GUIDANCE FOR AMENDING URBAN SOILS WITH ORGANIC AMENDMENTS

October 12, 2020

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ACKNOWLEDGEMENTS:

This document benefited from generous reviews and input provided by the following individuals:

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Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

"The nation that destroys its soil, destroys itself."

Franklin Delano Roosevelt

Guidance for Amending Urban Soils with Organic Amendments was created to provide detailed information and guidance on incorporating organic amendments into urban soils for the landscape industry and professionals from other related fields. Traditional site development methods commonly result in compacted soils that provide limited value for supporting landscape vegetation. These urban soils will slowly improve over decades through natural processes. However, incorporating organic amendments, such as compost, into urban soils after construction is complete and before landscape installation has been shown to improve soil quality, increase soil organic matter, increase infiltration, provide greater plant available water reducing the need for irrigation, and decreased runoff. Cumulatively, these persistent benefits work to improve landscape sustainability and resilience while reducing pressures on water supply and water quality.

This guide is separated in three parts that provide relevant background and instruction on amending urban soils:

- *Part I: Soils in the Urban Environment* – This introduces relevant soil characteristics and the how they affect soil functions. It also describes urban soil characteristics and the site development processes that produce them.

- *Part II: Organic Soil Amendments* – This provides an overview of organic soil amendment types and characteristics with a focus on compost production and qualities. This part also covers the potential benefits of incorporating organic amendments into urban soils.

- *Part III: Implementation* – This part covers the full process for amending urban soils, from evaluating soil conditions, to compost characteristics, considerations for amending, and instructions for installers. This is intended to guide landscape professionals through an evaluation of soils and amendments prior to incorporation. A subsection, Practical Instructions for Installers, provides a step-by-step guide for personnel responsible for amending soils properly.

References are categorized by topic to help readers quickly find links to supporting information and additional resources beyond this document. *Long-term Considerations* are included in the appendix and are divided into summaries *of Information Gaps and Limitations* followed by summaries of *Future Research Needs*, which establish that amending urban soils is a developing topic.

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PART I. SOILS IN THE URBAN ENVIRONMENT

"Be it deep or shallow, red or black, sand or clay, the soil is the link between the rock core of the earth and the living things on its surface. It is the foothold for the plants we grow. Therein lies the main reason for our interest in soils."

Roy W. Simonson, *USDA Yearbook of Agriculture*, 1957

OVERVIEW OF SOIL CHARACTERISTICS AND FUNCTIONS

Soil Texture

Texture classification is a way of characterizing soil based on the sizes of mineral particles. Individual particles of soil are classified by their size into three categories: sand (2 – 0.05 mm), silt (0.05 - 0.0002 mm), and clay (< 0.0002 mm) size particles (NRCS, 2020). The relative abundance of each type of mineral particle is used to describe the soil texture (Figure 1). In Florida, soil textures are most commonly coarse, generally dominated by sand sized particles near the surface. However, finer soils are frequently found in subterranean layers.

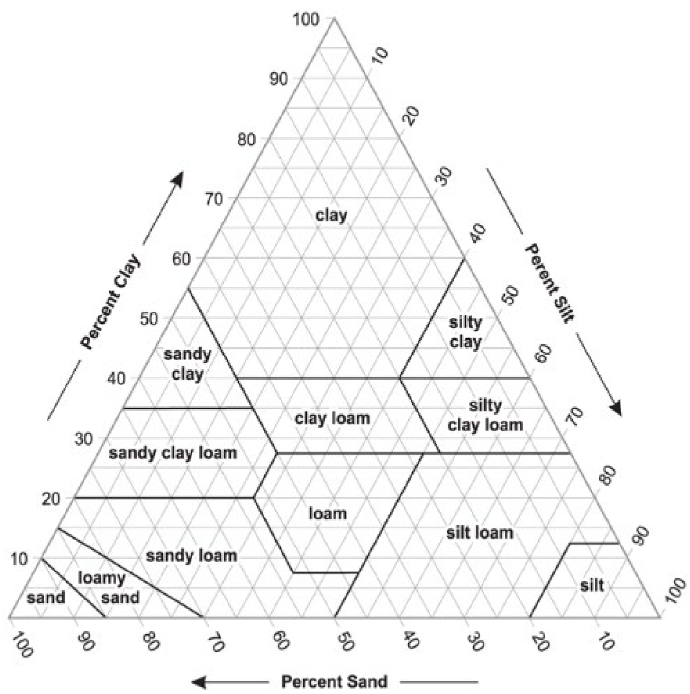

Figure 1. USDA soil texture triangle. Credit: USDA.

Organic Matter

Soil organic matter is the organic fraction of soil that is made up of microorganisms, living plant and animal matter, dead decomposing plant and animal tissues, and the stable material that remains after decomposition known as humus. Organic matter is about 50% carbon and contains nitrogen, phosphorus, and potassium, which are nutrients needed for plant growth. Other beneficial functions of organic matter in soils include:

- acting to maintain the soil's pH within a range suitable for most plants (pH range 5.5 – 7.5)
- reducing compaction and providing a structure to the soil
- helping to aggregate small particles, which creates spaces for water to soak into the ground and roots to grow

- supplying a food source for beneficial microorganisms as organic matter decomposes
- binding some pollutants, such as pesticide residuals, preventing them from moving into ground or surface waters
- increasing water retention in the soil
- increasing CEC (cation exchange capacity) to improve nutrient retention

In natural ecosystems, soils continually receive organic matter inputs from animals and decomposing organisms. Over time, perhaps a decade or more, these organic matter inputs can replenish nutrients in the soil. However, in urban landscapes, this material is often removed (e.g. grass clippings and leaves are bagged and removed from the landscape), and the cycle is broken. Compost and other organic soil amendments can be used to replace organic material that urban development has removed (Toor, et al., 2008).

Soil Composition

At a basic level soil is a mixture of mineral particles and organic matter that allows the exchange of air and water through it. All soils are natural products of parent material, topography, climate, organisms, and time (Jenny, 1941). In Florida, parent material and topography are the most distinctive factors affecting soil formation. Soils vary with depth, forming recognizable layers or horizons due to differences in soil processes such as accumulation and leaching processes.

Soil Structure

The orientation and configuration of particles forms the soil structure. In turn, this alignment of particles creates interconnected pores between particles that allows air and water to move in and out of the soil. Porosity is the fraction of the soil volume made up of these voids. A related measurement is the soil bulk density. This is the ratio of soil mass per volume of soil and is related to soil porosity via particle density.

The size and abundance of voids in the soil determine how quickly water can infiltrate into soil, flow through it, and how water is held in the soil. Large pores convey water much faster than smaller pores. This is the reason beach sands drain so rapidly and clays are used to line the bottom of ponds. Smaller pores also hold water much more tightly than larger pores. Sandy soils have very few small pores, while finer soils generally have more small pores.

Soil-Water Relationship

Like a sponge, soil can hold water so that it is available to plants. Soaking a sponge under a running faucet saturates the sponge. When the sponge is pulled out from under the flowing stream, water will drain out of the sponge. Similarly, there is a certain amount of water that soil cannot retain that drains into soil below and is not available to plants. The amount of water that remains in the soil when drainage ends is known as its field capacity.

If a wet sponge is squeezed very tightly, the sponge will lose much of the water it held before. However, there is some amount of water that will remain in the sponge, no matter how tightly it is squeezed. Soils are similar in this way as well. Some water on the surface of soil particles (adsorbed) and within very small pores is held so strongly that plants are unable to extract it from the soil. The water content at this point is known as the wilting point, because plants will wilt when soil water content decreases to this point. The water content between the field capacity and wilting point is known as the plant available water (Figure 2).

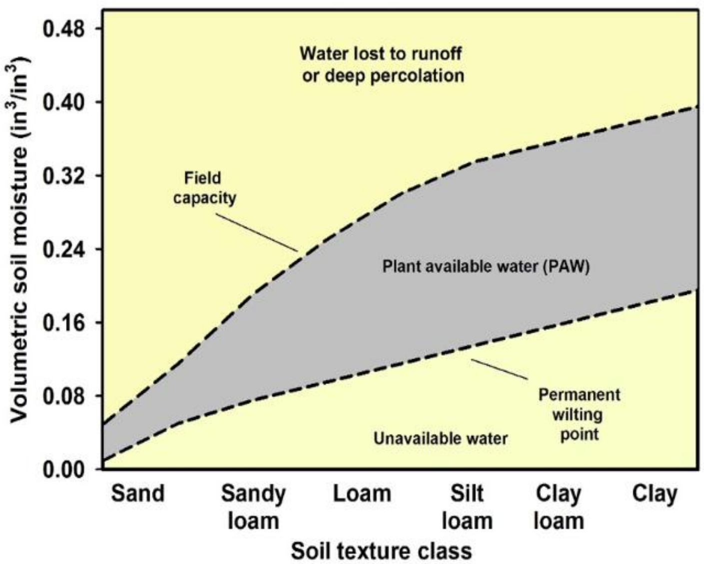

Figure 2. General relationship between plant available water, soil field capacity, permanent wilting point, unavailable water, and soil texture class. Credit UF/IFAS.

Florida Soil Profiles

Generally, north of Lake Okeechobee on the Florida peninsula and in the panhandle, the primary soil parent materials are sandy marine sediments. In south Florida, organics and calcium carbonates are the primary parent materials. Over time, warm temperatures and high rainfall throughout Florida have promoted microbial growth within the soils. These microbial organisms rapidly mineralize organic matter, particularly under warm, moist conditions, depleting the amount of organic material present. Therefore, Florida's soils typically contain lower organic matter than similar soils in more northern parts of the country (Mylavarapu et. al., 2019).

Soils are classified into 12 soil orders by the USDA. Seven of these 12 soil orders are found in Florida, with Spodosols and Ultisols being two of the most common. Florida contains the largest area of Aquods (sub order of wet Spodosols; characterized as wet, sandy soils with an organic-stained subsoil layer) on flatwood landforms of anywhere in the United States. The most extensive soil in the state and recognized as the state soil is the Myakka (Figure 3).

Figure 3. Myakka fine sand profile, a common Aquod soil found in Florida flatwoods, sloughs, tidal areas, and floodplains. Credit: UF/IFAS.

Spodosols are characterized as having a subsurface organic horizon that accumulated due to leaching of organic matter from an overlying horizon. This spodic horizon has an acidic pH and will contain aluminum and possibly iron as well. There is typically an overlying light-colored horizon dominated by sand to silt sized particles. Elevated aluminum concentrations can be toxic to vegetation. These soils are the most common in the Florida peninsula.

Ultisols, common in north Florida and the Florida panhandle, are characterized as having a sub-soil layer of clays that were leached from overlying soils. These generally have an overlying layer of lightly colored sand to silt sized particles. The clay horizon may contain high concentrations of aluminum. They can occur in a variety of locations, as well-drained upland soils or as very poorly drained soils. (UF/IFAS, 1993)

URBAN SOIL CHARACTERISTICS

SITE DEVELOPMENT PROCESS

Typically, on-site development activities begin with the clearing of vegetation and existing structures from the site (Figure 4). This is followed by cut (lowering the land surface) and fill (raising the land surface) to reshape the site contours to meet the overall needs of the site, primarily drainage and flood control. During these two stages, the existing topsoil may be scraped and stockpiled for later use on the site, or in other instances topsoil is included with the cut and fill dirt. It is cost effective to balance the site by having equal volumes of cut and fill to minimize transporting material off or onto the site.

Figure 4. Clear cut residential site after removal of topsoil; imported sand fill under house foundation slab. Credit: UF/PREC.

For areas where cut occurs, the surface layers or horizons are removed, exposing the deeper soil layers. This leaves deeper soil layers exposed at the surface. Though not always, these layers are generally much lower in organic matter, nutrients, and biological activity than surface soil layers that were cut. Spoil cut from grading roadbeds and installing utilities below the lot level of homes can frequently end up in what becomes the adjacent front yards.

Fill material (or dirt) used to raise site elevations is sourced from either the cut from elsewhere on site or is hauled in from an off-site source. In the former scenario, the cut material has either had the topsoil removed by prior scraping, or it makes up a very small percentage of the overall material that comes from low quality subsoil layers.

Off-site sources of fill typically originate from mines or pits relatively deep in soil profiles. These tend to be well drained but provide limited value (water and nutrient retention) for supporting landscape plants. Further, insects and other organisms, which can help to loosen soil and breakdown organic matter to release nutrients, are generally absent in the fill as well. In the construction of slab-on-grade homes, it is important that the material underneath the foundation be structurally stable to ensure the structural integrity of the home (Figure 4). For this reason, well drained sand material, sometimes referred to as “builder’s sand” is often used as fill material to bring lots up to grade. The culmination of these on-site cut and fill activities leaves a surface soil in landscape areas that is low in organic matter, nutrients, and biological activity, with very low water holding capacity.

Effects of Construction Activities

Once a lot is graded, building construction begins. The foundation is poured and the framing (walls and roof) is constructed. Plumbing, electrical, and gas are run through the building, drywall is hung, and floors installed.

In Florida, it can take as little as 65 days to go from a graded lot to an occupied residence. During construction, vehicle traffic regularly occurs in areas that will eventually be landscaped. The weight of vehicles and engine vibrations work to compact landscape soils. Rain events are common throughout Florida, and during certain times of the year, can be a daily occurrence. The combination of vehicle traffic with frequent wetting and drying cycles in the soil works to efficiently compact the soil to depths of 12 inches or more (Shober, 2010).

Installation of irrigation and landscaping are some of the final steps before home or building construction is completed and it is turned over to the owner. Planting beds are filled with shrubs and trees, and mulched. Similarly, sod is laid directly on to the soil with irrigation set to establish the lawn.

Typical Conditions of Urban Soils After Construction

The resulting landscape soil characteristics are very different from the pre-developed conditions in the same location. Cut and fill associated with site grading has removed or buried the dark topsoil, commonly replaced by compacted, lightly colored, coarse sand. Compaction reduces the soil infiltration rate and porosity, limiting how much water can enter the soil and increasing runoff. Due to the lack of organic matter and fine soil particles (i.e. silts and clays), water that enters typical urban soils mostly drains deeper into the soil profile, away from shallow plant roots. Soils can be so compacted that plant roots are unable to penetrate, leading to shallow rooting depths. The state of the soil at the end of construction will largely set the trajectory of the landscape for the near future. While soil compaction will be alleviated naturally over time, through wetting and drying cycles, gradual build-up of organic matter, and increased insect and organism activity, the process can take several decades (Cogger, 2005).

> Construction practices can drastically modify the soil and surface drainage on a site, creating problems that can last for decades.

Legacy Impacts of Soil Compaction

The growth of roots in the soil works to de-compact soil. Roots push into the soil and leave behind voids or channels that allow for movement of air and water. However, soils compacted from construction activities can be so dense that roots cannot penetrate them (Figure 5) - this is known as the growth limiting bulk density (Daddow & Warrington, 1983). Therefore, soil compaction inhibits the process that would naturally alleviate compaction. Compaction eventually lessens over time through other physical and biological processes, but again, this process can take decades.

Figure 5. Compacted sub-soil with original soil retained only around trees. Credit: UF-PREC.

Shallow rooting depth and limited water holding capacity of the soil also increase the likelihood of drought stress in landscape plants. Plants stressed by inadequate nutrient retention in the soil can lead to fertilizer being applied in larger amounts or applied more frequently. Stressed vegetation is also more susceptible to pests, diseases, and competition from other plants (weeds), leading to increased pesticide application to sustain plants. Trees with poor or shallow root systems are more susceptible to high winds and saturated soils, and could be a hazard during severe weather events. In worst case scenarios, the plants installed on the landscape die and have to be replaced, at a high cost to the property owner.

Frequent supplemental irrigation is often required to support and maintain plant health and quality. In Florida, landscape irrigation makes up a significant fraction of public supply, with some estimates of 50% or greater (Ferald and Purdum, 1998; Haley et al., 2007; Carr and Zwick, 2016; SJRWMD, 2020). Most of Florida's water supply, including drinking water, is groundwater pumped from aquifers. Groundwater withdrawals that exceed the natural aquifer recharge from rainfall have reduced the flows into springs and streams in Florida, some of the state's most valuable natural resources. As Florida's population continues to grow, water resources needed to sustain the population are becoming more strained, with a projected statewide deficit of 416 - 980 million gallons per day by 2035 (OEDR, 2020). Continuing this course of population growth and water use will necessitate development of alternative water supplies, such as reclaimed water, impounded surface water or desalination of sea water. These alternative sources require higher levels of treatment at greater expense, providing additional incentive for us to conserve our limited aquifer resources. Irrigation water from groundwater, reclaimed, and municipal sources (tap) is often alkaline with a pH over 7. Applying alkaline water has a liming effect on the soil, increasing the soil pH which can be detrimental to plants. This is particularly acute when soils are low in or devoid of organic matter in new home construction settings.

Both soil compaction and over irrigation can lead to excess nutrients from fertilizers feeding algal blooms in springs, streams, ponds, or estuaries.

Increased runoff from compaction provides greater risk of washing excess nutrients from the landscape (often from fertilizers applied to sustain turf and landscape plants) into stormwater ponds and downstream receiving waters. Excess nutrients lead to greater algal and aquatic plant growth in surface waters, such as streams, springs, rivers, and estuaries. At the same time, reduced infiltration increases dependence on irrigation and further reduces the amount of water that can soak into to recharge groundwater. Finally, excess irrigation can lead to leaching of nitrogen from the soil into groundwater. Groundwater in Florida naturally contains low levels of nitrogen; increased nitrogen concentrations feed algal growth that is commonly seen coating rocks and other material in springs and streambeds that are fed by groundwater (Fig. 6).

Figure 6. Excess nutrients from fertilizers can contribute to overgrowth of algae in Florida's springs. Credit: John Moran.

PART II. ORGANIC SOIL AMENDMENTS

"A cloak of loose, soft material, held to the Earth's hard surface by gravity, is all that lies between life and lifelessness."

—Wallace H. Fuller, in *Soils of the Desert Southwest*, 1975

OVERVIEW OF SOIL AMENDMENTS

Soil amendments are materials incorporated into the soil to modify properties or functions, such as drainage, aggregation and soil structure, water and nutrient retention, porosity, infiltration, drainage, and rooting depth. These materials have long been used to enhance soils in agricultural applications and have varied widely based on the material properties, rates, and intended use.

Amendments can be classified as organic or inorganic based on their composition. Most amendments tend to be organic materials due to their abundance and capacity to be completely integrated as part of the soil. Inorganic amendments are less common and are generally used for their physical and, to a lesser extent, chemical properties. Inorganic amendments are typically not biologically active. Some examples are perlite, a volcanic glass, and vermiculite, a mineral that expands when heated. Both vermiculite and perlite increase porosity and drainage when mixed with soils and do not breakdown in the soil. They are typically used in gardening and potting applications, and their applicability in Florida's urban landscapes is limited. Here we will focus on organic amendments.

Compost

Other than possibly tilling crop residue into soil, compost is the most common soil amendment used today. Compost is the resulting product of aerobic, biological decomposition of organic (biological) materials that generally does not resemble the raw starting materials (or feedstocks). When used as a soil amendment, compost is a source of organic matter that can enhance physical, chemical, and biological characteristics of soil (USCC, 2019).

What is compost?

Compost is the product manufactured through the controlled aerobic, biological decomposition of biodegradable materials. The product has undergone mesophilic and thermophilic temperatures, which significantly reduces the viability of pathogens and weed seeds and stabilizes the carbon such that it is beneficial to plant growth. Compost is typically used as a soil amendment but may also contribute plant nutrients.

—U.S. Composting Council

Compost in which the organic feedstock is fully decomposed with a stable carbon to nitrogen (C:N) ratio is considered to be mature. A high C:N ratio means there is more carbon in a material relative to nitrogen. Until this point, compost is consuming carbon to breakdown the organic feedstock at a high rate and is said to be immature. Application of an immature compost can be detrimental to plant growth because this will cause microbes to use up the N from the soil that plants need. To meet the State of Florida definition of mature compost, it must not reheat upon standing to greater than 20°C above ambient temperature and organic matter must be reduced by at least 60 percent compared to the starting material (F.A.C. 62-709.550(3)). These requirements are indications that the composting process has mostly completed, and the material is stable and mature. In reality, compost is a biologically active material that will continue to slowly metabolize organic matter at a much slower rate over time, which generates heat that could exceed the 20°C threshold. More direct evaluation of compost stability and maturity can be determined by the respiration rate (< 100 mg CO_2/kg/hr) and C:N ratio (typically < 20:1).

The feedstock of compost largely determines the properties of the finished product. Feedstocks are typically classified into “browns” and “greens”. Browns are manures, biosolids, or food wastes that typically have a high nutrient content and relatively low C:N ratio of less than 30:1 (Rynk et al., 1992). Greens are vegetation (e.g., yard waste) that typically has a low nutrient content and high C:N ratio of greater than 40:1 and as high as 600:1 for wood chips (Rynk et al. 1992). Browns and greens are combined in ratios to achieve a final C:N ratio typically of 20:1 or lower for the finished product. During the composting process, microbes will break down the organic feedstocks via aerobic digestion and some carbon will be lost to carbon dioxide production. It is important to specify a C:N ratio that is not too high or too low. Too high a C:N ratio will limit nitrogen availability in soil when it is amended, causing nitrogen deficiency in plants. Too low of a C:N ratio will release nitrogen, making it available to leach out of the soil, potentially into groundwater. Common feedstocks and considerations are provided in Table 1.

Table 1. General considerations for common feedstocks of compost production.

Feedstock	**Availability**	**Uses**	**Public Acceptance**	**Cost**	**Advantages**	**Disadvantages**
Biosolids[1,2]	• Sustainable supply • Higher quantities in urban areas	• Nutrient source • Organic matter source • Sorbent properties increase with increasing iron content	• Largely odor-driven • Pathogen concerns • Concerns largely driven by perception	• Materials generally free • Municipalities may pay for treatment, transport, and use	• Multi-purpose, multi-benefit soil amendment • Highly cost effective • EPA and FDEP regulated • Well characterized consistent quality	• Public concern/public perceptions • High nutrient loadings in some settings • May have high moisture content • May include emerging contaminants
Manures[2]	• Sustainable supply • Higher quantities near CAFOs	• Nutrient source • Organic matter source	• Well accepted	• Materials generally free • Transport and application fee	• Widespread and readily available	• Not consistently regulated • Variable quality • Not routinely treated for pathogens • Generally uncharacterized
Yard/wood waste	• Material available locally	• Organic matter source • Can be high C • Can be used for bulking and structure	• Yard waste can be odorous	• Materials may be free • Transport may be partially covered	• May be used to control erosion • Variable sizes available	• Broad category • Highly variable quality and characteristics • May be hard to obtain • Can contain herbicides

[1] Iron in biosolids can act as a sorbent, taking-up some heavy metal contaminants, such as lead (Pb) and arsenic (As).

[2] Biosolids must meet EPA and state regulations for use as an amendment. Manures must meet Federal and State BMP management standards.

The general descriptive definition of compost has led to a wide range in material quality and characteristics, which can be problematic and produce unintended results. For example, immature compost can result in offensive odors and excessive C:N ratios that limit nitrogen availability to plants. Material that does not reach inactivation temperatures during composting can harbor weeds and pathogens introduced by raw materials. Feed stocks can introduce contaminants (i.e. metals, pesticides, and biproducts) that may persist through the compost process and harm plants or other soil biology. The quality and overall consistency of a compost product depends largely on the quality of feed stocks and composting processes.

The US Composting Council (USCC) has sought to implement standards of compost quality to help consumers better understand and apply the material. Through this effort the USCC developed the Seal of Testing Assurance (STA) program that established a battery of tests to be run on composting processes and compost material. STA certified products are analyzed for pH, salts, nutrient content, moisture, organic content, maturity, stability, pathogens, and trace metals. STA certified products meet the definition of compost adopted by the USCC and are required to meet US EPA testing limits for heavy metals (40 CFR 503.13) and pathogens (40 CFR 503.32) in all batch testing. While the STA program does not set prescriptive limits on other parameters or characteristics, the program requires that producers provide consumers with a Compost Testing Data Sheet that includes test results, feedstock materials, and instructions for use. This testing data sheet is intended to inform the consumer about the product to allow the consumer to select the most appropriate product for their needs.

The US Composting Council's STA program ensures consistent quality standards are met by various composing procedures.

For production, feedstocks are typically blended at the appropriate ratios and piled into windrows, or linear mounds (Figure 7). In a typical composting process, microbes will begin breaking down the materials within the windrow. Composting is an aerobic process, requiring oxygen to occur, and it is exothermic, producing heat as a by-product. Monitoring and controlling the temperature of the windrows is key to sterilizing pathogens and weed seeds that may have been introduced via feedstocks. Over time, the microbial community within the windrow will consume the available oxygen. The bacteria also migrate out from the center, consuming any oxygen that enters the pile. Eventually, the oxygen availability becomes limiting to the decomposition rate of the pile. To reintroduce oxygen and continue composting until the material is stable, windrows must be turned every so often. Each time the windrow is turned, the decomposition rate increases until oxygen becomes limiting again or the composting process is nearing completion.

Figure 7. A windrow of compost undergoing aerobic decomposition; a close-up of the compost pile. Credit: UF/PREC.

Other composting processes exist, such as the Modified Static Aerobic Pile (MSAP) method. It also uses aerated windrows and adds a specific microbial inoculant that causes the composting process to migrate inward from the outside of the pile, as opposed to the traditional inside-out process. This reduces the need to turn windrows, minimizes objectionable odors, and deters wildlife.

State of Florida Definition of Mature Compost

Mature compost is a highly stabilized compost material that has been exposed to prolonged periods of decomposition. It will not reheat upon standing to greater than 20°C above ambient temperature. It has beneficial use and can be used in direct contact with roots. The material should be brown to black in color. This level of maturity is indicated by a reduction of organic matter of greater than 60%.

—Florida Administrative Code (F.A.C.) 62-709.550(3)

State Classification of Compost

Compost shall be classified based on the type of waste processed, product maturity, the amount of foreign matter in the product, the particle size and organic matter content of the product, and the concentration of heavy metals …

—F.A.C. 62-709.550 (1)

Florida recognizes compost types Y, YM, A, B, C, D and E based on their feedstocks, maturity texture and amount of foreign matter. Composting of biosolids is not included in F.A.C. 62-709, but instead covered separately by F.A.C 62-640.

Types Y, YM, or A have no usage restrictions. Feedstocks for Y, YM, and A are made from solid waste compost, which is no longer common practice.

Types B and C are restricted to use by commercial, agricultural, institutional, or governmental operations.

Other Organic Amendments

Organic materials that are commonly used as feedstocks to produce compost may also be used as stand-alone soil amendments (without composting). While compost is not the only organic amendment used for enhancing soil quality, it is the most studied material, due to its prevalence, historical use, ease of production, and ease of application. Compared to other organic amendments, compost has been researched far more than any other product for soil enhancement. Much of our understanding of compost effects on soil quality and function comes from agronomic studies.

Biosolids

During aerobic digestion of wastewater, microbial populations grow as they feed on the organics in the waste stream. The microbes flocculate together and eventually settle out of suspension as sewage sludge. Sewage sludge from wastewater treatment plants that have been treated to remove pathogens or reduce vector attractants are known as biosolids. Biosolids are nutrient rich organic materials that are commonly land applied for disposal, but can be distributed and marketed for public use if they meet certain federal and state level classification standards for elimination of pathogens, attraction of vectors, and reduction of metals concentrations. This typically involves heating and palletization (see Milorganite below) and the end products are most used as fertilizer substitutes or replacements after lawns are established rather than an amendment to the soil. Federal ceiling and average monthly concentrations for land application of Biosolids are included in 40 CFR 503.13. Biosolids can contain residual concentrations of emerging contaminants (e.g. pharmaceuticals, endocrine disrupting compounds), however, any risk to the environment or the public is not well established.

Federal Regulations for Treatment of Sewage Sludge (Biosolids)

Processes to Significantly Reduce Pathogens (PSRP)

4: *Composting (Class B)*—Using either the within-vessel, static aerated pile, or windrow composting methods, the temperature of the sewage sludge is raised to 40 degrees Celsius or higher and remains at 40 degrees Celsius or higher for five days. For four hours during the five days, the temperature in the compost pile exceeds 55 degrees Celsius.

Processes to Further Reduce Pathogens (PFRP)

1: *Composting (Class A/AA)*—Using either the within-vessel composting method or the static aerated pile composting method, the temperature of the sewage sludge is maintained at 55 degrees Celsius or higher for three days. (Other windrow options are also available.)

—Federal Regulations – Title 40, Chapter I, Subchapter O, Part 503, Subpart B (Land Application) and Subpart D (Pathogen treatment Process for Sewage Sludge)

US EPA Description of Composted Biosolids

Composting is one of several methods for treating biosolids to create a marketable end product that is easy to handle, store, and use. The end product is usually a Class A, humus-like material without detectable levels of pathogens that can be applied as a soil conditioner and fertilizer to gardens, food and feed crops, and rangelands. This compost provides large quantities of organic matter and nutrients (such as nitrogen and potassium) to the soil, improves soil texture, and elevates soil cation exchange capacity (an indication of the soil's ability to hold nutrients), all characteristics of a good organic fertilizer. Biosolids compost is safe to use and generally has a high degree of acceptability by the public. Thus, it competes well with other bulk and bagged products available to homeowners, landscapers, farmers, and ranchers.

—US EPA Office of Water – Biosolids Technology Fact Sheet: Use of Composting for Biosolids Management EPA 832-F-02-024 (US EPA, 2002)

Florida Classifications of Biosolids

Classifications are set by Chapter 62-640, F.A.C., which are based on federal regulations 40 CFR 503.13, 503.32 and 503.33 addressing metals concentrations, pathogens, and vector attraction. Mineralization of biosolids through composting falls under Chapter 62-640, F.A.C. (rather than 62-709).

Class AA **– Allowed to be distributed and marketed as a fertilizer. Equivalent to USEPA Class A EQ. Treated to eliminate pathogens and reduced level of degradable compounds that attract vectors (USEPA, 1994). Considered highest quality. Meet Class A requirements and the monthly average metals limits in Table 3 of 40 CFR 503.13.**

Class A **– Treated to eliminate pathogens; considered pathogen free. Pathogen limit: Fecal Coliform: < 1,000 CFUs per gram of total solids or Salmonella sp. Bacteria < 3 MPN per 4 g of total solids. 40 CFR 503.32 provides six alternatives for pathogen reduction (the fourth alternative if not allowed under Chapter 62-640, F.A.C.).**

Class B **– Pathogen limit: Fecal Coliform: < 2,000,000 CFUs per gram or undergo a Process to Significantly Reduce Pathogens (40 CFR 503 Appendix B) or equivalent process. Considered minimum quality.**

Milorganite

One form of biosolids is Milorganite, which is produced by heat drying and pelletizing biosolids. It is a trademarked, slow-release fertilizer developed by the Milwaukee Metropolitan Sewerage District in 1926. Milorganite contains organic iron (Fe) in addition to nitrogen and phosphorus, although research has not established it as an effective remedy for iron deficiencies in turfgrasses in Florida (Shaddox & Unruh, 2018). Milorganite is commonly sold in bags and bulk and may be included in fertilizer blends or soil amendment products.

Manure

Livestock waste (manure) is another material commonly used for amending soils. Manure should be allowed to mature for up to six months. This allows for volatilization of ammonia and other organic compounds released during decomposition. The moisture, nutrient content and relative stability of manures can be highly variable. Plants are able to readily absorb nitrogen from manures, a benefit but, also a disadvantage, as it does not persist as long after application as most other types of organic soil amendments (US EPA, 2007). Measures to minimize odors should be considered in populated urban areas, which can make using manure problematic.

Sphagnum Peat

Harvested from peat bogs, sphagnum peat is an organic material with a low pH. It aids in increasing water holding capacity, with a C:N ratio in the range of 15-30. However, it decomposes at a moderate to rapid rate (Trenholm, 2018).

POTENTIAL BENEFITS OF INCORPORATING ORGANIC SOIL AMENDMENTS

PHYSICAL BENEFITS

Soil amendments have been shown to effectively improve compacted urban soils in past studies (Pitt et. al, 1999; Olson et al., 2013; Bean and Dukes, 2016). The process of incorporating amendments into the soil is typically done via tillage or other tool to break up and work the amendment into the soil, directly altering the soil structure. The resulting physical properties of the amended soil are dependent on the properties of the soil and amendment. Breaking up the compacted soil increases infiltration and reduces runoff (Pitt et al., 1999; Bean & Dukes, 2016). This also increases the pore volume (porosity), which combined with the low particle density of organic amendments, reduces the soil bulk density.

Organic amendments play an important role in maintaining the improved soil structure from tillage, as tillage of coarse soils without an amendment can reconsolidate back to the compacted state over time (Somerville et al., 2018; Mohammadshirazi et al., 2017). Amendments help to maintain the orientation and structure of soil particles long after incorporation. While compacted coarse soils are the most common landscape material, incorporating organic amendments into fine textured clay soils can also improve soil structure, infiltration, and drainage.

Compost has been shown to increase the field capacity of sandy soils, and generally does not change the permanent wilting point of soil, which together increase overall plant available water in the root zone (Figure 8; Bhadha et al., 2017; Sax et al, 2017). Incorporation of organic amendments can also make soils less hydrophobic. Hydrophobic soils can repel water when they are extremely dry. These soil types are common in Florida and can result in dry, brown areas in landscapes that do not respond to irrigation. Organic amendments counteract this hydrophobicity due to adsorptive properties that allow more water to soak into the soil (NRCS 2000).

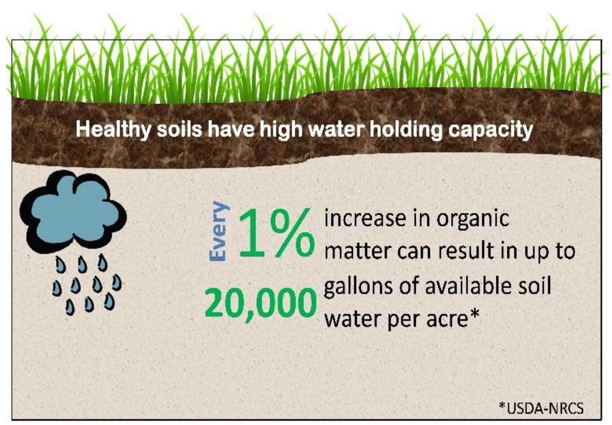

Figure 8. Organic matter increases water holding (field capacity). Credit: Jehangir Bhadha.

Vegetation Health

Many of the physical benefits of amending compacted soil with organic amendments translate to improved health of landscape vegetation. Tilling in amendments breaks up compacted soil layers, reducing the bulk density of soil and making it easier for plant roots to penetrate the soil. This tillage process makes it easier to establish a deep rootzone from which plants can access water and nutrients. Increased plant available water makes plants less susceptible to drought, and more resilient to diseases and pests. Compost and other organic amendments typically contain valuable macro and micro-nutrients that are made available over time to plants as the amendments are fully integrated into the soil. Increased soil moisture, organic content, and nutrients provides a favorable environment for soil microbial communities to establish, which helps to promote greater soil health.

Water Conservation Potential

Increased plant available water means turfgrass and landscape plants are less reliant on supplemental irrigation, which can lead to significant water savings for homeowners. Further, less water consumption reduces pressure on potable water supplies and allows water allocations to be shared among more properties. Research by UF/IFAS researchers have shown that incorporating compost prior to installing turfgrass reduced the need for irrigation by at least 25% while maintaining similar turf quality over a period of two years in a central Florida residential development (Radovanovic, 2020; Radovanovic & Bean, 2020).

Benefits to Builders and Homeowners

Improved soil conditions facilitate the rapid establishment of turfgrass and shrubs. This can improve aesthetics and property appeal. It is common for new landscapes to be irrigated daily or multiple times per day while establishing plants and turfgrass. This watering schedule is often left in place after the 60-day establishment period has passed. This leads to unnecessary over irrigation, wasting water and increasing the potential for pests and plants with shallow roots. Rapid establishment of the landscape and transition to one or two days per week irrigation schedule before homes are sold reduces the likelihood of long-term over watering. A landscape that is more resilient to drought, disease, and pests, is less likely to experience failure and need replacement. As previously noted, amended soils can reduce the need for supplemental irrigation, a major use of water in new homes. Water efficiency can also be an important selling point for home buyers.

Off-site/Regional Water Benefits

Organic soil amendments may enhance surface water quality by helping remove pollutants through filtration, adsorption and/or uptake by vegetation. Improving landscape soil quality via amendments may increase deep infiltration and groundwater recharge.

Potential benefits of organic soil amendments:

- healthier soil and vegetation
- reduced pests and use of pesticides
- water conservation
- water quality improvements
- aesthetic benefits for homeowners
- cost savings for builders and homeowners

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PART III. IMPLEMENTATION

"Soils are developed; they are not merely an accumulation of debris resulting from decay of rock and organic materials ... In other words, a soil is an entity - an object in nature which has characteristics that distinguish it from all other objects in nature."

—C.E.Millar & L.M.Turk, 1943

SOIL EVALUATION

Characterize Soils

Physical Characteristics

Before deciding to amend, a soils evaluation should be conducted to understand the in-situ properties and how amending would affect the properties. From this characterization, a determination can be made of the need or suitability for amending the soil by assigning a soil quality factor. Physical characterization involves assessing the soil texture and compaction. Most soil testing labs and some geotechnical consultants can perform texture analyses using only a few grams of sample. Though subjective and less precise, experienced soils professionals may also be able to determine soil texture by feel (USDA, 2017). The texture classification is determined from the relative composition of sand, silt, and clay sized particles. Though several classification systems exist, the most used is the USDA NRCS soil classification system (USDA, 2017).

Bulk density is a fundamental measurement of soil compaction. Soil compaction is the process of increasing the density of soil. Pockets of air are compressed or eliminated, and the proportion of space occupied by mineral particles increases. A decrease of a soil's bulk density through the addition of organic matter helps improve and maintain soil characteristics more favorable for healthy landscapes. To measure bulk density, a known volume of undisturbed soil is collected, dried to remove any water content, and weighed to determine the soil mass. The resulting mass is divided by the collected soil volume to determine the density in units of g/cm^3 or lbs/ft^3. Regardless of compaction level, sandier soils have higher bulk densities than soils with higher clay content. Therefore, it is important to evaluate the bulk density as a measure of compaction within the context of the soil texture. The Growth Limiting Bulk Density (GLBD) is one estimate for critical bulk density levels based on texture (Daddow and Warrington, 1983). Soil organic matter is retained during the bulk density analytical process and can contribute mass to increase bulk density values over mineral contributions alone. However, the low level of organics present within most new urban landscapes is not sufficient to significantly distort results, except for highly organic soils.

Biochemical Characteristics

Soil testing labs can analyze for a variety of biochemical properties in soil. The University of Florida Institute of Food and Agricultural Sciences (UF IFAS) Extension Soil Testing Lab provides many of these analytical services for a modest fee to the citizens of Florida.

Soil pH

Soil pH influences nutrient availability to plants and the ability of these nutrients to move through the soil. This is one reason plants prefer certain pH ranges. In Florida, soil pH can range widely from slightly acidic to strongly alkaline. The low pH of acidic soils can be adjusted by adding lime (CaO) to the soil. (These soils commonly have higher organic content than more alkaline soils.) Alkaline soils typically contain calcium carbonate ($CaCO_3$) derived from limestone. Acids are added to alkaline soils to buffer or lower their high pH. This can be done by adding organic matter, which contains relatively mild fulvic and humic acids, or by more aggressive treatments, such as adding elemental sulfur, which converts to (a strong) sulfuric acid. However, treatments will eventually need to be reapplied as acids are neutralized from reacting with $CaCO_3$ and leached from the root zone.

Organic Matter

Organic matter (OM) is a vital component of soil, providing several benefits already discussed. Urban soils typically begin with very low organic matter content (< 1% weight for weight (w/w)). Over time, natural accumulation of OM will occur in the soil, as vegetative material above the surface decomposes and gets incorporated with remnant roots and other sources in the soil below. This can take years or decades to fully develop. The US Composting Council recommends increasing soil OM content to at least 5% w/w to optimize soil properties. Soil testing labs will typically measure soil OM content based on the difference in dry soil weight before and after removing OM. The process may use a chemical oxidizer to convert carbon to carbon dioxide or heat the soil sample in a muffle furnace to > 550 °C. Compost amendments will preferably have OM content of 35-60%.

Salinity

High salinity can be detrimental to plant health. Evaluating the salt content or conductivity of landscape soils can inform landscape management practices and help avoid loss. Plants in landscapes vary in their tolerance to salt, but salinity is generally a stressor to plants, and turfgrasses tend to be less tolerant. When possible, high conductivity or salinity conditions should be avoided in the landscape.

Nutrients

Phosphorus export from soils is another factor to consider when evaluating soils. The Soil Phosphorus Storage Capacity (SPSC) is a measure of soil's ability to retain P and based on the Phosphorus Saturation Ratio, which depends on extractable P, AL, and Fe (Nair et al., 2010). Soils with SPSC values greater than zero have P content below saturation. However, soils with SPSC values less than zero have excess P and pose a risk to export this excess P into groundwater or surface runoff. This is of particular interest since different soil layers may have very different SPSC values. Further, compost is likely to decrease the SPSC of soil, thus it is better to have a large, positive SPSC value to buffer the additional P that compost contributes so as not to export P from the landscape.

Initial soil analysis for macro and micro-nutrient content can identify deficiencies that may be corrected through soil amendments.

Having soils analyzed for macro and micro-nutrient content will help to identify any deficiencies that may be addressed through amending the soil. Soil testing labs, including the UF IFAS Extension Soil Testing Lab can perform these analyses which typically test for phosphorus, potassium, calcium, and magnesium. Landscape soils can vary widely in content of nutrients depending on geology and historic land use and management. Nitrogen testing is possible but not recommended, as nitrogen levels can fluctuate quickly and testing at one time may not be representative of the long-term state of the soil. It is common for fill material to be very low in nutrient content, and incorporation of an organic amendment can provide needed nutrition to landscape plants which would otherwise require an external fertilization source. Soils containing limestone fragments will have a relatively high calcium content. Certain geologic formations in Florida contain phosphorus concentrations, particularly those with higher clay content, due to the natural formation of apatite minerals which contain phosphorus mostly in an insoluble form, but with some in a labile form that can be available to plant roots. The nutrient content of soils should be considered in combination with the nutrient content of organic amendments to be added.

Soil Quality Factor - Classification for Supporting Plant Establishment and Growth

After assessing the physical and biochemical characteristics of existing soil conditions (Figure 9), a determination should be made about the suitability of amending. Soils may already be acceptable and not need amending (ideal), amendments may improve soil quality (suitable, marginal), or soils may be unsuitable and not improve sufficiently by incorporating amendments (Table 2). Soils with a high content of organic matter, such as histolsols, would be the only scenario where amending with compost may not improve soil quality.

Table 2. Characteristic ranges for evaluating soil quality

Characteristic	**Ideal** Soil meets amended target	**Suitable** Soils acceptable, improve with amendments	**Marginal** Soils unacceptable, amending improves to acceptable	**Unsuitable** Amending will not address deficiencies
Bulk Density (g/cm^3)	< 1.4	1.4 - 1.7	> 1.7	Stone or bedrock
Organic Matter (%)	> 3%	2 - 3%	1 - 2%	< 1%
Soil pH	6 - 7.5	5.5 – 6; 7.5 - 8	5 - 5.5; 8 - 9	< 5, > 9
Limestone ($CaCO_3$ meqs)	< 1%	1 - 2%	2 - 10%	> 10%
Electrical Conductivity (mmhos/cm)[1]	< 0.50	0.51 - 1.25	1.26 - 2.00	> 2.00
Soil Phosphorus Storage Capacity (mg/kg)	> 100	> 50	> 0	< 0

[1] 1:2 Soil-water ratio; Sonon et al., 2015.

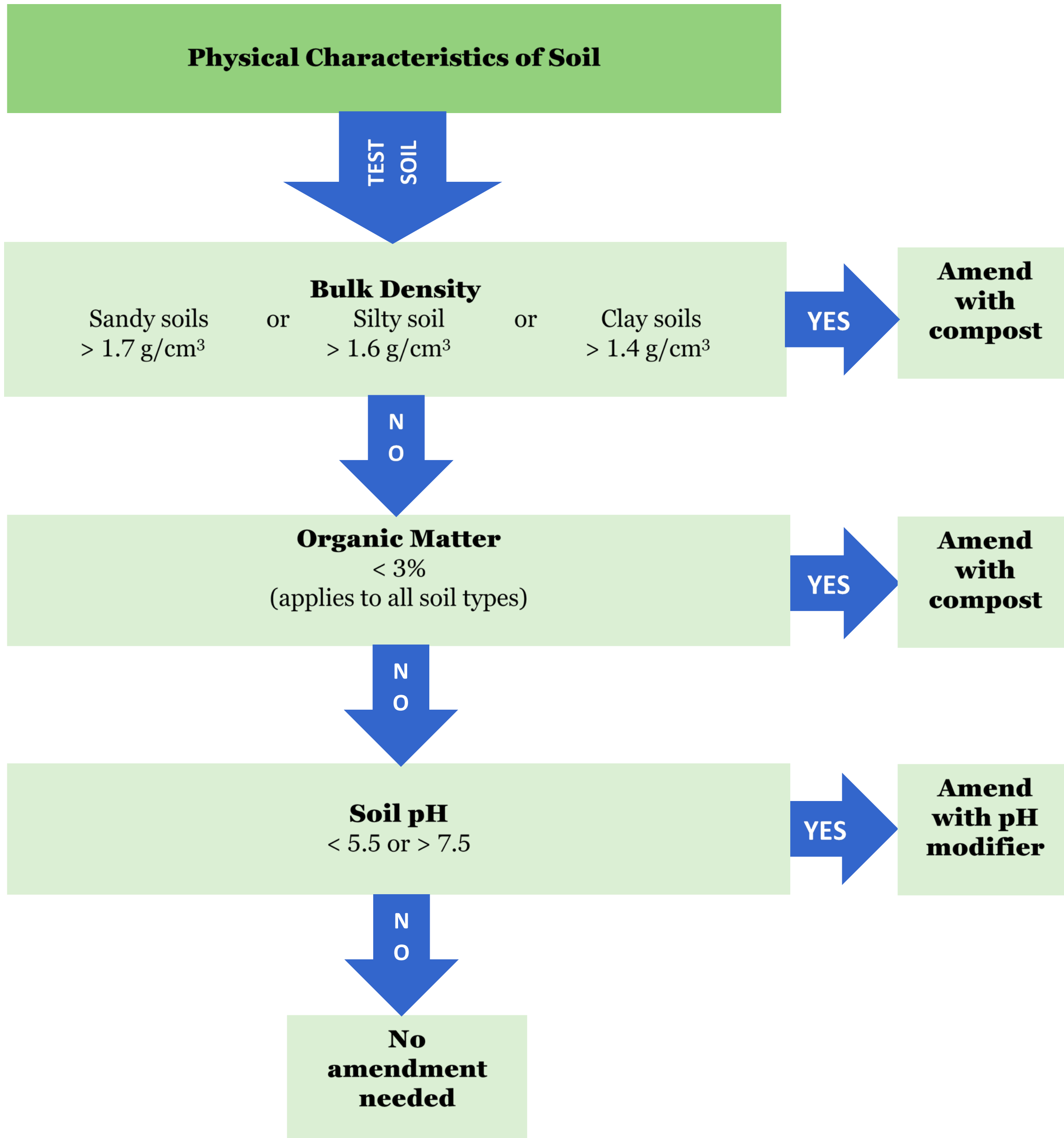

Figure 9. Decision tree for evaluating the need for soil amendment.

AMENDMENT CHARACTERISTICS FOR URBAN LANDSCAPES

As much as possible, it is important to make sure that amending soils does not create adverse effects for soils, water, or the landscape. While organic soil amendments, and more specifically compost, improve soil characteristics, poor quality materials can be harmful to landscape plants. Some of the most important potential effects to consider when amending soils and selecting an amendment are potential changes to pH, potential to increase salinity, risk of introducing pathogens, and risk of introducing compounds toxic to plants or animals. Neither source nor finished materials should include metals, glass, or other wastes that could contain sharp objects.

Avoid using poor quality compost which could contain pathogens, toxic chemicals, high levels of salt, or waste material such as metals, glass, or trash.

If using a compost as a soil amendment there are some easy ways to check the quality of the material. First, the materials should be dark in appearance and feedstock material (e.g. wood, leaves, etc.) should not be identifiable. It should have a crumbly texture and particles should be less than ½ inch. Compost should have an earthy smell. Offensive odors are usually an indication of immature compost. If it has a rancid or sour smell this indicates the material has not finished composting or is contaminated. Immature compost can continue composting in the soil producing offensive odors (ammonia volatizing) and reduce nitrogen availability.

COMPOST FOR URBAN SOIL AMENDING

Compost Feedstocks

Compost tends to have a mixture of "green" and "brown" feed stocks. Greens are generally vegetation debris from agricultural or urban landscape (e.g. leaves, limbs, wood chips, saw dust, mulch, etc.) with high C:N ratios. These largely provide the carbon source that bacteria need to perform the composting process. Browns are generally derived from food or waste materials. These tend to have much lower C:N ratios but contain micronutrients and other valuable organic compounds. Food may involve unsold or unused food or scraps. Waste sources may be animal manure, with or without bedding (e.g. equine). Biosolids may also be a feedstock for composts. Biosolids are classified based on their treatment for removing pathogens and reducing vector attractants. Class AA-EQ biosolids are the highest quality, virtually pathogen free, and have been treated to reduce vector attractants. While Class B biosolids are initially the lowest quality and have not undergone disinfection, they can be used as feedstocks into composting which can treat pathogens

Appropriate Gradation for Incorporation

Grading of compost material is an important step to ensuring desired outcomes of amending soils. Screening compost to remove any material greater than about $^{3}/_{8}$ to $^{1}/_{2}$ inch ensures that the material can be thoroughly incorporated into the soil and not create an uneven amended surface. This step also removes any large clumps of material that either may not incorporate evenly or may not be completely composted.

Compost Quality Metrics

Typical compost characteristics from literature are listed below in Table 3. In addition, preferred and acceptable properties from the US Composting Council's (USCC's) Seal of Testing Assurance (STA) are also included.

The US Composting Council established the Seal of Testing Assurance (STA) for compost producers. The STA program requires regular testing, labeling of certified products, and information disclosure to consumers. In addition, it requires producers to provide information on feedstock material upon request. Additives such as sulfur, biochar, or otherwise, can modify the finished product properties, but are not included here or addressed in this document.

AMENDMENT INCORPORATION CONSIDERATIONS

Initial Nutrient Leaching

Nitrogen and phosphorus availability in mature compost is highest when it is initially incorporated into the soil. These concentrations typically decrease rapidly and are similar to non-amended concentrations within a month or so. The increased nutrient availability can be beneficial to accelerating turfgrass establishment in landscapes. As a result, no nitrogen fertilizer should be applied to turfgrass during the establishment period (typically the first 30 to 60 days).

Do not apply fertilizers to areas prior to amending with compost.

Avoid Immature Compost

Immature compost can be detrimental to turfgrass and landscape plants due to high carbon content reducing nitrogen availability. Immature compost may also continue composting after soil incorporation, producing offensive odors, such as volatilization of ammonia. Odors and identifiable feed stock within the amendment are indications of immature compost and should not be used.

Costs Associated with Incorporation

The cost of incorporating organic amendments will depend on the bulk cost of material, equipment used to incorporate the amendment, and labor. In general, at least half of the costs associated with incorporating soil amendments are from transportation and labor. Assuming a cost of \$0.32/ft^2 for material and incorporation, over 7,000 ft^2 of proposed lawn area on a ¼ ac. lot results in a cost of \$2,230. The per area cost assumes hauling, spreading, and incorporation is completed by a sub-contractor. Costs would be expected to decrease as compost becomes more available locally and as demand increases.

Table 3. Characteristic values of compost summarized from literature, and preferred and acceptable ranges.

Property	Units	Min	Median	Max	USCC STA[a]	
					Preferred	Acceptable
Density	lbs/ft^3	30	45	48	—	—
Screened particle size	inch	—	—	—	3/8	1/2
Water content	% wt	30.7	40.5	65.9	40 – 50	35 – 65
pH	—	7.2	7.6	8.3	6.0 – 7.5	5.5 – 8.5
Conductivity	Mmhos/cm[b]	1.6	2.0	2.2	≤ 5	≤ 15
Carbon-nitrogen (C:N) ratio	—	11.6	14.6	20.0	—	—
Organic matter (OM)	% dry wt (% dw)	27.2	33.3	43.8	35 – 60	25 – 65
Nitrogen (% N)	% dw	0.9	1.3	2.0	—	—
Phosphorus (% P)	% dw	0.4	0.5	0.8	—	—
Potassium (% K)	% dw	0.6	1.0	1.8	—	—
Magnesium (% Mg)	% dw	0.4	0.7	1.1	—	—
Calcium (% Ca)	% dw	1.8	3.5	5.5	—	—

[a] US Composting Council Seal of Testing Assurance

[b] Equivalent to dS/m

In addition, other measures or requirements that can characterize the quality of the material are listed below:

- Stability (respiration rate): <100 mg CO_2-C/kg/hr (Hue & Liu, 1995)
- Maturity: % seed emergence
- Free of any substances that are toxic to plants.
- Reasonably free of artificial materials (< 1% by dry weight)

PRACTICAL INSTRUCTIONS FOR INSTALLERS

Avoid scheduling compost amending on days when significant rainfall is possible, as this can cause washout or erosion where concentrated runoff occurs.

Preparing the Area to be Amended

1. Soil amending should not occur until all on-site construction traffic has ended. All building construction, including outdoor pavement, and installation of major utilities should be completed. Installation of irrigation lines and components should occur after amending is complete to avoid risk of damaging irrigation lines during tilling.
2. The soil surface should be graded smooth and free of any foreign debris, trash, or rocks larger than 2 inches.
3. It is recommended that irrigation components, irrigation installation equipment, and sod be staged on-site in preparation to install irrigation system and lay sod as soon as possible after amending the soil.

Turf Areas

Apply Soil Amendment to Areas to be Sodded:

1. Using a small front-end loader or spreader, compost should be spread evenly over the surface (Figure 10) at a rate of 4 yd^3 / 1,000 ft^2, which is a depth of 1.3 inches.
2. Even out any shallow or deep compost areas to ensure even incorporation (Figure 11).
3. Spot check the material depth with a ruler to check that the material is 1 to 2 inches. No areas of bare soil should be visible.
4. Visually assess that compost has an even color and texture across the amending area.
5. When using mature compost, it is not necessary to add fertilizer as nutrients in compost are most available after initial incorporation.

Figure 10. Spread compost with front-end loader. Credit: UF/PREC.

Incorporate Soil Amendment

1. Using a rotary tiller, incorporate amendment to a depth of 6 inches into the soil (Figure 11).
2. The bottom of the tiller should be 6-8 inches below the top of the compost layer.
3. Avoid tilling deeper or using such techniques as deep chiseling since this risks damage to utilities (e.g. water lines, electricity, natural gas, etc.).
4. Any vehicle tracks made during tilling should be re-tilled and eliminated.

Figure 11. Hand repair any unevenly applied areas and incorporate compost using a rototiller. Credit: UF/PREC.

After Amendment Incorporation

1. Once the area is amended, check for uniform incorporation, looking for exceptionally light or dark areas.
2. Use a shovel to expose the side of the amended soil profile in multiple locations to check the incorporation depth. The predominant incorporation depth should be 6 inches below the amended surface, with no areas having less than a 4-inch incorporation depth. (Figure 12)

Figure 12. Check for a general 6-inch incorporation depth, 4-inch minimum in small areas. Credit: UF/PREC.

3. Check for high, low, or uneven areas of the amended surface to ensure proper incorporation.
4. No vehicle traffic shall be permitted once incorporation is complete as this can recompact the amended soil.
5. Install irrigation lines and components.
6. Rake or screed the amended surface until level to ensure sod lays level (Figure 13).
7. Install sod as soon as possible after amending to avoid erosion or washout from unexpected rain events.
8. Avoid excess foot traffic as this can recompact soils.

Figure 13. Level the amended surface after compost incorporation. Credit: UF/PREC.

Landscape Beds and Trees

For plants installed within planting beds, planting holes should be individually amended with compost. Add 1-2 inches of compost to the bottom of the hole and work compost into the bottom and sides of the planting hole.

Evaluate Incorporation

As compost quality can vary between batches, it is a good practice for establishing quality assurance to collect and analyze amended soil samples. This provides comparable data to soils prior to amending and can help inform the direct effects of compost amending. Common tests include pH, salinity, organic matter, and nutrient content.

Repair Damaged Areas

If washout occurs, the eroded areas should be regraded to the pre-erosion elevation with amended soil blended at the same ratio as the amended soil in the landscape. For small areas, they may be done using hand tools (e.g. shovels, rakes). For larger areas, larger equipment may be necessary to regrade the lot. In either case, avoid compacting amended soil to the maximum extent possible. If amended soils are compacted such that the soil surface is > 3 inches below the adjacent soil, then these areas should be re-tilled to restore the soil porosity and structure.

Caution should be used to avoid impacting irrigation lines or other utilities that may be below the soil surface. These areas should be raked or screed smooth before installing sod over top.

Take care not to damage any underground irrigation or utility service lines.

Do not till deeper than 6 inches.

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REFERENCES

BACKGROUND RESOURCES

Fernald, E., and Purdum, E. (1998). Water Resource Atlas of Florida. Florida State Univ., Institute of Public Affairs, Tallahassee, Fla.

Haley Melissa B., Dukes Michael D., & Miller Grady L. (2007). Residential Irrigation Water Use in Central Florida. *Journal of Irrigation and Drainage Engineering*, *133*(5), 427–434. https://doi.org/10.1061/(ASCE)0733-9437(2007)133:5(427)

Kranz, C. N., McLaughlin, R. A., Johnson, A., Miller, G., & Heitman, J. L. (2020). The effects of compost incorporation on soil physical properties in urban soils – A concise review. *Journal of Environmental Management*, *261*. https://doi.org/10.1016/j.jenvman.2020.110209

Mylavarapu, R., Harris, W., & Hochmuth, G. (2019). *Agricultural Soils of Florida* (EDIS Publication No. SL441). UF IFAS Extension. https://edis.ifas.ufl.edu/ss655

Nair, V. D., Harris, W. G., Chakraborty, D., & Chrysostome, M. (2010). *Understanding Soil Phosphorus Capacity.* (EDIS Publication No. SL336). University of Florida IFAS Extension. https://edis.ifas.ufl.edu/ss541

NRCS Soil Quality Institute. (2000). *Soil Quality Resource Concerns: Hydrophobicity*. USDA Natural Resources Conservation Service. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/resource/

Sonon, L, Saha, U., & Kissel, D. E. (2015). *Soil salinity: testing, data interpretation and recommendations.* University of Georgia Extension. https://extension.uga.edu/publications/detail.html?number=C1019

Tetra Tech, Inc. (2011). *Evaluation of Urban Soils: Suitability for Green Infrastructure or Urban Agriculture* (No. 905R11003; p. 26). U.S. Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100GOTW.PDF?Dockey=P100GOTW.PDF

Toor, G. S., Shober, A. L., & Reisinger, A. J. (2008). *Soils and Fertilizers for Master Gardeners: Soil Organic Matter and Organic Amendments*. University of Florida IFAS Extension EDIS Solutions for Your Life. https://edis.ifas.ufl.edu/mg454

UF/IFAS Extension. (1993). *Florida's state soil - Myakka Fine* Sand. https://soils.ifas.ufl.edu/media/soilsifasufledu/sws-main-site/pdf/about/Myakka-Fl-State-Soil.pdf

UF/IFAS Extension Sarasota County. (n.d.). *Elements of Composting*. Natural Resources, Waste Reduction, Composting. Retrieved October 20, 2019, from https://sfyl.ifas.ufl.edu/sarasota/natural-resources/waste-reduction/composting/what-is-composting/elements-of-composting/

US Environmental Protection Agency Office of Superfund Remediation and Technology Innovation. (1998). *An Analysis of Composting as an Environmental Remediation Technology* (No. EPA 530-R-98–008; Solid Waste and Emergency Response, p. 116). https://www.epa.gov/sites/production/files/2015-09/documents/analpt_all.pdf

US Environmental Protection Agency Office of Superfund Remediation and Technology Innovation. (2011). *Land Revitalization Fact Sheet* (No. EPA 560-F-11-008; Solid Waste and Emergency Response). https://www.epa.gov/sites/production/files/2015-08/documents/fs_improving_urban_soils.pdf

US Environmental Protection Agency Office of Superfund Remediation and Technology Innovation. (2007). *Use of Soil Amendments for Remediation, Revitalization and Reuse* (No. EPA 542-R-07-013; Solid Waste and Emergency Response). https://semspub.epa.gov/work/11/176023.pdf

US Environmental Protection Agency Office of Water. (2002). *Biosolids Technology Fact Sheet: Use of Composting for Biosolids Management* (No. EPA 832-F-02-024). https://www.epa.gov/sites/production/files/2018-11/documents/use-composing-biosolids-management.pdf

US Department of Agriculture Soil Science Division Staff. (2017). Soil Survey Manual, Ch. 3. Examination and Description of Soil Profiles. C. Ditzler, K. Scheffe, & H. C. Monger (eds.). Government Printing Office, Washington, D.C. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054253#particle_size

Warner, L. A., Lamm, A. J., & Chaudhary, A. K. (2018). Florida residents' perceived role in protecting water quantity and quality through landscape practices. Landscape and Urban Planning, 171, 1–6. https://doi.org/10.1016/j.landurbplan.2017.11.007

EFFECTS OF URBANIZATION

Bean, E. Z., & Dukes, M. D. (2015). Effect of amendment type and incorporation depth on runoff from compacted sandy soils. *Journal of Irrigation and Drainage Engineering*, *141*(6), 04014074. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000840

Bell, B., & Platt, B. (2014). *Building Healthy Soils with Compost to Protect Watersheds*. Institute for Local Self-Reliance. https://ilsr.org/wp-content/uploads/2013/05/Compost-Builds-Healthy-Soils-ILSR-5-08-13-2.pdf

Carr, M. H. & Zwick, P. D. (2016). *Water 2070: Mapping Florida's future – Alternative patterns of water use in 2070.* Tallhassee, FL; Dept. of Agriculture. https://1000friendsofflorida.org/water2070/

Daddow, R. L., & Warrington, G. E. (1983). *Growth-Limiting Soil Bulk Densities as Influenced by Soil Texture* (WSDG-TN=00005). Watershed Systems Development Group, US Forest Service. https://forest.moscowfsl.wsu.edu/smp/solo/documents/RPs/daddow_warrington_root_limiting_bulk_density.pdf

Ferreira, C. S. S., Kalantari, Z., Salvati, L., Canfora, L., Zambon, I., & Walsh, R. P. D. (2019). Urban Areas. In *Advances in Chemical Pollution, Environmental Management and Protection*. Elsevier. https://doi.org/10.1016/bs.apmp.2019.07.004

Gregory, J. H., Dukes, M. D., Jones, P. H., & Miller, G. L. (2006). Effect of urban soil compaction on infiltration rate. *Journal of Soil and Water Conservation*, *61*(3), 117–124. www.jswconline.org/content/61/3/117.short

Office of Economic & Demographic Research (OEDR). *Annual Assessment of Florida's Water Resources and Conservation Lands: 2020 Edition.* http://edr.state.fl.us/Content/natural-resources/LandandWaterAnnualAssessment_2020 Edition.pdf

Pitt, R., Lantrip, J., Harrison, R., Henry, C. L., & Xue, D. (2000). *Infiltration through disturbed urban soils and compost-amended soil effects on runoff quality and quantity.* (EPA/600/R-00/016 (NTIS PB2000-102012)). U.S. Environmental Protection Agency. https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=64168

Schwartz, S. S., & Smith, B. (2016). Restoring hydrologic function in urban landscapes with suburban subsoiling. *Journal of Hydrology*, *543*, 770–781. https://doi.org/10.1016/j.jhydrol.2016.10.051

Shober, A. L., & Denny, G. C. (2010). *Soil compaction in the urban landscape, SL 317*. UF/IFAS Extension. http://harris.agrilife.org/files/2011/05/SS529001.pdf

St. Johns River Water Management District (SJRWMD). (2020). *Watering restrictions: Frequently asked questions (FAQs).* SJRWMD, Palatka, FL. https://www.sjrwmd.com/wateringrestrictions/faqs/

BENEFITS OF ORGANIC SOIL AMENDMENTS

Ahmad, R., Jilani, G., Arshad, M., Zahir, Z., & Khalid, A. (2007). Bio-conversion of organic wastes for their recycling in agriculture: An overview of perspectives and prospects. *Annals of Microbiology*, *57*, 471–479. https://doi.org/10.1007/BF03175343

Bell, B., & Platt, B. (2014). *Building Healthy Soils with Compost to Protect Watersheds*. Institute for Local Self-Reliance. https://ilsr.org/wp-content/uploads/2013/05/Compost-Builds-Healthy-Soils-ILSR-5-08-13-2.pdf

Bhadha, J. H., Capasso, J. M., Khatiwada, R., Swanson, S. & LaBorde, C. (2017). *Raising Soil Organic Matter Content to Improve Water Holding Capacity*. (SL447). UF IFAS Extension. https://edis.ifas.ufl.edu/ss661

Carroll, M., & Felton, G. (2015). *Amending Soil with Compost to Reduce Stormwater Runoff and Lawn Fertilizer Use* (No. TT120; Turfgrass Technical Update, p. 4). University of Maryland. https://extension.umd.edu/sites/extension.umd.edu/files/_images/programs/hgic/Publications/non_HGIC_FS/TT120_Amending_Soil_with_Compost.pdf

Charles, A., Rochette, P., Whalen, J. K., Angers, D. A., Chantigny, M. H., & Bertrand, N. (2017). Global nitrous oxide emission factors from agricultural soils after addition of organic amendments: A meta-analysis. *Agriculture, Ecosystems & Environment*, *236*, 88–98. https://doi.org/10.1016/j.agee.2016.11.021

Cogger, C. G. (2013). Potential Compost Benefits for Restoration of Soils Disturbed by Urban Development. *Compost Science & Utilization*. https://www.tandfonline.com/doi/abs/10.1080/1065657X.2005.10702248

Loper, S., Shober, A. L., Wiese, C., Denny, G. C., Stanley, C. D., & Gilman, E. F. (2010). Organic soil amendment and tillage affect soil quality and plant performance in simulated residential landscapes. *HortScience*, *45*(10), 1522–1528. https://doi.org/10.21273/HORTSCI.45.10.1522

Radovanovic, J. (2020). *Water Quality and Quantity Impacts of Amending New Residential Lawns with Compost in Florida.* University of Florida. Gainesville, FL.

Radovanovic, J., & Bean, E. Z. (2020). Evaluation of amending compacted residential soils with compost on nutrient leaching. In Proceedings of *2020 World Environmental and Water Resources Congress.* ASCE. Rushton, VA. https://ascelibrary.org/doi/abs/10.1061/9780784482957.009

Sax, M. S., Bassuk, N., van Es, H., & Rakow, D. (2017). Long-term remediation of compacted urban soils by physical fracturing and incorporation of compost. *Urban Forestry & Urban Greening*, *24*, 149–156. https://doi.org/10.1016/j.ufug.2017.03.023

Tautges, N. E., Chiartas, J. L., Gaudin, A. C. M., O'Geen, A. T., Herrera, I., & Scow, K. M. (2019). Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and subsurface soils. *Global Change Biology*, *25*(11), 3753–3766. https://doi.org/10.1111/gcb.14762

Trenholm, L. E., Shober, A. L., & Bean, E. Z. (2018). *Preparing to Plant a Florida Lawn* (ENH 02; p. 4). UF IFAS Extension. https://edis.ifas.ufl.edu/pdffiles/LH/LH01200.pdf

US Environmental Protection Agency. (1997). *Innovative Uses of Compost: Disease Control for Plants and Animals* (Fact Sheet No. EPA530-F-97–044; Solid Waste and Emergency Response, p. 4). https://www.epa.gov/sites/production/files/2015-08/documents/disease.pdf

US Environmental Protection Agency. (1997). *Innovative Uses of Compost: Erosion Control, Turf Remediation, and Landscaping* (Fact Sheet No. EPA530-F-97–043; Solid Waste and Emergency Response, p. 8). https://www.epa.gov/sites/production/files/2015-08/documents/erosion.pdf

SPECIFICATIONS AND INSTRUCTIONS

Hartin, J., & Crohn, D. (2007). *Compost Use for Landscape and Environmental Enhancement* (Publication #442-07-002; p. 91). Integrated Waste Management Board. https://www.waterboards.ca.gov/rwqcb8/resources/docs/compost_use_for_landscape_and_environmental_2007.pdf

Hue, N. V. & Liu, J. (1995). Predicting compost stability. *Compost Science & Utilization,* 3:2, 8-15, https://doi.org/10.1080/1065657X.1995.10701777

Sullivan, D. M., Bary, A. I., Miller, R. O., & Brewer, L. J. (n.d.). *Interpreting Compost Analyses*. Oregon State University Extension. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9217.pdf

US Composting Council. (2005). *Landscape architecture/design specifications for compost use.* https://cdn.ymaws.com/www.compostingcouncil.org/resource/resmgr/images/newimagesfolder/Landscape-Architecture-Specs.pdf

US Composting Council. (n.d.). *Specify Compost*. Use Compost. Retrieved October 20, 2019, from https://www.compostingcouncil.org/page/SpecifyCompost

US Department of Labor, Occupational Safety and Health Administration. (n.d.). *Recycling: Organic Materials (Food Waste, Yard Trimmings, Wood Waste)*. Retrieved March 4, 2020, from https://www.osha.gov/SLTC/recycling/recycling_organic.html

RELEVANT REGULATIONS

Association of American Plant Food Control Officials. (2019). *Product Label Guide*. http://www.aapfco.org/pdf/product_label_guide.pdf

e-CFR: TITLE 40—Protection of Environment, TITLE 40—Protection of Environment Electronic Code of Federal Regulations § Part 503 Standards for the Use or Disposal of Sewage Sludge, Subpart B — Land Application. Retrieved March 4, 2020, from https://www.ecfr.gov/cgi-bin/text-idx?SID=0ba50303c290a7c55f91b4df8622c570&mc=true&tpl=/ecfrbrowse/Title40/40cfrv32_02.tpl#0

e-CFR: TITLE 40—Protection of Environment, TITLE 40—Protection of Environment Electronic Code of Federal Regulations § Part 503 Standards for the Use or Disposal of Sewage Sludge, Subpart D — Pathogens and Vector Attraction Reduction. Retrieved March 4, 2020, from https://www.ecfr.gov/cgi-bin/text-idx?SID=0ba50303c290a7c55f91b4df8622c570&mc=true&tpl=/ecfrbrowse/Title40/40cfrv32_02.tpl#0

Florida Administrative Code (F.A.C.). 2010. Chapter 62-709.550., Classification of Compost. Florida Department of State. https://www.flrules.org/gateway/ruleno.asp?id=62-709.550

Florida Department of Agriculture and Consumer Services. (2017). *How to Comply Fertilizer Manual*. https://www.fdacs.gov/content/download/3502/file/Fertilizer_Registration_and_Labeling_Guidelines.pdf

Michigan Water Environment Association. (2018). *Biosolid Facts - Supplement 1, Class A EQ product vs Class B Regulations*. Michigan Water Environment Association. https://www.mi-wea.org/docs/MWEA_Biosolid_Facts_Supplement_1_Comparison_of_Class_A_and_Class_B_biosolids_FINAL.pdf

RELEVANT RESEARCH

Badzmierowski, M. J., Evanylo, G. K., Ervin, E. H., Boyd, A., & Brewster, C. (2019). Biosolids-Based Amendments Improve Tall Fescue Establishment and Urban Soils. *Crop Science*, *59*(3), 1273–1284. https://doi.org/10.2135/cropsci2018.04.0271

Ducey, T., Novak, J., & Johnson, M. (2015) Effects of biochar blends on microbial community composition in two coastal plain soils. Agriculture. MDPI Agriculture, Basel, Switzerland, 5(4):1060-1075. https://www.mdpi.com/2077-0472/5/4/1060

Fan, J., Hochmuth, G., Kruse, J., & Sartain, J. (2014). Effects of Reclaimed Water Irrigation on Growth and Nitrogen Uptake of Turfgrass. *HortTechnology*, *24*(5), 565–574. https://doi.org/10.21273/HORTTECH.24.5.565

Fissore, C., Hobbie, S. E., King, J. Y., McFadden, J. P., Nelson, K. C., & Baker, L. A. (2012). The residential landscape: Fluxes of elements and the role of household decisions. *Urban Ecosystems*, *15*(1), 1–18. https://doi.org/10.1007/s11252-011-0189-0

Głąb, T., Żabiński, A., Sadowska, U., Gondek, K., Kopeć, M., Mierzwa-Hersztek, M., Tabor, S., & Stanek-Tarkowska, J. (2020). Fertilization effects of compost produced from maize, sewage sludge and biochar on soil water retention and chemical properties. *Soil and Tillage Research*, *197*, 104493. https://doi.org/10.1016/j.still.2019.104493

Hallas, J., & Mackowiak, C. L. (2019). *Florida Biosolids: Management and Land Application Rules*. University of Florida IFAS Extension, EDIS. https://edis.ifas.ufl.edu/ss634

Heyman, H., Bassuk, N., Bonhotal, J., & Walter, T. (2019). Compost quality recommendations for remediating urban soils. *International Journal of Environmental Research and Public Health*, *16*(17), 3191. https://doi.org/10.3390/ijerph16173191

Hobbie, S. E., Finlay, J. C., Janke, B. D., Nidzgorski, D. A., Millet, D. B., & Baker, L. A. (2017). Contrasting nitrogen and phosphorus budgets in urban watersheds and implications for managing urban water pollution. *Proceedings of the National Academy of Sciences*, *114*(16), 4177–4182. https://doi.org/10.1073/pnas.1618536114

Land Application and Composting of Biosolids. (2010). [Q&A / Fact Sheet]. Water Environment Federation. https://www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/biosolids/technical-resources/wef-land-app-fact-sheet---rev0510.pdf

Law, N. L., Band, L. E., & Grove, J. M. (2004). Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore county, MD. *Journal of Environmental Planning and Management. 47(5): 737-755.*, *47*(5), 737–755. https://doi.org/10.1080/0964056042000274452

Loper, S. J., Shober, A. L., Wiese, C., Denny, G. C., & Stanley, C. D. (2013). Nutrient leaching during establishment of simulated residential landscapes. *Journal of Environmental Quality*, *42*(1), 260–270. https://doi.org/10.2134/jeq2012.0098

Mohammadshirazi, F., McLaughlin, R.A., Heitman, J. L., & Brown, V. K. (2017) A multi-year study of tillage and amendment effects on compacted soils. *J. Environ. Manag.*, 203:533-541. http://dx.doi.org/10.1016/j.jenvman.2017.07.031

Petrovic, A. M. (1990). The Fate of Nitrogenous Fertilizers Applied to Turfgrass. *Journal of Environmental Quality*, *19*(1), 1–14. https://doi.org/10.2134/jeq1990.00472425001900010001x

Saha, S., Trenholm, L., & Unruh, B. (2005). Effect of Fertilizer Source on Water Use of St. Augustine grass and Ornamental Plants. *HortScience: A Publication of the American Society for Horticultural Science*, *40*. https://doi.org/10.21273/HORTSCI.40.7.2164

Shaddox, T. W., & Unruh, J. B. (2018). *Iron for Florida Turfgrasses* (EDIS Publication No. ENH1287). UF IFAS Extension. https://edis.ifas.ufl.edu/ep551

Shober, A. L., Denny, G. C., & Broschat, T. K. (2010). Management of fertilizers and water for ornamental plants in urban landscapes: Current practices and impacts on water resources in Florida. *HortTechnology*, *20*(1), 94–106. https://doi.org/10.21273/HORTTECH.20.1.94

Somerville, P. D., Farrell, C., May, P. B., & Livesley, S. J. (2020). Biochar and compost equally improve urban soil physical and biological properties and tree growth, with no added benefit in combination. *Science of The Total Environment*, *706*, 135736. https://doi.org/10.1016/j.scitotenv.2019.135736

Somerville, P. D., May, P. B., & Livesley, S. J. (2020). Effects of deep tillage and municipal green waste compost amendments on soil properties and tree growth in compacted urban soils. *J. Environ. Manag.* 227:365-74. https://doi.org/10.1016/j.jenvman.2018.09.004

Yuan, Y., H. Chen, W. Yuan, D. Williams, J. Walker, & w. Shi. (2017). Is biochar-manure co-compost a better solution for soil health improvement and N2O emissions mitigation? *Biogeochemistry*. Springer, New York, NY, 113:14-25. https://doi.org/10.1016/j.soilbio.2017.05.025

EXISTING ORGANIC SOIL AMENDMENT PROGRAMS

City of Fort Collins Utilities. (2016). *City of Fort Collins Soil Amendment Requirements*. https://www.fcgov.com/utilities/img/site_specific/uploads/Soil_Amendment_Brochure_2016.pdf?1476374839

City of Leander, Texas. (2017). *Composite Zoning Ordinance*. http://www.leandertx.gov/sites/default/files/fileattachments/planning/page/338/composite_zoning_ordinance_04.06.2017_0.pdf.

Denver Water. (2020). *Soil Amendment Program*. Contractors. https://www.denverwater.org/contractors/construction-information/soil-amendment-program

Lee County Solid Waste Division. (2014). *Lee County Composting Facility, SWANA 2014 Excellence Award Entry - Composting Systems* (p. 18). Lee County, Florida Solid Waste Department. https://swana.org/portals/0/awards/2014/Composting/Lee%20County%20CompostingSystems.pdf

APPENDIX

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LONGER-TERM CONSIDERATIONS

"We know more about the movement of celestial bodies than about the soil underfoot."

— Leonardo Da Vinci, circa 1500

INFORMATION GAPS AND LIMITATIONS

Assurance of Benefits

Many of the benefits of amending urban soils with organic materials have been translated from agricultural studies into the urban context. Only a few studies exist that have solely focused on the benefit of mitigating initial urban landscape soil conditions via amending. Of those studies conducted, these have largely been plot or meso-scale rather than lot level or in the built environment. Assuring that benefits translate from agricultural applications to urban contexts is a need for further promoting and gaining acceptance of amending urban soils. Benefits to the public include:

- landscaping and turf health
- water quality
- water conservation
- reduced fertilizer
- reduced long-term cost and maintenance

Compost Characteristics

As soil characteristics differ in composition, so does compost. Finished compost products can vary widely due to differences in feed stocks, composting process, post-processing, and incorporation of additives. While past studies have related compost applications to changes in soil characteristics, understanding the relationship between specific compost characteristics and the resulting amended soil characteristics, such as structure, soil-water relationships, and other effects, would be valuable to informing guidance on amending soils. Ideally, this would identify the essential characteristics of compost, or other amendments, to produce an intended effect or performance. This would likely increase acceptance and confidence in the use of soil amendments by professionals and government agencies through establishing fundamental relationships between amendment and soil characteristics, and the resulting amended soil characteristics.

Different soils have diverse characteristics, and not all composts are alike.

More research is needed to fully understand the benefits and limits of soil amendments.

Diversity of Soil Development Settings

Soil texture, the relative abundance of sand, silt, and clay particles in soil, strongly influences soil structure, bulk density, and pore size distribution, particularly in response to compaction. In turn, the pore size distribution largely defines how water moves through soil. Of the limited number of studies focused on urban soils, compost amendment has generally improved the quality of urban soils, via improved soil structure (orientation of particles and aggregates), decreased bulk density, increased infiltration, and reduced runoff. Studies have generally looked at the effects of amending a few select soils within a narrow range of texture with a few select soil amendments. One existing gap is a need to evaluate the variable effect that amending with different products has across soil texture gradients. In general, compost tends to improve the plant available water of mineral soils due to adsorptive properties of compost and improved soil structure that increases the number of small pores. By comparison, finer textured soils already have small pores with greater water holding capacity. The benefit of amending these finer textured soils with compost is increased infiltration. However, it is not clear where along the texture gradient these properties transition or stop. Understanding the relationship or limits of these properties to amendments and soil textures would greatly inform guidance for whether and how to amend soils.

Irrigation with some reclaimed water has been found to be beneficial to urban landscapes, as it provides a source of nutrients to the landscape. The concentrations of nutrients in the reclaimed water are significantly higher if the wastewater has only been treated to the secondary level (minimum requirement for reclaimed water in Florida), rather than to the tertiary level. By contrast, the nutrient concentrations remaining in tertiary wastewater are lower and unlikely to affect plant growth (Table 4; Fan et.al., 2014). Over time the nutrient loading from large volumes of reclaimed water can be substantial and should be accounted for in nutrient management of landscapes to avoid over-fertilization and leaching of nutrients into groundwater and export via runoff. Furthermore, reclaimed water generally has elevated salinity levels which can damage foliage on some plants. However, the specific effects of irrigation with reclaimed water on the benefits, persistence, and nutrient cycling from soil amendments have not been well established.

Table 4. Typical nutrient concentrations in reclaimed water. Source: Metcalf and Eddy (2000).

Nutrient Form	**Untreated wastewater, ppm**	**Concentration after secondary wastewater treatment, ppm**	**Concentration after advanced (tertiary) wastewater treatment, ppm**
Total Kjeldahl Nitrogen	31.5	13.9	0.9
Nitrate Nitrogen	0.1	1.4	0.7
Inorganic Phosphorus	6.1	3.4	0.1

Amending compacted soil generally improves infiltration, drainage, and could be expected to reduce runoff. Quantifying this reduction within Florida's urban areas could provide benefits such as reduced stormwater loadings volumes.

Factors that Could Diminish Benefits

As important as it is to understand the benefits that organic amendments provide to soils, it is just as important to understand the limitations. Determining these boundary conditions would reduce the risk of unrealized outcomes or over promotion of the practice.

Application of fertilizers and irrigation are practices that can be harmful if overused. Again, it is not necessary to add nitrogen fertilizer to sites that have compost amendment for at least 30-60 days, but possibly as long as through the first growing season. Excess nutrients can either wash off the site or leach into groundwater where they can ultimately fuel unwanted algal growth. Over irrigation wastes important water resources, can harm turf, encourage weeds, and increases disease incidence.

Assess Long- and Short-Term Benefits

Increasing soil organic matter increases water holding capacity in soils. The persistence of this initial incorporation of organic matter into soils is highly relevant to the longevity of benefits from amending soils. Research studies vary on the duration of realized benefits from compost amending. As soil carbon cycles are complex and with multiple feedback processes, teasing out the relative significance of factors is challenging. For example, increased soil moisture generally facilitates increasing soil organic matter, while increased soil organic matter tends to increase soil moisture. Dryer soil conditions typically facilitate the oxidation and loss of soil organic carbon. Determining the critical range of initial organic matter that promotes long-term persistence of organic matter and associated benefits under typical landscape conditions would inform guidance on the rates of material application.

FUTURE RESEARCH NEEDS

Leaching Potential of Compounds in Biosolids

A major current concern is the relevance and implications of using municipal wastewater biosolids as a feedstock for compost production. Remnant pharmaceuticals and personal care products (PPCPs) and endocrine disrupting compounds (EDCs) or biproducts may be contained in biosolids from wastewater treatment plants, which may persist through the composting process. The effects and longevity of these compounds and their biproducts if they are introduced into the urban landscape, even at low concentrations, via compost applications are not well established at this time. These risks to the environment and human health should be better understood and put into context with other activities (e.g. irrigating with reclaimed water, application of pesticides). More specific information is needed about the leaching of these compounds to determine:

- Potential interactions with nutrients (nitrogen and phosphorus)
- Amounts, duration, cumulative loads
- Factors influencing leaching rates

Leaching Assessment Protocol

Evaluating the leachability of nutrients or other compounds of concern from amended soils is important to assess the potential for effects on groundwater resources, as soil characteristics and vegetation vary under real-world conditions. Drainage lysimeters have commonly been used in agricultural and residential applications to collect leachate or drainage water from below the rootzone to assess impacts to groundwater. See guidance from UF/IFAS for the design, construction, and installation of lysimeters. For evaluating amended soil applications, ideally the soil profile is not disturbed once amendments have been incorporated. Thus, lysimeters should be installed before soils are amended (to prevent disturbance of the soil profile). Lysimeters should ideally be located in parts of the landscape that will be representative of vegetation or turfgrass area and away from areas receiving concentrated flow (e.g. near roofline, near gutter downspout, low area). These drainage volumes will vary based on the soil type, amendment type and rate, irrigation scheduling, rainfall, and evapotranspiration since the previous collection.

Optimum Application Rates for Objectives

Incorporating compost into sandy soils improves water holding capacity but also introduces nutrients into the landscape that have the potential to be leached or transported via runoff. An inverse relationship exists between the goal of increasing potential water conservation and the need to limit excess nutrients with increasing amendment rates. Therefore, it will be important to understand the tradeoffs between these two aspects for meeting the intended objectives. While 4 yd^3/1000 ft^2 is the most common application rate, lower rates may offer similar benefits if non-linear relationships exist.

Cost Effectiveness

As of the writing of this document, amending new residential landscapes is a niche practice within the building and development industry. Labor, transportation, and equipment costs are higher than the costs of the amendment material itself. As the practice scales up, it is likely that these non-material costs will decline. However, uncertainty of cost and how the practice relates to pay back period, marketability, and crediting or certifications are barriers to broader adoption. Providing the industry with reliable information about these factors would likely increase implementation.

Longevity of Benefits and Fate of Nutrients

Compost and other organic amendments commonly provide some nutrition to plants overtime. It has been well documented that there is generally an initial release of nitrogen soon after compost is applied to the landscape. Neither the duration of this initial release of nutrients nor the portion of total nutrients initially released are well established. As such, mobile nutrients that are not taken up by plants or otherwise fixed in the soil, could leach and become a nuisance loading to groundwater or transported via runoff. The duration of initial nutrient release and the quantity of nutrients released are one area of potential research. Studies should focus on how these factors relate to application rates, amendment characteristics, and the ability of amendments to offset or otherwise affect turfgrass management practices. Further, certain soil and hydrologic characteristics (e.g. clay content, mineralogy, depth to water table, soil pH, salinity) may buffer or facilitate the release of nutrients. Identifying the significance of these factors would better inform appropriate hydrologic and geologic settings for amending soils and appropriate rates.

Medium to Long-Term Effects of Amending on Soil Microbial Communities

Another widely accepted benefit of amending soils with compost is that it improves soil microbial communities, enhancing soil functions and health overall. Soil microbes drive a variety of plant and soil processes, which can affect a range of factors that influence landscape management. Enhancing soil microbial communities may reduce instances of fungal and disease outbreaks, facilitate more resilient plants and limit weed establishment, potentially decreasing the need for pesticide application. Establishing the medium to long-term benefits to soil microbial communities would better inform landscape management practices.

Potential for "Engineered Media"
(combining compost with other materials to enhance nutrient retention in various settings)

Finally, as the release of nutrients is a potential unintended consequence of amending soils, identifying methods to mitigate this effect would be valuable to water resource protection. There are various ways this may be addressed that generally fall into two categories – post-processing and management. Post-processing describes any modification or addition to the finished amendment material before application. There may be ways of treating the product to slow the release of nutrients. Blending certain additives with the amendment or amended soil may adsorb nutrients or facilitate fixation of nutrients reducing their mobility.

Adjusting management practices after amending may be another way to minimize nutrient exports. This may include temporarily adjusting irrigation settings, particularly during establishment, to reduce drainage and potential or runoff. It could also include temporary application or limited application of certain products to limit nutrient exports. Identifying effective methods to address the initial availability of nutrients following compost amendment would reduce the risk of impacting ground and surficial water resources.

Contribution of Soil Amending to Carbon Sequestration

Amending soils with compost made from materials that otherwise would have been converted to carbon dioxide is a way of sequestering carbon from the atmosphere. Applied over a large scale, amending soils with compost may have a significant cumulative effect on carbon sequestration.

Feedstock and Composting Method Effects on Amended Soil Structure and Chemistry

Certain feedstocks and composting methods may produce a diversity of products with varying benefits and drawbacks to landscape incorporation, particularly with addressing soil structure and chemistry. Incorporating additives into compost feedstocks or including them post-compost production may more effectively achieve soil improvement objectives with fewer undesirable consequences. Investigating the utility of various additives and their effectiveness in landscapes may achieve intended outcomes more directly.

Potential for Disease Suppression in Urban Landscape Plants

Healthier soil and plants are generally recognized benefits of compost incorporation. Whether directly or indirectly, compost additions generally improve growing conditions, creating more resilient plants. Compost helps to develop a healthy soil microbial community, which may suppress certain diseases harmful to vegetation. This can help reduce landscape maintenance and the use of fungicides or other products needed to support less resilient plants. Understanding these potential benefits would improve the applicability and utilization of amendments in the residential landscape.