COTTON GIN COMPOST AS AN ALTERNATIVE SUBSTRATE FOR HORTICULTURAL CROP PRODUCTION

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Brian Eugene Jackson

Certificate of Approval:

Jeff L. Sibley
Alumni Associate Professor
Horticulture

Amy Noelle Wright, Chair
Assistant Professor
Horticulture

Joseph M. Kemble
Associate Professor
Horticulture

Stephen L. McFarland
Dean
Graduate School

COTTON GIN COMPOST AS AN ALTERNATIVE SUBSTRATE FOR HORTICULTURAL CROP PRODUCTION

Brian Eugene Jackson

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COTTON GIN COMPOST AS AN ALTERNATIVE SUBSTRATE FOR

HORTICULTURAL CROP PRODUCTION

Brian Eugene Jackson

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Signature of Author

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Date

VITA

Brian Eugene Jackson, son of Eugene and Camelia Jackson, was born April 6, 1980 in Lumberton, North Carolina. He has one sister named Stacey. He graduated from Lumberton Senior High School in May 1998. He entered North Carolina State University in August 1998 and graduated with a Bachelor of Science degree in Horticultural Science and minors in Botany and Environmental Science in December 2002. Upon graduating he was employed as a research and teaching assistant at N.C. State in the Department of Horticultural Science under Dr. Stuart Warren and Dr. Paul Fantz. Brian entered graduate school at Auburn University in May 2003 and pursued a Master of Science degree under the diligent guidance and direction of Dr. Amy Noelle Wright. While at Auburn, he was employed as a graduate teaching assistant and later as a graduate research fellow. He received his Master of Science degree on August 8, 2005.

THESIS ABSTRACT

COTTON GIN COMPOST AS AN ALTERNATIVE SUBSTRATE FOR

HORTICULTURAL CROP PRODUCTION

Brian Eugene Jackson
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Nursery and greenhouse vegetable growers are always concerned about the availability and cost of materials used as substrates in their production systems. In recent years, alternative organic substrate components have increased in demand, yet pine bark (PB) remains the most common and traditional substrate for horticultural crop production. With increasing concerns over the availability and consistency of PB, the need for alternative substrates to be incorporated into production systems is even more urgent today that in the past. Cotton gin compost (CGC) is one such organic substrate that is abundant in the Southeastern U.S. and has potential use as a substrate, or substrate amendment for horticultural crops.

In a greenhouse study three common species, *Lycopersicon esculentum* 'Blitz', *Ficus benjamina*, and *Lantana camara* 'Hot Country', were grown in increasing ratios of PB:CGC. Plants were grown in Horhizotrons™ and root growth was evaluated every

week to observe root growth rates and distribution in the different treatments. Root growth of all species in all substrates containing CGC had increased root growth and higher proliferation of roots in the root ball.

In a greenhouse study, *Lycopersicon esculentum* 'Blitz' were potted into six PB:CGC substrate blends. Tomato yield and quality were evaluated over the course of two different studies conducted in 2004. Physical and chemical properties of each substrate were determined at the beginning of experiment. Tomato yield in both spring and fall of 2004 was similar in substrates containing CGC compared to the PB control. Total yields and marketable yields were similar among all seasons of each study (early, mid, and late) and no yield differences were shown among treatments. Cull percentages of total yield were low in both studies and did not differ in either study among any treatment.

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LITERATURE REVIEW

Agricultural wastes have been present since the beginning of agriculture and the quantities have steadily increased as production of crops has increased. The disposal of agricultural wastes remains a significant problem today as it did hundreds of years ago before modern technology. The amount of residues such as straw, stubble, leaves, tree limbs, grass clippings, and other unused crop residues is on the order of hundreds of millions of tons annually (Agricultural Wastes, 1971). Composting these materials has long been of interest to individuals, researchers, and growers. Due to recent laws and changes in public opinion about the environment, composting has now become a leading method to handle the increasing amounts of organic wastes. This review will discuss current practices and issues involving the uses and benefits of compost in the horticultural industry with emphasis on cotton gin compost (CGC) as a potential substrate for ornamental and vegetable crop production.

Compost and the Composting Process

Although composting has been practiced for thousands of years, it was not until the 20^{th} century that controlled scientific studies were conducted and published, illustrating the benefits of compost use in crop production. These studies helped to spur increased interest in composting and compost use, and gave way to the development of commercial composting facilities that supply finished compost products to horticultural producers (Fitzpatrick et al., 2005). The earliest known written reference to composting is found on clay tablets dated to the Akkadian empire, roughly 2300 B.C. and again in Roman literature and biblical references (Rodale, 1971). George Washington was recognized as being the United State's first official composter thanks to the "dung repository" he constructed to hold animal residues that he could later use to replenish the soil on his faming fields. More recently, beginning in 1990, data from the Environmental Protect Agency (EPA) indicated a steady increase in the composting activity across the U.S.: 4.2 million tons in 1990, 9.6 million tons in 1995, 13.1 million tons in 1998, 14.7 million tons in 1999, and 16.5 million tons in 2000 (EPA, 2000; Fitzpatrick et al., 2005).

Compost is controlled decomposition, the natural breakdown process of organic residues. Composting is the conversion of raw organic waste materials into biologically stable, humic substances that make excellent soil amendments (Thomasson and Willcutt, 1996). Composting occurs through the activity of microorganisms naturally found in soils. Under natural conditions, earthworms, nematodes, and soil insects such as mites, sow bugs, springtails, ants, and beetles do most of the initial mechanical breakdown of organic materials into smaller particles (Sylvia et al., 1999). Once optimal physical conditions are established, soil bacteria, fungi, actinomycetes and protozoa colonize the organic material and initiate the composting process (Sylvia et al., 1999). Numerous methods and technologies have been developed through the centuries for composting organic wastes. Windrow composting is one of the more popular methods using relatively little input. This is an open composting system where wastes are placed in rows and turned periodically, usually by mechanical equipment (Rodale, 1971). In addition to windrows, compost can also be generated in static piles, passively aerated windrows, forced aeration piles, enclosed or in-vessel composting, and in silo and reactor systems (Rodale, 1971; Fitzpatrick, 2005).

The primary factors affecting composting rates are temperature, moisture content, aeration, pH, carbon to nitrogen ratio (C:N), and microorganisms. Composting begins when the temperature reaches 45°C (113°F) and the process is complete when the temperature no longer remains at 45°C (Reddell et al., 1975). During the first initial temperature increase sugars and other easily biodegradable substances are destroyed, and during the phases of higher temperatures cellulose, lignin, and other substances that are less biodegradable are destroyed (Hoitink et al., 1991). High temperatures increase the efficiency of the thermophilic composting stage, but temperatures too high will drastically inhibit the process and should be monitored frequently to avoid potential problems (Avnimelech, 2004).

Maintaining accurate moisture levels in the compost pile is critical since the high amount of heat produced can result in a significant risk of the compost catching on fire (Hills, 1981). Adequate moisture is also crucial for the survival and productivity of microbial organisms that help break down the organic components. Microbially induced decomposition occurs most rapidly in the thin liquid films of water found on the surfaces of the organic particles (Sylvia, 1999). The ideal moisture content of the compost pile is between 45 and 60% by weight. Low moisture content will slow the composting process, and allow the compost to heat up and cool down more rapidly than wetter compost piles (Rodale, 1971). The most extreme consequence of low moisture content is the increased susceptibility to spontaneous combustion. Moisture content in excess of 60% means pore spaces in the compost pile will be filled with water rather than air, creating anaerobic conditions (Das and Keener, 1997).

Compost piles also need to remain well-aerated and contain 5 to 10% oxygen content during the active phase of the composting process. Oxygen is essential for the metabolism and respiration of aerobic microorganisms, and for oxidizing the various organic molecules present in the organic material (Handreck and Black, 2002). Composts must be either aerated passively or actively to maintain the needed oxygen levels within the piles at all times. Active aeration can be accomplished by various methods including drilling air holes, inclusion of aeration pipes, forced air flow, and mechanical mixing or turning (Rodale, 1971; Handreck and Black, 1984).

The acidity or alkalinity of the organic materials being composted affects the growth and survival of microorganisms. Compost piles with pH levels in excess of 7.5 will often lose ammonia more rapidly that compost with lower pH levels. The ideal C:N range is 25:1 to 35:1 (Geisel and Unruh, 2001). If the C:N ratio is greater than 20:1, microbes will use all the N for their own metabolic needs and if the C:N ratio is lower than 20:1, the microbes have surplus N and it can be lost to the atmosphere as ammonia gas, thereby increasing the odor of the compost (Butler, 2001; Raviv, 2002).

Most organic materials carry an indigenous population of microbes from the environment (Sylvia et al., 1999). Representatives of soil microorganisms including bacteria, actinomycetes, and fungi are normally present when the composting process begins (Carlile, 1991). Microbial populations change throughout the composting process, progressing from the mesophilic stage (approximately 20 to 40°C) into the thermophilic stage (above 40°C) and then through a gradual cooling period, the final stabilization stage (Carlile, 1991; Sylvia et al., 1999).

The elevated (thermophilic) temperatures achieved during the composting process permit faster biochemical reactions than are possible under ambient temperatures, accelerating pesticide, pathogen and weed seed degradation (Hoitink et al., 1991; Eitzer et al., 1997; Vandervoort et al., 1997). When composting materials are kept moist during the composting process, weed seed viability of most weed species will be destroyed even though the critical temperature may not be reached, as a result of compost phytotoxins (Eghball and Lesoing, 2000). Recent work by Ozores-Hampton et al. (2002) suggests that immature compost applied as a surface mulch may be an effective alternative weed control method, whether applied alone or in combination with chemical herbicides. Research conducted by Sterne et al. (1979) suggests that heat generated during the composting process will kill most of the common pathogenic fungi known to seriously infect and inhibit subsequent plant growth.

Benefits of Compost Use

Much has been learned over the last several decades about how the addition of organic matter affects the soil, as well as the benefits of different types of organic matter. Organic matter content in soil is essential for soil structure, water holding properties, microbial activity, and overall soil health (Brady and Weil, 2000). Composts are beneficial by providing a nutrient supply, reducing nutrient losses and improving cation exchange capacity (CEC), promoting better plant survival and growth, reducing soil compaction, improving soil water holding capacity (WHC), controlling erosion and providing weed suppression, and composts are beneficial by supplying microorganisms that perform many important functions in soils (Rodale, 1971; Raviv, 1998; Sylvia et al., 1999).

Composts often contain significant quantities of macronutrients and a full range of minor (micro) nutrients or trace elements (Raviv, 1998). Since they are needed in small quantities, applications of trace elements may not be required when using compost as plant substrates. In lightly textured soils (sandy) CEC is most often low. Adding compost raises the CEC of these lighter soils and enables the soil to better hold onto nutrients, such as potash, magnesium, and nitrogen, which can otherwise easily leach beyond the rooting depth of plants (Saharinen, 1998; Singer and Donald, 1999).

Good growth during plant establishment, and sustained growth afterwards requires adequate levels of organic matter in the soil to sustain its growth and development. It has been found that additional fertilizer alone cannot compensate when the organic matter in soil is low or nonexistent (Brady and Weil, 2000). This may be because landscape plants, many of which are not native, and need to establish quickly. Establishment is dependent upon enhanced root growth, which requires both adequate soil quality (good physical conditions) and an adequate volume of soil to explore (Singh and Sainju, 1998; Waisel, 2002). These conditions allow for rapid root growth, necessary to explore the soil for nutrients and water. Humus content in soil plays an important role in soil structure and aggregation, and the addition of organic matter will encourage the formation of stable aggregates in soil (Rodale, 1971; Singer and Donald, 1999). This increases the number and size of pore spaces in the soil, enhancing the rate at which water can be absorbed, and also increases the volume of air and water that the soil can hold. The application of organic matter in the form of compost will therefore improve soil structure, reducing bulk density, and improving moisture percolation, thereby providing a more suitable root environment for plants growth (Raviv, 1998; Brady and Weil, 2000). While percolation is improved, so is the soil's WHC, making water more available for a longer period of time in drier conditions (Bunt1988; Cole, 2004). In plant production systems the increased WHC could result in decreased irrigation frequency and volume, providing huge benefits to growers. The organic matter of compost also helps to reduce soil compaction allowing roots to more easily penetrate soils to locate nutrients and water (Allmaras, 1988; Raviv, 1998). Heavily (clayey) soils in particular have greatly improved tilth when the organic matter content is high (Singer and Donald, 1999).

Compost mulches act as a physical barrier to the soil surface providing benefits to landscape plantings by offering weed control, moisture percolation and conservation, and erosion control (Raviv, 1998). In addition to the physical advantages, composts will degrade over time and are incorporated back into the soil to add organic matter. Organic matter in compost is populated by microorganisms which supplement those already present in soils (Gattinger et al., 2004). The microorganisms utilize organic matter as an energy source and release humic substances that help form soil aggregates and improve the structure of soil (Sylvia et al., 1999). Microbes also cycle nutrients in the soil and release nutrients to plants from organic matter.

Cotton Gin Trash

Cotton gins must deal with overwhelming amounts of cotton gin trash (CGT) that is produced during the ginning process. Each year, the U.S. cotton industry harvests 17 to 18 million bales of cotton that go through the ginning process to separate the lint and seed from the CGT (Fava, 2004). Estimates range from 1.2 to 2.5 million metric tons of cotton gin by-products other than cottonseed are produced annually by U.S. cotton gins, creating a significant disposal problem in the ginning industry (Buser, 2001, Fava 2004). Typical cotton gin by-products consist mainly of fruit and vegetative parts of the cotton plant that were collected during harvest and removed by the cotton cleaning during processing at the gin. CGT is comprised of stems, leaves, bracts, hulls, some cotton fiber, weed seeds, and soil particles that are removed from the lint during the ginning process (Thomasson and Willcutt, 1996; Buser 2001). The fleshy cotton burr, also a component of CGT, is important because it is the primary repository of nutrients in the cotton plant. Cotton burrs contain a significant amount of Nitrogen (N), Phosphorus (P), and Potassium (K), as well as numerous micronutrients (Hills et al., 1981). Cotton burrs have a carbon nitrogen (C:N) ratio of 22:1, eliminating the nitrogen tie-up that occurs when wood or wood based products are composted. This C:N ratio allows CGT to be composted and then utilized as an amendment or growing media without causing severe nitrogen depletion to plants (Thomasson, 1990).

Two harvesting methods are used in cotton production in the United States and each produce different amounts of CGT. Stripper harvesting is used to harvest shorter cotton varieties in the southwestern United States, and it produces greater amounts of CGT than the spindle method (Buser, 2001). Approximately 238 (Pendleton and Moore 1967) to 671 (Kolarik et al., 1978) kg of CGT per bale of cotton with typical estimates of 320 to 455 kg/bale of CGT being produced for each 700 pound bale of cotton harvested by the stripper method (Parnell et al., 1994; Thomasson and Willcutt, 1996). In the southeast, cotton is harvested by spindle (picker) harvesting which gathers less debris and other non-fiber materials (Buser, 2001). Spindle harvest cotton produces 37 (Pendleton and Moore 1967) to 148 (Reeves, 1977) kg of CGT per bale of cotton with typical estimates of 34 to 68 kg/bale (Parnell et al., 1994; Todd, 1994). In 2001, 920,000 bales of cotton were produced in Alabama (USDA-NASS, 2002), which produced an estimated 28.4 million kg (31.3 thousand tons) of CGT.

The removal or disposal of CGT and cottonseed hulls generally poses a problem for cotton gins and cotton oil meal processing plants throughout the U.S. (Cohen and Lansford, 1993). Kolarik et al. (1978) reported that 37% of surveyed gins disposed of cotton gin by-products either at a profit or no cost to the gins, whereas the other 63% of gins paid for disposal. Disposal costs to gins and cotton producers is continually a major economic problem. It is estimated that the cotton ginning industry spends $15 to $25 million annually for cotton gin by-product disposal (Parnell et al. 1994).

In addition to occupying much needed space at ginning sites, when wet CGT can have a foul odor, and when dry it can present a serious fire hazard, necessitating appropriate methods of removal and disposal (Winterlin et al., 1981). Previous methods of CGT disposal have included field broadcasting, livestock feeds, landfill dumping, and incineration (Thomasson, 1990; Mayfield, 1991; Cohen and Lansford, 1993; Hills et al., 1981). Raw CGT was found not to be useful for land applications or as a soil amendment since the fresh organic material contained phytotoxic compounds and frequently resulted in nitrogen immobilization (Grasser, 1985). In addition, weed seeds and diseases, particularly Verticillium wilt found in the un-composted material, may be introduced in fields creating lasting problems with future crop production (Gordon et al., 2001).

Use of cotton gin by-products solely as a livestock feed throughout the Cotton Belt of the US is not widespread due to its limited protein availability, relatively poor digestibility in ruminants, and persisting chemical residues (Buser, 2001), however when chemically treated, studies have shown a strong potential for CGT to be used as a silage additive for ruminants (Lalor et al., 1975; Miron et al., 1995). Cotton gin trash is seldom disposed in landfills as the costs involved in transportation and dumping fees for approved landfill sites far outweigh the costs of other disposal methods (Cohen and Lansford, 1993). Prior to the Clean Air Act of 1970, incineration was the primary disposal method across the Southeastern United States for most gin operations (Smith, 1999). Incinerating CGT leaves relatively small amounts of ash and even more importantly it can be done on the gin site, eliminating expensive transportation costs (Mayfield, 1991). The cost associated with gathering and transporting CGT can prevent potential utilization options away from the gin site (Parnell et al., 1991). With all the disposal efforts used currently, and in the past, only a small portion of the available CGT is actually being utilized in a productive or profitable way (Holt et al. 2000).

Cotton Gin Compost

The main beneficial disposal method for CGT is to compost the waste, producing a material that can be useful and potentially profitable (Rodale 1971; Fava, 2004; Tejada et al., 2001). Cotton gin trash is most frequently composted in windrows, which are elongated piles of stacked raw material that are porous enough for air to pass through passively (Rynk and Richard, 2001). Cotton gin trash has also been previously shown to compost well in static piles when mixed with other organic materials including beet vinasse (Diaz et al., 2002) and rice hulls (Papafotiou et al., 2001). Composting CGT has also been shown to reduce dry matter weight by 50% and volume by 60%, making this material easier to handle and transport than the raw product (Mayfield 1991).

Composting is a legitimate method to reduce the threat of weed and disease infestation of CGT that has been a concern for many growers . A study conducted by Griffis and Mote (1978) reported 0% germination of several common and problematic weed species after being composted in CGC, including purple moonflower, sesbania, pitted morningglory, redroot pigweed, and johnsongrass. The destruction of weed seeds in the composting process is the result of adequate moisture and warmth that cause germination, followed by an increase in temperature that destroys the plummule or cotyledon of the emerging weed seeds (Cole, 2004).

Some major cotton producing states in the southeast do not allow the spreading of any biomass, even when composted, on land because of environmental regulations or the needed land resources are not available (Parnell et al., 1991). The regulations placed on the land application of CGC were spurred by the threat of non-biodegradable chemicals leaching from the compost into the soil. In recent years the United States Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) have required that all chemicals used on cotton be biodegradable within a two week period of the application.

The method of composting utilized will determine the amount of time required for the composting process to be complete. According to Parnell et al. (1991), quality compost can be generated in as little as 90 days. Mote and Griffis (1978) reported that compost could be properly generated in as little as 65 days compared to much longer time frames described by others. Regardless of the method used, compost can be achieved in relatively short time, which can quickly reduce stockpiles of CGT at gins, and provide a potentially marketable substrate to consumers.

Physical and Chemical Properties of Substrates

The success of a horticultural substrate is mainly based on the behavior of the plants grown in them, therefore high quality substrates with the proper physical and chemical properties result in high yields and excellent quality (Verdonck and Gabriels, 1988). The purpose of container substrate is to physically support plants and to supply adequate oxygen, water, and nutrients for proper root functions (Reinikainen, 1993; Handreck and Black, 2002). When plants are grown in containers their roots are restricted to a small volume, consequently the demands made on the substrate for water, air, nutrients and support are much more intense than those made by field-grown plants which have an infinitely greater volume of soil in which to facilitate root growth (Bunt, 1988). Several factors influence how to choose substrates for horticultural crop production beginning with the type/species of plant being grown. Substrates should be suitable for the growth technique employed in a particular production system and it should be a permanent substance that can sustain long growing periods with minimal shrinkage or degradation (Reinikainen, 1993).

Recommendations and standards have been set for horticultural substrates to give growers an idea of materials that could be used as components for their substrate blends (Cole, 2004). In addition, the suggested physical and chemical properties of substrates are outlined in The Best Management Practices (BMP) Guide for Producing Container-

Grown Plants (Yeager et al., 2000). This reference suggests the following ranges for desired physical properties for container substrates after irrigation and drainage (% volume basis): air space 10 to 30%, water holding capacity 45 to 65%, total porosity 50 to 80%, and bulk density 0.19 to 0.70 g/cm^3. The BMP guide also suggests that substrates amended with controlled release fertilizers should have pH levels in the range of 5.0 to 6.0 (varies with species being grown) and have electrical conductivity (EC) levels between 0.2 and 0.5 mS/cm (mmhos/cm). Cation exchange capacity of substrates is important in all substrates to retain nutrients against leaching by irrigation water or rainfall. The term “buffering capacity” is often used interchangeably with CEC. For soil less container substrates, CEC varies significantly among substrates with sand having typical values of 0.5 meq/100 ml and sphagnum peat moss with values as high as 11.9 meq/100 ml (Yeager, 2000).

Numerous methods are used to determine physical and chemical properties of horticulture substrates. A common procedure for determining substrate physical properties is the North Carolina State University Porometer (Fonteno et al., 1981). The determination of chemical properties of horticultural substrates can be conducted in several popular methods including Spurway/acid extraction, saturation extraction, bulk solution displacement, and the pour-through nutrient extraction procedure (Markus, 1986; Warncke 1986; Nelson and Faber, 1986; Wright, 1986).

Composts in Horticulture

Although composting has been practiced for thousands of years, it was not until the 20th century that controlled scientific studies were published illustrating the benefits of compost use in crop production. The two main horticultural uses of composts are as soil amendments and as components in container substrates (Raviv, 2005). Composts may also reduce the need for substrate disinfestation or for fungicide drenches, due to suppressive effects often found on a number of common soil pathogens (Hoitink and Kuter, 1986.)

Raviv (2005) lists three main reasons for the increased use of composts as a component in horticultural container substrates: 1) In many cases, nonedible crops, such as ornamentals, forest and garden trees and shrubs, etc., can serve as a safe outlet for composts that be considered as nondesirable for food crop production. 2) Various composts act as well as peat moss does in container substrates, while their cost is considerable lower. 3) Mature composts may suppress many soilbourne diseases. Research has been conducted through the years to confirm and further explore these reasons to explore the potential of marketing and successfully incorporating these organic materials into current horticulture production systems.

Raw materials that can be composted are nearly endless. Common materials include cow manure, chicken manure, human manure, seaweed, leaves, grass clippings, sawdust, crop residues, peanut and rice hulls, coconut coir, bagasse, olive and grape marc, and agroindustrial wastes to name a few (Rodale, 1971; Sylvia et al., 1999; Prosser and Prosser, 2002; Garcia-Gomez et al., 2002). Uniform horticultural standards for composted products have been hard to establish because of the various raw materials that are being used (Cole, 2004). The U.S. Composting Council has developed a set of standards for composts to serve as guidelines for proper treatment and use of composts.

Research has been conducted on numerous composts to evaluate their potential as substrates or substrate components in ornamental plant production, ranging from biosolids (municipal) waste (Klock, 1997; Evans and Rainbow, 1998; Hicklenton et al., 2001; Wilson and Stofella, 2001; Bugbee, 2002; Wilson and Stoffella, 2003) to agroindustrial wastes (Bragg, 1998; Garcia-Gomez et al., 2002) to pruning wastes (Benito et al., 2005) to coconut coir (Bryson and Barker, 2002; Hernandez-Apaolaza et al., 2005) to poultry wastes (Bilderback and Fonteno, 1993; Tyler et al., 1993; Evans, 2004) to yard trimmings (leaves and green wastes) (Klock-Moore, 1999; Spiers and Fietje, 2000; Prasad and Maher, 2001; Chen et al., 2003) to cork materials (Aguado et al., 1993; Carmona et al., 2003; Carmona et al., 2003) to agricultural wastes (Inbar et al., 1988; Jespersen and Willumsen, 1993) to olive-mill waste (Papafotiou et al., 2004) to rubber tire chips (Calkins et al., 1997) to polyester fleece (Schroeder and Foerster, 2000) to seagrass (Orquin et al., 2001) to earthworm castings (vermicompost) (Atiyeh et al., 2000; Atiyeh et al., 2000; Hildago and Harkness, 2002; Chaoui et al., 2003) to paper mill wastes (Chong, 2003) to ground bovine (Evans, 2004) to name a few. The possibilities are endless and the research continues on these, and other organic materials.

Despite limited available information on utilizing composts in tomato production, there is research published evaluating composts as potential substrates in tomato transplant and greenhouse vegetable production ranging from grape marc (Reis et al., 1998) to coconut coir (Arenas and Vavrina, 2002) to sugarcane waste (Stoffella and Graetz, 2000) to yard wastes (Ozores-Hampton et al., 1999; Maynard, 2000) to sorghum bagasse (Sanchez-Monedero et al., 2004) to wood fiber (Gruda and Schnitzler, 2004) to municipal solid waste (Castillo et al., 2004) to worm waste (vermicompost) (Hashemimajd et al., 2004) to pulp mill solids (Levy and Taylor, 2003).

Cotton Gin Compost As A Horticultural Substrate

The amount of potting media used in the southeastern United States horticultural industry has more than doubled in recent years, with pine bark and peat moss being the primary substrates used (Shumack et. al., 1991). After 1970, much of the CGT produced in the cotton ginning industry was composted, and uses for CGC were examined. Studies have shown CGC to be generally beneficial to growth and yield of various plants when used in place of, or as an amendment to, existing growing substrates (Thomasson, 1996). Incorporating CGC to soil as an amendment has been shown to add nutrients to and increase the WHC of certain soils (Mayfield, 1991). CGC also has a high CEC, high porosity, and it contains organic nitrogen that is preserved during the composting process being slowly released to the environment after maturity (Papafotiou et al., 2001).

From the research previously conducted with CGC for growing ornamental crops, positive results have been obtained. A greenhouse study with Coleus x hybridus ‘Golden Bedder’, golden bedder coleus, found substrates containing 20-60% CGC produced plants with height, shoot, weight, and visual quality equal to or better than those grown in a 100% PB substrate (Owings, 1994). An experiment using CGC in the production of flowering plants found that up to 60% of the peat in a growing media with perlite could be replaced with CGC with no negative effects on height and flowering (Papafotiou et al., 2001). Sloan et al. (2004) stated that the addition of CGC to PB resulted in improved plant growth compared to PB alone for *Viola* x *wittrockiana, Catharanthus roseus*, and *Lagerstroemia indica*. A study using 'Fizzy White' kale and 'Orange Boy' marigold found that shoot dry weight and foliar color ratings of plants grown in CGC amended soil were equal or slightly greater than those of plants grown in peat amended substrates (Shumack et al., 1991). Shumack et al., (1991) also stated that more investigation needs to be done to explore the possibilities for incorporating CGC in to standard substrate mixes for the production of ornamental plants. With these findings, one of the most promising areas for using large quantities of the CGC, as well as other agricultural wastes, is in the production of horticultural crops.

Project Goal

Currently, limited research on the use of CGC on greenhouse tomato production has been conducted. One of the few greenhouse studies conducted with tomatoes showed that a 3:1 ratio of CGC and poultry liter (PL) used in a 20:1 ratio of soil to compost blend, produced higher tomato yields that using commercial fertilizers (Pessarakli and Tucker, 1984). This study used tomato varieties that are not currently in use, therefore possibly limiting the practical application for today's growers using current tomato varieties.

One objective of this project is to evaluate the yield of 'Blitz' tomato, a common greenhouse tomato cultivar, when planted in varying ratios of CGC and PB and to determine the most adequate application rate of the CGC, and its effects on tomato fruit quality and yield. Research objectives will also focus on evaluating root growth of several horticultural crops when grown in CGC amended PB substrates to determine growth response, thereby exploring the possibility of utilizing CGC as a substrate, or substrate amendment for container production.

Information from this research may lead to the commercial use of CGC as a substrate for greenhouse tomato production, giving growers an alternative to buying the expensive, and often inconsistent PB substrate. In addition, these findings could create a market for CGC, making it a potentially profitable agricultural waste that can increase the income of ginning operations around the country. Useful recommendations can be made to nursery and greenhouse vegetable growers so that they have the option to use CGC as an alternative substrate in their production system.

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CHAPTER II

ROOT GROWTH OF THREE HORTICULTURAL CROPS GROWN IN PINE BARK AMENDED COTTON GIN COMPOST

Abstract

Previous research has shown shoot growth of ornamental plants grown in composted organic substrates to be similar to that of plants grown in traditional substrates, but little work has been done to investigate root growth in these composted substrates. In 2004 'Blitz' tomato (*Lycopersicon esculentum* Mill. 'Blitz'), 'Hot Country' lantana (*Lantana camara* Mill. 'Hot Country'), and weeping fig (*Ficus benjamina* L.) were placed in Horhizotrons™ to evaluate root growth in 100% pine bark (PB) and three PB: cotton gin compost (CGC) substrates containing by volume, 60:40 PB:CGC, 40:60 PB:CGC, and 0:100 PB:CGC. Horhizotrons™ were placed in a greenhouse, and root growth in all substrates was measured for each cultivar. Physical properties (total porosity, water holding capacity, air space, and bulk density) and chemical properties (electrical conductivity and pH) were determined for all substrates. Physical properties of 100% PB were within recommended guidelines and were either within or above recommended ranges for all PB:CGC substrate blends. Chemical properties of all substrates were within or above recommended guidelines. Root growth of all species in substrates containing CGC was similar to or more enhanced than root growth in 100% PB.

Index words: agricultural waste, Horhizotron™, substrate, root establishment, media.

Species used in this study: 'Blitz' tomato (*Lycopersicon esculentum* 'Blitz'); weeping fig (*Ficus benjamina*); 'Hot Country' lantana (*Lantana camara* 'Hot Country').

Significance to the Horticulture Industry

Three horticultural crops were grown in PB substrates containing 0, 40, 60, and 100% CGC. Results herein demonstrate that PB can be amended with CGC for an increase in root growth rate and development when compared to root growth in 100% PB. Utilizing CGC as a substrate or substrate component with PB can provide a reliable and beneficial substrate option for plant growers.

Introduction

Pine bark (PB) and peat are two of the most common substrate components currently used in horticultural crop production. The supply, consistency, and cost of these materials has often been a concern for growers throughout the United States. These concerns have prompted the search for alternative substrates and substrate components that can be successfully utilized for quality crop production.

Research has been conducted through the years to evaluate the use of various composted materials as potential substrates for horticulture plant production. Substrates must have physical and chemical properties conducive for plant growth and be uniform, consistent, light weight, affordable (8, 9), and absent of weed seeds and harmful pathogens (5). Choosing an adequate potting substrate is a critical step in meeting the demands for growth of healthy plants.

Cotton gin trash (CGT) is the term used to describe the by-products of the cotton ginning process that includes the leaves, stems, hulls, and some lint from cotton (*Gossypium* sp. L.) (6, 17). One use of CGT requires the materials to be composted to produce cotton gin compost (CGC), a potential substrate component for the production of horticultural crops. 'Golden Bedder' coleus (*Solenostemon scutellarioides* L.) grown in substrates containing 20-60% (volume basis) CGC produced plants with height, shoot dry weight, and visual quality equal to or higher than plants grown in a 100% PB substrate (10). 'Purple Rain' pansy (*Viola ×wittrockiana* Gams.) and 'Carolina Beauty' crapemyrtle (*Lagerstroemia indica* L.) grown in a PB substrate with 33% CGC had a more vigorous shoot growth response than plants grown in 100% PB (15). Most recently, Cole (3) reported that 'Winter Gem' boxwood (*Buxus microphylla* Sieb. & Zucc.), 'Firepower' dwarf nandina (*Nandina domestica* Thunb.), and 'Renee Mitchell' azalea (*Rhododendron indicum* L. & Sweet) grown in CGC amended substrates had similar shoot growth and visual root system quality as plants grown in 100% PB.

When plants are produced in containers their roots are restricted to a small volume; consequently the demands made on the substrate for water, air, nutrients, and support are more intense than those made by plants grown in a field production situation where unrestricted root growth can occur (2). Vigorous root systems are essential for growth and development of healthy plants. A healthy, functioning root system increases the surface area available for the uptake of water and mineral elements. In addition, the root system architecture provides physical support, storage, and anchorage needed by plants (14, 18, 20).

Frequently excluded from horticultural research, root growth and root system architecture are important factors influencing plant performance and survival (21). Understanding root growth and development is important to improving plant quality and production success. When stepping up plants to a larger container size, uninterrupted growth and overall plant health are highly dependent on the formation of new roots outside of the original root ball into the substrate of the new container.

The capability to observe and measure roots as they grow into a substrate is very useful in determining root growth preference in various substrates. In addition, studying the location and depth of root formation within the container profile provides valuable information to understanding root architecture and development. Some techniques used to study root growth in the past include the container-type rhizotron, rhizobox, and portable rhizotron (1, 7, 11, 19). These devices are often expensive and may provide limited information. Other methods limit root growth studies to either visual observations using a rating scale or dry weight analysis, both of which are destructive. Recently, the Horhizotron™, a light weight, inexpensive, and easily constructed instrument for measuring horizontal root growth has been developed (21). This new instrument provides a simple, non-destructive method for measuring root growth and development in various root environments and substrates. Unlike other container-type rhizotrons where roots are hidden until they reach the edge of the container, the Horhizotron™ allows roots to be observed and quantified as they grow from the original root ball and penetrate into the surrounding substrate. The design of this instrument allows the effect of several different substrates on root growth to be evaluated on an individual plant.

The objective of this study was to utilize the Horhizotron™ to evaluate root growth of 'Blitz' tomato (*Lycopersicon esculentum* Mill. 'Blitz'), weeping fig (*Ficus benjamina* L.), and 'Hot Country' lantana (*Lantana camara* Mill. 'Hot Country') when grown in various blends of PB and CGC. Physical and chemical properties of substrates in this study were also compared.

Materials and Methods

CGW was obtained from the Milstead Farm Group, Inc., Shorter, AL and windrowed for six months to compost at E.V. Smith Research Center, Shorter, AL. In July 2004, the CGC was sifted through a 15 mm screen to remove foreign debris, rocks, and clods of CGC. Four substrate blends of milled PB and CGC were mixed (by vol) in the following ratios: 100:0 PB:CGC (100% PB), 60:40 PB:CGC, 60:40 PB:CGC, and 100:0 PB:CGC (100% CGC). Based on initial pH values varying rates of dolomitic limestone were added to substrates to achieve pH levels near 6.0. 100:0 PB:CGC was amended with 2.1 $kg \cdot m^{-3}$ (3.6 $lb \cdot yd^{-3}$), and 60:40 PB:CGC was amended with 1.1 $kg \cdot m^{-3}$ (1.8 $lb \cdot yd^{-3}$). No amendment was made to 40:60 PB:CGC and 0:100 CGC substrates where pH was already in the desired range of 6.0. On July 3, 2004, eight week old seedlings of 'Blitz' tomato were removed from 11.3 liter (3 gal) containers and placed individually in separate Horhizotrons™ [2 ft × 2 ft × 1 ft (0.6 m × 0.6 m × 0.3 m)] (21) on greenhouse benches at the Plant Science Research Center at Auburn University, Auburn, AL. On August 16, 2004, weeping fig and 'Hot Country' lantana were removed from 11.3 liter (3 gal) containers and placed in separate Horhizotrons™ on greenhouse benches at the Paterson Greenhouse Complex, Auburn University. Root balls of all plants were positioned in the center of each Horhizotron™, firmly touching the edges of each wedge-shaped quadrant [8 × 10.5 inches (20.3 × 26.67 cm)] (21). Each of the four quadrants were randomly filled with one of the substrate blends to the height of the root ball. Horhizotrons™ containing 'Blitz' tomato plants were under drip irrigation supplying water and fertilizer at rates according to recommended guidelines for greenhouse tomato production (16). Four drip emitters were evenly distributed down the center of each quadrant supplying 240 ml of Veg-Gro 3-15-27 (3N-6.6P-22.41K; Veg-Gro Supplies Ltd., West Auckland, New Zealand) at 24 ppm N and Calcium nitrate 15.5-0-0 (15.5N-0P-0K; Hydro Agri North America Inc., Tampa, FL) at 46.5 ppm N for a total of 70.5 ppm N supplied at each of six daily watering cycles. Horhizotrons™ with weeping fig and 'Hot Country' lantana were hand watered daily and fertilized weekly with Polyon®20-20-20 (20N-8.8P-16.6K; Pursell Industries, Sylacauga, AL) liquid feed applied at the rate of 200 ppm N. This study was a randomized complete block design (RCBD) with each Horhizotron™ representing an individual block. There were five blocks per species used in this study.

Root length and location in the quadrant profile were measured as newly formed roots grew out from the root ball and along the face of the glass quadrants. A transparent grid placed on the two glass sides of each quadrant allowed observation and measurement of the five longest roots on each side of the quadrant. The five longest roots of 'Blitz' tomato on each side of the four quadrants were measured three days after transplanting (DAP) and every three days thereafter until they reached the end of the 25 cm (10 in) quadrants. Roots of weeping fig and 'Hot Country' lantana were measured 7 DAP and then once weekly using the same method. Over the course of the study root measurements were discontinued when roots reached the end of the Horhizotron™ quadrant.

At the conclusion of the study root development in each quadrant was evaluated visually. A rating scale of 0-5 was used (0 = no root growth; 1 = 20% of the quadrant face was filled with roots; 2 = 40% of the quadrant face was filled with roots; 3 = 60% of the quadrant face was filled with roots; 4 = 80% of the quadrant face was filled with roots; 5 = 100% of the quadrant face was filled with roots). Due to the design of the Horhizotron™, each individual plant grows in all four substrate blends simultaneously, rendering shoot growth measurements unnecessary.

Physical properties including air space (AS), water holding capacity (WHC), total porosity (TP), and bulk density (BD) were determined for each substrate blend using the North Carolina State University Porometer (NCSU-P) (4). Properties were determined using three representative samples of each substrate.

Data were analyzed using GLM procedures (13) . Regression analysis of root growth over time was performed for all species within each substrate treatment. Fisher's Least Significant Difference (P = 0.05) was used to separate means of the visual root evaluation at the end of the experiment.

Results and Discussion

Root Growth. All species exhibited linear rates of root growth over the course of the experiment in all four substrates (Figures 1, 2, and 3).

Through the first two measurement dates (6 DAP) 'Blitz' tomato grown in all CGC blended substrates had similar or more root growth than that of plants grown in

100% PB (data not shown). Beginning with the third measurement (9 DAP) through the conclusion of the study (21 DAP), root growth was similar among all treatments (Figure 1). At all measurement dates there was more root growth in CGC amended substrates than in 100% PB for weeping fig. At 21 DAP, root growth of weeping fig in substrates containing 60 and 100% CGC reached the end of the quadrants and were no longer measured (Figure 2). After 28 DAP, roots in substrate containing 40% CGC reached the end of the quadrants (data not shown). Roots grown in 100% PB were the last to reach the end of the quadrants after 35 DAP (data not shown). 'Hot Country' lantana exhibited more root growth in all treatments containing CGC compared to 100% PB through the third measurement date (3 weeks) at which time, roots in these treatments had grown to the end of their quadrants (Figure 3). Roots in 100% PB took twice as long (6 weeks) to reach the end of the quadrant (data not shown).

Visual rating of root growth of 'Blitz' tomato was significantly higher in the two substrates containing 60 and 100% CGC when compared to root growth in 20% CGC and 100% PB substrate blends (Table 1). Root ratings of weeping fig and 'Hot Country' lantana reflected the increased root development across all substrates containing CGC when compared to 100% PB (Table 1). At the conclusion of this study root development in all CGC blended substrates was considerable enough to firmly hold the substrates together when plants were pulled vertically from the Horhizotrons™. The quadrant containing 100% PB shattered upon being pulled from the Horhizotron™ as a result of the lesser developed root system. Once the 100% PB quadrant shattered, the contour of the original 3 gal container could still easily be seen.

Physical properties. Air space (AS) was highest in 100% PB, but was within the desirable range recommended by *The Best Management Practices Guide for Producing Container-Grown Plants* (BMP) for physical properties of container substrates (22, Table 2). AS was lowest in 40% and 60% CGC substrates, falling slightly below recommended ranges (Table 2). Water holding capacity was highest in all substrate blends containing CGC with each slightly above the BMP recommended range of 45 – 65% (Table 2). Total porosity was highest in 100% CGC which was expected due to the smaller particle size of the CGC and decreased as the amount of CGC decreased in each substrate. The TP of all substrates, including 100% PB, were within the recommended BMP range of 50-85% (Table 2). Bulk density was lowest in 100% PB and highest in 100% CGC. BD increased as the percent of CGC increased in each of the four substrates. All substrates were well within the range of 0.19 to 0.70 $g \cdot cm^{-3}$ recommended by BMP guidelines (Table 2).

Chemical properties. After adjusting the initial pH of the 100% PB and 40% CGC, all substrates were measured again, and all four substrate blends had consistent pH values, and were within, or slightly above the BMP recommended guidelines (Table 2). EC values were also measured, and substrates containing CGC were well above the desired ranges (Table 2), with EC values increasing as the percent of CGC increased in each substrate. High EC values are likely due to high organic nitrogen (N) that can be present in CGC at rates as high as 3% dry weight (12). With irrigation, EC levels quickly decreased as salts were leached from the substrates, likely explaining why root injury of plants growing in the CGC substrates did not occur.

At 6 DAP, root growth of 'Blitz' tomatoes grown in CGC amended substrates was similar to those grown in 100% PB. PB is one of the conventional, and most widely used substrates for greenhouse tomato production. It is probable that substrate showed no effect on root growth after only a few days due to the vigorous growth rate and development of tomatoes when grown under ideal conditions in a greenhouse environment. These results suggest that CGC can be used as a substrate or substrate component for tomato greenhouse production based on the positive response in root growth and development exhibited in this study. Research is underway to evaluate the yield and quality of tomatoes when grown in the same CGC blended substrates used in this study. Future data on tomato fruit yield and quality in conjunction with the results of root growth and development in this study will provide further evidence of the potential use of CGC as a substrate in commercial greenhouse tomato production.

Results show that weeping fig and 'Hot Country' lantana had more root growth in CGC amended substrates than when grown in PB alone (Figure 2 and 3). Considering that this study was conducted in only a few weeks, it is important to note that even though root growth in these two species occurred more quickly in CGC amended substrates, root growth in 100% PB was not necessarily undesirable. This experiment provides strong evidence that roots can grow effectively and vigorously into substrates containing CGC. This can be important in nursery production operations where plants are transplanted to larger containers to obtain larger sized plants needed for commercial and retail sale.

The incorporation of CGC is shown to enhance the physical properties of a PB substrate, thus producing desirable characteristics for plant growth. When added to PB, CGC can increase the pH and EC of the substrate and also greatly increase the WHC of the substrate. Increased WHC can be beneficial to plants that prefer wetter soils or it could decrease the irrigation needed to maintain optimum moisture levels for plant production. With increasing interest to facilitate and maintain healthy root growth and establishment of horticultural crops, utilizing CGC can be an effective way to achieve production of various horticultural crops.

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Table 1. Effect of substrate on root rating of three species.

Species	PB:CGC ratio[z]	Root rating[y]
'Blitz' tomato	100:0	3.6c[x]
	60:40	3.1c
	40:60	4.2b
	0:100	4.8a
weeping fig	100:0	2.6c
	60:40	3.8b
	40:60	4.5a
	0:100	4.4ab
'Hot Country' lantana	100:0	2.0b
	60:40	4.2a
	40:60	4.5a
	0:100	4.7a

[z]PB = pine bark, CGC = cotton gin compost.

[y]Roots were evaluated visually using a scale of 0-5 (0 = no root growth; 1 = 20% of the quadrant was filled with roots; 2 = 40% of the quadrant was filled with roots; 3 = 60% of the quadrant was filled with roots; 4 = 80% of the quadrant was filled with roots; 5 = 100% of the quadrant was filled with roots).

[x]Means separation within species by Fisher's LSD at $P = 0.05$. Means followed by the same letter within a species are not significantly different.

Table 2. Physical and chemical properties of four pine bark (PB) : cotton gin compost (CGC) substrates.

PB:CGC Ratio[z]	Water Holding Capacity[y] (%)	Air Space[y] (%)	Total Porosity[y] (%)	Bulk Density $g \cdot cm^{-3}$	Final EC mmhos/cm	Final pH
100:0	53.15b[x]	18.51a	71.66c	0.20c	0.26d	6.07a
60:40	67.88a	8.35c	76.22b	0.21c	2.03c	5.89a
40:60	69.58a	7.58c	77.16b	0.24b	4.87b	6.05a
0:100	69.12a	12.37b	81.50a	0.27a	9.81a	6.15a
BMP Guidelines[w]	45-65	10-30	50-85	0.19-0.70	0.8-1.0	5.0-6.0

[z]PB = pine bark, CGC = cotton gin compost.

[y]Values are based on percent volume of the substrate and were measured at container capacity.

[x]Means separation within columns by Fisher's LSD at $P = 0.05$. Means followed by the same letter within a column are not significantly different.

[w]BMP = Best Management Practices recommended ranges (in percentages) for substrates used in general nursery production (Yeager et al., 2000)

Figure 1. Root growth of 'Blitz' tomato measured every three days after transplanting (DAP) when grown in pine bark (PB) and three PB amended cotton gin compost (CGC) substrates.

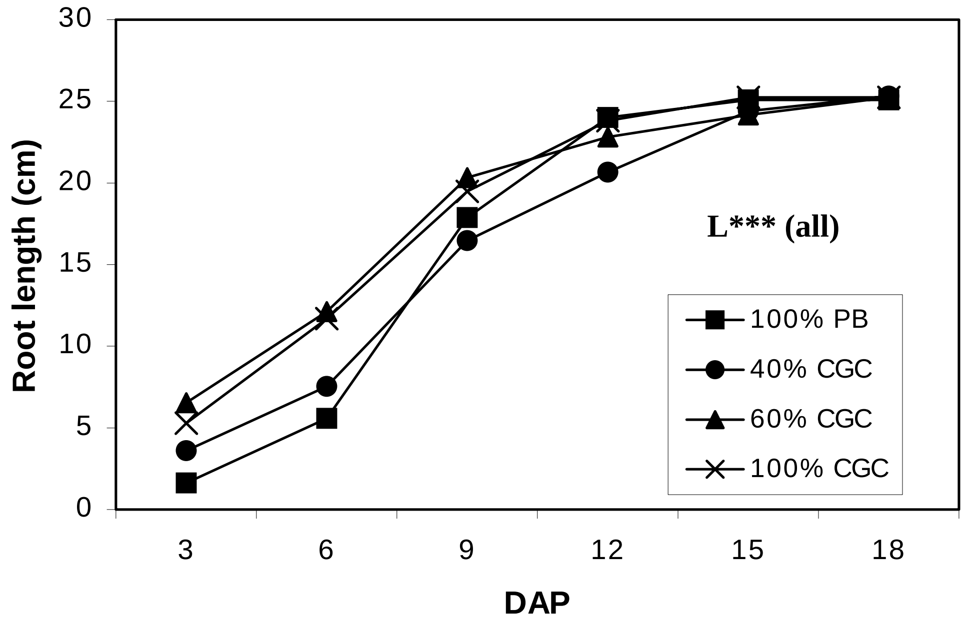


Figure 2. Root growth of weeping fig measured every seven days after transplanting (DAP) when grown in pine bark (PB) and three PB amended cotton gin compost (CGC) substrates.

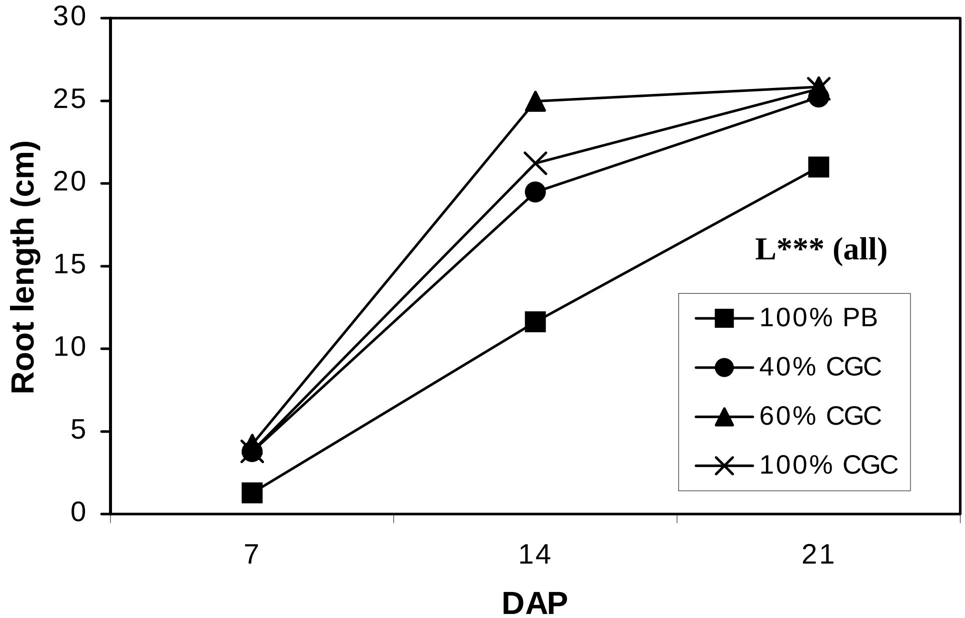
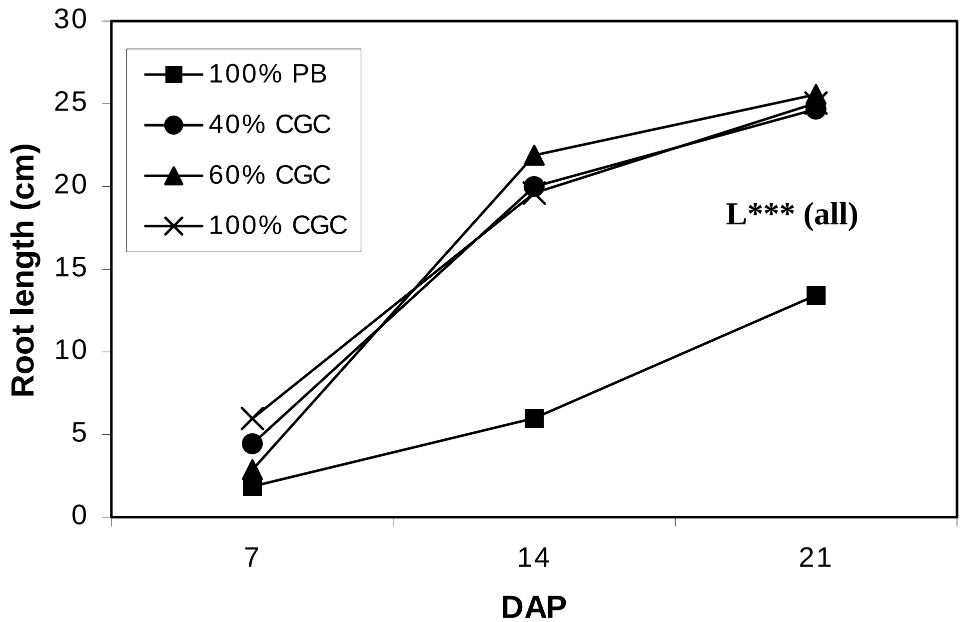


Figure 3. Root growth of 'Hot Country' lantana measured every seven days after transplanting (DAP) when grown in pine bark (PB) and three PB amended cotton gin compost (CGC) substrates.



CHAPTER III

RATES OF COTTON GIN COMPOST AMENDMENTS TO PINE BARK AFFECT HARVEST YIELDS OF GREENHOUSE TOMATOES

Abstract

Tomatoes are the most abundantly produced greenhouse vegetable crop in the United States. The use of compost substrates has increased in recent years for the greenhouse production of many vegetables, bedding plants, and nursery crops. 'Blitz' tomatoes were grown during the spring and fall growing seasons in 2004 in six substrate blends of pine bark (PB), a traditional production substrate in the southeastern U.S., and cotton gin compost (CGC), an agricultural by-product, to assess the potential use of CGC as a viable replacement for PB for the production of greenhouse tomatoes. Treatments ranged from 100% PB to 100% CGC. Plants grown in substrates containing CGC produced similar total yields during both cropping seasons in 2004 compared to plants grown in 100% PB. In both experiments marketable yields were similar across all treatments. Similarly, cull fruit was not different among treatments. Substrates containing CGC had significantly higher EC levels both initially and throughout both growing seasons than 100% PB. Initial and final pH of all substrates were similar during both studies and remained within recommended ranges for greenhouse tomato production. Water holding capacity increased as the percent CGC increased in each substrate blend, indicating the need for adjusted irrigation volume on substrates

containing CGC compared to the 100% PB control.

Introduction

Increased demand for tomatoes (*Lycopersicon esculentum* Mill.) for fresh consumption and export have facilitated the need for large scale greenhouse production (Ismail et al., 1993). Total acreage in greenhouse tomato production increased 40 percent between 1996 and 1999, making tomatoes the leading greenhouse vegetable crop in the United States (Dodson et al., 2002). Commercial production of compost from organic materials produced by farms, households, or industries has been promoted as a means of simultaneously reducing the volume of organic wastes being dumped in landfills or improperly discarded while producing a product useful for plant production (Levy and Taylor, 2003). Composts can enhance soil organic matter, soil structure, infiltration, tilth, and water holding capacity. In addition, the composting process can suppress weeds and their germination, inhibit harmful pathogens and diseases, and provide some nutritional value (Brown et al., 1988; Noble and Roberts, 2004). Many types of aggregate and organic substrates are currently available for the production of greenhouse tomatoes including peat moss, perlite, rock wool aggregate, glass wool, pine bark, sawdust, and several others (Papadopoulos and Ormrod, 1991; Snyder, 1998). More recently, composted organic materials have been utilized for both ornamental and greenhouse vegetable crop production. Tomato plants grown in composted wood fiber were shown to have no significant shoot or root growth differences compared to plants grown in a traditional peat substrate (Gruda and Schnitzler, 2004). Municipal solid waste has also been used to produce tomato transplants with shoot growth equal to that of transplants grown in the standard peat:perlite substrate blend (Castillo et al., 2004). Composts produced from mixtures of sewage sludge, vermicompost, biosolids, and plant residues such as rice hulls and yard waste have shown potential as alternative substrates for tomato production with equal or increased shoot and root dry matter compared to tomatoes grown in a 67% sand and 33% soil substrate (Hashemimajd et al., 2004).

Another organic waste with growing popularity and interest is an agronomic by-product of the cotton industry. Each year, the U.S. cotton industry harvests 17 to 18 million bales of cotton that go through the ginning process to separate the lint and seed from the cotton gin trash (CGT) (Fava, 2004). CGT is the term used to describe the by-products of the cotton ginning process that consist mainly of reproductive and vegetative parts of the cotton plant that were collected during harvest (Thomasson, 1996; Buser, 2001). It is estimated that 1.2 to 2.5 million metric tons of cotton gin by-products other than cottonseed are produced annually by U.S. cotton gins, creating a significant disposal problem in the ginning industry (Buser, 2001). One use of CGT requires the materials to be composted to produce cotton gin compost (CGC). CGC has been studied with positive results suggesting its use as a potential substrate component for the production of horticulture crops (Papafotiou et al., 2001; Sloan et al; 2004; Cole et al., 2005).

With limited information available demonstrating the successful use of organic composted materials as substrates in greenhouse tomato production, there are no generally accepted recommendations or guidelines for their utilization (Rippy et al., 2004). Specifically, there is a need to determine if cotton gin compost (CGC) can be utilized as an amendment to, or replacement of, pine bark (PB) for greenhouse tomato production. The objective of this study was to evaluate CGC as an amendment to, or replacement of, pine bark for the greenhouse production of tomatoes.

Materials and Methods

Cotton gin waste (CGW) was obtained from the Milstead Farm Group, Inc., Shorter AL, and windrow composted for six months at the E.V. Smith Research Center, Shorter, AL. In Jan. 2004, CGC was obtained from E.V. Smith for the purpose of this study. During the same month the CGC was sifted through a 15 mm screen to remove foreign debris, rocks, and clods of CGC in preparation for the spring experiment. Six substrate blends of milled PB and CGC were mixed (by vol) in the following ratios 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100. Thus, treatments contained 0%, 20%, 40%, 60%, 80%, or 100% CGC. This procedure was repeated in Aug. 2004 to mix substrates for the fall season of this study, with CGC being used from the same batch obtained in Jan. 2004 which had been dry-stored. Substrate analysis was conducted in 2004 at the Soil Testing Laboratory, Auburn University, using three representative samples of each substrate blend. Sample analysis provided initial nutrient content of each of the treatments. As a traditional substrate in greenhouse tomato production, 100% PB was used as the experimental control. Based on initial pH values determined from three representative samples of each substrate blend, varying amounts of dolomitic limestone were added as follows to achieve a pH near 6.5: 100:0 PB:CGC received 1.5 $kg{\cdot}m^{-3}$, 80:20 PB:CGC received 1.3 $kg{\cdot}m^{-3}$, 60:40 PB:CGC received 0.9 $kg{\cdot}m^{-3}$, 40:60 PB:CGC received 0.7 $kg{\cdot}m^{-3}$, 20:80 PB:CGC received 0.4 $kg{\cdot}m^{-3}$, and 0:100 PB:CGC received 0.4 $kg{\cdot}m^{-3}$.

Plants were arranged in a randomized complete block design (RCBD) with three sub-plots of each treatment within each block. Blocks were oriented North to South in a greenhouse bay measuring 10.1 m × 9.1 m [91.9 m^2] at the Plant Science Research Center at Auburn University, Auburn, AL. The greenhouse was equipped with a Modine high efficiency gas heater and an evaporative pad system for cooling. Maximum daytime temperature was set at 27°C, and minimum night temperature was 18°C. Seeds of 'Blitz' tomato (*Lycopersicon esculentum* Mill.) (Paramount Seeds, Inc. Palm City, FL) were planted in 36-count cell flats (4 × 7.5 × 5.5 cm cell size) containing Premiere Pro-Mix BX (Premier Horticulture Ltd., Dorval, Quebec, Canada). Tomatoes for the spring 2004 study were seeded on 16 Dec. 2003 and were grown for seven weeks under natural light conditions on greenhouse benches. Tomatoes for the fall 2004 study were planted on 13 July 2004 and grown for seven weeks at the same location under natural lighting. In each study, seedlings were irrigated twice daily and fertilized once weekly with 15N-7P-14K (Scotts Co., Marysville, Ohio) at the rate of 100 ppm N. Seedlings were transplanted on 2 Feb. 2004 (spring), and on 17 Aug. 2004 (fall). One seedling was transplanted into each 10-L Bato Hydro Bucket (Bato Trading B.V., Zevenbergen, The Netherlands) pre-filled with each treatment. Prior to filling, a 3.2 cm hole was drilled in the bottom of each container to facilitate adequate drainage when irrigated. Each hole was covered with a double layer of mesh screen to prevent substrate erosion from the container. Once filled with substrate, each Bato container was placed on a single layer of cinder blocks (block dimensions 19.1 cm × 19.1 cm × 39.4 cm) to elevate the containers above the greenhouse floor so that leachate could be collected from beneath.

Once transplanted, plants were fertigated in six cycles daily using 1.89 $L{\cdot}h^{-1}$ drip emitters. One emitter was placed in each of the four corners of the containers to ensure consistent moisture on all sides of the plant. Plants were fertigated automatically by a MC-8 Plus Irritrol irrigation controller (Irritrol Systems, Riverside, CA) at 0700, 0900, 1100, 1300, 1500, and 1700 HR. Fertilizer concentrations were increased based on the development of the tomato plants (Table 1) and followed closely with the recommended application rates according to Snyder (1998). Nitrogen (N) concentration of the fertilizer solution for each stage of plant growth and fruit development were as follows: Stage 1, transplanting to anthesis of flowers on first cluster, plants received 71 ppm N; Stage 2, first cluster fruit set to second flower cluster anthesis, plants received 81 ppm N; Stage 3, second cluster fruit set to third flower cluster anthesis, plants received 101 ppm N; Stage 4, third cluster fruit set to the fifth flower cluster anthesis, plants received 154 ppm N; and Stage 5, fifth cluster fruit set until termination, plants received 175 ppm N (Table 1). Fertilizer solutions were mixed weekly and stored separately in 114 L tanks. Tank 1 contained Veg-Gro 3N-6.6P-22.41K (Veg-Gro Supplies Ltd., West Auckland, New Zealand) and magnesium sulfate (Pennington Seed Inc, Madison, GA). Tank 2 contained calcium nitrate (15.5N-0P-0K, Hydro Agri North America Inc., Tampa, FL) and potassium nitrate (13.8N-0P-36.9K, Haifa Chemicals Ltd., Haifa Bay, Israel). Fertilizers were injected into irrigation lines via an A10 Advantage Dosmatic injector (Dosmatic U.S.A., Inc, Carrollton, TX).

Tensiometers (Model LT; Irrometer Company, Inc., Riverside CA) were placed in one container of each treatment at each end of the greenhouse (two total for each treatment) to monitor soil moisture levels for each treatment, thereby maintaining consistent substrate moisture levels across all treatments. Irrigation volume for each treatment over the course of each study was modified as needed in conjunction with plant growth, daily weather conditions, and tensiometer readings. Initially 100% PB and 20% CGC substrates received 1.7 L/plant daily, 40% and 60% CGC substrates received 1.44 L/plant daily, while 80% and 100% CGC substrates received 1.2 L/plant daily. Near the conclusion of this study, daily irrigation rates had increased so that 100% PB and 20% CGC received 3.4 L/plant, 40% CGC received 3.6 L/plant, and 60%, 80%, and 100% CGC substrates received 3.8 L/plant. Once weekly all containers were hand watered with tap water to thoroughly flush all substrates eliminating any potential salt build-up.

Tomatoes were grown under common commercially accepted practices as outlined by Snyder (1998) for each study. Plants were strung when they reached approximately 0.7 m tall using twine suspended from overhead support wires. As the plants grew, the twine was periodically wrapped around the stem, and vine clips were added for additional support. Axillary suckers were removed when they reached approximately 7.6 cm in length. Manual pollination was completed every other day during the flowering period by vibrating the flower clusters with an electric toothbrush. Pollination was performed between 11:00 AM and 2:00 PM as recommended by Snyder (1998).

Foliar samples were analyzed during the spring and fall to monitor the nutrition of plants growing in each treatment. Foliar samples consisted of seven to ten recently matured, fully expanded leaves taken from plants within each treatment. Foliar nutrient levels were determined using inductively coupled argon plasma spectrophotometer (ICAP 9000, Thermo Jarell Ash, Franklin, MA).

Plants in the spring study were grown until seven fruit clusters had developed, at which time plants were topped by removing the terminal bud of the main stem. Plants in the fall study were grown until each plant produced five fruit clusters before the terminal bud was removed. Each crop was terminated when all fruit matured and had been harvested. The spring crop was terminated on 10 June 2004, and the fall crop on 3 Dec. 2004. Tomato production in the spring was not extended beyond the June termination date due to the excessive heat during the months of July and August. Tomato production in the fall season was not extended beyond mid December because of the increased occurrence of disease during the winter months (Snyder, 1998). In both crops, fruit clusters were pruned to four or five evenly sized fruit per cluster. Truss (inflorescence) string clips were attached to each fruit cluster to provide stability and support to the enlarging fruit.

Tomatoes were harvested weekly at the light red stage of fruit maturity where 60 to 90% of the skin surface and interior fruit aggregate were red in color (USDA, 1997). Marketable fruit were >58 mm in diameter and free from visible defects including irregular shape, growth cracks, blossom scars, blossom end rot, and zippering (USDA, 1997; Snyder, 1998). Within marketable fruit, the following grades were determined based on the size of harvested tomatoes: medium 58-63 mm; large 64-72 mm; extra large 73-88 mm; and jumbo >88 mm. Fruit with defects plus fruit <58 mm were classified as culls. Total yield for each season was the sum of total marketable yield plus total cull yield. In the spring study multiple harvests made within a single week were pooled and then grouped as either early season (weeks 1 and 2), mid season (weeks 3, 4, and 5), or late season (weeks 6, 7, 8, 9). In the fall study multiple harvests within a week were pooled and then grouped as early season (week 1), mid season (weeks 2, 3, 4, 5, and 6), or late season (weeks 7 and 8).

Physical properties including air space (AS), water holding capacity (WHC), total porosity (TP), and bulk density (BD) were determined for each treatment using the North Carolina State University Porometer (NCSU-P) (Fonteno et al., 1981). Properties were determined from three representative samples of each treatment. Leachate pH and EC were measured at experiment initiation and periodically throughout each growing season using a handheld Myron DS/pDS meter (Model EP-11; Myron L Company, Carlsbad, CA).

Data from each study were analyzed separately using GLM procedures (SAS Institute, 1990). Regression analysis was performed for total yield and yield by early, mid, and late season harvests over treatment. Least Significant Difference ($P = 0.05$) procedures were used to determine differences among treatments for yield at early, mid, and late harvest periods, leachate EC, and percentages of marketable and cull yield for each study.

Results and Discussion

Total Yield. Data from the spring and fall studies were pooled and analyzed. GLM indicated a significant ($P < 0.001$) season × harvest date interaction. This indicated that the effect of treatments on total yield differed in the spring and fall. Regression analysis also indicated that effect of treatment on yield showed no differences among early, mid, and late season harvests in both studies (P = 0.344), therefore total crop yield was analyzed. Spring and fall yields were not similar possibly due to seasonal day length, temperature, and light intensity differences occurring at different times of the year. Plants in each study were also topped to end production earlier in the fall than in the spring, resulting in less total yield in the fall which is expected in commercial production in the southeast. Effect of treatments on total yield was similar within early, mid, and late harvest periods meaning that the effect of treatment was consistent throughout the experiments. Early, mid, and late season harvests within each study were pooled as a result of no significant differences in total yield. Total yield was then analyzed for differences among treatments for each study separately. Total yields were similar across all treatments in both spring and fall (Figures 1 and 2).

Marketable Yield. Total marketable fruit yield in the spring did not differ among treatments among early, mid, or late season harvests and no significant differences were reported across treatments (Table 2, Figure 3). Within marketable yield, fruit grades were not significantly different across treatments among early, mid, and late harvest periods or across treatments for either study. Each of the grades showed little differences across treatments for the fall and spring (Table 3). The percentage of total fruit comprised of marketable fruit and cull fruit was similar among all treatments in the spring and fall (Figures 3 and 4). Total marketable yield in the fall was significantly higher in treatments containing 40, 60, and 80% CGC than in 100% PB control, while no significant differences were shown in the spring (Table 2).

Culls. Defect types within culls were similar within early, mid, or late season harvests ($P = 0.001$) meaning that the effect of treatment was consistent throughout both experiments. Yield of fruit with growth cracks, scars, and irregular shapes were not different among treatments for both studies (Table 4). Other fruit with defects including those that were too small or had blossom-end rot or zippering, had similar yields in the fall, but showed slight treatment differences in the spring in both PB and CGC treatments (Table 4). The overall cull percentages were not significantly different and were minimal compared to the high marketable percentages of the total yield for each season (Figures 3 and 4).

Chemical Properties. Leachate pH remained steady in all treatments throughout the spring and fall crops (Table 5). EC values measured initially and throughout both studies were higher in all substrates containing CGC (Table 5). Despite higher EC in substrates containing >40% CGC, no adverse effects were shown on tomato plants or on the overall total yield among the substrate treatments in the study (Table 5, Figures 1 and 2). In addition, weekly flushing of the substrates with tap water could explain the absence of salt burn or foliage symptoms in spite of high EC levels. EC did decrease significantly in the final measurements compared to the initial (Table 5), potentially due to usage of available nutrients by the quickly developing plants. Substrate analysis indicated significantly higher concentrations of all macronutrients tested in all CGC treatments compared to 100% PB (Table 7). Foliar analysis of plants in both studies indicated that all macronutrients with the exception of potassium were within or close to the recommended range for both studies (Tables 8 and 9). Potassium was below the recommended range in both studies (Tables 8 and 9). Tissue analysis also indicated consistent micronutrient concentrations in both studies with copper and boron being within the recommended ranges and iron, zinc, and manganese being below the suggested guidelines (Tables 8 and 9).

Physical Properties. Water holding capacity (WHC) was higher in all treatments containing CGC than in the 100% PB control (P = 0.0001, Table 6). Tensiometers used in each treatment allowed irrigation to be adjusted which maintained consistent moisture among treatments throughout the study to compensate for the much lower WHC of the 100% PB substrate. The ability of the compost to hold more water can reduce the irrigation volume needed in greenhouse tomato production, a potentially significant benefit for large scale greenhouse growers. The differences in physical properties had no apparent effect on tomato yield.

Based on the results of our study, all PB:CGC blends were considered suitable for greenhouse tomato production. With careful management, we were able to achieve similar yields in each treatment over the course of two studies. However, of the PB:CGC ratios we evaluated, results indicated that the 40:60 PB:CGC blend might provide the most suitable blend for greenhouse tomato growers. Tissue analysis results indicate that plants acquired nutrients similarly regardless of the substrate in which they were grown, and produced similar total yields regardless of the initial nutritional content of the substrates. Treatments having no effect on earliness of fruit yield or overall grade differences, signifies that no adverse or added effects should be expected from incorporating CGC with PB into a production system. Evidence in these studies suggest CGC can be used as an amendment to, or as a replacement for PB, with yields and plant composition similar to that achieved with the traditional PB substrate.

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Table 1. Fertilizer application rates and nitrogen (N) concentration (ppm) for each development stage of tomato plants grown conventionally in a greenhouse cropping system.

	Source	I^z	II^y	III^x	IV^w	V^v
Solution A	3-15-27	9.1 kg	9.07 kg	9.07 kg	9.07 kg	9.07 kg
	$MgSO_4$	0.0 kg	0.0 kg	0.0 kg	2.0 kg	2.0 kg
Solution B	$Ca(NO_3)_2$	3.4 kg	4.2 kg	5.6 kg	7.1 kg	8.7 kg
	KNO_3	0.0 kg	0.0 kg	0.0 kg	2.7 kg	2.7 kg
Total N (ppm)		70.5	81.0	100.9	154.3	175.4

^{z}I – Transplanting to anthesis of 1st cluster
^{y}II – 1st cluster fruit set to anthesis of 2nd cluster
^{x}III – 2nd cluster fruit set to anthesis of 3rd cluster
^{w}IV – 3rd cluster fruit set to anthesis of 5th cluster
^{v}V – 5th cluster fruit set until termination

Table 2. Average marketable and cull fruit yield per plant grown in six pine bark (PB) : cotton gin compost (CGC) substrate blends for two growing seasons in 2004.

	Total Marketable[y] (g)		Total Culls[x] (g)	
PB:CGC	Spring	Fall	Spring	Fall
100:0	2161.0a[z]	896.6c	204.0a	56.2a
80:20	2054.1a	939.9bc	259.3a	56.2a
60:40	2157.8a	1123.7ab	281.9a	64.6a
40:60	2260.8a	1182.5a	360.5a	78.6a
20:80	2168.4a	1154.8ab	356.7a	67.8a
0:100	2092.9a	1000.4abc	291.8a	70.1a

[z]Means separated within columns by Fishers's Protected LSD at $P = 0.05$.

[y] Marketable fruit: Jumbo = fruit >88 mm in size; X-Large = fruit between 73-88 mm in size; Large = fruit between 64-72 mm in size; and Medium = fruit between 58-63 mm in size (USDA, 1997). All fruit were also free from visible defects.

[x]Cull fruit: Too small (<58 mm in diameter); irregular shape; scars; growth cracks; blossom end rot; zippered.

Table 3. Marketable yield per plant grown in six pine bark (PB) : cotton gin compost (CGC) substrate blends for two growing seasons in 2004.

	Jumbo[y] (g)		X-Large[y] (g)		Large[y] (g)		Medium[y] (g)	
PB:CGC	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
100:0	434.0bc[z]	18.0b	1326.4a	422.2c	380.7a	396.2a	20.0ab	60.3a
80:20	382.7c	34.2b	1225.4a	578.1bc	418.2a	280.0ab	27.9a	47.7ab
60:40	539.4abc	78.0ab	1271.0a	740.4ab	322.7a	284.4ab	24.7a	20.9b
40:60	642.9ab	112.2a	1425.2a	822.0a	183.9bc	231.3b	8.8ab	17.1b
20:80	729.2a	78.4ab	1231.5a	800.0a	205.1bc	230.0b	2.7b	46.4ab
0:100	636.0abc	68.7ab	1290.8a	653.8ab	157.9c	237.5b	8.3ab	40.3ab

[z]Means of total fruit were separated within columns by Fisher's protected LSD at $P = 0.05$.

[y]Jumbo = fruit >88 mm in diameter; X-Large = fruit between 73-88 mm in diameter; Large = fruit between 64-72 mm in diameter; and Medium = fruit between 58-63 mm in diameter (USDA, 1997). All fruit were also free from visible defects.

Table 4. Cull yield in grams per plant grown in six pine bark (PB) : cotton gin compost (CGC) substrates blends over two growing seasons in 2004.

	Too Small		Irregular Shape		Scar		Growth Crack		Blossom End Rot		Zippering	
PB:CGC Ratio	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
100:0	3.34b[z]	8.24a	84.01a	16.15a	16.21a	0.00a	76.61a	31.81a	0.00b	0.00a	23.81ab	0.00a
80:20	11.18ab	0.00a	46.5a	15.62a	49.45a	0.00a	134.75a	37.78a	0.00b	2.79a	17.37ab	0.00a
60:40	16.27ab	2.57a	85.99a	18.37a	16.10a	0.00a	152.43a	36.15a	6.21b	4.95a	4.92b	2.55a
40:60	27.4a	2.26a	78.60a	15.39a	56.56a	3.76a	158.24a	46.89a	18.59b	10.25a	21.09ab	0.00a
20:80	10.64ab	0.00a	111.78a	14.76a	45.72a	0.00a	123.77a	44.61a	58.92a	5.09a	5.88b	3.36a
0:100	9.98ab	3.95a	60.28a	0.00a	20.20a	0.00a	136.57	52.27a	16.41b	13.89a	48.35a	0.00a

[z]Means were separated within columns by Fisher's protected LSD at $P = 0.05$.

Table 5. Initial and final leachate pH and EC of six pine bark (PB) : cotton gin compost (CGC) substrates during two growing seasons in 2004.

	Spring				Fall			
	EC (mmhos/cm)		pH		EC (mmhos/cm)		pH	
PB:CGC	Initial	Final	Initial	Final	Initial	Final	Initial	Final
100:0	0.3e[z]	1.9e	6.4a	6.4ab	0.3e	1.9d	6.3b	6.4a
80:20	0.7e	2.9d	6.4a	6.3ab	0.7de	1.9d	6.4ab	6.5a
60:40	2.0d	3.5d	6.3a	6.3ab	1.4cd	2.9c	6.6ab	6.4a
40:60	4.9c	4.2c	6.5a	6.2b	2.1c	3.4bc	6.6ab	6.7a
20:80	6.9b	6.1a	6.5a	6.3ab	5.9b	4.5a	6.5ab	6.6a
0:100	9.8a	5.2b	6.5a	6.4a	8.6a	4.2ab	6.7a	6.7a

[z]Means separated within columns using LSD procedures at $P = 0.05$.

Table 6. Physical properties of six pine park (PB) : cotton gin compost (CGC) substrates.

PB:CGC Ratio	Water Holding Capacity[z] (%)	Air Space (%)	Total Porosity (%)	Bulk Density ($g \cdot cm^{-3}$)
100:0	53.2d[y]	18.5a	71.7d	0.20c
80:20	62.4c	9.6c	72.0d	0.21c
60:40	67.9b	8.4cd	76.2c	0.21c
40:60	69.6ab	7.6cd	77.2c	0.24b
20:80	72.5a	6.9d	79.4b	0.25ab
0:100	69.1ab	12.4b	81.5a	0.27a

[z]Values are based on percent volume of the substrate and were measured at container capacity.

[y]Means separation within columns using LSD procedures at $P = 0.05$.

Table 7. Substrate elemental analysis of pine bark (PB) : cotton gin compost (CGC) blends in 2004.

Macronutrients

PB:CGC Ratio	B (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Mo (ppm)	Zn (ppm)	Ni (ppm)
100:0	-	-	-	-	-	-	-
80:20	-	-	-	-	-	-	-
60:40	0.18d[z]	-	-	-	-	-	-
40:60	0.37c	-	-	-	-	-	-
20:80	0.62b	-	-	-	-	-	-
0:100	0.96a	-	-	-	-	-	-

Micronutrients

PB:CGC Ratio	Ca (ppm)	K (ppm)	Mg (ppm)	P (ppm)
100:0	23.00e[z]	42.03f	8.37e	1.00e
80:20	20.93e	201.43e	9.23e	27.10d
60:40	55.97d	505.00d	38.03d	38.50c
40:60	157.50c	1185.00c	131.67c	58.60b
20:80	232.70b	1842.67b	223.83b	80.87a
0:100	323.67a	2774.00a	324.20a	77.33a

[z]Means separated within columns by Fisher's Protected LSD at $P = 0.05$.

Table 8. Foliar analysis of 12 week old tomato plants grown in pine bark (PB) : cotton gin compost (CGC) substrate blends in fall 2004.

	Macronutrients				
PB:CGC Ratio	N (%)	Ca (%)	K (%)	Mg (%)	P (%)
100:0	5.28a[z]	1.56a	3.30a	0.49a	1.09ab
80:20	4.23a	1.50a	3.25a	0.48a	1.23a
60:40	5.31a	1.67a	3.05a	0.41a	0.96bc
40:60	5.28a	1.47a	3.06a	0.47a	1.08ab
20:80	5.22a	1.21b	2.73b	0.38a	0.84c
0:100	5.25a	1.62a	3.24a	0.49a	1.00bc
MSU Guidelines[y]	4.0-5.5	1.0-5.0	4.0-7.0	0.4-1.5	0.3-1.0

	Micronutrients				
PB:CGC Ratio	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	B (ppm)
100:0	12.83a[z]	105.67a	33.43a	27.07a	54.4bc
80:20	10.33b	106.37a	25.37c	21.70b	51.2d
60:40	7.93c	76.50b	20.40e	20.13c	56.9b
40:60	7.10d	76.00b	27.33b	20.63bc	60.17a
20:80	8.50c	72.67c	21.03e	18.40d	51.83cd
0:100	6.90d	70.27d	22.77d	20.07c	62.17a
MSU Guidelines[y]	5-25	100-250	30-150	40-300	35-100

[z]Means separated within columns by Fisher's Protected LSD at $P = 0.05$.
[y]Guidelines based on Mississippi State University Extension Publication, Greenhouse Tomato Handbook, (Synder, 1998).

Table 9. Foliar analysis of 12 week old tomato plants grown in pine bark (PB) : cotton gin compost (CGC) substrate blends in spring 2004.

		Macronutrients			
	N	Ca	K	Mg	P
PB:CGC Ratio	(%)	(%)	(%)	(%)	(%)
100:0	4.36a[z]	1.55ab	3.70a	0.42a	0.70a
80:20	4.28ab	1.54ab	3.57ab	0.44a	0.57b
60:40	4.27ab	1.68a	3.55ab	0.42a	0.56b
40:60	4.21ab	1.58ab	3.61ab	0.46a	0.51bc
20:80	4.27ab	1.64a	3.49ab	0.43a	0.56b
0:100	4.05b	1.40b	3.39b	0.41a	0.46c
MSU Guidelines[y]	4.0-5.5	1.0-5.0	4.0-7.0	0.4-1.5	0.3-1.0

		Micronutrients			
	Cu	Fe	Zn	Mn	B
PB:CGC Ratio	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
100:0	19.67a[z]	51.17a	16.67a	34.90a	54.60c
80:20	14.93a	48.77ab	15.10a	27.33b	62.93bc
60:40	11.97a	44.90bc	15.00a	39.53a	61.60bc
40:60	14.40a	47.53abc	14.57a	25.20b	72.17a
20:80	15.87a	41.50cd	15.87a	35.77a	66.27ab
0:100	14.30a	38.80d	16.07a	21.80b	69.23ab
MSU Guidelines[y]	5-25	100-250	30-150	40-300	35-100

[z]Means separated within columns by Fisher's Protected LSD at $P = 0.05$.
[y]Guidelines based on Mississippi State University Extension Publication, Greenhouse Tomato Handbook, (Synder, 1998).

Figure 1. **Average total yield (marketable + cull) per plant grown in six pine bark (PB) : cotton gin compost (CGC) substrate blends for spring 2004.**

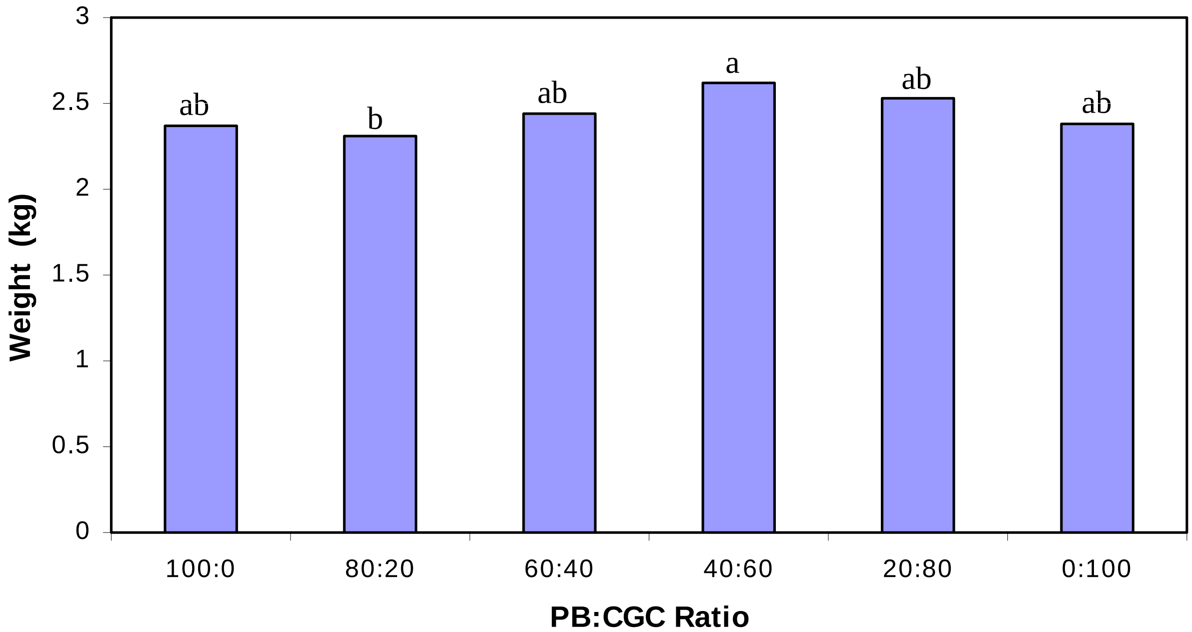

Figure 2. Average total yield (marketable + cull) per plant grown in six substrate pine bark (PB) : cotton gin compost (CGC) substrate blends for fall 2004.

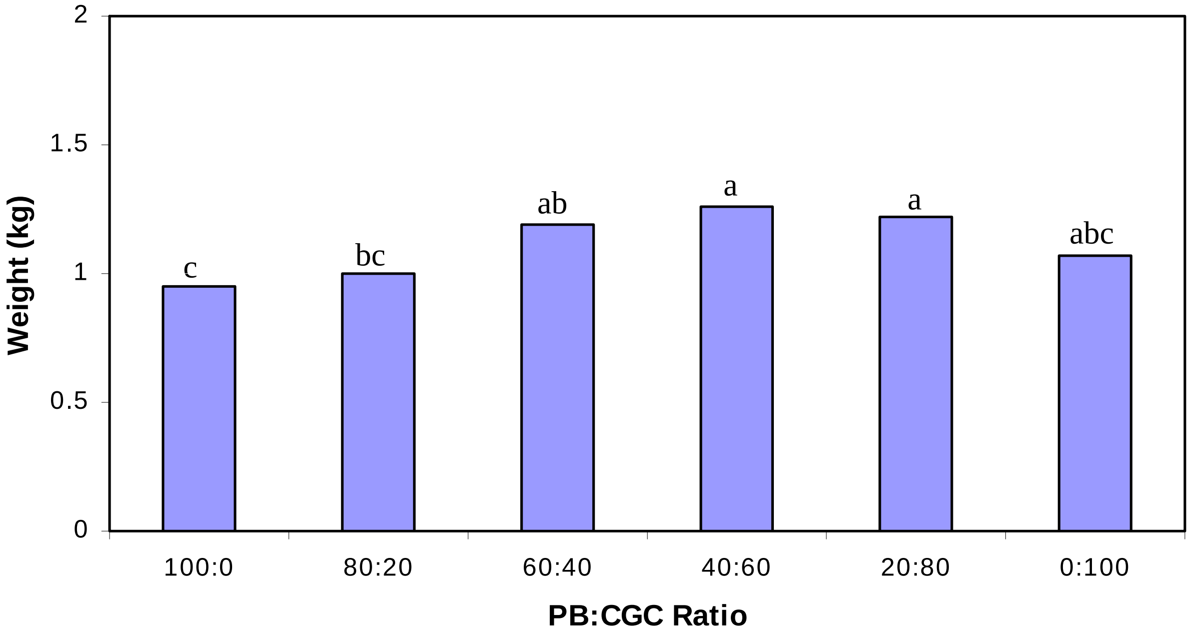

Figure 3. Total marketable and total cull fruit as percentage of total fruit yield grown in six pine bark (PB) : cotton gin compost (CGC) substrate blends in spring 2004.

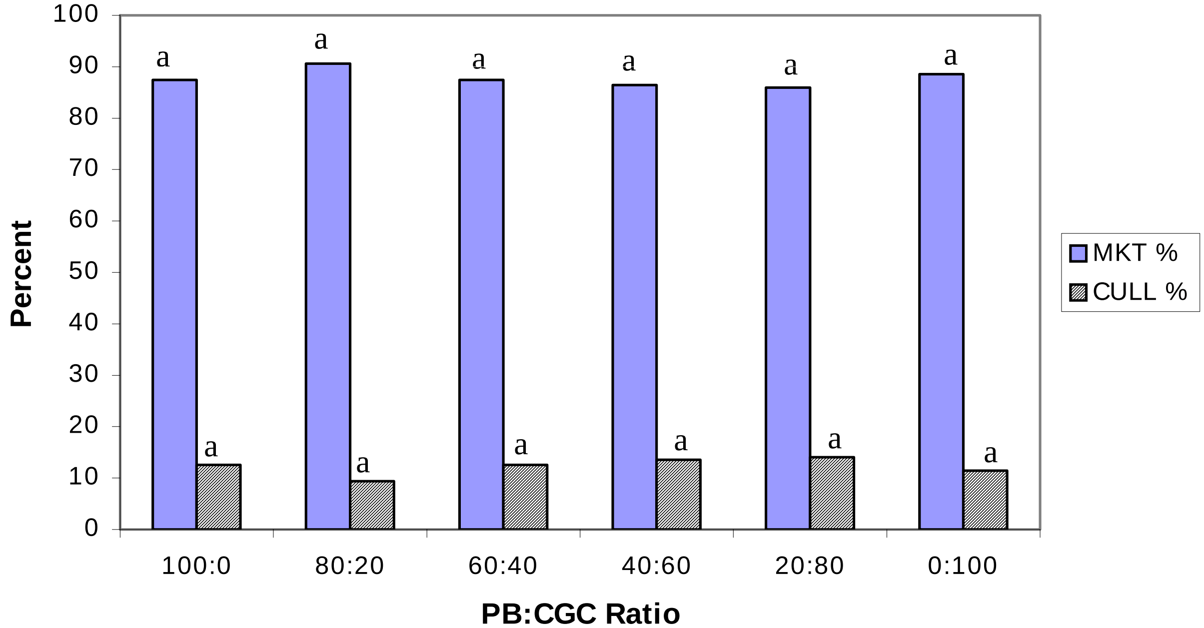

Figure 4. Total marketable and total cull as percentage of total yield grown in six pine bark (PB) : cotton gin compost (CGC) substrate blends in fall 2004.