Land Application of Compost and Other Wastes (By-Products) in Florida[1]

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I. Introduction

Compost is the product resulting from the controlled biological decomposition of organic material that has been sanitized through the generation of heat and 'processed to further reduce pathogens' (PFRP), as defined by the U.S. EPA (Code of Federal Regulations Title 40, Part 503, Appendix B, Section B), and stabilized to the point that it is beneficial to plant growth (the official definition from US Composting Council). Organic materials used for composting are mainly yard wastes (trash) and food wastes in Florida. More than 5.5 x 10^6 Mg of composts could be produced from yard trash and food waste in the state. Animal manure and biosolids can also be composted , but are discussed in other sections of the larger document. "Other wastes" as discussed herein [food processing wastes, coal ash, wood ash, drinking water treatment residuals (WTRs), and phosphogypsum] are by-products of leading Florida industries and are available in large quantities for reuse. Approximately 5 x 10^6 Mg food processing waste (citrus and vegetable alone), 1.85 x 10^6 Mg coal ash (from 28 coal burning power plants), 5 x 10^4 Mg wood ash, 10^9 Mg phosphogypsum (from the state's phosphorus fertilizer industry), and significant, but unknown, amounts of drinking water treatment residuals (WTRs) are available.

Most Florida soils are sandy or gravelly, low in organic matter, have too high or low soil pH, and have poor water and nutrient holding capacities. Studies conducted in Florida have proved that composts made from a number of organic waste products, as well as selected solid wastes (or by-products) themselves, can be used as soil amendments to increase soil organic matter, supply nutrient, modify soil pH, remediate As and P contamination, and improve soil physical properties. However, few of the untreated by-products are utilized commercially directly as soil amendments, except as composts. Even compost is not widely utilized. Currently Florida produces about 1.5 x 10^5 Mg of composts annually, which represents only 2.7% of available organic materials for composting, and less than 0.01% of potential needs for agricultural and landscape purposes. Factors affecting utilization of these by-products are cost, availability, quality, environmental concerns, and regulations. Landfilling or other disposal alternatives for these wastes are often more convenient and cheaper. Availability in the local area and quality of final compost are important issues for users. State regulations often do not favor reuse or make reuse difficult for the average consumer. More research and extension efforts are needed to develop better and more consistent products, to develop better management practices for compost applications, and to educate regulators and users.

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[1] The purpose of this document is to summarize research and regulatory guidance on the use of composts and other wastes in Florida. Our literature search was largely limited to studies conducted in Florida.

II. Regulation/guidelines for composting and use of composts and other wastes in Florida

Management of compost and wastes, except WTRs, are regulated by the Florida Department of Environmental Protection (FDEP) based on Florida Statutes with specific Florida Administrative Codes (FAC) (Table 1). WTRs are currently regulated based only on the FDEP guidelines.

Table 1. Florida Administrative Code (FAC) or guidance on compost and other wastes for land application.

Waste	FAC	Florida Administrative Code
Compost	62-701	Solid Waste Management Facilities
	62-709	Criteria for the Production and Use of Compost Made from Solid Waste
Food processing	62-701	Solid Waste Management Facilities
Coal ash	62-701	Solid Waste Management Facilities
Wood ash	62-701	Solid Waste Management Facilities
	62-702	Solid waste combustor ash management
Drinking water Treatment residuals	N/A	Guidance for land application of drinking water treatment sludge (FDEP, 2006)
Phosphogypsum	62-673	Phosphogypsum Management

Composting/composts

Florida composting is regulated by Florida Administrative Code (FAC) 62-701 (Solid Waste Management Facilities) and FAC 62-709 (Criteria for the Production and Use of Compost Made from Solid Waste). FAC 62-701 contains general provisions for solid waste management facilities, whereas FAC 62-709 is specific to composting and compost use. FDEP is currently considering revisions that will make the state rule even more restrictive for proper management of organic wastes in Florida (Kessler Consulting, Inc., 2006).

Composting facilities in Florida fall into 3 regulatory categories: exempt, registration (yard trash processing), and full permit facilities. Back yard, on-farm, and micro-scale composting are exempt from state regulation, because these composting operations are not judged to have adverse impacts on public health and the environment. Facilities composting only yard waste are eligible for registration and are subject to fewer restrictions regarding processing and distribution of compost. All other types of organic recycling facilities, like those composting food residuals, are subject to greater restriction than similar sized facilities that compost only yard trash (DWM, 2000; Jamieson et al., 2003; Olexa et al., 2003; Kessler Consulting, Inc. , 2006).

Based on physical and nutrient characteristics (e.g., feedstock, product maturity, foreign matter content, particle size, and trace elements concentrations) of the compost, Florida divides compost into 7 grades: yard trash, yard manure, and types A, B, C, D, and E composts (DWM, 2000). Yard trash and manure composts contain low concentrations of trace elements and have unrestricted use. Use of type D compost has greater restrictions on public contact, and type E compost must be disposed of pursuant to 62-701, F.A.C., unless demonstrated that use of this material will not endanger the public or the environment (Table 2). The trace metal concentrations of compost are governed on 4 levels ("codes", Table 3) and are tied to compost class and subsequent uses (Table 3). There are no specific pathogen requirements, though fecal coliform testing is required for reporting purposes (DWM, 2000).

Coal Ash:

Coal ash (fly ash and bottom ash) is solid waste regulated at the federal level using the Resource Conservation and Recovery Act of 1976 (RCRA) and Subtitle C or D may apply. Subtitle D is for nonhazardous wastes that are subject to individual state laws. Most states including Florida have exempted coal ash from hazardous waste regulation. Coal ash management is covered by FAC 62-701, which has no specific requirements for land application. Nevertheless, FLDEP required the permit for using coal ash following FAC 62-701, 62-709, and 62-4.070 which make almost impossible for agricultural use.

Wood Ash

Wood products burned in air curtain incinerator facilities in Florida include landscape debris, yard waste, private operation waste, and emergency reduction waste from natural disasters. Production and use of wood ash are not specified with a Florida Administrative Code, but can be regulated under FAC 62-701 (Solid Waste Management Facilities) or FAC 62-702 (Solid waste combustor ash management). FDEP Memo (# SWM-05.6) states that "clean" dry wood may be burned in air curtain incinerators or combustors, and (in some cases) through simple open burning. Clean wood includes only wood that is free of paint, glue, filler, pentachlorophenol, creosote, tar, asphalt, or other wood preservatives or treatments. Wood ash from the burning of yard trash may be used as a soil amendment or incorporated into mulch or compost products under the same conditions as yard trash.

Table 2. Compost classification based on the type of feedstock, product maturity, foreign matter content, particle size and heavy (trace) metal concentrations (FAC 62-709.550.600).

Type	Characteristics	Use restriction
Y	Made from yard trash, mature/semi-mature, any texture, <2% foreign matter, code 1 heavy metals	Unrestricted use
YM	Made from yard trash & manure, mature/semi-mature, any texture, <2% foreign matter, code 1 heavy metals	Unrestricted use
A	Made from solid waste, mature, fine texture, <2% foreign matter, code 1 heavy metals	Unrestricted use
B	Made from solid waste, mature/semi-mature, fine/medium texture, <4% foreign matter, code 1 or 2 (low or medium) heavy metals	For agricultural, public contact allowed
C	Made from solid wastes, mature/semi-mature, any texture, <10% foreign matter, code 1, 2, or 3 (low, medium, or high) heavy metals	For agricultural public contact allowed
D	Made from solid wastes, not mature, any texture, >10% foreign matter, code 1, 2, or 3 (low, medium, or high) heavy metals	For land fill, land reclamation; public contact not allowed
E	Made from solid wastes, metals exceed standards (code 4 metals)	Must be disposed

Table 3. Trace metal limits in composts based on FAC 62-709. 550.

Heavy metal	Metal "Code" Concentrations (mg kg^{-1} dry weight)			
	1	2	3	4
Cadmium	<15	15-<30	30-100	>100
Copper	<450	450-<900	900-3,000	>3,000
Lead	<500	500-<1,000	1000-1,500	>1,500
Nickel	<50	50-<100	100-500	>500
Zinc	<900	900-<1,800	1,800-10,000	>10,000

Drinking Water Treatment Residuals (WTRs)

There is no Florida Administrative Code for land use of WTRs. However, FDEP published the "Guidance for land application of drinking water plant sludge" in 2006. Based on a characterization study of WTRs (Townsend et al., 2001, the report cited by the guidance), FDEP has determined that "beneficial land application of lime sludge from drinking water systems is not expected to create any significant threat to public health or the environment. For this reason, no additional regulation or approval by the Department is required prior to this use. The Department recommends that sludge be applied at a rate no greater than 9 Mg per acre per year in order to minimize movement of metals into the environment. In addition, the land application of the sludge must meet the three general criteria (i. not be a hazardous waste; ii. not cause violation of groundwater and surface water standards and criteria; and iii. not cause fugitive dust emissions or objectionable odors or create a public nuisance)". However, FDEP does not approve the land application of alum or ferric sludge, unless the person seeking to apply the sludge can provide reasonable assurance that no threat to public health or the environment will exist based upon site-specific or material-specific criteria.

Phosphogypsum

Phosphogypsum must be stockpiled in stacks after a 1989 US Environmental Protection Agency (EPA) rule banning its use based upon the trace amount of radioactivity in the phosphogypsum. Land application of phosphogypsum would only be possible if the EPA raises the limit on radioactivity (370 Bq kg^{-1}). Florida Administrative Code 62-673 specifically addresses phosphogypsum management. The regulation (62-673.300) clearly states that 1) No person shall dispose of, or store prior to disposal, any phosphogypsum except within a phosphogypsum stack system permitted by the Department; and 2) the material is subject to the licensure requirements of Chapter 404, F.S.

III. Current use of composts and other wastes in Florida

1. Characteristics of compost and other wastes in Florida

Compost

Compost is an organic matter source that can improve the chemical, physical, and biological characteristics of soils or growing media (Table 4). Composts are made from organic feedstocks, mainly yard wastes and other organic wastes from Municipal Solid Wastes (MSW). According to the latest Florida Department of Environmental Protection report (FDEP, 2007a), Florida collected about 3.7 x 10^7 Mg of MSW, which includes about 4 x 10^6 yard trash (yard waste), and about 37% of the yard trash (not MSW in general) was recycled in 2005. More than 1.5 x 10^6 Mg food wastes were collected, but only ~1% was reused. In excess of 5 x 10^6 Mg of composts could be generated from yard trash and food waste (Table 5). However, less than 1.5 x 10^5 Mg of compost is produced annually in Florida (Ozores-Hampton and Obreza, 2007). There are 83 private and public facilities registered with FDEP to produce composts (FDEP, 2007b). The Solid Waste Solid Waste Facility Inventory Report identifies 29 active facilities in 2007. Because Florida's regulatory definition of "compost" includes mulch, screenings and other products, most of the active composting facilities do not produce compost, but only mulches and other non-decomposed products. Florida Organic Recycling Center for Excellence (Kessler Consulting, Inc., 2006) reported that as of September 2005, FDEP permitted only 5 composing facilities (Sumter County, Black Gold, Reedy Creek, Busch Gardens, and Jacksonville Zoological Gardens). Regulations, waste composition, and cost play critical roles in explaining the lack of compost facilities. The regulations strongly favor processing rather than composting because a full permit is required for compost facilities, with some exceptions. Most of yard waste is woody materials and more suitable as a bulking agent than as compost feedstock. Costs of producing compost are often higher than landfill tipping fees or the sale of mature compost. Florida has a large potential compost market, but the demand for compost is not well-developed. Slivka et al. (1992) estimated that that the state's agricultural industry, alone, could use more than 2 x 10^7 Mg of compost a year and needs as much as 4.2 x 10^7 Mg of compost for landscaping and other uses. Shiralipour (1998) pointed out that critical factors affecting marketing of compost were availability, cost, and quality.

Food processing wastes

Food processing wastes can come from plant and animal materials. The Florida food processing industry is dominated by productions of processed citrus, vegetables, and sugar, and generates greater than 5 x 10^6 Mg wastes annually (Barker et al. 2000). The wastes are mainly used for animal feed and high value uses such as essential oils, chemical and pharmaceutical materials (flavonoide and d-limonene) (Westendorf and Myer, 2004; Goodrich, 2006). There is no report of directly using the wastes as soil amendments. The Florida sugarcane industry processes greater than 1.3 x 10^7 Mg of sugarcane a year and produces large amounts of solid waste including, bagasse. Bagasse is not widely used on land but has been judged a valuable soil amendment in Florida (Stoffella et al., 1996). Ash resulting from burning bagasse is allowed to be used as a soil amendment (FDEP Memo # SWM-05.6).

Coal ash:

The American Coal Ash Association (ACAA, www.acaa-usa.org) estimated that > 1.2×10^8 Mg of coal combustion products, including ~ 8.8×10^7 Mg of fly and bottom ash, was produced in 2003. Less than 38 percent of coal ash produced was utilized, and agricultural use was only 0.02 million tons per year, or about 0.02% of coal ash produced (ACAA, 2001). Miller et al. (2000) estimated that Florida produced ~ 1.85×10^6 Mg ash from 28 coal burning power plants, and used ~ 13,000 Mg on crop land and forests in 1994. Despite the potential for more widespread use, agricultural use of coal ash has been limited by high transportation and application costs as well as by concerns that the products contribute trace elements to crops and surrounding ecosystems (Gainer, 1996).

Wood ash

Wood ash is the residue remaining after the combustion of wood. Historically, wood ash was mainly used to produce potash for fertilizer and to produce alkali for industry. However as other potash production technologies became more economical, the value of wood ash as a raw material has decreased. Today, approximately 3×10^6 Mg of wood ash are produced annually in the United States (Risse and Harris, 2007). Whereas ~ 80% of all wood ash is land applied in the Northeast United States, less than 10% is land applied in the Southeast; the remaining 90% is placed in landfills. The estimated annual production of wood ash in Florida ranges from ~ 20,000 to 50,000 Mg. In a survey of more than 80 Southeastern paper mills, 60% of the responding mills reported an interest in land application (Risse and Harris, 2007). Wood ash composition can be highly variable depending on geographical location and industrial processes. Arsenic and chromium are the two primary elements that require special attention for wood ash management (Shieh, 1998). Long term uses of the wood ash can build up trace elements in soils, which can limit the beneficial use of wood ash in agriculture.

Drinking-water treatment residuals (WTRs)

Drinking-water treatment residuals are waste products of water purification that, by virtue of their composition and reactivity, have potential for environmental remediation as a soil amendment (Livesey and Huang, 1981; Hughes et al., 2005). Drinking-water treatment residuals are primarily sediment, metal (aluminum, iron or calcium) oxide/hydroxide, activated carbon, and polymers removed from the raw water processed during the water purification process (Elliott and Dempsey, 1991; Maurer and Bollet, 1999). Using the metal salts causes the WTRs surfaces to be enriched in Al- and Fe-oxide and hydroxide functional groups. This enrichment increases the WTRs affinity and capacity to sorb P (ASCE, 1996; O'Connor et al., 2002; Dayton et al.,. 2003; Sarkar et al., 2006; Makris et al. 2004a,b). Various sources of WTRs have different physicochemical properties and sorption characteristics. Some water treatment facilities employ advanced treatment processes to meet strict drinking water standards for arsenic or radionuclides. The WTRs formed as a result of such processes can contain problematic metals (e.g., arsenic and selenium), radionuclides (e.g., radium 226/228), nitrates, and salts. More than 2×10^6 Mg of WTRs are generated from drinking water facilities in the US daily (Prakash and Sengupta, 2003). The total amount generated in Florida is unknown, but the quantity of materials is expected to be significant, and to increase as the population increases. Drinking-water treatment residuals can be disposed: a) directly to a receiving stream; b) to sanitary sewers; c) to a landfill, assuming that the residual contains no free-draining water and does not have toxic characteristics as defined by the toxicity characteristic leaching procedure (TCLP) test; and d) by land application (Chwirka et al., 2001). Land application is an attractive and less expensive alternative means of WTRs disposal and may have the added benefit of immobilizing P and other oxyanions in poorly sorbing soils. The high amorphous Al or Fe content of the WTRs can increase a soil's P sorption capacity of poorly P-sorbing soils (Elliott et al., 1990; Elliott et al., 2002; O'Connor et al., 2002).

Phosphogypsum

In excess of 4×10^7 Mg of phosphogypsum, a waste product of phosphate mining, are produced per year and add to an estimated 1 billion Mg stored in 25 stacks in Florida (FIPR, 2007). This storage constitutes a potential long-term ecological problem in Florida. The reason that USEPA requires stacking of phosphogypsum is due to radiation that exceeds the radiation limit set by USEPA. The USEPA limit is much lower than the limit in other phosphogypsum-producing countries. Solubility of radium sulfate is much lower than calcium sulfate, meaning that with time the calcium sulfate dissolves in Florida's climate, effectively concentrating the radium sulfate, and increasing the radiation problem within the stacks.

Phosphogypsum can alleviate aluminum toxicity in subsoils, can act as a source of plant available Ca, S, and P, and can promote soil aggregation and carbon sequestration. The use of phosphogypsum in agriculture is hampered by low level radioactivity. In 1992, the EPA ruled that phosphogypsum intended for most applications, including agricultural and construction use, must have a certified average ^{226}Ra concentration ≤ 370 Bq/kg. Central Florida phosphogypsum ranges from 740-1295 Bq/kg. Phosphogypsum formed during the chemical processing of north Florida rock has only 185 to 370 Bq/kg and has potential for land application.

Table 4. Characteristics of composts and other wastes.

Waste	Characteristics
Compost	Organic matter, macro- and micro-nutrients, suitable for land application
Food processing	Organic matter, macro- and micro-nutrients, suitable for land application
Coal ash	Fly ash: fine, powdery particles, primarily oxides, sulfates, phosphates, partially converted dehydrated silicates, and other inorganic particulate matter residual from coal combustion Bottom ash: heavy, coarse, granular, primarily silica, alumina, and iron, as well as low amounts of calcium, magnesium sulfates, and other inorganic materials
Wood ash	Organic and inorganic residue, fine texture, high pH (9-13), good source of Ca, Mg, K, P, and micronutrients
Drinking water Treatment residuals	Fine texture, high organic carbon, Ca, Fe or Al, activated carbon, and polymers, wide range of pH
Phosphogypsum	Mainly gypsum, high Ca and S

Table 5. Estimated total masses, current usage, and potential market for composts and other wastes in Florida.

Waste	Total/potential mass (x 10^3 Mg)	Used for land application (x 10^3 Mg)	Potential for land use (x 10^3 Mg)
Compost	5,500	150	62,000
Food processing	>5,000	Very low	Very low
Coal ash	1,850	Very low	Very low
Wood ash	20-50	<5	Very high
Drinking water Treatment residuals	unknown	Very low	Very low
Phosphogypsum	1,000,000	Very low	Very low

2. Benefits of composts for land application reported in Florida

1). Increased nutrient supply

Composts can be valuable sources of nutrients, particularly N and micronutrients. However, the nutrient concentrations and availabilities in composts vary considerably depending on the mineralization rates of composts, and the initial concentrations available in the feedstocks used to create the compost. Mineralization of compost depends on compost composition, maturity, and the soil conditions (moisture, temperature, etc.). Approximately 25% of organic N is mineralized from municipal solid waste (MSW) composts (Stoffella et al., 1997; He et al., 2000). Numerous studies have been conducted to evaluate nutrient availability from compost amendments applied in crop systems in Florida. Compost has been demonstrated to be a partial substitute for inorganic fertilizer for tomato (*Lycoperscion esculentum* Mill.; Stoffella and Graetz, 2000) and bell peppers (*Capsium annuum* L.; Roe et al., 1997). Csizinszky and Stanley (1998) reported that concentrations of inorganic N, P, K, Ca, Mg, Al, Fe, Mn, and Zn in soils increased linearly with increasing compost rates from 0 to 33.6 Mg ha^{-1}. Similar findings were also reported by Clark et al. (1995), Roe et al. (1997), and Litvany and Ozores-Hampton (2002).

2). Increased soil organic carbon content

Composts usually contain > 300 g organic C kg^{-1} and their incorporation into soil can increase soil organic C contents (He et al., 1992). Zinati et al. (2001) conducted a field investigation on (i) accumulation of total organic C and (ii) on the increases in amounts of soil organic C in the humin, humic acid, and fulvic acid fractions in a gravelly calcareous soil amended with three composts or inorganic fertilizer. Clean organic waste compost (COW) (100% yard waste plus food waste), co-compost (75% yard waste and 25% biosolids), and biosolids compost (100% biosolids) applied at 72, 82.7 and 15.5 Mg ha^{-1}, respectively, were incorporated into soil beds. Total organic C contents in the amended soils were 4-, 3-, and 2-fold higher in COW compost, co-compost, and biosolids compost treatments, respectively, than those in fertilizer treated or non-treated soils. The use of COW compost to amend soils significantly increased the amount of organic C in the humin, humic acid, and fulvic fractions, whereas similar changes were absent in soils treated with inorganic fertilizer or non-treated soils.

3) Suppressed soil borne diseases and nematodes

Composts can suppress soil-borne nematodes and plant pathogens, and may represent alternatives to fumigation with methyl bromide in vegetable crop production systems (Stoffella and Li, 2000), but results have been inconsistent (Table 6). MSW compost significantly reduced root knot nematode, but increased the number of tomato stem cankers caused by *Alternaria solani* and *Phoma destructive* (Bryan et al., 1997). MSW compost reduced the incidence of *Rhizoctonia* root rot in southern peas (*Vigna unguiculata*) as compared with the untreated control (Ozores-Hampton et al., 1994). However, using similar composts, Mannion et al. (1994) found no effects on plant-parasitic nematode populations during a 2 yr experiment. Ritzinger et al. (1997) found inconsistent effects of composts on the root-knot nematode (*Meloidogyne incognita*) populations in okra (*Hibiscus esculentus* L.) plots, yet the effects of compost on okra growth were consistently beneficial.

Table 6. Effects of compost amendment on the incidence of nematodes and bacterial wilts of vegetables grown in Florida.

Disease/ Nematode	Crop	Compost†	Rate ($Mg\ ha^{-1}$)	Soil	Crop Response§	Citation
Nematode (1)‡	Tomato	MSW	29.6	Gravelly	+	Bryan et al., 1997
Stem canker (1)					-	
Root rot (1)					-	
Nematode (1)	Okra	YW		Fine sand	-	Ritzinger et al., 1997
Nematode(11)	Tomato	BS	16	Gravelly	-	Mannion et al., 1994
		YW	48			
		YW/BS	28			
Nematode(1)	Squash		16	Gravelly	+	Mannion et al., 1994
Bacterial wilt (1)	Tomato	YW		Loam fine sand/ Loamy sand	n/+	Chellemi et al., 1992
		YW/PL			n/+	
		YW/CM			n/+	
		BS			n/-	
		Mushroom			+/n	
Nematode(9)	Okra	YW/BS		Gravelly	+/-	Wang et al., 2007

† MSW – municipal solid waste; YW – yard waste; BS – biosolids; PL- poultry litter; CM – cow manure.

‡ Numbers in parentheses represent number of nematodes or diseases evaluated.

§ Responses of n/+ and n/- mean no response or positive response and no response or negative response, respectively.

4). Increased crop yields

In Florida, crop yield responses to compost amendments have been evaluated for black-eyed peas (*Dolichos sphaerospermus*), broccoli (*Brassica oleracea*), corn (*Zea mays* L.), cucumber (*Cucumis sativus* L.), eggplant (*Solanum melongena* L.), okra, pepper, snap bean (*Phaseolus vulgaris* L.), squash (*Cucurbita pepo* L.), tomato, and watermelon (*Citrullus vulgaris* Schrad.) (Ozores-Hampton et al., 1998). In most experiments, composts had positive effects on vegetable production, but in a few cases, compost amendments reduced crop yields (Table 7). Responses of vegetable growth are significantly affected by compost composition, maturity, and soil conditions. Because of poor compost quality, tomatoes grown in MSW compost-amended calcareous soil had lower marketable yields in the first year than tomatoes grown in unamended soil. However, in the second year, tomato yields were significantly greater in the compost-amended soils (Bryan et al., 1997). Obreza and Reeder (1994) also suggested that the lower yields of tomato from compost amended plots in their experiment were caused by incorporating immature compost. Responses of crop to compost amendments largely depend on compost quality, and reliable methods to assess compost maturity, stability, and pathogen suppressivity should be developed.

Table 7. Yield responses of tomato to compost amendments from experiments conducted in Florida.

Compost†	Rate (Mg ha^{-1})	Soil	Crop Response	Citation
MSW/BS	30	Gravelly	-	Bryan et al., 1997
MSW/BS	30	Gravelly	+	Bryan et al., 1997
MSW/BS	75, 112	Fine sand	-	Obreza and Reeder, 1994
MSW	30	Gravelly	+	Bryan et al., 1997
MSW	13, 27	Fine sand	+	Obreza and Reeder, 1994
MSW	60, 120	Gravelly	+	Bryan et al., 1995
YW	12, 24, 36	Fine sand	+	Csizinszky and Stanley, 1998
PR	188	Fine sand	+	Stofella and Grazt, 2000

† MSW – municipal solid waste; YW – yard waste; BS – biosolids; PR – Plant residue.

3. Benefits of other wastes for land application in Florida

Food processing waste

Sugarcane filtercake is a waste byproduct of the sugarcane industry. The filtercake residue is mixed with water and piped from the processing mill into fields and allowed to remain in bogs for more than one year. The end product is compost with a soil-like appearance that is particularly high in calcium (Ca). Sugarcane filtercake compost has been used as a partial substitute for peat in containerized seedling production systems of citrus and tomatoes (Stoffella et al. 1996; Stoffella and Graetz, 1996). There is no known research on land application of food processing wastes for citrus and vegetables.

Coal ash

Numerous benefits can result from the application of coal ash to agricultural soils, including improvement of soil texture, modification of soil pH, and provision of essential plant nutrients for crop production. Townsand and Hodgson (1973) reported that the particle fractions of coal ash samples ranged from 45-70% silt and 1-4% clay. The fine-sized ash particles should increase the total porosity of fine textured soils. Coal ash consists of >40 elements, including most of the micronutrients needed for plant growth. Application of coal ash increases nutritional bioavailability in amended soils. Li, et al. (2002) applied a mixture of fly ash and biosolids to a gravelly soil in south Florida. These researchers found that the product improved tomato yield by 14-71% and increased concentrations of extractable Fe, Ni, and Mo in the soil; however only concentrations of Mn and Mo were increased in plants. Research completed by the Electric Power Research Institute (EPRI) indicates that mixtures of fly ash, bottom ash, and biosolids can be ideal growth media for horticultural ornamentals and turfgrass sod. The mixtures have low density, a wide particle size distribution, resistance to decomposition, and high availability in urban areas. Chen and Li (2006) indicated that utilization of fly ashes as container substrate amendments may represent a new market for the beneficial use of coal combustion byproducts.

Wood ash

The only refereed publication found related to beneficial land use of wood ash in Florida is Chirenje and Ma (2002). The study was conducted on acidic sandy soil (pH 5.6) in Hawthorne, Florida during 1995-1997. The boiler wood ash was applied at rates of 900 and 1800 Mg ha^{-1} either on surface or incorporated to a depth of 47 cm. Application of wood ash increased soil pH (>9), plant available water (~12%) and reduced soil bulk density. Plant available macronutrients (Ca, Mg, K, and P) and micronutrients [iron (Fe), Mn, copper (Cu), and Zn)] increased substantially after ash application.

WTRs

Poorly P-sorbing soils are abundant in Florida, which are characterized by low P sorbing capacities, and are often accompanied by high water tables. The combination of characteristics makes such soils vulnerable to P losses and negative water quality impacts (He et al., 1999; Novak et al., 2004). Land application of WTRs can be a cost-effective treatment for effectively sorbing excess levels of labile P in soils. The high amorphous Al or Fe content of the WTRs can increase a soil's P sorption capacity (Elliott et al., 1990; O'Connor et al., 2002; Elliott et al., 2002). Several studies have shown that land-application of WTRs significantly reduced runoff-P from agricultural fields (Haustein et al., 2000; Gallimore et al., 1999; Dayton et al., 2003). Other studies showed that WTRs reduced P leaching in Florida Spodosols (Elliott et al., 2002; O'Connor et al., 2005; Silveira et al., 2006), and eventually prevented P losses to contaminate groundwater (Oladeji et al., 2008). Agyin-Birikorang et al. (2007) reported that WTR-immobilized will remain fixed for a long time (>7.5 y), and that within the commonly encountered pH range of agricultural soil, WTR-immobilized P is stable (Agyin-Birikorang and O'Connor, 2007). Studies elsewhere (Texas) showed that another contemporary environmental problem that could be amenable to remediation with WTRs is contamination of soils, waters and wastes with arsenic and perchlorate (Makris et al., 2006; Sarkar et al., 2006).

Phosphogypsum

According to Alcolordo, et al. (1998), three main avenues of use for phosphogypsum have been explored: 1) recovery of the sulfur value is technically feasible but not currently economical; 2) use as a base and as fill in road construction is both feasible and economical, but is not permitted by the Environmental Protection Agency (EPA) at the present time because of the material's radionuclide content; and 3) use as a soil amendment. Phosphogypsum is an excellent source of calcium and especially sulfur on agricultural land. Based on a field study with application of lime and phosphogypsum to stargrass, Rechcigl and Mislevy (1997) observed that application of phosphogypsum resulted in increased yields. No refereed publication related to beneficial use of phosphogypsum in Florida can be found after 2000.

III. Concerns surrounding reuse of compost and other wastes in Florida

Composts

Composts are produced from organic wastes and, consequently, environmental concerns are always an issue in compost utilization. Of particular concern is the possibility that compost may contribute to trace element accumulation in treated soils (Zinati et al., 2004), and contamination of the edible parts of crop plants (Ozores-Hampton et al., 1997). Excess nutrients or metals released from composts can also be leached from the root zone by irrigation or rainfall (Li et al., 1997). Ozores-Hampton et al. (1997) measured trace elements in tomato and squash fruits from a compost-amended field, and found no significant changes in concentrations of Cd, Cu, Pb, Ni, and Zn due to compost treatments. Accordingly, the authors suggested that use of compost at reasonable field-application rates was suitable for producing vegetables for human consumption. Precautions, safety hazards, and regulations pertaining to composts have been reviewed by Epstein (1997), Ozores-Hampton et al. (1998), and Moss et al., (2002). High variability in the quality of operations between and within compost production facilities contributes to unpredictable compost quality. Often, immature composts result in plant phytotoxicity. The introductions of human pathogens, viable weed seeds, and high salt concentrations to compost-amended soils are also potential hazards in cropping systems. Moss et al (2002) indicated that primary concerns with respect to MSW and yard waste composts include organic contaminants and herbicides. However, these concerns were not studied or reported by scientists in Florida.

Coal ash

Environmental impact is always an issue in the land application of coal ash products. Of particular concern is the possibility that trace metals released from fly ash may be leached into groundwater. High application rates (40 or 80 Mg ha^{-1}) of the coal fly ash increased total concentrations of trace metals in amended surface soil (Li and Chen, 2006). These metals may have the potential to leach through sandy or rocky soils into groundwater. The maximum concentrations of some metals in leachates were higher than the maximum contamination level specified for drinking water. However, the high concentrations of most metals in leachates are not only due to the application of coal fly ash since soils in south Florida have relatively high Fe, Cu, Zn, Cd, and other trace metals. Environmentally sound use of coal fly ash as a soil amendment may require setting maximum limits for trace metals in coal ash.

WTRs

Florida regulators are much more concerned about trace metals, notably As and Al for land use of WTRs. Jain et al. (2005) reported that Al-WTR produced in Florida contain total As concentrations (8.5-16.9 mg kg^{-1}) that greatly exceed the industrial limit of soil cleanup target level (SCTL) for arsenic. However, recent studies have shown that As contained in Al-WTR is essentially non-labile, and that Al-WTR could indeed be used as a sorbent for As in soils (Makris et al., 2006; Sarkar et al., 2006). Water treatment residuals are also reported to potentially induced plant P deficiencies (Basta et al., 2000). Plant (*maize*) P uptake reductions and germination problems were observed when Al-WTR was applied (up to 40 Mg ha^{-1}) (Rengasamy et al., 1980). Fescue grass yields were decreased in WTR-amended soil columns (up to 80 Mg ha^{-1}) in lieu of decreasing plant-available P concentrations (Lucas et al., 1994). In addition to agronomic limitations involving P (over-applied WTRs induced plant P deficiencies); there are concerns about potential Al phytotoxicities. Florida studies have shown that when appropriate quantities of WTR (based on the chemical characteristics of WTR) are land applied, that P deficiency and Al toxicity symptoms are not observed in plants (Oladeji, 2006). The availability/accessibility of sufficient quantities of WTRs and costs of transportation and application can be major limitations to commercial use of WTRs. Field application rates of WTRs are usually large (25 to 56 Mg ha^{-1}), and can out-strip local WTR supplies when hundreds of hectares require treatment (Makris and O'Connor, 2007). Costs of transportation and application (labor and special equipment) for such large quality of materials will probably prohibit widespread land application of WTRs, but opportunities for focused use remain.

Phosphogypsum:

The major environmental concerns for land application of phosphogypsum are radioactivity due to Ra in marine-deposited phosphorus rock (Miller et al., 2000). EPA has determined that phosphogypsum can be used in unlimited quantities in agriculture as long as its radium (^{226}Ra) content is ≤ 370 Bq/kg. This limit generally permits the use of phosphogypsum from north Florida, but does not allow the use of central Florida phosphogypsum, which generally contains ~925 Bq/kg (Alcolordo et al., 1998).

Current research

Composts

Florida is a leader in research on compost utilization. The biomass program at UF/IFAS was established in 1980, and many compost research projects have been conducted since. Hyatt (1995) cited 56 compost research projects in 1993, and 19 of these projects were conducted in Florida. Florida scientists continue to be active in compost research. Based on publications from the last 5 years, current research areas in Florida are 1) using compost for container media (Wilson et al., 2006); 2) determining impact of compost on water quality (Jaber et al., 2006); 3) using compost for roadsite restoration (Harrell and Miller (2005); 4) developing testing methods for compost stability (Wu and Ma, 2002); 5) determining nitrogen mineralization rates (Ben-Avraham et al., 2007); and 6) suppressing nematodes (Wang et al., 2007).

Coal ash

Li et al. (2002) conducted a 3-year study of fly ash as soil amendments to improve soil fertility in south Florida sponsored by the Department of Energy. They found that fly ash is useful as a soil amendment to improve soil fertility and crop yield, and has insignificant impact regarding accumulation of trace metals in soil, plant, fruits, and groundwater quality. A greenhouse study indicated that fly ash was a good liming agent for container plants (Chen and Li, 2006). Several laboratory experiments were also performed to determine trace metal leaching from Florida soils amended with fly ash (Li and Chen, 2006; Sajwan et al., 2007).

Wood ash

There are no reports available for research related to land use of wood ash in Florida since 2000.

WTRs

Jain et al. (2005) collected alum-, ferric- and lime-based WTR samples from 34 water treatment facilities in Florida and determined their characteristics. The research results were used to develop FDEP guidelines for the land application of WTRs in Florida despite abundant data that Jain et al. (2005) concerns were not well founded. O'Connor and his collaborators conducted many experiments on land application of WTRs and published several refereed publications in the last 5 years on the beneficial use of WTRs in Florida (O'Connor et al., 2002; Makris et al., 2004a; Makris et al., 2004b; Makris et al., 2005a; Makris et al., 2005b; Makris et al., 2005c; O'Connor et al., 2005; Silveira et al., 2006; Van Alstyne et al., 2006; Makris and O'Connor, 2007; Agyin-Birikorang et al., 2007; Agyin-Birikorang and O'Connor, 2007; Oladeji et al., 2006; Oladeji et al., 2007).

Phosphogypsum

Rechcigl and his collaborators conducted many experiments and published many papers on land use of phosphogypsum in Florida. However, their last research project on phosphogypsum was "Predicting the long term impact of high rates of phosphogypsum applications on radioactivity in soil, groundwater, and bahiagrass forage, and on radon emissions" and was completed in 1998. There is no report available for research related to land use of phosphogypsum in Florida since then.

IV Research needs

1. Improve estimates of (and field validate) N mineralization rates from organic wastes in a variety of climatic conditions in FL. Estimation is critical for determining appropriate application rates.
2. Field validation of the Florida P-Index and BMPs associated with land application of wastes.
3. Standardize analytical methods of solid wastes. Develop a quick method for determining maturity of compost.
4. Develop passive (low maintenance) composting systems for producers
5. Develop and demonstrate simple composting devices for household use
6. Continue to be at the forefront of regulation and BMP development for waste utilization and educational efforts to better inform decision makers and the general public about sustainable and environmentally friendly waste utilization.
7. Evaluate economically viable alternatives for transporting and applying waste materials
8. Research factors for market development for compost and other wastes
9. Develop a database to document all research reports conducted in Florida

V. Outreach needs

1. Develop extension programs to educate regulators, policy makers, and local officers
2. Educate the public to encourage recycling and reuse of wastes.
3. Involve land owners and growers in research and demonstration projects
4. Develop a better website for recycling and reusing wastes
5. Develop simple and easy to read educational materials
6. Back up extension programs with solid research
7. Encourage researchers to include education, social and political factors components in their research program
8. Encourage researchers to develop research and extension intergraded projects

General outlook of compost and other wastes' utilization in Florida

Tremendous amount of yard wastes and other wastes are generated from urban and various industries in Florida and tonnage of wastes will be greatly increased as the population of the state increases. Most of these wastes were not utilized, but either land filled or stock piled. Limitation of landfill spaces and environmental impact of these facilities are become more and more serious problems. Land use of these wastes is viable disposal solution. Florida is one of leading states on research of compost and other solid waste utilization. Many research reports and publications done in Florida are available and demonstrated beneficial effects of land uses of compost and other wastes and approaches to avoid negative impacts on environment. However, road blocks seem always to exist for utilization of composts and other wastes. Regulatory resistance is insurmountable. Educating regulators probably is only way to break the block. Incentives from the state government will also be needed to make reuse of these wastes are economically feasible.

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Research Needs for Reducing Unavoidable Nutrient Losses from Horticultural Crops

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Field-scale

1. Development and evaluation of tools for managing drainage under high water table conditions. Use of such tools can reduce the drainage volume, nutrient loadings, and water use. Examples include : a) prediction of water table response to a rainfall and drainage event for different soil types and using these relationships to make drainage decisions; b) soil moisture-based drainage management; and c) delaying the drainage by reducing the drainage rate and volumes. Quantify the effects of using these practices on water use, quality, plant disease, and crop production.

2. Determine the flooding tolerance and survival of plant pathogens for some of the most commonly grown commercial citrus rootstocks and vegetable varieties under different drainage conditions. Evaluate new varieties that may have enhanced flooding tolerance. This should be in conjunction with topic 1 above to design crop-specific drainage management practices that may reduce the rate and volume of drainage, conserve water, and reduce nutrient loadings without impacting the crop yield.

3. Tools to analyze hydrologic conditions of drainage infrastructure to: (1) determine the need for changes to the system (water control structures, ditch capacity, pumps, etc.) to provide adequate drainage to protect crops while retaining as much water on-site as possible, and (2) develop operating criteria to effectively manage the system under various rainfall scenarios.

4. Evaluate the effectiveness of summer flooding on water and nutrient discharges, plant disease, production, and farm income.

Farm-scale

5. Quantification of water and nutrient dynamics in stormwater impoundments. Identification and evaluation of strategies to enhance the nutrient treatment efficiency of impoundments. These include modifications to increase the hydraulic efficiency and increased retention by soil (amendments) and plants (biomass harvesting).

6. Development and evaluation of tailwater reuse strategies on water and nutrient discharge, production, and farm income. The tailwater reuse includes the construction of new storage facility as well as modifications to the existing stormwater impoundments to facilitate water reuse.

7. Effectiveness of ditch management (cleaning and vegetative filter strips) practices on nutrient discharges.

Watershed –scale

8. Use of agricultural areas (e.g. impoundments) for water harvesting and using this water for on-farm irrigation to "banking and trading" with urban sector for economic benefits to the landowner. Effects of these strategies on watershed water supply, surface water flows, ground water levels, water quality, and wildlife.

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