Compost Use In Florida

Produced by the Florida Center for Solid and Hazardous Waste Management for the Florida Department of Environmental Protection, December, 1998

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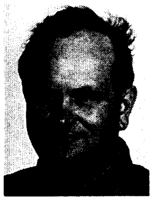

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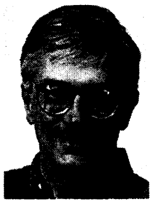

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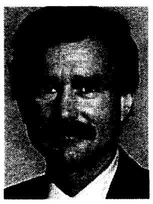

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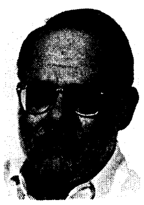

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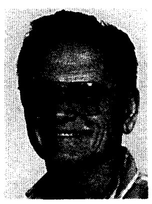

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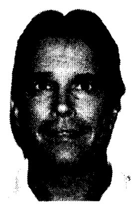

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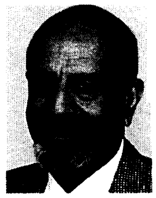

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FIGURES AND TABLES

Beyond the Backyard Compost Pile

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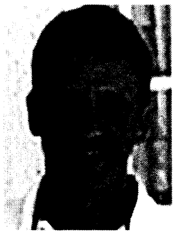
The use of compost is proving to be an environmentally-friendly, potentially profitable business for Florida 's agricultural interests.

In 1992, to address the problem of decreasing space in Florida's landfills, the State of Florida prohibited the disposal of grass clippings and other yard refuse in lined landfills. However, the ban also gave rise to a promising industry based on a natural process as old as life itself: cornposting. Compost, a mixture consisting largely of decayed organic material, occurs naturally every time trees shed their autumn leaves. As the dead leaves decompose, they protect and enrich the soil underneath. Now this simple, natural process is being transformed into a sophisticated science, one that extends far beyond the backyard compost heap and that offers numerous benefits for Florida's agricultural interests and the environment.

Given Florida's year-round growing season and porous, sandy soils, the humus-like substance which results from cornposting has numerous practical applications in the state. These include field crops and vegetables, landscaping and horticulture, citrus groves, golf courses, forest lands, and phosphate mine reclamation.

Florida now has 12 permitted cornposting facilities and dozens of mulching facilities, which help to recycle more than 1.3 million tons of urban plant debris annually. And solid waste managers are targeting other organic materials as potential candidates for cornposting, including food, liquid, and animal residues.

This guide presents an overview of some of the beneficial uses of composts in Florida and discusses the factors that influence the production, quality, and use of compost. Included are the results of 10 scientific studies by researchers at the Institute of Food and Agricultural Sciences (IFAS), demonstrating how compost can have a positive impact on agricultural operations in Florida. The information is intended to help agricultural interests, regulatory agencies and the general public better understand cornposting and the use of compost products, and its great potential in improving Florida's soils and environment. O



WILLIAM HINKLEY

JOHN D. SCHERT

A note about terminology

Once considered refuse or waste, yard trimmings and other organic materials are increasingly being viewed as valuable resources to be reused and recycled. Hence, throughout this publication, the terms "urban plant debris" (UPD), "residuals," and "biosolids" have replaced the more commonly used terms "yard waste" and "sewage sludge" to reflect the changing public perception about these materials. Other helpful terminology is defined in the glossary on page 55.

Compost and Waste Management in Florida

Florida's growing population, year-round growing season, and large agricultural industry provide a unique environment for the development of organic recycling/composting programs.

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Florida is the fourth most populous state and one of the fastest-growing in the United States. Its mild climate and year-round sunshine attract hundreds of new residents to the state every day and over 40 million tourists each year. For Florida's solid waste managers, this booming population, plus the load from tourists, translates into a growing waste stream. In 1995, Florida's population was more than 14 million, and the total municipal solid waste (MSW) generated that same year was close to 23 million tons — a waste generation rate of approximately 9 pounds per person per day. These figures are approximately twice the national average of about 4.3 pounds per person per day.

Keeping Pace With a Growing Population

To manage this burgeoning waste stream, Florida relies on a variety of methods, including waste reduction and recycling, landfilling, and combustion. Waste reduction programs are designed to limit the production of waste, reducing the need to manage it. Recycling programs recover valuable materials from the waste stream so that the materials can be reused. Landfills serve as disposal facilities for non-recovered materi.als.

In an effort to maximize the recovery of valuable materials from the waste stream, in 1988, the Florida legislature enacted the Solid Waste Management Act that mandated a 30 percent recycling goal for Florida counties. The impact of this legislative initiative has been impressive. In response, counties have implemented curbside and drop-off recycling programs, encouraged recycling participation within the commercial sector, and developed a variety of urban plant debris mulching and cornposting programs. Today, Florida has more than 300 curbside recycling programs, 12 permitted cornposting facilities, and numerous other mulching facilities. According to Florida Department of Environmental Protection (FDEP) statistics, more than half of Florida's 52 counties have achieved recycling rates of 25 percent or higher.

Expanding the Focus

From 1989 to present, the amount and percentage of materials recycled in Florida has increased steadily. Despite the success of existing recycling programs, Florida's solid waste managers have their eyes on the next decade. They continue to expand their programs to target new materials and to explore other sources for the recovery of additional materials. To maximize recovery rates, solid waste professionals have turned their attention to materials which have been relatively neglected. These include paper, comprising 26.3 percent of all municipal solid waste (Figure l-l), and construction and demolition debris, comprising 22.6 percent of the waste stream.

With Florida's warm climate and lush subtropical landscapes, urban plant debris (UPD) presents the most interesting potential for increased recycling in the state. As Figure l-l indicates, UPD represent 14.4 percent of Florida's MSW stream. In 1992, to encourage recycling of this valuable organic material, the Florida Legislature passed a law prohibiting the disposal of UPD in landfills designed to accept municipal solid waste. In response, the majority of Florida's counties have implemented source-separated UPD collection systems. Researchers estimated that by 1995 more than 3.3 million tons of UPD were generated in Florida every year. Yet studies indicated that only approximately 53 percent of these organics were recycled.

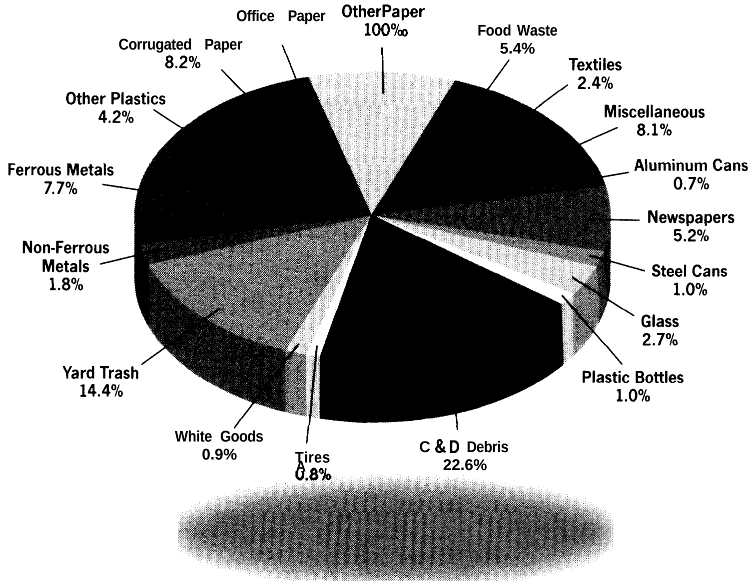

Figure 1-1: *Composition of Florida's Waste Stream (Jan. 1, 1995-Dec. 31, 1995)*

Undeniably, there was room for improvement.

That improvement began in 1995, when the FDEP approved the deregulation of UPD composting, a move that cleared the way for industry expansion. At the same time, cornposters have begun focusing their efforts on establishing consistent product definitions, quality control standards, and uniform testing. If Florida's emerging compost industry is to flourish economically, buyers of composted organic material need to know exactly what they are buying and be assured that each product's quality is consistent.

At the same time, researchers have focused their attention on evaluating the composting process and exploring opportunities for expanding its use. The commercial marketing of compost products has been encouraging. Compost has found one niche in agricultural applications in the cattle and citrus industries. Additionally, favorable government purchasing policies have helped to expand markets. For example, the Florida Department of Transportation has adopted specifications for composted materials and mulches made from urban plant debris, and has demonstrated the cost effectiveness and superior performance of organic compost materials in its Right-of-Way landscaping and maintenance programs. In this supportive environment, Florida can expect to experience continued growth in urban plant debris processing and cornposting.

Anticipating Future Trends

Florida's growing resident and non-resident population, year-round growing season, and large agricultural industry combine to provide a unique environment for the development of other organic recycling/composting programs. In addition to UPD, other organic materials are gaining notice as potentially recoverable portions of the waste stream. This renewed interest in organics has spawned a variety of innovative research and development projects, including MSW composting and vermicomposting projects.

Other recent projects have moved beyond traditional urban plant debris processing and composting to target other organic materials, including food, liquid, and animal residuals. Florida's organic recycling programs continue to expand with the support of innovations in collection methods (especially co-collection of organics in split collection vehicles), and increased on-site processing.

For organics recycling to occur, compost safety standards must be defined, and safe, economically sound uses for compost must be identified through coordinated research programs. Such a market development research effort is under way through a partnership involving the Florida Department of Environmental Protection, the Florida Center for Solid and Hazardous Waste Management, and the University of Florida's Institute of Food and Agricultural Sciences.

Perhaps the most important factor influencing developments in Florida's solid waste management practices is the increasing pressure to improve the efficiency and accountability of municipal solid waste management programs. Variable rate collection programs are expected to grow, driven by the push for greater reduction in sources, and an increase in return on investment. In Florida's present economic, legislative and regulatory environment, the future for recycling organics looks particularly bright. In sum, Florida's composting industry is like a sleeping giant about to awaken to a coming decade of healthy growth and energetic activity, when recycling of organics will play an increasingly important role in managing Florida's MSW stream. O

Compost Operations in Florida

Margie Lynn Stratton and
Jack E. Rechcigl

Florida, home to some of the largest and most successful commercial composting facilities in the United States, is among the nation's leaders in composting. For example, the Enviro-Comp facility in Jacksonville, which produces 400,000 tons of compost per year, is one of the largest composting facilities of urban plant debris (UPD) in the country. Palm Beach County Solid Waste Authority, producing 60,000 tons of compost per year, operates one of the nation's largest and most successful co-composting facilities (biosolids and urban plant debris).

Another of Florida's claims to fame: the Sumter County composting facility, begun in 1988, has the longest continuous operating experience in MSW composting. In all, Florida has 83 compost facilities (Ken McEntee, personal communication; Composting News, Ohio), which compost everything from food residuals to industrial waste.

Food refuse composting. *Three Florida composting facilities reportedly compost food residuals (Goldstein and Block, 1997a). One, a municipal facility operated by the Soil and Water Conservation District in Homestead Florida, processes wastes from a correctional facility. Another, Reedy Creek Energy Services of Lake Buena Vista, Florida processes food refuse from Disney World (Goldstein and Block, 1997a). A third, Environmental Earthworm Projects, Inc. in Orlando, processes fruit and vegetable trimmings from food processors and urban plant debris.*

An additional food refuse composting facility is being considered in Central Florida. If this site is developed, it is expected to handle the urban plant debris, food refuse, and biosolids for 7 correctional facilities.

Biosolids composting. *As of December, 1997, nine operational biosolids composting facilities were reported in Florida (Goldstein and Block 1997b). They include Cooper City Utilities, Eustis, Meadowood Utility, Miami-Dade Water Sewer, South Plant, Nocatee, Ocoee, Palm Beach County, Reedy Creek, and Sarasota. Two facilities, Apopka and Miami, are in the planning stages.*

Industrial composting. *Industries in Florida include food processing, seafood processing, phosphate, clay, sand and gravel mining, softwood lumbering, manufacture of transportation equipment, electrical equipment, chemicals and chemical fertilizers, metals, paper and paper goods, printed materials, and cigars, all of which may be potential composters of by-products. At this time it is not reported how many manufacturing plants compost by-products. However, much food processing refuse in Florida is fed to livestock (Barker, et al., in press).*

Agricultural composting. *Agriculture is one of the most prominent economic industries in Florida. Citrus crops, vegetables (particularly tomatoes), sugar-cane, soybeans, peanuts and pecans, watermelons, cantaloupe, and strawberries are the major crops. With the exception of sugarcane bagasse, which is usually burned for fuel or sometimes stubble-mulch planted, most crop residues are used to feed livestock. Crop residues can also be composted and used on-site.*

Backyard composting. *The Florida Master Composter program, designed by Dr. George Fitzpatrick (UF/IFAS), teaches backyard composting in several Florida counties. Hillsborough County, which developed the program during the past five years, has actively run workshops with 30 households in five sites throughout the county, and has about 30 graduates. A much newer program in Brevard County has just a handful of graduates.*

Master Composters are trained during a five-week, 25-hour course using a comprehensive handbook and interesting, varied composting demonstrations and workshops. Graduates then donate 25 hours of time helping to teach composting to others. Graduates also receive a backyard compost bin. (Polly Ryan, Hillsborough County Cooperative Extension Service, personal communication).

Compost education. *Along with the Master Composter Program, associations such as Florida Organic Recyclers Association (FORA), and institutions such as the University of Florida/Institute for Food and Agricultural Sciences publish and supply bulletins, reports, and handouts for workshops and conferences with the goal of educational outreach. Much more outreach is expected in compost education in the near future.*

What is Compost?

Once considered waste products, composted urban plant debris and other organic materials have the potential to breathe new life into Florida's sandy, nutrient-poor soils.

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Composting is a biological process in which microorganisms convert organic matter into a stabilized, humus-like substance. Many of the organic materials used for composting are inappropriate in their raw form for use on land or around living organisms because of the presence of odors, weed seeds, human pathogens, and storage and handling constraints. Cornposting helps to break down organic residues, stabilize nutrients, destroy weed seeds, and control possible toxins or diseases (Barker, 1997; Stratton et al., 1995; Hoitink and Keener, 1993; Haug, 1993). The resulting compost has numerous horticultural and agronomic benefits and is environmentally safe for use on soils around plants, humans, and animals (Stratton et al., 1995; Barker, 1997).

Controlled decomposition occurs as the result of the activities of naturally occurring macro- and microorganisms (Figure 2- 1). Bacteria, actinomyces, and fungi are the primary microorganisms involved in decomposition. To grow and multiply, these microorganisms require carbon as an energy source, nitrogen to build proteins, moisture, and oxygen. Enzymes, the active proteins, are produced by bacteria and assist in breaking down complex carbohydrates into simpler forms, which bacteria can use for food. The nutrients that become available during decomposition remain in the compost within the bodies of new microorganisms and as humus. Not all decomposition is microbial; in fact, it starts with macroorganisms, including earthworms, grubs, millipedes, spring tails, and centipedes, which assist in the process by digging, chewing, and mixing compostable materials.

The cornposting process does not stop at a specific point but continues until the remaining nutrients are consumed by the last remaining organisms and until most of the carbon is converted into carbon dioxide and water (Rynk, 1992).

Compost has many beneficial uses. Compost improves soil aeration, soil drainage, the water-holding capacity of sandy soils, the percentage of organic materials in soils, and the ability of soils to absorb and hold nutrients.

Cornposting Past and Present

The simplest form of cornposting — the decomposition of plant materials where they fall — has been occurring naturally for millions of years. In natural settings, such as under forest canopies, cornposting occurs as leaf litter decomposes into humus. With the advent of crop cultivation and animal husbandry, the resulting plant residues and animal manures were sometimes decomposed by gathering them into mounds or piles to allow cornposting to occur.

Farmers, greenhouse operators, nursery crop managers, landscapers, orchardists, backyard and organic gardeners have been making small compost heaps informally for decades, often simply to save the cost of transporting and disposing the materials. During the past few decades, cornposting has become a sophisticated and somewhat well-researched science. And while cornposting is still practiced on a backyard or small-farm scale, more and more often, it is now carried out on a large scale as part of local municipal waste management programs. On a municipal level, cornposting operations usually require sophisticated machinery and engineering (Stratton et al., 1995; Hoitink and Keener, 1993; Haug, 1993).

The first recorded method of cornposting community wastes was developed in India by Sir Albert Howard in 1925. This method, called the Bangalore or Indore system, simply involved alternate layering of wastes in trenches. Over time, as the scope and scale of cornposting increased with the amounts and types of waste products handled, innovative methods were devised to speed or ease the process. The layers were mounded, spread, aerated with forced air, turned, enclosed, exposed, chopped, ground, dried, wet, sifted, dumped from platforms, conveyed up belts, or separated at the source, for example. For the most part, the various processes were named for the company or inventor involved with the latest innovation and are summarized in a review article by Stratton et al. (1995).

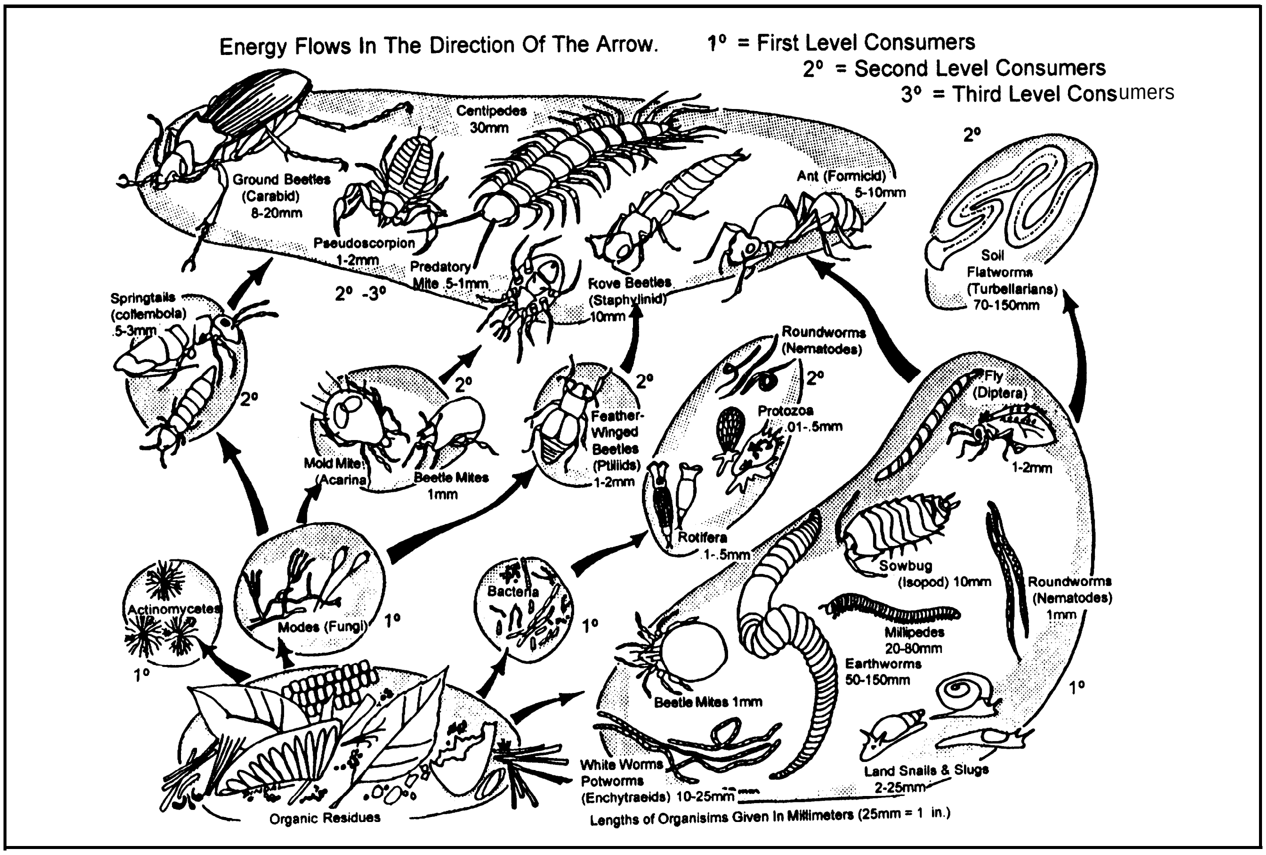
In the United States during a recent 5 year period, cornposting facilities have increased from 2,200 to almost 3,500 (Christopher and Asher, 1994; Ken McEntree personal communication). During the 14 years prior to 1997, biosolids composting facilities have increased from 90 total projects nationwide (61 operating facilities) to 332 total projects (262 operating facilities) as reported by Goldstein and Block (1997’0). Seven states reported a decrease in biosolids cornposting from 1996 to 1997 (Goldstein and Block, 1997b).

Compost Materials

Any number of materials, or *feedstocks,* can be composted, including grass clippings and other types of urban plant debris, biosolids (commonly known as sewage sludge), and other organic materials. Recently, there has been an increased interest in cornposting municipal, industrial, and agricultural by-products (Stratton and Rechcigl, 1998). Municipal solid waste, commonly called trash or garbage, has been composted and applied to many crops, including forage pastures, with improved yields and other benefits (Shiralipour et al., 1992a; Stratton and Rechcigl, 1997). Coal bottom and fly ash, cement kiln dust, biosolids, water treatment sludges, food processing by-products, animal and plant residues, by-products from metal smelting, paper and wood industries by-products, tannery sludges, textiles production by-products, rock dusts, chemical and drug production by-products have all been composted and land-applied (Stratton and Rechcigl, 1998).

Unfortunately, not everything that can be composted is composted. Barker (1997) estimates that 827 million tons of compostable materials are produced each year, largely by agriculture, municipalities, and industry. However, only 140 million tons, or 17 percent, of those are collected for cornposting.

Figure 2-1: *Food Web of the Compost Pile*



Source: Dr. Daniel Dindal, cited in Michigan Department of Natural Resources (1989). ***Yard Waste Composting Guide***

Cornposting Methods

Currently, some of the best processes for cornposting municipal solid waste or biosolids include separating the source materials at their point of origin (source separation), reducing the size of the materials (size reduction), and carefully mixing, aerating, and curing the compost for a few to several months to ensure compost maturity and stability.

The composition and method of processing compost varies greatly with the feedstock composted (Stratton et al., 1995; Barker, 1997). If two or more materials are composted together, a method known as *co-composting,* the cornposting process may be accelerated and the composition of the final product may be greatly enhanced as a soil amendment and conditioner (Stratton and Rechcigl, 1997). For example, two materials composted together may include one high in carbon, such as woody plant materials, and one high in nitrogen, such as biosolids. With proper mixing and ratios, and attention to aeration, particle size, moisture content and other engineering considerations, the resulting carbon-to-nitrogen ratio helps to speed and enhance the composting process while also producing a high quality end product (Stratton et al., 1995; Haug, 1993; Barker, 1997). In Florida, the Palm Beach County Solid Waste Authority's cornposter is such a facility.

For each combination of materials, compost mixes and ratios of feedstocks, as well as methodology and processes, are specifically engineered for the materials being composted and may be site-specific (Haug, 1993). Much research is currently directed at cornposting of previously disposed resources and by-products of several industries (Stratton and Rechcigl, 1998).

Compost maturity has been determined in a number of ways by a number of different researchers. In general, maturity refers to properties of the compost that include, but are not limited to

- lack of plant toxins, such as acetic acid, phenols, and ammonia
- stabilization (temporary immobilization) of nutrients such as nitrate-N, phosphorus, iron or other elements which could otherwise enrich ground or surface waters
- the absence of detrimental bacteria, fungi and noxious odors
- the presence of desirable microorganisms, and
- a noticeable reduction of heating upon rewetting (Stratton et al., 1995).

Several quick bioassays have been developed to check compost maturity. An easy method is a seed germination test on compost extract. (A. Shiralipour, University of Florida, personal communication). Others prefer carbon dioxide release (Graetz, 1996) or oxygen uptake measurements.

Developing a Market for Compost Products

The potential market for compost products in Florida is great. The challenge is convincing the consumer to use compost.

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The growth of the compost industry in the United States and Florida is being driven by the increasing cost of land-filling waste, public support for resource conservation, and legislative mandates for waste diversion — not by demand for compost products. Yet if compost is to become a valuable resource to be managed for profit, new markets for its use must be developed.

How Much Compost Can Florida Handle?

In 1996, about 23 million tons of MSW were collected in Florida (FDEP, 1997). Researchers estimate that, if the organic fraction of this waste stream were to be biologically decomposed, about 5.5 million tons of compost would be generated. But key questions remain. Specifically, is the market capacity in Florida sufficient to use the compost produced? What is the present market capacity for composted products? And how can Florida build markets for composted products?

According to one study (Slivka et al., 1992), the state's agricultural industry alone could use more than 20 million tons of compost each year. And statewide, as many as 42 million tons of compost could be used annually within a 50-mile radius of urban centers with populations of more than 100,000. The researchers imposed the distance constraint of a 50-mile radius based on the perceived limited economic viability of shipping farther than 50 miles. In other words, the potential use for composted products in Florida is more than 7.5 times the amount of compost that could be produced each year.

In 1992, the average annual rate of compost penetration in U.S. markets was less than 2% of its potential uses (Slivka et al., 1992). If the rate of compost penetration in the Florida market follows the national trend, compost use in the state is only about 840,000 tons a year. Clearly, Florida has a market development challenge, not a lack of market.

Developing a Viable Market

For any type of compost to be marketable, regardless of origin, it must pass minimum product standards for protection of public health and the environment. And commercial compost must consistently meet the requirements of end uses, which may vary widely. Many communities are finding it necessary to meet or exceed all the requirements, and then put additional efforts into marketing strategies that involve education and market development.

The long-term feasibility of commercial cornposting depends largely upon building a market by demonstrating safe use and establishing benefits, both practical and financial. Table 3-l outlines the steps recommended for successful compost market development.

Establishing Market Niches and Overcoming Barriers

New commercial cornposters are discovering that not all compost users are created equal. Each requires a specific product, and the range of quality may vary widely. For example, high-value end-uses, such as a growing medium for landscape nurseries, require refined, mature, high quality composts. On the other hand, lower-value end-uses, including use as a landfill cover or in reclamation of surface mines, can accept any class of general-use compost. Experienced compost marketers have discovered that a low-quality compost will

Table 3-1.

Steps for Successful Compost Market Development

I. Conduct Market Assessments

A. Identify market requirements for compost product(s)

B. Assess market capacity (current and potential)

II. Conduct chemical analyses on compost and plant tissues

A. Demonstrate the limits in heavy metals and toxic material content

B. Demonstrate the absence of odors and pathogens

C. Define methods to assure maturity and stability

III. Demonstrate the benefits of compost application and the values associated with these benefits:

Benefits	Associated Values
Increased water-holding capacity	Water conservation
Increased cation-exchange capacity	Fertilizer saving
Improved plant growth response	Yield increase
Suppression of diseases	Pesticide reduction

IV. Develop ongoing working relationship with end-users through educational programs

A. Workshops

B. Field days

C. Fact sheets

D. Media outreach to grower associations

E. Publication of findings in regional newsletters and trade journals

not be marketed successfully to high-value end-users, nor will a low-value end-user pay the premium price for high quality compost. Yet both groups will require a safe and reliable product.

Easing Concerns Over Compost Quality

Quality is a function of the physical, chemical, and biological characteristics of compost. Desirable physical characteristics of compost include a dark color, uniform particle size, a pleasant earthy odor, the absence of physical contaminants (such as glass or plastics), consistency, and moisture content of approximately 50%. Desirable chemical characteristics include balanced nutrient levels (nitrogen-phosphorus-potassium, and other elements) and low levels of heavy metals, PCBs, pesticides and salts. In terms of desirable biological characteristics, the compost must be mature, with high organic-matter content, and be free of pathogens and weed seeds.

One of the most important steps in improving compost quality is minimizing the presence of hazardous materials such as heavy metals. The highest quality compost with the lowest levels of potentially harmful contaminants — particularly heavy metals and physical contaminants — is derived from source-separated organic materials that were not mixed with other materials during collection or cornposting. Following the trend in Europe, the United States is beginning to move away from mixed MSW and toward source-separated organic cornposting. (For more on quality assurance of compost, see page 21.)

Meeting the Needs of the Consumer

As with all successful products in the marketplace, compost must meet the requirements of the end-user. Three factors are of particular importance to compost users: availability, cost, and quality. Compost must be consistently available for end-users when they need it. If they choose to haul it themselves, it must be in an easily accessible location. The cost of compost is a composite of the costs of the product, its transportation and its application. Although availability and cost are important factors in the development of compost markets, it appears that quality may be the decisive factor. It is often stated that high-quality compost will always find a market.

Teaching Consumers to Trust Compost

Communities with commercial cornposting facilities have discovered that producing the finest product and making it conveniently available are not enough to entice some potential consumers to try compost. A solid educational program is necessary in order to substantiate the benefits of using the product. Fortunately, scientists and educators at the Institute of Food and Agricultural Sciences at the University of Florida (Smith and Shiralipour, 1997) have done much work in communities to build convincing arguments that commercial composts are safe and can be used beneficially (Gallaher 1995b). First, the IFAS team designed a set of projects to demonstrate the absence of pesticides in commercial composts and is now studying the process for biological remediation during cornposting. Additionally, the scientists proved that they could measure compost maturity and stability and indicate nitrogen availability. Next, they demonstrated low levels of compost toxic metal contents and the low levels of these metals in crop parts. Finally, they established that applying compost improved physical and chemical properties of soils for vegetable crops, assisted in retention of water and nutrients in turfgrass soils, and helped establish woody ornamentals in landscape beds. Through the efforts of IFAS scientists, communities now have the educational tools they need to convince potential consumers that applying mature compost is a beneficial and economically viable alternative to conventional soil treatments. Q+

Regulations Affecting Compost Production and Use

Federal and state regulations focus on safety of compost products.

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Regulations affecting compost and its use address both product procurement provisions and environmental requirements. Procurement provisions are aimed at encouraging markets for recycled products. Environmental regulations set limits needed to classify compost so it can be used safely. Both federal and state regulations address these issues.

Federal Regulations for Product Procurement

The Environmental Protection Agency (EPA) guidelines for procurement of compost are contained in Title 40 of the Code of Federal Regulations, Part 247. Only one provision specifically mentions compost — Section 247.15, which concerns landscaping products. This provision includes compost "made from yard trimmings, leaves, and/or grass clippings for use in landscaping, seeding or grass or other plants on roadsides and embankments, as a nutritious mulch under trees and shrubs, and in erosion control and soil reclamation." This section also includes hydraulic mulch products containing recovered wood used for hydroseeding and as an over-spray for straw mulch in landscaping, erosion control, and soil reclamation. Title 40 regulations can be accessed at the EPA web site at http://www.epa.gov/epacfr40/ (Environmental Protection CFR Pilot).

The EPA has also developed a series of fact sheets for its "Buy-Recycled" program. The fact sheet for landscaping products, EPA530-F-97-034, and other information, including a list of manufacturers, may be accessed at http://www.epa.gov/epaoswer/non-hw/procure.htm.

Federal Regulations for Environmental Requirements

The two federal regulations concerning compost are 40 CFR Part 257 and Part 503. Section 257.3-5 contains provisions for the application of municipal solid waste to land used for growing food-chain crops. This section appears to need revisions to reflect adoption of federal biosolids regulations.

40 CFR Part 503 addresses biosolids (also known as sewage sludge or domestic wastewater residuals). These regulations can be accessed at the EPA web site mentioned above.

State Requirements for Product Procurement

Florida recognizes that compost is an important component of recycling. Section 403.7065, Florida Statute (ES.), requires state agencies, as well as others who use state funds, to procure products or materials with recycled content where they are reasonably available. Note that the definition of "recycled content" includes composted materials. Further, specific provisions for state procurement of compost are found in Section 403.714, ES. This section specifies that state agencies must "procure compost products when they can be substituted for, and cost no more than, regular soil amendment products, provided the compost products meet all applicable state standards, specifications, and regulations." This provision further requires the development of uniform product specifications for procurement and use of compost by all state agencies. Copies of these specifications may be obtained by contacting the Florida Department of Management Services, Division of Purchasing at 4050 Esplanade Way, Tallahassee, Florida 32399-0950.

State Environmental Requirements

Two Department of Environmental Protection (DEP) regulations specifically address compost use in Florida, depending on the feedstock processed into the compost product. These are Chapter 62-709 (Criteria for the Production and Use of Compost Made from Solid Waste) and Chapter 62-640 (Domestic Wastewater Residuals), Florida Administrative Code (F.A.C.). Copies of these rules can be obtained from the Department's web site at: http://www.dep.state.fl.us or from one of the DEP District Offices.

Solid waste

State regulations governing the use of compost made from solid waste are found in Chapter 62-709, F.A.C. The majority of this chapter contains requirements for the compost-producing facility itself. However, this rule also contains a classification scheme and use restrictions based on the type of compost produced.

Compost made from solid waste is classified based on the type of waste processed, compost maturity/stability, the presence of foreign matter, the size of holes in the sieve used to screen the compost, the organic matter content, and the concentration of heavy metals. The concentration codes used in the classification scheme are identified in Table 4- 1. The values for "Exceptional Quality" limits specified in the federal regulation are included in this table for comparison.

Table 4-2 illustrates the classification scheme for composted materials. The requirements for Type Y and Type YM are identical. However, a classification for "yard trash only" was mandated by the Florida legislature.

TABLE 4-1
Quality Limits for Compost

	DEP Solid Waste Compost — Concentration Codes (VALUES IN MG/KG)				EPA Part 503
Parameter	**1**	**2**	**3**	**4**	**Biosolids**
Cadmium	<15	15–<30	30–100	>100	39
Copper	<450	450–<900	900–3,000	>3,000	1,500
Lead	<500	500–<1,000	1,000–1,500	>1,500	300
Nickel	<50	50–100	100–500	>500	420
Zinc	<900	900–<1,800	1,800–10,000	>10,000	2,800

TABLE 4-2
Classification of Compost made from Solid Waste

	Types of Compost Made from Solid Waste						
Classification criteria	Y	YM	A	B	C	D	E
Type of waste processed							
Yard trash only	X					X	
Manure or yard trash with manure		X				X	
Other than only yard trash or manure			X	X	X	X	X
Product maturity							
Mature	X	X	X	X	X		
Semi-mature	X	X		X	X		
Fresh						X	
Foreign matter content							
<2% dry weight	X	X	X*				
>2%, but <4% dry weight				X*			
>4%, but <10% dry weight					X	X	
Sieve size and organic matter content							
<10mm; organic matter >25% (fine)	X	X	X	X	X	X	
<15mm; organic matter >30% (medium)	X	X		X	X	X	
<25mm; organic matter >35% (coarse)	X	X			X	X	
Heavy metal concentration by code							
1	X	X	X	X	X	X	
2				X	X	X	
3					X	X	
4							X

* This material may not contain any foreign matter, such as glass or metal shards, of a size and shape that can cause injury.

Compost maturity, for purposes of this regulation, is determined by whether the compost will reheat to more than 20 degrees Centigrade (36 degrees Fahrenheit) above ambient temperature and the percent reduction in organic matter.

Classification of a compost made from solid waste affects how it can be used. Only such composts classified as Y, YM or A have unrestricted distribution. Types B and C are restricted to use by commercial, agricultural, institutional or governmental operations. In other words, the only restriction placed on Types B and C is that they cannot be distributed for use by the general public. Further, only Type B can be used in situations, such as in a park, where contact with the general public is likely. Compost classified as Type D can only be used at landfills or land reclamation projects where contact with the general public is not likely.

Finally, any solid waste compost classified as Type E must be disposed of in a landfill unless it can be demonstrated that its use will not harm the public or the environment. Most compost products made from solid waste have been classified as Types Y, YM or A.

There are also restrictions regarding the total amount of heavy metal that can be applied to soils. These restrictions, expressed as pounds per acre, are cadmium — 4.45; nickel and copper — 111; zinc — 222; and lead —445. As these values are based on the most restrictive soil cation exchange, the rule also contains a provision that allows a user to demonstrate, through an analysis of the cation-exchange capacity and other physical and chemical characteristics of the receiving soil, that a higher application rate would still provide an equal degree of protection.

While this section discusses the current requirements, the concentrations for heavy metals in the classification scheme were established in 1989 and were based on the criteria used to regulate biosolids prior to adoption of 40 CFR Part 503 by the Environmental Protection Agency. These EPA standards were also used in the DER's Residuals Rule, Chapter 62-640, F.A.C. Further, not only are the classification concentrations in the Solid Waste Compost Rule out-of-date, they are also based on different risk assumptions and methods of calculation than are the Soil Cleanup Target Levels used for other reuse-type decisions within the Division of Waste Management. Given that Rule 62-709.600(8), F.A.C., stipulates that "compost shall not be used in any manner that will endanger public health and welfare and the environment," and given the need for consistency within the Division for approving reuse projects, it is anticipated that rule development will be initiated to update this rule and to incorporate the Soil Cleanup Target Levels for heavy metals in compost.

Biosolids

State of Florida regulations governing the use of biosolids are contained in Chapter 62-640, F.A.C. The DEP Division of Water Facilities provided a summary of regulations affecting residuals use in ***Biosolids Management in Florida: Beneficial Use of Domestic Wastewater Residuals*** (DEP May 1997).* Chapter 2 of that document "Regulations Affecting the Beneficial Use of Residuals," addresses residuals classified as "Class A" or "Class B" under both state and federal regulations, and residuals classified as "Class AA" under state regulations.

In summary, only biosolids that have received the highest degree of treatment for pathogen reduction and that also meet the most stringent pollutant limits specified in the regulation are designated as Class AA. Most or all of the biosolid compost currently produced in Florida meets the Class AA requirements. These residuals are subject to the "Exceptional Quality" limits specified in the federal regulations and the Class AA limits listed in the state rule. While use of biosolids meeting these criteria does not require an Agricultural Use Plan, nutrient content information and recommended application rates must be provided to the user.

A Matter of Safety

It is important to remember that the criteria established in the environmental regulations address product safety and not the requirements of a particular end-user. O

*Copies are available free of charge from the DEP's Bureau of Water Facilities, 2600 Blair Stone Road, Tallahassee, FL 32399.

Compost and Quality Assurance

Compost products made with an emphasis on quality and consistency will have no shortage of uses or users.

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Composts are made from a changing assemblage of organic feedstocks. For this reason, there can be a great deal of variation in the chemical and physical parameters of compost. The quality of the compost can influence the soil's pH, soluble salt levels, exchange capacity, aeration, particle size distribution, bulk density and water-holding capacity. Consequently, the highest quality compost products frequently compare favorably with peat and other high value organic substrates. The low quality compost materials may retard plant growth, and, in extreme cases, may contribute to plant mortality.

Plant producers should be aware that certain quality parameters can make the difference between successful and unsuccessful use of compost products.

Assessing Compost Quality Parameters

Compost products are used in four general ways: (1) as a stand-alone container growing medium, (2) as a component in a container growing medium mixture, (3) as an organic top dressing, and (4) as an incorporated soil amendment.

Although there is no perfect growing medium for all crops under all growing conditions, numerous authors have described general recommendations. For example, for container grown foliage crops, Joiner (198 1) recommends the following general parameters: bulk density: 0.30 grams per centimeter cubed (g/cm^3) (dry), 0.60-1.20 g/cm^3 (wet); percent pore space: 5-30%; percent water-holding capacity: 20-60%; pH: 5.5-6.5; soluble salts: 400-l ,000 ppm; cation-exchange capacity: 1 O-l 00 $meq/100\ cm^3$.

A variety of plant species are sensitive to high salt concentrations. Salts in the growth medium disrupt water uptake or directly affect the physical functions of plants. If these types of plants are exposed to high salt concentrations, their growth might be suppressed or seized. Therefore, composts with high salt concentrations could cause toxicity in sensitive plant species. Even a high rate of compost application with low salt content might cause injury in such plants. Thus, a high quality compost physically may be low quality if the salt concentration is high.

Of the four general uses for compost, the stand-alone container growing medium category requires the highest quality compost. When compost products are used as components in growing medium mixtures or are applied directly to agricultural soils, a lower quality of compost product may be acceptable. For example, Rynk et al. (1992) indicate that a soluble salt concentration of less than 2.5 decisiemen per meter (dS/m) is necessary for a stand-alone container medium, but a value of less than 6.0 (dS/m is acceptable when the compost product is to be used as a component in a growing medium mixture, and a value of less than 20 dS/m is acceptable when the compost product is to be used as an incorporated soil amendment. If salt levels are a concern, it is wise to wait until a rain or other watering event occurs to dilute the salts.

Numerous factors can influence the likelihood that any compost product will have sufficient quality as a rooting medium. These include the parent material from which the compost product was made, the pre-processing and postprocessing procedures to which the substrate was subjected, the amount of time of active cornposting and the maturity of the compost product, the amount of inert material in the compost product, the concentration of regulated elements (heavy metals), and the presence of pathological microbiological organisms.

Parent Material

The composition of the parent material can sometimes influence the quality of the compost product. The parent material may affect the particle size, nutrient content and soluble salts in the final product. Very fine composts tend to separate and block drainage in pots, while a compost with coarse, fibrous properties creates a porous mediurn that facilitates drainage. For example, a compost made from biosolids (sewage sludge) supports more rapid growth in container-grown viburnum *(Viburnum suspensum)* than do composts made from nitrogen-poor materials such as garbage, urban plant debris, and stable sweepings (Fitzpatrick and Verkade, 199 1).

Preprocessing and Postprocessing

Procedures employed at the cornposting facility before and after the active cornposting period can sometimes influence compost quality. For example, sludges frequently are stabilized and conditioned prior to cornposting. If a sludge is stabilized by treatment with ferric chloride and lime, a common practice in many wastewater treatment facilities, the level of soluble salts in the finished compost product may be significantly higher than in compost made from sludge that had been stabilized using a wet-air oxidation process. When cornposts made from sludges treated with stabilization and conditioning preprocessing procedures were used to grow the non-salt-tolerant container crops *Spathiphyllum* 'Mauna Loa' and *Schefflera arboricola,* plants grown in the compost with higher soluble salt levels were significantly smaller than plants grown in composts with lower soluble salts (Figure 5-l). However, both compost products resulted in plants that were significantly larger than those grown in a control medium consisting of 40% peat, 50% pine bark and 10% sand (Fitzpatrick, 1986).

Other processing procedures, such as screening, can influence the physical quality of the cornpost products by making them more homogenous and, consequently, easier for the grower to mix and apply. Smaller plants usually require composts that have passed through small diameter screens. Plants grown in large tubs or in soil with incorporated composts may do well with coarser material.

Active Cornposting Time and Compost Product Maturity

The earliest references on cornposting time published in the modern era (e.g., Howard and Wad, 193 1) indicate an optimum cornposting time of approximately 6 months for mixtures containing 25% of high nitrogen material, such as animal manure, and 75% of high carbon material, such as plant debris. Many current commercial compost producers promise a stabilized end product in a much shorter period because of the capability for preprocessing, mixing, aerating and managing moisture content. Producers may feel a strong economic incentive to accelerate active cornposting into the shortest possible time period. If the processing time is too short, an immature compost may result. Commercial plant producers who purchase compost products from such sources must be mindful of the negative effects associated

Figure 5-1: *Spathiphyllum 'Mauna Loa' grown in a compost **product** that had an average electrical conductivity of 3.9 dS/m (left) attained an average size of 1.39 times the control. Plants grown in compost with 7.5 dS/m conductivity (middle) attained an average size of 1.19 times the control. Control medium conductivity averages 3.5 dS/m (Fitzpatrick, I 986).*

with immature composts. These include biological blockage of nitrogen uptake (nitrogen-rob), deformity or death of plant parts by phytotoxic chemicals in immature composts, increased mobility of certain toxic elements in the soil, and similar effects (Jimenez and Garcia, 1989). Many growers who use compost products store newly delivered material for 6-12 months, allowing it to decompose further, as insurance against possible phytotoxic effects.

Inert Material Content

Certain types of parent materials are often likely to contain noncompostable substances, such as particles of glass, plastic, and metal objects. These materials may be unsightly and hazardous, particularly if the inert materials have sharp edges. If a compost is made exclusively from materials such as yard trimmings, leaves, or other plant debris, inert material usually is not a problem. If, however, a compost is made from municipal solid waste, inert materials might cause problems, particularly if the parent materials had not been subjected to sufficient preprocessing to segregate inert materials. Some states have passed environmental regulations limiting the amount of inert materials allowed in compost products. In Florida, state regulations mandate that inert materials may not exceed 2%, by weight, in compost products marketed for unrestricted horticultural uses. In other areas, compost producers and brokers have developed self-regulation programs. For example, compost producers in Ohio will not sell a compost product for nursery use if the inert material level exceeds OS%, by weight (Tyler, 1993).

Regulated Elements

One of the almost universal concerns related to compost use is the question of regulated elements. The U.S. Environmental Protection Agency has issued recommendations for the maximum permissible levels of 10 heavy metals in compost products: arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium and zinc. Many states have passed their own regulations, using the federal recommendations as guidelines. While there can be substantial differences in heavy metal concentrations between different types of compost products that may be attributable to the parent material and the relative level of preprocessing, the overwhelming majority of compost products available at the present time fall well within federal and state guidelines (Chaney and Ryan, 1993). In fact, commercial composts in Florida are required to meet these guidelines.

The safety of compost products is further assured by the reduction of toxic heavy metals in waste streams brought about by the implementation of industrial pretreatment programs, as well as by quality control programs practiced by commercial compost producers and monitored by governmental regulatory authorities.

Biological Status

A common concern held by many people relative to compost use is the possible presence of pathogenic organisms. The high temperatures reached during active cornposting (from 130 to 140 degrees Fahrenheit) have been shown to reduce to insignificant levels any pathogens that might have been present in the parent material (Burge, 1983; Haug, 1993). However, since commercial cornposting is frequently conducted on a large scale, involving hundreds of tons per day, questions have been raised about whether cool spots exist in places within active compost piles and whether pathogenic organisms could reinoculate the final product. These issues are normally addressed by examining representative samples of compost products and conducting microbiological screenings. Usually, the pathogens themselves are not cultured. Rather, the compost samples are tested for the presence of indicator organisms, such as fecal coliform bacteria. Indicator organism tests are simple, reliable and are required by both federal and state regulations. They serve as an additional safeguard to insure the maintenance of compost quality and safety.

Another microbiological issue of concern is the presence of the ubiquitous thermo-tolerant fungus *Aspergillus fumigatus*, a saprophyte frequently found in decaying organic materials. *A. fumigatus* is one of the relatively few fungi that can be pathogenic to humans, since the human body temperature, 37 degrees C, is the optimum temperature for its growth (Oliver, 1994). However, the relatively small number of confirmed cases of aspergillosis, coupled with the ubiquity of *A. fumigatus* in the environment, implies that the susceptibility of humans is rather low. A recent review of the literature indicates that humans with suppressed immune systems may become ill after only minimal exposure to *A. fumigatus*. But healthy individuals from the general population appear to show no significant health impacts from exposure to this fungus (Maritato et al., 1992). Moreover, the average horticultural worker is exposed to many substrates containing *A. fumigatus*, such as soil, peat, sawdust, wood chips, and other products. If horticultural workers do not experience any aspergillosis symptoms from contact with these kinds of products, it is not any more likely that they would experience symptoms as a result from exposure to compost products.

Weed seeds are also a concern. Shiralipour (1990) and McConnell placed weed seeds in plastic mesh bags, which were then placed in cornposting piles. Exposure of the weed seeds to temperatures of 150 degrees Fahrenheit for only a few hours was adequate to kill the weeds.

Growing Possibilities for Quality Compost

The potential for using compost by agricultural interests is great. If compost products are made with an emphasis on quality and consistency, it is likely that use of these materials will continue to expand in crop production. **O**

How to Produce High Quality Compost

The right mix of raw materials combined with state-of-the-art technology yields a high quality end product.

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A compost recipe usually is a combination of organic materials, or feedstocks, capable of producing a balanced end product, one that is nontoxic to plants, people, and animals and that improves soil quality. Common fodder for cornposting includes tree bark, manure, leaves, cardboard, food waste, soiled paper, wastewater residuals (biosolids), grass clippings, tree trimmings — in effect, just about anything organic and biodegradable in nature. A balanced recipe must also factor in such parameters as proper moisture levels, carbon-to-nitrogen ratio, particle size, and porosity of the final mix.

Sometimes, it is necessary to analyze the physical and chemical characteristics of individual organic sources to help develop recipes. Certain organic materials, for instance, may contain contamination from sources such as heavy metals, pesticides, plastics, or salts. Care must be taken to limit the contamination of raw materials.

After the raw materials have been selected, they must be combined prior to cornposting. Mixing can be done in special units designed for this purpose or by front end bucket loaders that pick up and toss materials into a homogenous mix. Many combinations can be tried and mixes can be changed often, based on the availability and uniformity of the raw materials and the needs of the market.

Common Cornposting Systems

Cornposting technology can be as simple as using a pitchfork and people power, or as sophisticated as computer-controlled, state-of-the-art machines will allow. Generally speaking, the better the technology that is used, the higher is the quality of the compost. Three types of compost technologies currently are the most widely used:

Windrow composting, the least sophisticated of the three, involves placing a mixture of organic waste materials into long, narrow piles approximately six feet high by twelve feet wide and as long as is necessary. The compost process is accelerated by frequent turning of the windrow with a front-end loader or custom designed machinery built for this purpose. Turning fluffs the pile and increases porosity of the mixture, which helps to improve the introduction of ambient air into the windrow.

Aerated static pile composting provides for mechanical introduction of ambient air and requires no turning of the organic mixture once the pile is formed. By controlling air mechanically, this process allows the use of larger piles. When cornposting with this method, an air plenum is constructed and the organic mixture is placed in piles on top of the air plenum. Piles are built as high as equipment allows, normally eight to twelve feet. Air is either pushed into or pulled from the pile by a blower connected to the air plenum system. Aerated static piles can be constructed individually or in extended piles. Individual piles, constructed all at once, allow the processing to occur in batches. Extended piles consist of a series of cells created over the course of many days and stacked against each other to form one long rectangular pile. A temperature sensor placed within the pile works in conjunction with the blower to control temperature and oxygen concentrations within the pile.

In-vessel *composting* involves confining the compost process to a variety of containers or vessels. Different in-vessel systems use a variety of methods to enhance and accelerate the compost process. However, each system usually includes some method for aeration, mixing, compost process temperature control, and containment of odors. In-vessel systems generally are the most costly of the three major technologies because of high capital construction costs. Most are proprietary systems that require greater operation and maintenance expenses and a higher skill level to operate.

Once a recipe has been established, the mixture will be incorporated into the compost technology chosen, either windrow, aerated static pile, or in-vessel cornposting. These technologies were designed to accelerate the decomposition process of organic materials. How these processes are managed will either speed up or slow down the decomposition process, ultimately influencing the quality and cost of the product.

Digestion

During the cornposting process, microorganisms occurring naturally in organic materials transform them into compost through digestion. That is, the microorganisms break down the various organic materials into simple compounds that are more uniform and biologically less active. In order to accelerate the cornposting process, these organisms need an environment that allows them to flourish.

The main aspects for proper management in the cornposting process include temperature, aeration, and moisture control. Low temperatures are indicative of reduced microorganism activity and could indicate a lack of oxygen or inadequate moisture conditions. Most often, low temperatures are the result of lack of oxygen.

Once the cornposting process is believed to be complete, testing should be performed to ensure that the cornposting goals have been met and the desired compost produced. Common test methods measure the carbon-to-nitrogen ratio, respiration rate, moisture, pH, and weed seeds. Additional tests are run based on regulatory, environmental, or end-use requirements.

Curing

The curing process further assures that a uniform and well-digested compost is produced. The length of the curing period depends on how well the organic materials were decomposed during the digestion process and on the ultimate end-use of the compost.

During the curing period, the compost continues to decompose but at a slower rate than that which occurs during digestion. This continued decomposition improves the compost characteristics and is an important part of the overall cornposting process quality control program.

Maintaining aerobic conditions in curing piles is usually difficult to achieve. Anaerobic conditions can develop which may lead to odors and the development of compounds that could be detrimental to plants. If compost is to be distributed from curing piles, it should be turned two to three times to release odors and reintroduce aerobic conditions prior to distribution.

Curing can occur outside or under-cover. Under-cover operations usually have fewer problems because rainfall does not factor into the curing process. When curing outside, consideration should be given to the effects of rainfall, which can be either beneficial or detrimental, depending on the moisture content of the compost. Good drainage, a solid base for equipment operations, and large block curing stockpiles will maintain compost quality. (For more on block stockpiling, see page 26.)

Finishing

Finishing, or post-processing, is usually undertaken to provide a uniform and customized product that is acceptable and marketable to customers. Considerations include particle size, moisture content, carbon-to-nitrogen ratio, color, texture, removal of contaminants, and nutrient and bacterial content. Finishing can include screening, blending, introducing additional nutrients and bacteria, drying, and bagging.

The most common finishing practice is screening, which can significantly improve the value and quality of compost to be distributed. Screening can improve the appearance, texture, nutrient content, and carbon-to-nitrogen ratio of the compost, as well as remove unwanted materials. Screening also creates fractions for specific end uses.

The economics of finishing also should be considered. The costs of finishing should be evaluated along with the value and demand for the product.

Storage

Maintaining some inventory of finished compost products is usually inevitable. Storage of compost materials may also be accomplished throughout the curing, finishing, and distribution processes.

Storage of materials can be under-cover, in containers, or outside. Under-cover and container storage will help prevent the effect of weather conditions on materials. Container storage will also allow the potential for control of odors, if necessary. Outside storage usually is the least costly but can be the most problematic. Outside storage considerations include the type of storage pad, stormwater drainage and collection, odor potential, and Mother Nature. An improved area that manages stormwater to reduce the effects on the materials is essential. Movement of materials when the wind direction is away from homes, businesses, or other receptors is important.

Sizing of stockpiles to prevent weather conditions from affecting materials includes the use of block stockpiling. Block stockpiling is the process of making piles as high as possible without running equipment up on the sides of stockpiles, and as long and wide as possible, taking into consideration fire prevention needs. Block stockpiling reduces the surface exposure of materials to outside weather conditions. Because of the insulating characteristics of compost materials, higher heat levels are also maintained within the storage pile to prevent the reintroduction of weed seeds and human disease-causing bacteria.

Typically, the heat generated from the cornposting process will also prevent rainfall from affecting the compost. Most moisture that falls on the block stockpile will evaporate within a few days. (I)

The Effects of Compost on Soil

When used as a soil amendment, compost can improve soil quality, help conserve watev, and may reduce the need for fertilizers and pesticides.

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When used in sufficient amounts, compost has both an immediate and long-term positive impact on soil properties. Compost products provide a more stabilized form of organic matter than raw wastes and can improve such physical properties as water-holding capacity, water infiltration, water content, aeration and permeability, soil aggregation and rooting depth. Compost products also decrease soil crusting, bulk density, runoff, and erosion. The chemical properties of soils that have been treated with compost are often improved, as well, as are soil biological activities.

Water-Holding Capacity

The application of compost products can markedly increase the water-holding capacity of soils. The increase is attributed to improved pore size distribution (Pagliai et al., 1981). Pores in the range of OS-50 micromillimeters (mm), called storage pores, hold water necessary for growth of plants and microorganisms.

Most mineral soils used for an agricultural purpose should receive compost rates of 10 to 15 tons/acre to increase water-holding capacity by five to 10 percent. When 146 tons/acre of MSW compost was applied, the water-holding capacity increased by 43 percent (McConnell et al., 1993). In Gallaher's usage of compost in a corn crop, the compost treatment increased soil water storage by an amount equivalent to two acre-inches of rainfall or irrigation (Gallaher and McSorley, 1994).

In sandy soils of Florida with low water retention, both the frequency of irrigation in agricultural farms and energy consumption resulting from water pumping should decrease as a result of compost application.

Soil Bulk Density

The use of heavy equipment for crop planting and harvesting increases soil bulk density of agricultural soils due to compaction. This causes limitation of pore spaces, which decreases the aeration and water-holding capacity of soils. The incorporation of compost products in compacted soils, on the other hand, decreases bulk density and increases pore volume, the rate of water infiltration and the volume of air in the soil medium (McConnell et al., 1993). The reduction in bulk density of mineral soils depends on the rates of compost application, the soil type, and the degree of soil compaction.

Soil Erosion

Compost plays an important role in control of erosion by both water and wind. The degree of soil erosion by water depends on the strength of soil aggregates to withstand raindrop impact and surface flow. Composts with high organic matter content perform well for controlling erosion by water.

For controlling wind erosion, long-term research has shown that use of normal-size MSW compost is more effective than the very fine variety' Small particle size and lightweight compost products are susceptible to wind erosion under arid conditions.

Soil pH

Soil pH affects the availability and absorption of nutrients by plants, particularly micronutrients. Most compost products have a near neutral or slightly alkaline pH with a high buffering capacity. Elevation of pH by compost application can bring about strong absorption of and, in some cases, precipitation of cadmium (Cd), manganese (Mn), lead (Pb), and zinc (Zn) in soil particles, resulting in lower accumulations of these elements in plant tissues.

Most agronomic crops grow well when the soil pH is between 6.0 and 7.0. Addition of compost to acid soils and subsequent pH elevation reduces or eliminates aluminum (Al) or manganese (Mn) toxicity, which can occur when soil pH is below 5.5. (Hernando et al., 1989).

The change in pH values of mineral soils by compost application depends upon the composted material and the initial soil pH and the soil's buffering capacity. Incorporation of compost at rates of 10 to 20 tons/acre usually increases by 0.5 to 1 .O unit in acid soils (Hernando et al., 1989).

Cation-Exchange Capacity

Cation-exchange capacity (CEC) is the sum total exchangeable cations that soil can absorb. Cation-exchange capacity of soils is important in retaining nutrients against leaching by irrigation water or rainfall. Sandy soils tend to show the greatest increase in CEC by compost application. In a Florida sandy soil, a compost application rate of 15 tons/acre increased CEC by about 10% (Hortenstine and Rothwell, 1973). High rates of compost application (more than 10 tons/acre) increased soil CEC, while low rates (less than 10 tons/acre) did not change or had minimal effect on CEC. Research results indicate that application rates of 15 to 30 tons/ acre would increase the CEC of most mineral soils used for agricultural purposes by a minimum of 10% (McConnell et al., 1993).

Nutrient Content

Although compost products contain a considerable quantity of macro and microelements, the nutrient content of compost products is lower than commonly used chemical fertilizers. And although nitrogen (N) and phosphorus (P) contents of compost are higher than most agricultural soils, the availabilities of these nutrients are low. One reason is that release of nitrogen from an organic source such as compost is in a mineral form that is unavailable to plant roots. Compost nitrogen is a valuable slow released nitrogen source. The rate of microbial mineralization and release of available nitrogen from structural forms in the compost depend on the local climate and the soil type. The first year rate may vary from 5% to more than 75% (Sommers and Giordano, 1984).

Because of the warm and humid climate and sandy soils in Florida, the rate of nitrogen mineralization is very high; therefore, plant response to compost nitrogen is much quicker than in cold regions of the U.S., such as the northeast, with lower annual rainfall and heavier soils.

Incorporation of compost types with high carbon-to-nitrogen ratios will elevate the carbon-to-nitrogen ratios of soils. A soil carbon-to-nitrogen ratio above 30 causes nitrogen immobilization, or nitrogen-rob, and nitrogen deficiency in plants. Nitrogen-rob occurs when microorganisms consume the available plant nitrogen in the soil in order to decompose the compost. Application of nitrogen as a mineral fertilizer usually corrects this type of nitrogen deficiency. Alternatively, if cropping can be delayed a few months, the compost will stabilize in the soil, correcting the problem.

Application of compost as a soil amendment reduces nitrogen leaching from soil. Therefore, utilization of compost as a soil amendment could reduce the amount of commercial nitrogen fertilizer applied and decrease the possibility of nitrate groundwater contamination (Shiralipour et al., 1992b).

The nitrogen content of a composted product depends on the feedstock and processing technology used to produce the compost. The nitrogen-phosphorous-potassium (N-P-K) ratio of most composted MSW is such that application to soils at a rate selected to satisfy the nitrogen needs of a crop might result in excess additions of phosphorus and insufficient levels of potassium. Consequently, the use of supplemental fertilizers may be required to bring the nutrient levels in balance with crop demand. As with all fertilization practices, the amounts of nitrogen, phosphorus and potassium required for crop production are best determined by soil testing.

The quantity of other macro and microelements in compost products depends on the feedstock's type and origin and the method of compost production. Their availability is also controlled by mineralization or compost decomposition rate. Nevertheless, keep in mind that composts are seldom used as fertilizer but as an overall soil conditioner.

Soil Microorganisms

The activity of soil microorganisms is affected by compost application. Microorganisms play an important role in decomposition of soil organic matter, which leads to formation of humus and available plant nutrients. An increase in soil organic matter content through compost application can promote root activity, as specific fungi function symbiotically with roots, assisting them in the extraction of nutrients from soils.

Earthworms

The population of earthworms is also increased by the addition of sufficient levels of compost products. The soil movements and tunneling by the earthworms results in enhanced aeration and water infiltration.

Soil-Borne Plant Pathogens

Application of compost has been advocated by "organic" farmers for many years as a way to reduce or eliminate the use of pesticides and soil fumigants. Indeed, suppression of soil-borne plant pathogens by organics has been well documented by some investigators (Hoitink et al., 1993). This occurs through a phenomenon known as *antagonism* or *amensalism*. Microorganisms that produce substances toxic to competing populations will naturally have a competitive advantage. For example, a species of bacteria commonly found in compost produces antifungal volatiles (Fiddaman and Rossal, 1993). Hoitink et al. (1993) have shown that wood waste compost was at least as effective as fungicides in controlling *Phytophthora* root rots. In such cases, it appears that composts increase host vigor and their ability to resist infection by pathogens. Thus, compost application can eliminate or reduce the use of pesticides. **O**

The Benefits of MSW Composts in South Florida

Compost use offers an economical way to enrich the nutrient-poor soils of South Florida.

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South Florida has a combination of geographical and environmental conditions that make it unique to the continental United States. Because South Florida is situated on a formerly submerged coral shelf, there is very little naturally occurring topsoil. In addition, the region's subtropical environment ensures a constant, rapid, and continuous degradation of any naturally occurring organics With the exception of the Everglades agricultural region, this has prevented an accumulation of rich soils preferred by agricultural producers. However, plenty of warmth, sunlight, and water help compensate for the lack of rich soils. Through the addition of relatively large amounts of fertilizers, pesticides, fungicides, and herbicides, bountiful good quality crops, including vegetables, tree crops, ornamentals, turf, and landscape materials, can be grown successfully. Researchers are now discovering that the addition of composts, especially municipal solid waste composts, can be particularly beneficial in this region.

Using MSW Compost in South Florida

During the 1992-1993 crop year, approximately 20,000 tons of Second Nature MSW compost, produced by Reuter Recycling of Florida, was distributed over 315 acres of South Florida farmlands distributed from Florida City to Boca Raton. Two different compost rates (20 and 40 tons per acre, plus a control rate of 0 tons) were applied at four different locations, with diverse soil types, ranging from sandy to rocky, that produced a variety of crops, including beans, eggplant, peppers, tomatoes, squash, zucchini, herbs, and others. In the compost test areas, average crop yield increases of between 28% and 44% were experienced in controlled, large-scale research plots in the fields. Results also demonstrated increased nutrients, decreased crop water requirements, nematode and pathogen suppression, a reduction of the impact of crop production on groundwater supplies, and a reduction in weed populations in compost-amended areas. There were also indications of possible pest suppression in compost-treated areas.

While the crop responses to the compost applications were crop-specific, a general trend toward larger plants was observed for most crops. There were also carry-over crop benefits seen during the following season, with indications of further carry-over through to the third season. Further, the reduction in chemical dependency for crop production will favorably impact both the farmer and the environment in the near future. All of these observations are consistent with results recorded throughout the history of compost production, of the benefits of amending native soils with composts.

South Florida is also home to one of the largest ornamental plant production areas in the United States. Tremendous amounts of potting soils and topsoils used in landscaping and container plant production are consumed in South Florida each year. One of the basic components of potting soils is peat moss. The major topsoil component used for landscaping is muck, a highly degraded form of naturally occurring sedge peat found in limited areas of Florida. The normal function of this material in nature is as a natural water filtration medium that cleanses surface water as it percolates through the ground into the underground aquifers that make up our groundwater. Removal of this sedge peat or muck surface substrate for usage as a potting media or topsoil effectively removes a like amount of natural water purification capability, thus reducing the water quality as well as the amount of clean water available for public consumption. Finding a suitable substitute for the muck and sedge peat fractions of potting medias and topsoils is a critical task. It is becoming increasingly clear that MSW composts appear to have the ability to act as that substitute. Research ongoing at the University of Florida has clearly demonstrated the ability of MSW compost to replace peat moss one-for-one in potting soils. Demonstration projects at a number of different commercial nurseries verified the study results. Landscape topsoil production using MSW composts as one of the major components proved to be a successful commercial endeavor, with the end product having already been successfully used on numerous landscape projects. Project expansions into turf production and public works are also planned.

How Compost Benefits Citrus Crops

Applying compost to Florida citrus trees may reduce disease, stimulate treegrowth and increase crop yield.

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Citrus is the most economically important and widely planted crop in Florida, covering about 675,000 acres in Central and South Florida. Between 1992 and 1994, more than 10.3 million new trees were planted on sandy soils, mostly low in organic matter, and poor in nutrient exchange and water-holding capacity. Recent studies have demonstrated that composted municipal solid waste (CSMW) and composted urban plant debris (CUPD) may be beneficial to citrus by reducing the incidence of root infection, stimulating growth of young trees, and increasing yield and fruit size in Central Florida citrus groves.

The center of the citrus industry is within a 100-mile radius of a densely populated area of the state, where more than 7 million people produce 5 kg of solid waste per person per day, one that holds the potential for providing the citrus industry with low-cost compost.

Potential Uses of Compost in Citrus Groves

In citrus nurseries and groves, *Phytophthora nicotianae* Breda de Haan (synonym = P. *parasitica* Dastur) is often an endemic root pathogen that causes girdling of the trunk as a result of bark infection, and slow decline in canopy vigor and fruit production as a result of rotting of fibrous roots (Graham and Timmer, 1992). Applications of fungicides control fungal infection of bark and roots and increase fibrous root density (Timmer et al., 1989). Although fungicides suppress the pathogens, which leads to increased yields and fruit size of orange and grapefruit trees on Phytophthora-susceptible rootstocks, yield response is often variable. Therefore, fungicides are not recommended unless populations of P. *nicotianae* exceed a threshold of 10 to 15 propagules per cm^3 of soil.

When fungicides are used, they usually are applied to the soil through the irrigation system two to three times over several seasons. However, soil-applied pesticides are prone to loss of efficacy after prolonged use and, since they are water soluble, have the potential to leach into the groundwater after excessive irrigation or rainfall (Kookna et al., 1995). Fungal resistance to the metalaxyl has been found in Florida nurseries, raising concerns about the long-term usage of this fungicide in citrus groves (Timmer et al., 1998).

An alternative strategy to fungicides for sustained control of soil-borne diseases is to periodically apply composted organic materials as amendments to suppress fungal root pathogens. Composted bark, when incorporated into potting media, suppresses soil-borne diseases of ornamental plants (Hoitink and Grebus, 1994). In Australian avocado groves, root rot caused by *P. cinnamomi* has been effectively controlled by intensive mulching with organic amendments and applications of gypsum (Broadbent and Baker, 1974).

In our studies of citrus, composted waste from different sources reduced the incidence of root infection of citrus seedlings through direct suppression of P. *nicotianae* in soil (Widmer et al., 1998a). We conducted greenhouse and field studies to examine the potential for compost to suppress P. *nicotianae* and improve root health.

Responses of Young Trees to Composted Municipal Waste

Three trials from 1991 to 1996 demonstrated that mulch treatments of compost are highly effective for growth stimulation of young citrus trees in newly established groves (Widmer et al., 1996,1998b). Responses were seen for soils typical of both the ridge and flatwoods production areas.

While greenhouse bioassays predicted that compost might suppress the pathogen (Widmer et al., 1998a), populations of P. *nicotianae* were either not affected or even increased by compost. Despite pathogen activity in compost-amended soils, the trees performed nearly as well as those in noninfested soils and significantly better than those in nonamended soils. Stem diameter and root mass of young trees increased 20-30% in response to post-plant treatments with surface mulches as well as incorporation treatments at planting. The growth response is best explained by increased tolerance to the disease rather than pathogen suppression. Tolerance is attributed to improvement of conditions in the root zone for more efficient water and nutrient uptake.

Operationally, the CMSW and CUPD is most effectively and efficiently applied with a New Holland 3000 side-discharge spreader as a 5- to 10-cm thick mulch layer within the tree row to cover about 80% of the root system. Although the application rates are quite high, ranging from 150-170 metric tons per hectare, the mulch lasts up to 2 years before reapplication is necessary. Reduction of mulch layers to 2-5 cm thick decreased the tree response and mav reauire vearly re-application to be effective. Current trials are designed to establish the optimum rate of CMSW and CUPD and the mechanism for the growth enhancement of young citrus in low organic matter sandy soils.

Young trees received adequate fertilizer and scheduled irrigation so compost did not substantially increase their nutrient status. Soil water-holding capacity was elevated at the interface between the mulch and the mineral soil, as was soil temperature. The proposed major benefit of CMSW and CUPD, increased soil water availability to tree roots, will be further substantiated by measures of soil and plant water relations.

Responses of Bearing Trees to Compost

Composted municipal waste applied as 5- to IO-cm thick mulch layers increased the yield and fruit size of Marsh grapefruit and fruit size of Valencia orange two and three years after application (Widmer et al., 1997). The responses occurred in groves with marginal soils and ill-adapted rootstocks that were predisposed to damaging populations of P. *nicotianae.* The effect of compost on root density was site-specific. Compost increased root density of the Valencia sweet orange trees on Carrizo citrange rootstock in a high pH, limestone-rich soil. However, compost decreased root density of the Marsh grapefruit trees on sour orange rootstock in a low organic matter sand soil (depressional sand soak). The roots in the organic mulch layer were usually lighter in color and healthier in appearance than those in the mineral soil below. The mulch layer provided a zone of favorable conditions for growth and function of fibrous roots.

The increase in yield of trees in very sandy, slightly acid soils versus the non-response in calcareous, alkaline soils may be related to the root density effect of compost at the different sites. Trees in the very well drained sand soak soil treated with CMSW were more densely foliated and showed little sign of water stress compared to the stressed, nontreated trees. CMSW and CUPD have slow mineralization rates, due to their moderate to high carbon-to-nitrogen ratios (Eichelberger, 1994), so mulches did not increase nitrogen status of the tree (Widmer et al., 1997).

The mulches substantially improved moisture-holding capacity of the soil, as demonstrated for compost applications to other Florida crops in similar soils (Obreza and Reeder, 1994; Turner et al., 1994). Under more favorable conditions for water uptake, apparently fewer roots were required to take up water and water mobile nutrients (e.g. nitrogen and potassium), bringing about a 30% decrease in root density after compost application in well-drained sand soak soil. Hence, trees were able to produce more and larger fruit instead of supporting the high density of roots required by a tree in the low water- and nutrient- holding capacity sand.

In finer textured, high pH calcareous sand, where root density was 25-35% of that in the sandy soil, compost apparently worsened the soil conditions (high calcium and somewhat alkaline pH) that normally limit performance of certain rootstocks like Carrizo citrange (Castle et al., 1993). Although the mulch layer provided a favorable site for root growth in calcareous soil, yield of trees was not increased even after 3 years.

Thus, as for young trees, the principal effect of the compost was improvement of soil water-holding capacity. This condition enhanced pathogen reproduction in the mulches because P. *nicotianae* was favored by high soil moisture (Duncan et al., 1993). However, compost appeared to increase tolerance to Phytophthora root rot. The benefits of compost for increasing water and nutrient availability in soils low in organic matter enhanced root health and uptake efficiency, and thereby reduced the impact of fibrous root disease

Observations of Cumposted Municipal Wastes on Florida Citrus

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Sun-Ray and Southern farms are citrus grove operations of 9,000 acres in Highlands County, Florida. During the past five years, composted wastes have been applied to “sand soak" areas — sandy soils low in organic matter and pour exchange capacity. The following are sume of the observations from these applications.

Timing

These materials are best applied during a period with frequent rainfall. The summer period, particularly the month of August, is best. When cumpust is applied during a wet a” far better result is acquired,

We have applied municipal wastes composted with biosolids, urban plant debris campusted with biusulids, wuud mulch composted with biusulids, and various forms of composted chicken manure. The campusted wood mulch with biosolids proved to be the must consistent, and the tree response was lunger lasting. Chicken manure proved to be a good short term green-up to carry the trees through stress.

Placement

Applications in the tree row seem to give better response than applications trunk to trunk across the bed, The tree row application should be at a rate of at least twu tans per acre.

Economics

A consistent cumpust product is required to enable an efficient application. Suffieient benefit can be achieved if the compost product can be applied under the tree fur less than $30 per ton.

and probably other soil stresses as well.

Current Status of Research on Citrus

Some limitations in the use of compost have been encountered. Foremost is the availability of a high quality source of compost near the citrus industry that can be supplied with minimal delivery cost. Most of the research has been conducted with a co-composted municipal solid waste (approx. 90%) with waste water residuals (10%) from Sevierville, Tennessee, supplied by Bedminster Bioconversion. Co-composted CMW has a favorable carbon-to-nitrogen ratio (19: 1) and slow rate of N mineralization (Eichelberger 1994), so nitrogen leaching is not a concern.

The local CMSW (Reuter) tested in the early 1990s is no longer available because the plant shut down. Evaluation of CUPD from another source has only recently been initiated. A grower/cooperator conducted a preliminary trial with CUPD in 1996 and reported that the material was very fibrous, containing palm branch wastes and other coarse woody residuals that made spreading difficult. The CUPD material also may have been high in salts. Thus far, residual salts in the Bedminster CMSW have not been a problem for citrus, due to the very sandy soils that facilitate rapid leaching of salts and to the long term nature of the response on perennial citrus trees (at least one year to detect growth responses). The CUPD material spread in 1997 did not share the problems experienced with the 1996 material, but this points out the need for compost to be consistent in quality through time if they are to be used commercially.

Another major limitation to proceeding with further trials is the availability of a commercial applicator with the New Holland or equivalent spreader in south-central Florida. Two cooperators representing about 25,000 acres of commercial grove land are at present unable to use compost because they are unwilling to purchase a spreader, given the high capital cost (approximately $lO,OOO-14,000) and the uncertain availability of high quality compost. Nevertheless, our results have stimulated their interest in further trials of local compost sources, especially in sandy soils with low organic matter.

Our current evaluation of the benefits of compost used as mulches focuses on both young and old groves in sand soak soils, where citrus trees have not responded to extra water and nutrient inputs and, thus, probably are not manageable without soil amendments. Reduced rates of compost produced by local municipalities in close proximity to the citrus

Figure 9-1. *Composted municipal waste increased growth of young Orlando Tangelo trees on Cleopatra mandarin rootstock 17% (trees on right) compared to nontreated controls (trees on left) 2.75 years after application to a typical ridge soil (Candler fine sand) at the Citrus Research and Education Center, Lake Alfred.*

Figure 9-2. *Composted municipal waste (CMW) is applied to bearing citrus trees with a New Holland 3000 side-discharge spreader as a 5-10cm thick mulch layer within the row to cover about 80% of the root system. The rate at this location ranges from 150- I 70 metric tons per hectare of treated soil area.*

industry are now under evaluation to further quantify the benefits and costs of compost applications. Although the responses are positive, it is unlikely that the horticultural benefits will offset the high cost of production and transport of compost. However, if landfill space becomes a problem in the future, the cost of production and transport of compost eventually may be borne by the municipalities. For example, Los Angeles County now pays citrus growers to accept urban plant debris for use in their citrus groves (J. A. Menge, University of California, Riverside, personal communication).

Growing Field Crops with Compost

The use of urban plant debris compost can increase crop yield and decrease forage cost production.

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In Florida, tropical corn is better adapted to local soils than conventional corn varieties usually developed for the midwest. Tropical corn acreage in the southern United States increased from about 1,500 acres in 1985 to approximately 45,000 acres in 1991. Recent estimates indicate a potential of 150,000 to 200,000 acres of tropical corn with the primary use as a late season planted silage crop. Sorghum [***Sorghum bicolor*** L. (Moench)] is another valuable silage crop that is adapted to late sowing conditions. In Florida, about 18% of the 142,000 acres of full-season corn and 5% of the 42,000 acres of double-crop corn is grown with conservation tillage management. A significant acreage of soybean (Glycine max L. Merr.), cotton (***Gossypium hirsutum*** L.), small grains, forages and other crops, such as vegetables, peanut (***Arachis hypogaea*** L.), tobacco (***Nicotiana tabacum*** L.) , etc., are also grown on Florida's infertile and highly leachable sandy soils.

Land on which these crops are grown offers an opportunity to recycle urban plant debris (UPD, also known as yard waste) in a safe and effective manner, while at the same time increasing crop yield and decreasing cost of production. Mulching and addition of organic material also may increase the tolerance of plants to nematode damage.

Impact of UPD Compost on Soil Properties

Large applications of UPD can have a major impact on improvement in soil quality, often associated with a positive crop response.

Soil nutrients. The UPD used in one study had a carbon-to-nitrogen ratio of approximately 35: 1 (Gallaher and McSorley, 1995a). In order to alleviate nitrogen-rob (N-rob) of crops, the compost needs to be incorporated into the soil a minimum of 3.5 to 4 months before planting to allow equilibration to occur (D.A. Graetz, Soil and Water Science Department, University of Florida, personal communication). Nitrogen-rob does not appear to be a major problem when the UPD is used as a mulch and the required addition of nitrogen fertilizer is placed below the mulch (Gallaher and McSorley, 1995a).

The cumulative applications of UPD totaled 360, 300, and 240 tons/acre for some treatments depending on the experiment during a 3-year period. Soil organic matter more than doubled in some treatments over a 3-year period. Significant increases were also measured in soil pH, extractable plant nutrients, cation-exchange capacity and water-holding capacity. Tests are now underway to determine if a reduction in the costly input of fertilizers and lime may be offset by the addition of compost.

Soil **water storage.** UPD compost applied as a mulch resulted in the greatest amount of soil water storage in the top 2 feet of soil in three Florida UPD-treated corn experiments. In one experiment, the UPD mulch treatment had 2.3 1 acre-inches more water stored in the top 2 feet than the control. The estimated value of this soil water storage over the control ranged from $23.92/acre to $41.46/acre, depending on the type of irrigation that would be required to apply the same amount of water. Use of UPD as a mulch conserved 6 to 10% more soil water than the same amount of UPD incorporated, and 40% to 75% more stored soil water compared to no UPD (Gallaher and McSorley, 1994).

Long-term effects. All of the soil properties, including organic matter, nitrogen, and cation-exchange capacity, were dramatically increased from application of UPD, the magnitude of which was highly correlated with the amount of UPD applied. Organic matter reached a peak in the third year after UPD application and seemed to be maintained for the next two years at the highest UPD rates. Soil nitrogen appeared to peak one year after the last application of large amounts of UPD. Extractable nutrients were also increased by application of UPD (data not shown). Data seemed to fluctuate somewhat for phosphorus, perhaps as a result of more than one mechanism, such as farmer fertilization, soil fixation versus extractable, and crop uptake. It is clear that large quantities of phosphorus was applied in UPD.

Extractable potassium peaked the year of the last application of UPD then declined. This may be consistent with what would be expected, since large quantities of potassium are taken up by a corn crop, potassium is highly leachable in a sandy soil, and it is somewhat replaceable on exchange sites even though, in this case, the cation-exchange capacity had increased.

Extractable calcium and magnesium appeared to peak and be maintained, or in the case of calcium, may have even increased after the last year of UPD applications.

The cation-exchange capacity seemed to peak one year after the last application of large amounts of UPD. Continued soil analyses of these plots in future years would be useful in determining the duration of the impact that UPD has on continuing changes in soil variables.

Compost Effects on Nematodes

The increased nutrient levels and water-holding capacity of soils amended with compost may increase plant tolerance to nematode damage (Watson, 1945).

There is evidence that the addition of certain organic compounds may stimulate fungal parasites of nematodes (Rodriguez-Kabana, 1991). However, the most important effect of organic amendments on plant-parasitic nematodes may be the reduction of populations from toxic byproducts of decomposition. Ammonia and urea were shown to suppress several nematode species in tests, and the decomposition of some forms of organic nitrogen can release byproducts which are toxic to nematodes (Rodriguez-Kabana, 1986). The most effective of these amendments are those with low carbon-to-nitrogen ratios that can release ammonia into the soil (Rodriguez-Kabana, 1986).

Regardless of the mechanism involved, the addition of organic amendments may serve to alleviate some of the adverse effects on crop growth caused by plant-parasitic nematodes. Of the plant-parasitic nematodes found at some UPD Florida field corn research sites, *Paratrichodorus minor* was significantly decreased from application of UPD (McSorley and Gallaher, 1996). Other nematodes, such as *Meloidogyne incognita,* were not consistently affected by compost applications. Effects of the high carbon-to-nitrogen-ratio compost on these agricultural sites may provide beneficial effects only after several years of UPD application.

In another study, transplanted seedlings of squash *(Cucurbita pepo)* and okra *(Hibiscus esculentus)* and the use of conventional tillage incorporated UPD appeared to result in best yields (Gallaher and McSorley, 1995b). These results were based on limited data and a limited time for soil properties to be impacted by compost and to translate into crop response. Totally different results may be found between conventional tillage versus no-tillage after soil properties have been enhanced from use of UPD.

From this same study, it was concluded that the main benefit of UPD against nematodes did not appear to be reduction of nematode populations, but improved growth and tolerance of host plants in nematode-infested sites. Sweet corn yields were equal for UPD treatments both conventional tillage-incorporate and no-tillage-mulch, and both gave yields superior to the conventional tillage control without UPD (Gallaher and McSorley, 1995b).

Response of Corn to UPD Compost

There was a consistent trend for corn forage yields to increase as the cumulative total UPD application rate increased. A high correlation was found between corn forage yield (Table 10-l) and all of the soil property variables presented. These data also show that the effects of UPD application, at the high rates used in these studies, had a long-term benefit on soil quality and crop yield, extending well beyond the last year of UPD application (1994). It has not yet been determined how long these benefits will persist.

Increased corn forage yields from use of UPD ranged from 2.5 ton/acre to 6 ton/acre, valued at 34/ton (based on 30% dry matter), depending upon the experiment. Increased yield was positively correlated with the increased soil organic matter, improved soil fertility conditions, and greatly increased soil water storage capacity. Mulched no-tillage UPD treatments consistently had greater amounts of stored soil water compared to the conventional tillage-incorporated UPD treatments (Gallaher and McSorley, 1994).

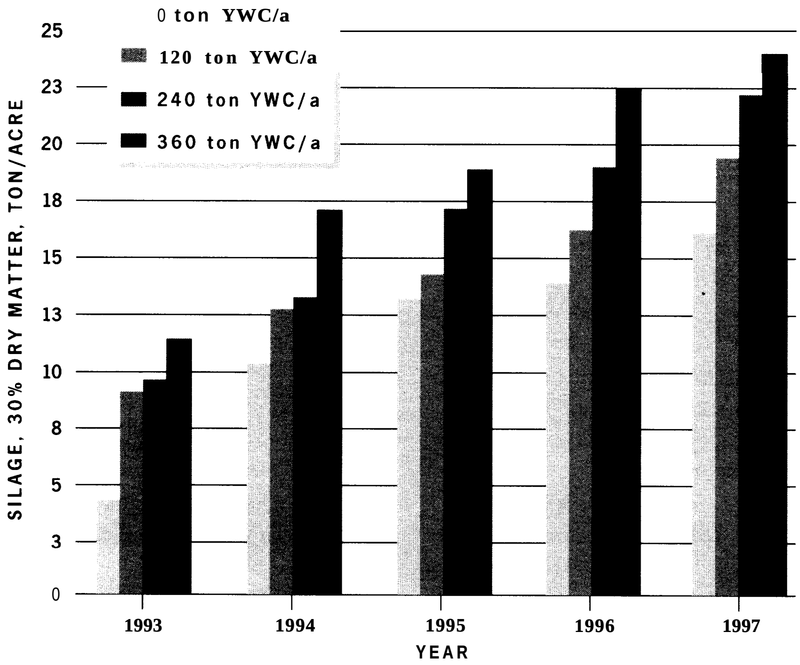

Table 10-l: *Compost Use and Corn Silage Yield. Corn silage yield from use of yard waste compost (YWC) on Haufler Farm, Gainesville, Florida (values of YWC are in ton /acre cumulative from applications in 1992, I993 and 1994.*

In California, test blocks showed that when the organic matter level is raised through large scale addition of organic amendments, impressive changes take place (Woolley, 1995). When the organic matter is doubled to 4%, there is a four- to five-fold increase in water retention, resulting in a 10% to 25% reduction in irrigation required in a normal rain year. Further research is required to determine what periodic level of re-treatment with compost will sustain these benefits.

Economics of Cornposting

In 1989, Florida produced an average of 16 tons per acre corn silage on nearly 20,000 acres of corn silage harvested. Economic benefits from reduction of fertilizer inputs and increased water conservation to corn silage alone could amount to $200 per acre. For example, depending on the nutrient concentrations and ratios in composted waste materials, a typical net return of $322 per acre (30 tons silage per year) from double-cropped corn for silage was reported by Gallaher et al. (1991).

If nutrients from biodegradable solid waste were used instead of fertilizer to replenish soil nutrients removed by the corn silage crops, the net return would increase to $536 per acre, a net $2 14 per acre increase. If UPD provided these nutrients on 5,000 acres of double-cropped corn silage, a fertilizer savings of over $1,000,000 would be realized the first year alone.

These savings were calculated based on the assumption that, because of societal benefits, municipalities wish to recycle biodegradable solid waste on farmland and, therefore, there would be no cost to the farmer for materials, hauling and spreading. Purchase and transportation costs might result in no financial advantage to the farmer for disposal of or use of UPD on sandy soil farmland, even though soil properties and corn forage yields increased. If the cost of UPD and its transport to the field were to be as much as $2/ton, then the advantages of the UPD essentially disappear, and cost would exceed the price of silage at the farmers storage pit (Hildebrand et al., 1997). The challenge for future researchers and policy-makers is to balance societal and economic benefits.

Use of Composts on Florida's Vegetable Crops

When used with care, compost can give Florida's vegetable crops a boost.

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Florida is a major vegetable-producing state, with 418,000 acres under cultivation each year (Florida Agricultural Statistics Services, 1997). Sandy soils used to grow Florida vegetables have low native fertility, so they require relatively high fertilizer inputs. However, minimizing fertilizer leaching or runoff has become important as a result of potential negative environmental impacts. If water and fertilizer conservation could be increased, grower input costs and negative environmental effects could potentially decrease.

In recent years, composts produced from a wide range of waste materials have become available in Florida on a large scale (Smith, 1995). While environmental regulators are mainly concerned about trace metal concentrations in compost, growers have different interests once compost has passed regulatory health and safety standards (Ozores-Hampton et al., 1998a). From a commercial vegetable grower's point of view, compost quality is judged by its moisture and nutrient concentration, pH, soluble salts, organic matter concentration, carbon-to-nitrogen (C:N) ratio, water-holding capacity, bulk density, cation-exchange capacity, particle size, presence of weed seeds, and odor (Ozores-Hampton, et al. 1998a).

Pros and Cons of Applying Compost to Vegetable Crops

When compost is incorporated into soil, observed benefits to crop production have been attributed to improved soil physical properties. Compost usually contains large quantities of plant-available micronutrients (Ozores-Hampton et al., 1998a). However, soil improvements are mainly attributed to increased organic matter concentration rather than increased nutrient availability. (Gallardo-Lara and Nogales, 1987). Significant quantities of nutrients (particularly nitrogen, phosphorus, and micronutrients) become bioavailable with time as compost decomposes in the soil. Amending soil with compost provides a slow-release source of nutrients, as opposed to mineral fertilizer, which is usually water-soluble and is immediately available to plants.

Crop injury has been linked to use of poor-quality compost, such as that from early stages of the cornposting process (Zucconi et al., 1998a). The type and degree of plant injury is directly related to compost maturity and soluble salt content. Optimum chemical and physical parameters for composts that might be used in vegetable crop production are listed in Table 1 l-l.

In Florida, soil application of immature compost consistently resulted in "N-immobilization," where available forms of inorganic N were converted to unavailable organic N followed by growth inhibition of vegetable crops such as beans, corn, peppers, tomatoes, and squash (Kostewicz, 1993; Gallaher and McSorley, 1994; Bryan et al., 1995). When immature compost is applied and a crop is planted immediately, growth inhibition and stunting may be visible for 40 to 60 days. When using compost with C:N ratios higher than 25 or 30, N fertilizer should be applied, or planting delayed for 6 to 10 weeks to allow the compost to stabilize in the soil (Obreza and Reeder, 1994).

Research on vegetable compost utilization in Florida has established several potential applications: soil amendments, soil-borne disease suppression, biological weed control, alternative to polyethylene mulch, and as a transplant media.

TABLE 11-1
Physical properties of compost used in vegetable production*.

Physical Properties	Optimal Range	Effect
Moisture (%)	35–55	Higher moisture, increased handling/transportation costs
Organic matter (%)	50 or more	Higher organic matter lowers application rate
pH	5.0–8.0	In acidic soil, alkaline compost will raise pH
Water holding capacity (WHC) (%)	20–60	Higher WHC leads to lower irrigation frequency
Soluble salts ($dS \cdot m^{-1}$)	less than 6.0	Higher than 6.0 means potential toxicity
Bulk density (lb/cu yd fresh weight)	500–1000	Higher moisture content means a greater bulk density
Particle size	Passes 1 inch screen	Increase soil porosity
C:N ration	15–25:1	Higher C:N ratio causes "N-immobilization"
Maturity (G.I.[y])	Over 60	GI lower than 60 indicates phytotoxicity
Compost stability	Stable	Instability can cause "N-immobilization"
Weed seeds	None	Uncomposted materials disseminate weeds

[z] FDACS, 1995.
[y] G.I = (% seed germination x root length growth in % of control)/ 100.

Compost as a Soil Amendment

Amending Florida soils with composted materials such as biosolids, MSW, and urban plant debris (UPD) has been reported to increase crop yields of bean, black-eyed pea, okra, tomato, squash, eggplant and bean, water-melon and tomato, corn, and bell pepper (Bryan and Lance, 1991; Ozores-Hampton and Bryan 1993a, 1993b; Ozores-Hampton et al., 1994b; Obreza and Reeder, 1994; Gallaher and McSorley, 1994). In calcareous soil, application rates of biosolids compost as low as 3 to 6 tons/acre resulted in crop yield increases for tomatoes, squash, and beans (Bryan and Lance, 199 1; Ozores-Hampton et al., 1994b). In sandy and calcareous soil, MSW compost application rates of 40 tons/acre resulted in crop yield increases for bean (Obreza and Reeder, 1994). (Figure **1 1-** 1) Contradictory crop response results were found when a compost with low nutrient content was compared to a traditional fertilizer program. However, combining such compost and inorganic fertilizer has generally been more effective in producing a positive plant response than separate application of either material alone.

One concern of using biosolids or MSW-based composts is the possible presence of unwanted elements in the compost and their uptake by crops. Compost that does not meet EPA 503 standards for metals concentration in biosolids cannot be marketed and is thus unavailable to be applied to agricultural land. Research in Florida on tomatoes and squash grown on calcareous soil where biosolids, MSW, and co-composted biosolids-MS W that met the 503 standards were applied showed no trace metal accumulation in the edible plant parts (Ozores-Hampton et al., 1994b and 1997).

If all of Florida's organic fraction of solid waste was converted to compost, it could easily be assimilated by the Florida vegetable industry. If only 20 tons/acre of compost (fresh weight) were applied to each of the 418,000 acres of vegetables annually grown in Florida, 8.4 million tons of compost could be recycled each year (Smith, 1994). The actual rate and frequency of compost use should be determined by compost properties such as nutrient concentration or N mineralization rate, and soil physical and chemical properties.

Soil-borne Disease Suppression

The colonization of compost by beneficial microorganisms during the latter stages of cornposting appears to be responsible for inducing disease suppression. Compost does not kill the pathogens that cause disease as fungicides do. Instead, compost controls the pathogens by keeping the beneficial micro-organisms active and growing. Therefore, pathogenic agents either will not germinate or will remain inactive (Ozores-Hampton et al., 1994a).

In Florida, few experiments in vegetable crop production under field conditions have investigated the use of compost in controlling soil-borne pathogens. Municipal solid waste (MSW) was incorporated into calcareous soil in Dade County at 36 and 72 tons/acre and compared to an untreated control (Ozores-Hampton, et al., 1994a). A two-crop rotation of bush beans and southern peas were seeded. Bean emergence and yield were improved by 25% in the

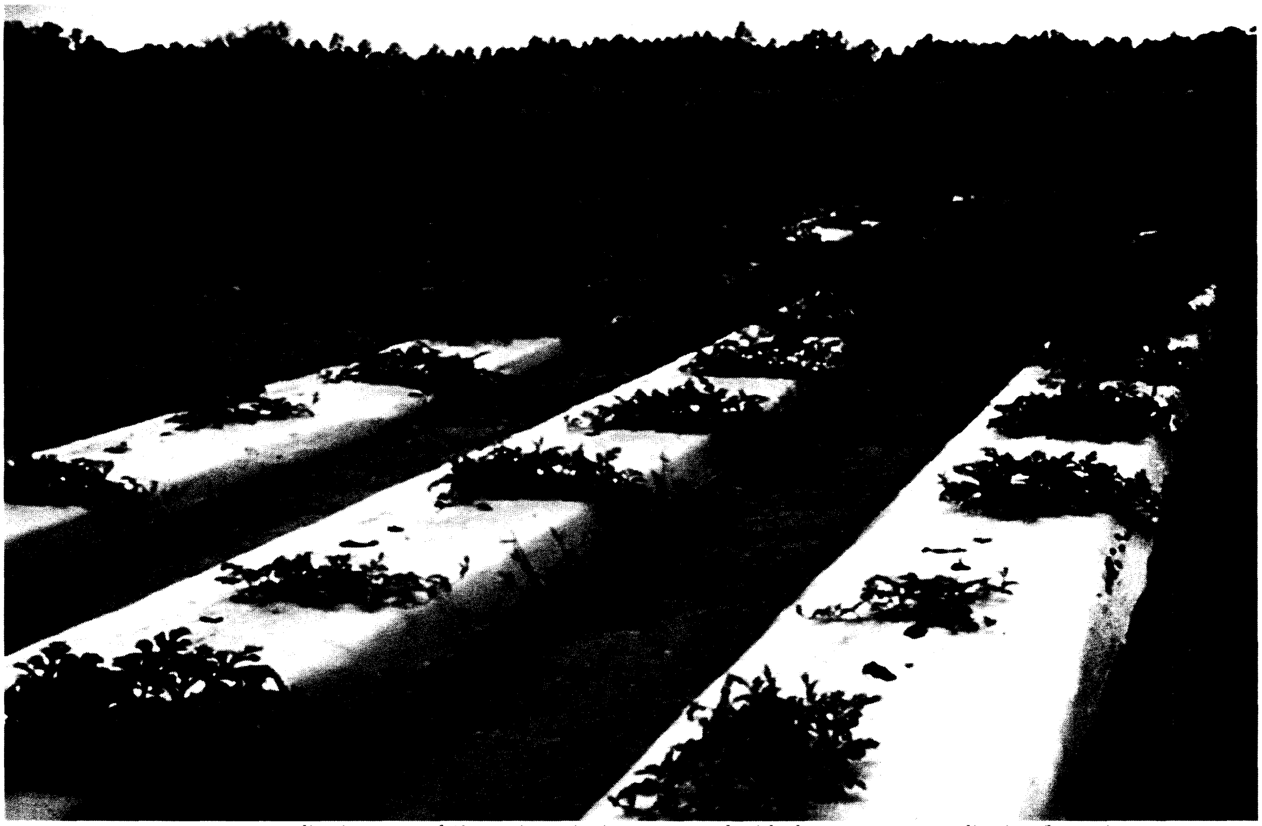

Figure 11-1: MSW *compost application rates of 40 tons/acre (top) as compared with the no compost application (bottom) on watermelon. Comvost-treated plots yielded 22.35 tons/acre compared with 16.15 tons/acre in control plots with no compost.*

compost treatment compared to the untreated control. Ashy stem blight of bean caused by ***Macrophomima phasolina*** was severe in areas with no compost application, but was almost completely eliminated where MSW compost had been applied (Figure 1 l-2). MSW compost reduced the damage by ***Rhizoctonia*** root rot in southern pea considerably compared with the untreated control. In the areas with no compost application, severe infections caused plant stunting and premature death, with significant yield reduction.

Biological Weed Control

Weed growth suppression is an important attribute of surface-applied mulch. An organic mulch suppresses weeds by its physical presence as a surface cover, or by the action of phytotoxic corn-pounds contained in it (Ozores-Hampton et al., 1998b). Weed seed germination inhibition by burial under mulch is due to the lack of growth-promoting factors such as light, temperature, or moisture. Chemical effects of phytotoxic compounds (volatile fatty acids and/or ammonia) in compost can decrease weed seed germination. In Florida, a water extract of 3-week-old UPD and immature MSW compost decreased germination of several perennial and annual weeds in petri dishes (Shiralipour et al., 1991). Under field conditions, application of immature 4-week-old MSW compost at 3 inches (45 ton/acre) or greater thickness completely inhibited weed germination and growth for 240 days after treatment in vegetable crop row middles. Inhibition of germination or subsequent weed growth may be attributed to both the physical effect of the mulch and the presence of phytotoxic compounds (fatty acids) in the immature compost (Ozores-

Figure 11-2: *MS W compost application rates of 72 tons/acre (front) nearly eliminated ashy stem blight, compared with the no compost application (back) on bush beans.*

Checklist for Compost Utilization on Vegetable Crops

1. Use of immature compost can cause detrimental effects on plant growth. H&h C:N ratio compost can result in N-immobilization if it is below 25:1 to 30:1. We recommend assaying compost for the presence of phytotoxic compounds using a cress seed germination test. In this test, a compost sample is saturated with water, and the extract is squeezed from the sample. A portion of the extract is used to moisten filter paper in a petri dish, on which mess see& are placed and allowed to stand fur 24 hours. The germination index (GI) is measured as GI = [(% cress seed germination x root length in % of the control)100]. If GI is less than 60, allow about 90 days between the time of compost application and planting of the crop, or apply nitrogen fertilizer. For example, if cress germination and root length on compost was 40% and 1 inch, and the control 80% and 2 inches, respectively, therefore we obtained a 50% cress seed germination and 50 % root length as % of the control Thus, the GI = 25, indicating immature compost. An alternative measure is to continue composting the material to maturity before it is applied.

2. Most vegetable crops are sensitive to high soluble salts, especially when they are direct-seeded. We recommend measuring the soluble salts concentration of a saturation extract. If the electrical conductivity (EC) is below 6.0 dS/m, no salt toxicity should occur. If the EC is above 6.0 dS/m, the amended soil should be leached by rain or irrigation with water before planting seeds (only a few crops can tolerate this salt level).

3. Lack of equipment to spread cumpust in vegetable fields is a concern. We encourage cumpust facilities to play an active role in developing spreading equipment.

Source: Ozores-Hampton et al., 1998a.

Hampton et al., 1998a). Similar weed reduction was obtained with mature MSW compost (100 tons/acre) in row middles of bell pepper compared with an untreated control, but herbicide provided improved weed control over mature compost (Roe et al., 1993b).

Alternative to Polyethylene Mulch

Polyethylene mulch regulates soil temperature and moisture, reduces weed seed germination and leaching of inorganic fertilizer, and is a barrier for soil fumigants. Removal and disposal of polyethylene mulch has been a major production cost to Florida growers. Therefore, utilization of composted waste materials in combination with living mulches in a bell pepper production system was investigated (Roe et al., 1992, and 1993a). Traditional raised beds were covered with polyethylene mulch, MSW, wood chips, or biosolids-UPD co-compost (100 tons/acre), and bed sides were either planted with a St. Augustine grass living mulch or not planted. Bell pepper yields were higher on compost mulch plots than on unmulched plots but lower than on polyethylene-mulched beds.

Compost as a Transplant Medium

The vegetable transplant industry relies on peat moss as a major ingredient in soilless media (Vavrina and Summerhill, 1992). Peat is an expensive, non-renewable resource. In Florida, alternative soilless media has been investigated to grow tomato, cucumber, bell pepper, and citrus seedlings (Vavrina, 1994; Roe and Kostewicz, 1992); Stoffela et al., 1996). Seed emergence and seedling growth was similar to traditional peat:vermiculite media when peat was partially replaced with compost. Negative growth effects were reported when the medium was 100% compost, especially when immature, unstable compost was used or the compost did not have adequate fiber content to assure a desirable bulk density. O

Compost Uses for the landscape and Nursery Industries

High quality compost frequently compares favorably with peat as a growing medium for Florida's nursery and landscape plants.

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Of all the different agricultural uses for compost products, use as a growing medium component in ornamental crop production frequently receives high priority because of the relatively high value of nursery and greenhouse crops and the continual cultural requirement for organic matter for rooting substrates (Slivka et al., 1992; Tyler, 1993; Tyler, 1996). Every time a container plant is sold, the rooting substrate is sold with it, necessitating the need for new potting mixtures to start new crop production cycles.

The attractiveness of ornamental crops as outlets for compost product marketing does not come without cost, however. Since the plant's root system is in direct and continual contact with the compost product, any concerns regarding compost quality are most acute with container crops. Plant producers must keep in mind that the way compost products should be used is not necessarily the same way that natural humus products, such as peat, are used.

Using Compost for Ornamental Crop Production

Compost materials have been used successfully to grow a wide spectrum of nursery crops, from flowering annuals (Wootton et al., 1982) to container-grown tropical trees (Fitzpatrick, 1985). In a demonstration project conducted in 1979-1980 at a commercial nursery in southern Florida, a number of container-grown ornamental species grew to marketable size significantly faster than plants grown in a growing medium composed of 6 peat: 4 sawdust: 1 sand, by volume (Fitzpatrick, 198 1). One of the species tested, dwarf oleander Nerium ***oleander,*** grown in IO-inch diameter containers for 5 months, averaged approximately 1.25 times larger when grown in the compost mixture as compared to the control (Figure 12-1). Moreover, compost products have been successfully used in field nurseries as soil amendments to increase productivity in various tree species (Gouin, 1977 — Gouin and Walker, 1977).

Numerous other research studies and reviews have been published on how compost products can be used to improve production of nursery crops. Sanderson (1979) reviewed a large number of published studies and reported significant increases in productivity across a wide variety of nursery crops. More recently, Shiralipour et al. (1992a) reviewed published studies on compost use in a wide variety of crops, including nursery crops, and reported significant increases in crop productivity.

Unlike other applications of compost in agriculture, the stand-alone container medium category requires the highest quality of compost. One example of the influence of compost quality on compost performance as a component in a horticultural growing medium is the level of total salts in the substrate. The level of soluble salts in composts made from sludges stabilized with ferric chloride and lime may be considerably higher than in compost made from sludge that has been stabilized using a wet-air oxidation process. One study compared the use of these two types of sludges for growing the non-salt tolerant container crops ***Spathiphyllum*** Mauna Loa and ***Schefflera arboricola.*** The plants grown in the compost with higher soluble salt levels were significantly smaller than plants grown in composts with lower soluble salts. However, both compost products resulted in plants that were significantly larger than plants grown in a control medium consisting of 40% peat, 50% pine bark and 10% sand (Fitzpatrick, 1986).

Figure 12-1. *Dwarf oleanders* (Nerium oleander) grown *in I O-inch diameter containers for 5 months in a trial conducted at a commercial nursery averaged I.25 times larger than plants grown in a control growing medium comprised of the nursery's standard mix of 6 peat:4 sawdust:1 sand, by volume (Fitzpatrick, 1981).*

Figure 12-2. *West Indian mahogany* Swietenia mahagoni *grown in compost alone with no fertilization and irrigated with well water (second from right) did not achieve growth comparable to trees grown in a peat, pine bark and sand medium fertilized at normal nursery crop rates (control [right]). Trees grown in compost medium with no fertilization and irrigated with sewage effluent (secondfiom left) grew larger than trees grown in peat, pine bark and sand medium, with no fertilization and irrigated with secondary effluent. Compost medium did not supply sufficient nutrients in fast growing tress such as mahogany and schefflera. In slower growing trees, the compost and effluent supported growth rates comparable to the rates observed in the control (Fitzpatrick, 1985).*

Growers also should be aware that while many compost products contain significant levels of certain plant nutrients, they rarely contain these nutrients in sufficient concentrations to provide all of an ornamental crop's requirement. For example, in one study in which tropical trees were grown in containers, the compost products did not provide sufficient nutrients when used without fertilization, especially in fast growing trees such as schefflera (Brassaia actinophylla) and West Indian mahogany ***(Swietienia mahagoni)*** (Figure 12-2) (Fitzpatrick, 1985). In this same study, slower growing trees, such as pink tabebuia ***(Tabebuia pallida)*** and pigeon-plum ***(Coccoloba diversifolia),*** grown in biosolids compost and irrigated with secondary treated sewage effluent, grew at rates that were not significantly different from rates observed in trees grown in a peat, pine bark and sand medium fertilized at normal nursery crop levels. Apparently, the levels of nitrogen (N) in the effluent (average 6.8 mg/L, SD=5.8) were sufficient to augment nutrients provided by the compost medium in the slower growing trees, but not in the faster growing species.

Expanding Horizons

Careful attention to growing medium characteristics can allow faster and more economical production of ornamental crops. Since nursery crops have a recurring need for a growing medium as each growing cycle is completed, compost marketers have the opportunity to develop products that can be very attractive to ornamental plant growers. Provided the compost products are made with emphasis on quality, it is likely that use of compost materials will continue to expand in nursery crop production.

Use of Compost on Turfgrasses

Compost may help build better turfgrasses on some 148,000 acres of golf courses in Florida.

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There are more than 5 million homes with turfgrass lawns in Florida, and more than 1,300 golf courses, an increase of more than 15 percent since 1994, The average Florida golf course is 114 acres in size. Thus, more than 148,000 acres in Florida are dedicated to golf courses. Golf course maintenance expenditures average $3,585 per acre annually. Money generally is available and will be spent by golf courses for maintenance practices that are proven to be beneficial.

Beneficial Effects of Composts on Turfgrasses in Florida

Numerous articles recently have discussed the potential use of compost on golf courses. Most of these focus on using compost for topdressing, and some discuss the use of golf course-generated organic waste as compost feedstock. However, there is little documentation of actual compost use on golf courses, other than as mulch around ornamental plantings. The use of compost as a soil amendment during golf course construction is rarely discussed.

Because of a lack of scientific studies aimed specifically at utilizing compost in golf courses in Florida, discussions on the subject will be based upon inferences from uses of composts in other turfgrass situations and from other regions. Detailed, specific, proven recommendations for compost use on golf courses in Florida cannot be given at this time.

Of the research that has been conducted on golf courses in Florida, most has related to using compost as a soil amendment to improve the native sand soils which generally are droughty, infertile, and have little capacity to retain nutrients and other agrochemicals. We have consistently demonstrated that overall turfgrass quality, in terms of visual appearance and vegetative density, is improved by the incorporation of composts in the root zone at rates up to approximately 30% by volume (Cisar and Snyder, 1995; Snyder and Cisar, 1996). In these studies, various municipal composts were spread over the soil surface at a depth of approximately two inches and incorporated by rototilling to a depth of approximately six inches.

Particularly in the months shortly following compost application, drought resistance has been observed (Cisar and Snyder, 1995). The time following a rainfall or irrigation event until turfgrass wilting was observed to be increased in those plots that received the compost incorporation. In greenhouse studies, leaching of several organophosphate insecticides was reduced by compost addition, and the addition of compost did not increase leaching of nitrate or phosphorus (Cisar and Snyder, 1995).

Compost clearly provides much needed plant nutrients for turfgrass growth, which is reflected as increased uptake of nutrients by turfgrass grown in compost-amended soils (Table 13-1). In one compost source study that is still underway, the positive turfgrass growth and visual turfgrass quality effect of compost incorporation has been observable for more than 2.5 years.

We believe the major nutritional benefit of the compost is due to the quantity of nitrogen it contains, which is slowly released to the turfgrass over time. In this regard, some sources of compost contain more nitrogen than others. Those that are amended with biosolids have analyzed higher in nitrogen than composts made exclusively from urban plant debris, and turfgrass growth has been greater in soils amended with such materials (Snyder and Cisar, 1996). The composts contain other nutrients as well, but some fertilizer may be needed

TABLE 13-1
Effects of Compost on Nutrients in Turfgrass

Date	Element	No compost	With compost	Statistical significance[1]
D/M/Y		---- (mg m^{-2}) ----		
8/4/93	N	31	37	ns
	P	9	10	ns
	K	19	26	*
27/4/93	N	23	58	**
	P	8	22	*
20/5/93	N	205	658	*
	P	45	162	**
	K	144	493	**
7/6/93	N	172	825	**
	P	34	189	**
	K	121	649	**
29/7/93	N	339	855	**
	P	98	222	**
30/9/93	N	1693	3119	*
	P	649	1119	*
	K	1342	2811	*

[1] **, *, and ns represent P<0.01, 0.05, and P>0. 10, respectively.

TABLE 13-2
Relationship Between Turfgrass Topdressing Rates and Depth.

Application rate	Application depth
Yd^3/1000 ft^2	inches
0.05	0.015
0.1	0.03
0.2	0.07
0.3	0.09
0.4	0.13
1.0	0.32

to provide a balance of nutrients with respect to the nitrogen content of the compost. In this regard, potassium may be relatively low in some composts.

Potential Uses of Compost Amendments in Golf Turf

A number of articles have appeared in golf course trade magazines in recent years encouraging the use of compost on golf courses. However, in most cases, little information is presented that specifically describes the use of compost. For example, Wilkinson (1994) listed many benefits of using compost on golf courses, but provided few examples of its use or specifics about using compost on various portions of the course. Thus it appears that the task still remains to combine existing data on the benefits of compost to turfgrass with a consideration of the various possible uses on a golf course in order to suggest methods and markets for compost uses on golf courses.

Golf courses can be compartmentalized into four main sectors: greens, tees, fairways, and roughs. On an area basis, fairways and roughs account for more than 90 percent of the golf course. Although greens and tees constitute only a small portion of the entire area, they receive a vast majority of the overall maintenance dollars and effort expended on the course.

Greens Construction

Modern greens generally are constructed according to rigid specifications delineated by the United States Golf Association (USGA). The specifications allow for inclusion of organic matter in the form of sphagnum peat, but the use of other materials is not recommended. It may be possible to substitute compost for sphagnum peat, but any such mixture should be analyzed in the laboratory before use to confirm adherence to USGA-specifications for the root zone mix. For this reason, no blanket recommendation can be made for the use of compost in greens construction.

Topdressing

Routine soil application on the surface of greens (topdressing) to control thatch and increase surface smoothness and ball roll on mature and new golf course greens is an essential golf course cultural management operation. Topdressing adds a thin layer of soil, usually no more than 1/8-inch depth at the surface of the turf, after which it is incorporated by mechanical and physical action with brushes or mats. At this rate, approximately 0.4 cubic yards of topdressing per 1000 ft^2 of surface area are required (Table 13-2). Frequency and rates of topdressing are based on targeted use. In Florida, topdressing is applied to bermudagrass as often as bi-weekly. Light rates of topdressing are preferred for quality greens (Beard, 1982). Topdressing rates range from 0.05 yards per thousand square feet for well-performing greens with minimal thatch to 0.4 cubic yards per thousand square feet for bermudagrass greens with a thatch problem (Beard, 1982). Greens in Florida generally comprise 6 to 8 thousand square feet each.

Topdressing materials should closely match the texture of the existing soil medium if soil root zone modification is not the goal. Soil layering should be avoided as this reduces water and air movement through the profile. Thus, topdressing may not consist purely of compost. Instead, topdressing materials generally consist of sand- and soil-sized particles, in addition to organic materials (Beard, 1982).

Furthermore, organic matter addition to topdressing is an area of controversy. Some experts recommend pure sand for topdressing of greens, as sufficient organic matter is found in thatch (McCarty and Elliott, 1994). On the other hand, Adams and Gibbs (1994) recommend topdressing applications with a low amount of organic matter to dilute the residual organic matter and to avoid the increased surface hardness from pure sand applications.

Regardless of the philosophy on the benefits of including organic matter in topdressing, many golf course superintendents routinely apply topdressings that have organic matter mixed in as an additive to improve nutrient and water retention. A number of organic materials have been used in soil mixtures, with peats being the most popular. Composted leaf blade materials generated by the course also have been used. Following current management practices, more compost would be utilized in topdressing for greens than for any other portion of course, because topdressing is not routinely used on the remainder of the course. Greens are mowed very closely, so compost used in topdressing must be very fine, and not contain fragments of metal, glass, and plastic.

Tees

Tees probably could be constructed with 10% by volume compost, or perhaps somewhat more, and there would be an agronomic benefit for the grass. Initial “grow-in” likely would be faster, less fertilizer would be required for maintenance, and irrigation might be reduced somewhat.

Fairways

Fairways constitute the bulk of the golf course acreage. Compost probably could be used beneficially in fairways during construction, with incorporation in the surface soil at rates of 10 to 20% by volume, and up to 30% in well drained areas. Bunkers and fairway mounds often are droughty and difficult to manage, and compost use in bunker and mound construction might be especially valuable. Utilization of compost in fairway construction could aid in “grow-in” and maintenance, reducing the required amount of fertilizer and possibly water for at least several years.

Roughs

Roughs are second in area only to fairways. Compost incorporation into areas devoted to roughs could be especially useful, since fertilization and irrigation probably could be reduced. In all but poorly drained areas, compost incorporation at rates up to 30% by volume should be permissible.

The Role of Compost in Disease Management on Golf Courses

Intensively managed golf greens are particularly exposed to stresses caused by plant diseases. In recent years, alternative methods of disease control, including the use of composts and biological control agents, have been suggested (Nelson, 1992). The mechanism of control is thought to be through suppression of disease by either a direct effect of microorganisms in the compost on the pathogen or from more favorable soil conditions which encourage soil microflora diversity, leading to suppression.

Cornposting Golf Course Wastes

Using golf course leaf blade clippings and other plant-derived materials as an organic amendment to topdressing has been an “in-house” practice of some superintendents for a number of years. However, there has been little scientific study to base recommendations for using such materials. Potential problems arising with incorporating organic matter from such sources include introduction of pathogens, weeds, nutrient-rob from poorly composted materials, source inconsistency, and play interruption from poorly sized organic materials. Golf courses may also be limited by low storage capacity and availability of composted topdressing and labor support to adequately prepare the topdressing materials. Companies that could conduct the compost operation at the golf course, and vendors who could supply composted topdressings, as needed, could fill this marketplace niche (Ostmeyer, 1993).

For golf courses that want to do on-site preparation of composted topdressings, few guidelines exist. The dry soil topdressing mix should be sieved to remove large objects and may require fumigation to kill off pathogens, weed seeds, and undesirable vegetative propagules (Beard, 1982). The organic matter fraction portion should be sized to avoid segregation after application to the turf surface. According to Beard (1982), the final preparatory step for the topdressing mix should be composted for a period of up to eight to ten months to regenerate soil flora and fauna. Composted topdressing should be stored in a well-ventilated shed and be sufficiently dry at the time of application (Beard, 1982). **O**

Compost Use on Forest lands

Using compost on Florida's forest lands may be an acceptable means of recycling organic residuals.

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The recycling of composted residuals through forest lands is generally beneficial because of increased growth of timber with a low health risk for the remote human food-chain. Composted waste utilization on forest lands has been documented nationwide and in Florida as an acceptable alternative for waste recycling (Cole et al., 1986; Riekerk, 1986; Jokela et al., 1990). Recycling the slow-release materials carefully and sparingly on the highly absorptive porous forest soils maintains acceptable ecological conditions and runoff water quality. The added organic matter increases the absorptive capacity and decreases the acidity of Florida's forest soils. These processes, in turn, increase the retention of heavy metals against leaching into the water table (Fiske11 and Pritchett, 1979).

Compost Utilization in a Slash Pine Plantation Forest

This project built upon a previous study of the benefits of compost application to a slash pine flatwoods site prior to planting. In that case, composted MS W application nearly doubled the yield of wood without measurable adverse effects (Jokela et al., 1990). The main objectives of the silvicultural municipal solid waste (MSW) compost utilization study was to investigate the effects of composting on water-holding capacity, soil chemistry, soil/ground water quality, and tree survival and growth (Riekerk, 1995) and to demonstrate conservation of water by increasing the soil retention capacity with amendments of organic waste products.

The sites were in the Austin Cary Memorial Forest near the University of Florida in a cleared area of sandy soil with a 3 ft deep water table, and in a six-year old slash pine (*Pinus elliottii*) plantation forest on poorly-drained soil. This site design was chosen to evaluate the effects of leaching depth on groundwater contamination, and of weed competition on tree survival.

Five-row plots within each site received on average a low (59), medium (96), and high (127) dry ton/acre of compost during the fall of 1992. Half-length 50 ft plots received 100 lb mixed fertilizer + 100 lb urea +200 lb lime (nutrient-only) or 68 dry ton/acre wood chips (carbon-only) to separate their combined effects in compost. The nutrient application with wood chips averaged about 50% of the low compost rate, and that with fertilizer was about 75%. The carbon-to-nitrogen ratio of the compost on the seedling site was 30, on the forest site 34, and of wood chips 58, while the moisture contents were 33%, 26% and 45%, respectively. The urea had 46% nitrogen, the lime 28% calcium, and the mixed fertilizer 10% each of nitrogen, phosphorus and potassium. The compost on the cleared site was disked into the soil and then planted with slash pine seedlings, but that on the forested site was only top-dressed between tree rows to avoid root damage (Figure 14- 1).

Compost, surface soil, soil/ground water sampling and analysis lasted only for a year, but periodic tree measurements were continued over 5-l /2 years.

Water-Holding Capacity

The data from the seedling site indeed showed reduced soil bulk density, which increased field soil water content of all treatments. The high-rate compost application significantly increased saturated water-holding capacity in the seedling site.

Similar results were reported for MSW compost applications up to 20 ton/acre in a young slash pine plantation (Bengston and Cornette, 1973).

Soil Surface Chemistry

The compost treatments increased the pH, mineral and organic matter levels, as could be expected from the relatively high application rates. Similar results have been reported by others (Fiske11 and Pritchett, 1979; Fiske11 et al., 1979). Post-treatment organic matter analyses showed a 1.5–2.0 fold increase in organic matter for the high corn-post treatments with up to 3% organic matter in the topdressed forest soil.

The wood chips with the high soluble phosphorus content increase the phosphorus in the surface soil as much as it was expected. The high levels of phosphorus in percolating soil water suggest significant leaching, but the lack of a treatment response of the phosphorus level in ground water (at both sites) may have been caused by mineral and biological fixation in the sodic horizon (Fiske11 and Pritchett, 1979).

Soil and Ground Water Quality

All treatments increased phosphorus levels in soil water of the seedling site, including a significant rise in phosphorus by the high-rate compost. In contrast, the addition of similar rates of compost to agricultural soils under laboratory conditions reduced water-extractable phosphorus levels by fixation (Graetz, 1994).

Because of an unexpectedly high phosphorus level in soil water from the control plot of the forest site, significantly increased phosphorus levels could not be demonstrated for the treatments. However, the phosphorus level in soil water from the control of an earlier study on the site was about 0.24 ppm (Burger, 1979), suggesting significant increases by the treatments.

The highly variable nutrient levels of soil water were increased mostly by an initial flushing effect, with the exception of nitrate-nitrogen in the high-rate compost and wood chip plots of the seedling site. A comparison of the average nitrate-nitrogen levels in water-extracts with those in soil water showed much lower ratios under compost than wood chips, suggesting nitrification of the large amount of water-soluble ammonium-nitrogen in the compost. Denitrification apparently reduced nitrate-nitrogen levels under the wet, organic-rich and neutral pH levels of the high-rate compost, but significant nitrogen immobilization may have been the dominant process under the wood chips with a very high carbon/nitrogen ratio of 58 (Graetz, 1994). The relatively low nitrate nitrogen level in soil water under wood chips of the forest site also suggested nitrogen immobilization, but nitrification is low in the acid soil of this site (Burger, 1979).

The high pH and conductivity levels under the compost layers were generated by the significantly increased amounts of potassium and calcium in soil water, which in turn were exceeded by those of water-soluble laboratory compost extracts. The soil/ground water ratio for copper (Cu) was similar to that in a loamy soil column leaching study where the process of Cu mobility was associated with the soluble Cu supply from compost rather than being complexed by dissolved organic matter that was trapped by the subsoil (Giusquiani et al., 1992).

The chemistry of soil water may be important for tree nutrition; however, that of ground water is of environmental concern. While soil water under all the compost treatments had higher levels of nutrient elements than the control, only the high-rate compost application generated ground water quality levels that exceeded accepted standards for a significant time interval. The main contaminant was nitrate-nitrogen, as was expected from its ionic mobility and its documentation by previous studies (Riekerk, 1986).

Tree Survival and Growth

The addition of nutrient-rich MSW compost obviously has a fertilizer effect on plant growth.

Figure 14-1. *Applying compost to an existing pine plantation.*

The effect of compost on average-tree volume was a 42% increase by high, 33% by medium and 25% by low applications, while that by wood chips was 33% and fertilizer was 29% after 66 months. The latter responses suggest that about half of the corn-post effect was derived from the added organic matter (water-holding capacity) and half from improved nutrition. Tree mortality in the fertilizer plot created a plot volume 63% higher than that of the control while the others grouped around 37% more. This compares to about 70 percent of biomass weight after 16 years in an earlier study, which is in part due to increased wood density with age (Jokela et al., 1990).

Recommendations for Compost Application on Forest Lands

The information from this study suggests that for a large-scale application, better methods are required for a more even distribution of the compost over the site. Top dressing in an existing pine plantation is feasible with a straight-walled live-bottom wagon, but incorporation may damage the roots. Application of paper-mill sludge pellets with a centrifugal fertilizer spreader has been done operationally in northeast Florida.

Compost application rates for tree growth improvement can be as high as 130 dry ton/acre, but transport and application costs and increased tree mortality makes a medium rate of 100 dry ton/acre more effective. In addition, established limits of environmental water quality standards in Florida restrict the application rate for poorly-drained sandy pine flatwoods to 400 lbs/acre of nitrogen per year, or about 100 dry ton/acre of compost every five years. Earlier trials in a plantation establishment showed that optimal growth could be realized at 100 tons/acre or less. **O**

Reclamation of Phosphate Mine lands with Compost

The phosphate mining industry annually reclaims an average of 4,000 to 5,000 acres of mine lands in Florida, making it a viable market for compost products.

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The phosphate industry in Florida produces more than 75 percent of the United States' supply of phosphate. The industry is concentrated in five southwest Florida counties that include Hillsborough, Polk, Hardee, Manatee and Desoto, where over 90 percent of Florida's phosphate is mined. In 1996, the mining industry began reclamation at a 100 percent equivalency that requires one acre to be reclaimed for every acre mined. The phosphate mining industry on average reclaims between 4,000 and 5,000 acres a year of mine lands in Florida.

Statutory and Economic Considerations

The cost to reclaim phosphate land is between $3,000 and $8,000 per acre. Earth-moving contributes the largest single expense. Mining reclamation costs for "old-lands" — those mined before July 1, 1975 — are subsidized by the State Comptroller from the Minerals Trust Fund, which is funded by a phosphate severance tax. After that date, state statutes required mandatory reclamation of mine lands by the phosphate industry itself.

The Comptroller reimburses the industry for reclamation of the old lands at a rate of $4,000 an acre for mined-out areas and $2,500 an acre for clay settling areas and other land forms. Of the 87,000 acres of old lands mined before 1975, almost half remain to be reclaimed.

Traditional Use of Organic Material by the Mining Industry

In Florida, the level of organic matter required by the Department of Transportation for establishment of vegetation is 1 percent. Soil found on mined phosphate lands usually has less than one half of one percent organic matter. The mining industry manages its soil to recover its organic content. Topsoil found in overburden is set aside for future use. Peat is seldom available. Muck is the primary material used, but its availability varies. Muck is found in wetland areas with depths ranging from a few centimeters to several meters. As part of a permit to mine wetlands, mining companies typically are required to remove and stockpile muck prior to mining and to use it later to reclaim wetlands.

At the present time, the primary reclamation activity where organic material may be required is in the re-creation of wetlands. The main reasons to save muck found on phosphate lands are its ability to provide a low cost source of wetland seeds for plant establishment and its ability to retain moisture during the dry season.

Some of the problems experienced by the industry with the mining of muck are: 1) it is not uniform in particle size, 2) it may contain nuisance plant seeds, 3) while stockpiled, its moisture level should be maintained to preserve seed and to avoid wind disbursement, and 4) muck may be found with a relatively low organic content level (around 20 percent.)

Wetland creation involves the additional expense of soil recontouring of elevation to create hydrological conditions needed to form wetlands. Another associated cost to the mine company is the processing of muck that includes excavation, transfer, stockpiling and application.

Blending of recycled urban plant debris with muck in order to obtain biological diversity of seed is one option for future field trials. To use recycled urban plant debris organic material in wetlands mitigation projects, it should have the following parameters: 1) be free of weed seed, 2) have a preferred pH range between 5.0 to 6.3) contain a particle size that will not float,

4) have a level of maturity that releases nitrogen, 5) have an organic content range between 35 and 65 percent.

Mining Industry% Past and Present Use of Recycled Organic Material

The industry has had limited exposure to the use of urban plant debris organic material. Historically, there have been a few small scale field experiments where urban plant debris organic material was used in demonstration projects. It has been used in turf establishment on quartz sand slopes and on phosphogypsum stacks.

The industry now requires that organic material be particle size-reduced, managed for weed seed and delivered by motor carrier to the reclamation site. Mining activity in Florida is located on the northern edge of the southern climate zone, which is subject to invasive, nuisance plants. For this reason, a weed seed-free material is required. Another concern by the industry is the availability of a sufficient quantity of acceptable material to meet its reclamation needs.

The Industry's Conversion to the Use of Recycled Organic Material

The most important indicator of successful reclamation is plant performance. State regulations allow one year for revegetation and one year for vegetative establishment. Soil that has been mined needs improvement to support vegetation. Addition of organic material results in increased soil fertility and the ability of vegetation to become established and self-sustaining. The use of recycled urban plant debris organic material by the phosphate industry will increase following successful demonstration projects. The industry is now exploring the development of a low cost means of land application of organic material that does not exceed its present reclamation costs per acre.

Future Uses and Benefits of Recycled Yard Waste Organic Material

The lands with the greatest potential for use of urban plant debris organic material as a soil amendment are the more sterile upland areas that receive sand tailings and the clay settling areas, where the organic content is less than one half of one percent. The successful establishment of turf in upland areas acts as a buffer to filter storm water runoff that reduces water turbidity in wetlands. Organic material also can be substituted for the application of clay that is placed in sand, where it is used to improve the cation-exchange capacity and moisture retention.

The establishment of vegetation aided by the use of organic material will improve the properties of soil structure and reduce soil erosion. The addition of organic material aids the soil's physical and chemical properties by improving cation-exchange capacity, increasing water-holding capacity, reducing the acidity in soils, and providing plant nutrients. Soil biological properties are improved by reintroduction of a microbial population in the soil.

Sheet cornposting. State regulations regarding the duration of time allowed for completion of reclamation is determined by the size of the land and the character of the soil. On a 400-acre tract of land, the state normally allows a total of six years, including four years for earth-moving, one year for revegetation and one year for plant establishment. A longer reclamation period is allowed for upland soils that contain sand tailings and clay settling.

Sheet cornposting offers a large-scale processing potential but requires, as a precondition, the availability of a large tract of land and ample time. The sheet cornposting process involves the formation of windrows with specially designed delivery trailers containing live bottoms. The windrows are strategically positioned for the future even distribution of material when spread to a depth of one or two feet over large land areas. At two feet of depth, the sheet cornposting process accelerates decomposition by creating a lower temperature than found in windrows. This provides a broader range of microbial activity while improving the availability of oxygen and retaining rain water that accumulates on the bottom six inches. At a future date, the remainder of the decomposed material is cut into the soil prior to plant revegetation.

The significance of the scale of operation is illustrated by the fact that, at two feet of depth, an acre will hold 1,000 tons and a 100-acre tract will hold 100,000 tons.

Sand dam. The phosphate industry has reduced its dependence on deep well water and now relies heavily on recycling the water used to transport the slurry mix of mined ore. It also uses water as a medium to separate non-phosphate material. Quartz sand is removed from the matrix of ore material and is used to construct dams found in an elaborate network of retention lakes and canals used to remove clay and reuse the water.

Quartz sand is low in nutrients and organic matter and has poor water retention qualities. To comply with the requirements of turf establishment on dams constructed of sand, the industry applies a mixture of bahia and bermuda seed to the dam face wall. The industry reports that, within three years, sympathetic weed growth inundates the seeded areas. Contributing to this condition is the four-to-one slope of the dam and the mid-range size of the quartz sand particle that allows water to percolate, creating arid conditions for turf establishment.

The industry is interested in experimenting in a field trial over a two-acre area of a sand dam face. Urban plant debris organic material will be blended with the sand at 0, 30 and 50 percent ratios and applied to one foot depth. The year-long demonstration project will attempt to show that, as the material decomposes, it will provide moisture and nutrient retention needed to assure extended turf establishment, helping to further stabilize the slope.

Phosphogypsum stacks. This is another area where the mining industry may be able to use large amounts of urban plant debris organic material. Very little research is available using urban plant debris as a medium amended on slopes. Here the objective is to create soil conditions that improve the establishment and survival of turf grass on phosphogypsum stacks and that help remediate the effluence impact of surface water runoff that may include soluble salts, fluoride and radon.

The establishment of turf on gypsum stacks has proven difficult as a result of a very acidic pH range between 3.0 and 5.0. Composted urban plant debris organic material with a higher pH range of around 8.0 is expected to raise the soil pH while also improving moisture and nutrient retention qualities to the soil.

Roadway stabilization. Phosphate mines use long pipeline routes to transport the mined ore slurry to benefaction plants where the phosphate rock is separated. The pipelines require service roads and the routes cross areas high in sand content. Yard waste organic material provides a temporary stabilization material for the road surface while providing texture to the sand and reducing dust.

Erosion control. There are watershed areas from rainfall that erode upland areas. Recycled urban plant debris mulch has been effective in reducing erosion when placed in a row or small berm across the top of the area subject to erosion in upland areas. **O**

GLOSSARY

Biosolids: The solid material removed from wastewater after domestic sewage has been processed at wastewater treatment plants. Also known as "residuals" or "sewage sludge" (adapted from Biosolids Management in Florida, 1997).

Compost: "Solid waste that has undergone biological decomposition of organic matter, has been disinfected using cornposting or similar technologies, and has been stabilized to a degree which is potentially beneficial to plant growth and which is used or sold for use as a soil amendment, artificial top soil, growing medium amendment or other similar uses" (Rule 62-701.200(21), Fla. Administrative Code).

Contamination: Unwanted material. Physical contaminants can include sharps, metal fragments, glass, plastic, and stones; chemical contaminants can include trace heavy metals and toxic organic compounds; biological contaminants can include pathogens. In excessive amounts, a contaminant can become a pollutant (adapted from Cornposting Council, 1994).

Curing: The last stage of cornposting that occurs after most of the readily metabolized material has been decomposed or stabilized. It provides additional biological stabilization (Cornposting Council, 1994).

Feedstock: Organic materials that can be composted. Commonly-used feedstocks include grass clippings and other urban plant debris, biosolids and municipal solid waste.

Heavy Metals: A group of metallic elements with concentrations that are regulated because of the potential for toxicity to humans, animals, or plants. Trace elements include copper, nickel, cadmium, lead, mercury, and zinc if present in excessive amounts (Cornposting Council, 1994).

Humus: A complex amorphous aggregate, formed during the microbial decomposition or alteration of plant or animal residues and products synthesized by soil organisms; principal constituents are derived of lignins, proteins, and cellulose combined with inorganic soil constituents; dark or black carbon-rich relatively stable residue resulting from the decomposition of organic matter (Cornposting Council, 1994).

Macronutrients: Nutrients used by plants in high quantities.

Mature Compost: Material that has gone through the windrow or in-vessel process for "sanitation" and has been sufficiently cured for stability so as not to introduce phytotoxic acids. Mature compost will not deplete soil nitrogen to support additional biological decomposition but will be beneficial to soil and plants grown in the amended soil (adapted from Cornposting Council, 1994).

Micronutrients: Nutrients required by plants in small quantities but toxic at high levels, including boron, chlorine, copper, iron, manganese, molybdenum, and zinc.

Mulch: A soil surface cover used to retain moisture by retarding evaporation, discourage weed growth, stabilize temperatures by insulating the soil, and stabilize the soil against erosion from rainfall (adapted from Cornposting Council, 1994).

Nitrogen Immobilization (N-rob): A condition in which microorganisms in immature compost consume the available plant nitrogen in the soil to decompose the compost. Allowing the compost to stabilize for a few months before planting or applying nitrogen as a mineral fertilizer usually corrects the problem.

Organic Matter: Any carbonaceous material (exclusive of carbonates) of animal or vegetable origin, large or small, dead or alive, consisting of hydrocarbons and their derivatives.

Pathogens: Organisms or microorganisms, including bacteria, mold, fungus, virus, and protozoa capable of producing an infection or disease in a susceptible host. Measures to control pathogens include industrial hygiene, effective design and operation for biodegradation of pathogen nutrients and adequate and uniform aeration and temperature/time to assure pathogen destruction (adapted from Cornposting Council, 1994).

Phytotoxins: Toxins that may endanger plant viability or functionality. (Cornposting Council, 1994).

Screening: A production step to mechanically classify materials by size through the use of screening equipment.

Soil Conditioner: (Soil Amendment) A soil supplement that physically stabilizes the soil, improves resistance to erosion, increases permeability to air and water, improves texture and resistance to crusting, eases cultivation, or otherwise improves soil physical quality (Cornposting Council, 1994).

Stability: A level of biological activity in a moist, warm, and aerated biomass sample. Unstable biomass consumes nitrogen and oxygen to support biological activity and generates heat, carbon dioxide, and water vapor. Unstable, active compost demands nitrogen if applied to the soil and can cause nitrogen deficiency in the soil mix and be detrimental to plant growth, even causing death of plants in some cases (Cornposting Council, 1994).

Urban plant debris: Grass clippings and other yard trimmings.

Water Table: The upper surface of ground water (Cornposting Council, 1994).

Windrow: An elongated formation of urban plant debris where the dimension of construction, the particle size, and the manner of rotation provides a state to control temperatures. Windrows have a large exposed surface area which encourages passive aeration and drying.

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