. Using composted wastes on Florida vegetable crops. HortTechnology 8:130-137.

Roe, N. E. 1998. Compost utilization for vegetable and fruit crops. HortScience 33:934-937.

Roe, N. E. 2001. Compost effects on crop growth and yield in commercial vegetable cropping systems. pp. 123-134. In: P. J. Stoffella and B.A. Kahn (eds.). Compost utilization in horticultural cropping systems. Lewis Publishers, Boca Raton, FL.

Rosen, C. J., T. R. Halbach, and B. T. Swanson. 1993. Horticultural uses of municipal solid waste composts. HortTechnology 3:167-173.

Parr, J. F. and S. B. Hornick. 1992. Utilization of municipal wastes. In: B. Metting (ed.). Soil microbial ecology: Application in agriculture, forestry, and environmental management. Marcel Dekker, New York.

Shiralipour A., D. B. McConnell and W. H. Smith. 1992. Use and benefits of municipal compost: a review and assessment. Biomass Bioenerg. 3:267-279.

Spencer, R. and N. Goldstein. 2006. Mixed MSW composting is "steady as she goes." BioCycle 49(11):18-22.

Yadava, U. L. 1986. A rapid and nondestructive method to determine chlorophyll in intact leaves. HortScience 21:1449-1450.

Table 1. Concentrations ($\mu g \cdot g^{-1}$ dry weight) of 15 elements from saturated extracts of the municipal solid waste compost (MSWC) used as a soil amendment for the production of okra and watermelon.[z]

Element	Ca	K	Mg	P	Al	B	Cd	Cr
Concentration	196.0	196.0	23.8	1.2	0.7	1.2	<0.1	0.1
Element	Cu	Fe	Mn	Na	Ni	Pb	Zn	
Concentration	4.0	0.5	0.2	312.3	0.1	<0.1	1.0	

[z] The municipal solid waste compost was derived from household wastes without any presorting. The MSWC analyzed was a composite sample randomly collected from five locations of the compost pile prior to field application. The analysis was conducted by the Soil Testing Laboratory of Auburn University, AL.

Table 2. Yields of okra grown in soil with an non-amended control and four levels of compost derived from mixed municipal solid waste for the early, middle, last, and total harvests (kg).

Treatment ($Mg \cdot ha^{-1}$)[z]	Early 6 harvests	middle 6 harvests	last 6 harvests	Total
0	6.27 b[y]	11.83 b	7.88 a	25.97 b
25	7.06 ab	13.19 ab	8.54 a	28.78 ab
50	9.08 a	16.00a	9.40 a	34.48 a
75	7.95 ab	13.19 ab	10.28 a	31.42 ab
100	7.92 ab	14.18 ab	7.90 a	30.00 ab

[z] Municipal solid waste compost was spread evenly on raised bed surface and incorporated into the top 30 cm of soil two days before seeding.

[y] values in columns followed by the same letter are significantly different, $P \leq 0.05$, Tukey's studentized range (HSD) test.

Table 3. Yield and number of watermelon grown with an non-amended control and four levels of compost derived from mixed municipal solid waste.

Treatment ($Mg{\cdot}ha^{-1}$)[z]	Yield (kg)	Number
0	203.25 b[y]	24.00 a
25	221.60 ab	25.50 a
50	224.88 ab	24.25 a
75	204.28 b	24.50 a
100	249.64 a	28.00 a

[z] Municipal solid waste compost was spread evenly on surfaces of raised beds and incorporated into the top 30 cm of soil two days before seeding.

[y] values in columns followed by the same letter are significantly different, $P \leq 0.05$, Tukey's studentized range (HSD) test.

Table 4. Effect of municipal solid waste compost on heavy metal concentration in edible parts of okra and watermelon.

Edible part	Treatment ($Mg \cdot ha^{-1}$)	Cd	Cr	Cu	Ni	Pb	Zn
Okra pod $\mu g \cdot g^{-1}$ dry weight	0	<0.1[z]	<0.6	15.20	1.68	<0.1	32.87
	25	<0.1	<0.1	24.29	1.22	<0.1	37.45
	50	<0.1	<0.4	29.89	1.46	<0.1	39.75
	75	<0.1	<0.1	20.49	0.96	<0.1	34.40
	100	<0.1	<0.9	27.38	1.64	<0.1	47.67
Watermelon pulp $\mu g \cdot g^{-1}$ dry weight	0	<0.1	<0.1	19.28b[y]	1.49	<0.1	17.28
	25	<0.1	<0.1	20.83ab	0.99	<0.1	21.82
	50	<0.1	<0.2	24.18ab	1.82	<0.1	23.75
	75	<0.1	<0.5	19.18b	3.00	<0.1	27.22
	100	<0.1	<1.8	30.51a	2.51	<0.1	31.28
Watermelon juice $mg \cdot L^{-1}$	0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2
	25	<0.1	<0.2	<0.1	<0.1	<0.1	<1.2
	50	<0.1	<0.5	<0.1	<0.1	<0.1	<0.7
	75	<0.1	<0.1	<0.2	<0.1	<0.1	<0.4
	100	<0.1	<0.1	<0.1	<0.1	<0.1	0.5

[z] Values with symbol "<" were treatment averages with at least one observation had below detection limit (BDL) concentration (<0.1 $\mu g \cdot g^{-1}$) for that treatment and 0.1 was used to calculate treatment averages. For such averages, statistical analysis was not possible.

[y] Treatment averages in columns followed by the different letters are significantly different ($P \leq 0.05$) with Tukey's studentized range (HSD) test.

VII. FINAL DISCUSSION

MSW is composted in a variety of ways, such as co-composting with other municipal wastes, composted from source separated MSW or mixed MSW composting. It is no surprise that utilization of MSWC in horticulture has a full range of responses from comparable to premium soilless substrate components and improving soil fertility in field application to phytotoxic or stunted plant growth.

Certain protocols have to be established and followed throughout research efforts with MSWC utilization in horticulture. It is often irrelevant or very difficult to compare experimental results of testing different composts with a variety of species under even more diversified cultural conditions. Two practical approaches of overcoming the above mentioned difficulty exist: 1) use a few model species to compare different MSWCs, and 2) use multiple species to test single MSWC. We followed the second approach by using 19 different ornamental species/cultivars in container production to test the suitability of MSWC as soilless substrate component. Tested plants included different requirements or tolerances for substrate acidity, salinity, moisture, fertility, fast-growing plants such as weeping fig to slow-growing plants such as compacta holly, from floricultural crops with short production period, such as begonia or petunia, to nursery crops usually requiring more than one growing season, such as yaupon holly. Overall, replacement of pine bark (PB) with MSWC up to 50% (in volume) often had at least equivalent growth to PB alone, while cultural conditions and species often played a larger role than ratios of MSWC in the substrate. We conclude that MSWC can be a viable alternative to pine bark up to at least 50% MSWC for most crops. Among problems associated with using MSWC in substrate blends, high soluble salt concentrations were the most frequently reported. Other factors attributing to plant growth differences included changes in pH, water availability, or air space, maturity of the MSWC used, and phytotoxicity of trace elements, etc.

Like other composts, the MSWC we tested had above neutral pH. Two *de facto* standard substrate components, i.e. pine bark and sphagnum peat, are acidic in nature and often there is the need to raise pH 1 to 2 units. Thus MSWC is complementary when mixing with pine bark or peat and may reduce or eliminate the use of pH amendment. Therefore, there is need to further quantify and compare the pH amendment effect of MSWC with lime or other commonly used compounds.

Extra nutrients from MSWC were often cited to promote its utilization. Container production of ornamental crops is almost exclusively dependent on artificial irrigation and fertilization, which are often standardized in application rates, frequency, and delivery methods. Previous studies reported MSWC and other kinds of composts may provide partial nutrient requirement for crop growth mostly in treatments receiving no or little fertilization. Such nutritional values were generally only available in a short period (less than 2 months). Our study suggests that nutritional benefit of MSWC is likely minimal for macro elements such as N, P, or K when crops were receiving routine fertilization. Therefore we do not recommend reducing fertilizer rates because of MSWC in substrate blends unless MSWC's nutrient values are well validated and quantified.

There were findings of phtotoxicity caused by high trace elements concentrations from composts including MSWC. On the other hand, MSWC has the potential to be a slow releaser of trace elements. Therefore, we recommend conducting routine elemental analysis of MSWC to pinpoint its potential nutrition values or toxic effect of trace elements. In many commercial nurseries, fertilizers of multiple micro nutrients are routinely used and are generally in very small amounts compared with N, P, and K. Whether the inclusion of MSWC in the substrate can reduce or eliminate the use of such micro nutrients also needs to be addressed.

There is no magic substrate blend that can provide premium growth for all crops. It is imprudent to conclude a certain substrate component is simply as good or not as good when testing PB or peat new alternatives. More relevant is how such a component should be incorporated or blended according to its unique physical and chemical properties and types of crops to be grown.

While only one growing season, our study on field production of okra and watermelon with MSWC as soil amendment indicates a positive response in crop yield and no risk to human health. More extensive research is necessary for other vegetable crop production and multi-year, multi-application of MSWC. Studies are equally necessary to be conducted in areas with different climatic, soil, and weather conditions for proper utilization of MSWC in those areas.

It is hoped that the research results presented in this dissertation are able to strength the knowledge pool of MSWC utilization in horticulture. With multiple ornamental crops tested in both greenhouse and container nursery settings, users (commercial nursery and greenhouse growers as well as amateur gardeners) and producers (middle to large-scale composting facilities) of MSWC are more likely able to properly select and use various MSWC products.

A natural extension of this substrate research is to study ornamental crops at multiple levels. Research activities should be able to integrate important management practices, such as irrigation, fertilization, pesticides and other chemical application, with natural growth factors such as climatic and weather conditions and relate those crop growth factors to crop biochemistry, physiology, and stand-level biology and ecology. Such effort was attempted and a case study of modeling water requirements for container production using overhead irrigation is included in the Appendix.

APPENDIX

A1. Modeling of Water Requirements for Container Production Using Overhead Irrigation

Abstract

Within the environmental horticulture industry, which is the fastest growing segment of agriculture in the United States, container nurseries are the major plant production system. Container nursery production systems are among the most intensively managed plant growth systems with large flux of materials (plants, water, nutrients, pesticides, labor, etc.) and energy. Plant production depends on an artificial supply of water (scheduled irrigation) and nutrients (mainly controlled-release fertilizers). The research presented in the following pages uses both process-based and empirical modeling approaches to quantify the precise water requirement of container-grown ornamental plants.

Significance to Industry

The container nursery industry has been a pioneer in using controlled-release fertilizers to increase nutrient use efficiency, however, its irrigation technology for small containers largely remains unchanged for the last half century. A common practice is to over-irrigate, trading a higher input of water to insure high value ornamental products against water deficits. Over-irrigation has been both economically and scientifically well based until very recently, as short periods of drought could significantly reduce both current and long-term plant growth in some cases, which also means significant economic loss. However, such a philosophy of luxurious irrigation is facing challenges from many directions demanding a different approach for the future. Increasing competition for water resources, stricter regulations on water environment, and extreme and unpredictable weather conditions as a part of the global climate change are but a few challenges. Modeling of water requirements for overhead-irrigated container production is a new but promising approach that has yet to be fully studied.

Introduction

Overhead irrigation is the primary irrigation system for small container production of ornamentals (pots less than 7 gallons in size) and there are no foreseeable alternatives to the cost and ease of overhead irrigation of small containers in the coming decade (Beeson et al., 2004). However, the actual irrigation application efficiency of overhead irrigation is very low, often in the range of 15% to 30%. When containers are pot-to-pot spaced, the theoretically maximal percentage of water falling within containers is 78.5% and this percentage decreases to 37.3%, 44.1%, and 48.7% respectively for 1-, 2-, and 3-gallon containers with spaces of 3 inches between containers in linear alignment. Besides direct effect of spacing, increases in total leaf area, canopy shedding, and canopy retention of water later lost by evaporation can significantly lower water falling in containers (Beeson and Knox, 1991; Beeson and Yeager, 2003). Because of the difficulty of uniform irrigation and other reasons, irrigation is most often applied to the point of about 10- to 15% of leachate even when carrying out best management practices.

Besides irrigation application efficiency, many factors arise when the water use efficiency is considered. Physical properties of substrates, container size, shape and color, weather conditions (such as wind, humidity, and temperature), and plant requirements are just a few of the many factors.

Low irrigation efficiency and lower water use efficiency have not been a big issue in most areas until recently. However, a panel of nursery irrigation researchers, nursery growers, and directors of nursery organizations reached a consensus that the availability and consumption from groundwater or public surface waters by container nurseries will decline significantly in the coming decade (Beeson et al., 2004). Various methods and technologies to increase water use efficiency are being considered. Conventional approaches include grouping of plants according to water requirements and plant or container sizes, increasing the water holding capacity of artificial substrate, while maintaining other necessary properties, increasing irrigation application uniformity, better irrigation system design, and scheduling of irrigation (such as cyclic irrigation and water in the morning) etc. Recently, recycling or recirculation of water from collection structures has been adopted by many nurseries. The most obvious choice to address irrigation needs of the future nursery industry is implementation of effective irrigation management techniques and other best management practices.

Modeling Approaches

One alternative approach to improve container nursery irrigation efficiency is precision irrigation or plant requirement-based irrigation. In this approach, substrate moisture sensors have been investigated for use in irrigation scheduling. Another aspect of this approach is modeling. Irrigation modeling has a long history of research and wide application in agriculture. However, research of modeling approaches within the nursery plant production industry, especially those grown in containers, is rare (Beeson, 2005). Intensive modeling of irrigation requirements in agronomic crops resulted in one simple, basic equation:

$$ET_A = ET_0 \times K_c$$

where ET_A is the actual evapotranspiration (ET), ET_0 is the reference crop evapotranspiration, and K_c is the crop coefficient. ET_0 can be calculated from methods derived from the Perman-Monteith equation (Monteith, 1998). This basic equation provides a foundation for modeling of irrigation requirements of container production (Beeson, 2005). Cheap computer calculation capacity, widely available from the internet, and inexpensive weather stations have made the reference evapotranspiration (ET_0) readily available to most nurseries. The main challenge of development and application of an irrigation model is the determination of crop coefficient K_c. This issue is especially critical in container-grown ornamentals as the number of species/cultivars in any middle-size nursery is often in the range of hundreds and initiating time of crop production can occur throughout the year for small containers. Other issues unique to container production exist and should be included in any good irrigation model. Models have been developed for ornamentals grown in 1- to 5-gallon containers with production periods up to two years (Beeson, 2005). The development of these models appears to provide a sound platform for modeling container-grown plant ET_A. However, the results are primitive and practical application of a modeling approach has a long way to go.

Results and Discussion

We present here a conceptual model for determination of water requirements for container plant production using overhead irrigation. The approach is to develop a real-time parameterized irrigation decision support system (DSS) based on a combination of empirical models and process-based models developed for container-grown ornamentals using overhead irrigation. Process-based models are dynamic representations of crop processes in a systems context. All quantified processes should have a sound physical or physiological basis. The goal of such models is to simulate and explain crop development and behavior as a function of environmental and management conditions or of genetic variation (Sinclair and Seligman, 2000). Many processes are involved in water consumption by plants in containers. The accuracy of water requirement quantification largely depends on how well these processes are being understood. Empirical models or statistical models are models with black-box parameters fitted using measurements from field or laboratory, regardless of the mechanisms or processes between parameters. Empirical models developed for a specific circumstance cannot be readily applied once conditions are changed. While process models represent rigor and soundness, empirical models often represent good utility. A hybrid approach of employing both process models and statistical models is necessary for modeling irrigation in container production.

With models being developed, a decision support system is necessary for application of model results in real nursery production. The DSS bridges the gap between complexity but with soundness of scientific research and user-friendliness and good utility of technology delivery. With inputs of meteorological parameters, plant parameters, and cultural parameters, the DSS will be incorporated into an automatic irrigation control system, which controls irrigation frequency and amount according to plant water requirements and real-time weather conditions. Another goal of such an irrigation control system is to have a capacity to adjust irrigation strategy in response to short-term weather forecasts and long-term climatic changes.

Literature Cited

Beeson, R.C., Jr. 2005. Modeling irrigation requirements for landscape ornamentals. HortTechnology 15:18-22.

Beeson, R.C. Jr., M.A. Arnold, T.E. Bilderback, B. Bolusky, S. Chandler, H.M. Gramling, J.D. Lea-Cox, J.R. Harris, P.J. Klinger, H.M. Mathers, J.M. Ruters, and T.H. Yeager. 2004. Strategic vision of container nursery irrigation in the next 10 years. J. Environ. Hort. 22:113-115.

Beeson, R.C., Jr. and C.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848-850.

Beeson, R.C., Jr. and T.H. Yeager. 2003. Plant canopy affects sprinkler irrigation application efficiency of container-grown ornamentals. HortScience 38:1373-1377.

Monteith, J.L. 1998. Evaporation models. In Peart, R.M. and R.B. Curry (eds.) Agricultural Systems Modeling and Simulation. Marcel Dekker, Inc. New York, NY. Pp. 197-234.

Sinclair, T.R. and N. Seligman. 2000. Criteria for publishing papers on crop modeling. Field Crops Res. 68:165-172.

A2. Water Analysis of Auburn City Water*

Element	Ca	K	Mg	P	Al	As
Concn.(ppm)	27.4	1.8	9.8	0.1	< 0.1	< 0.1
Element	B	Cd	Cr	Cu	Fe	Mn
Concn. (ppm)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Element	Na	Ni	Pb	Zn		
Concn. (ppm)	2.3	< 0.1	< 0.1	< 0.1		
Alkalinity	HCO_3^-					
Concn. ($mg \cdot L^{-1}$)	80					

* Sample was collected from Auburn city water from the Department of Horticulture of Auburn University on Feb. 12, 2008