A Comparative Fava Bean Growth Assay Using Berkeley's Municipal Solid WasteCompost

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ABSTRACT

The city of Berkeley provides its residents with free municipal solid waste compost that can be used as an organic amendment for plant cultivation. In order to understand its efficacy as an organic amendment of urban soil, I planted a crop of fava beans in 3 treatments: bare soil, soil amended with Berkeley municipal solid waste (MSW) compost, and soil amended with commercial industrial compost. I measured stem height and diameter, vegetative mass, and weed mass. Weed mass increased in both treatments compared to the control and stem height increased in the commercial compost compared to the control, but not compared to the MSW compost treatment. In fact, I found no significant differences between the two compost treatments for stem height, stem diameter, vegetative mass, and weed mass. This suggests that Berkeley’s MSW compost is a comparable organic amendment to commercial compost for the purpose of growing food crops in urban soil. This information can help bolster public support for similar recycling initiatives in other municipalities and guide the decisions of low-budget urban agriculturalists in the Bay Area when choosing between organic amendments available for cultivation.

KEYWORDS

municipal compost, municipal solid waste, urban soil, urban agriculture, organic agriculture, organic matter, cover crops

INTRODUCTION

Urban agriculture enhances public health from multiple angles, as it promotes food sovereignty, facilitates community health, and provides ecosystem services. For example, adults in Oakland, California consume one third of the amount of fruits and vegetables recommended by USDA dietary guidelines, and list price and time constraints as barriers to produce consumption (Mook et al. 2016). If only a tenth of the vacant land in Oakland was converted to urban agriculture, it could produce an amount of vegetables equal to 5% of the current consumption rate in the city (McClintock 2013). At this scale, urban agriculture can provide residents with a source of vegetables that is resilient to changing food prices and circumvents distribution barriers (Sicili 2014). Beyond food production, urban gardens generate community health by facilitating social cohesion, relieving stress, and facilitating outdoor exercise (Forrest & Kearns 2001, Kingsley et al. 2009). At a greater scale, improving soil structure through urban agriculture provides environmental benefits by lowering average temperatures in the city and abating the impacts of carbon emissions by storing carbon in soil aggregates and microbial biomass (Hermann et al. 2011, Ryals et al. 2016). Urban gardeners interested in manifesting these benefits should note that Berkeley zoning laws allow small-scale organic farms to operate without a permit (Bradford 2018). However, historic uses of urban soils often create unique biological challenges for people interested in growing food.

Historic uses of urban land can lead to heavy metal accumulation, nutrient leaching, topsoil erosion, and soil compaction (Li 2019). These problems create challenging growing conditions that can be addressed by incorporating organic matter into the soil (Sicili 2014, Altieri et al. 2016). Amending soil with organic matter can aid plant growth by improving soil aggregation, nutrient adsorption, and water retention (Glab 2014). Therefore, amending an urban soil with organic matter enhances plant growth by making it easier for plant roots to penetrate soil, absorb water and nutrients, and suppress soilborne plant pathogens (Termorshuizen et al. 2006). Urban agriculturalists must still remember that lead from historic uses of paint and gasoline are heterogeneously concentrated throughout the urban landscape (McClintock 2012), although not at levels considered harmful to human health if ingested (Kohrman and

Chamberlain 2013). Urban gardens in Berkeley have not been found to contain elevated levels of trace metals (Altieri et al. 2014), but lingering concerns can be addressed by amending contaminated soil with organic matter to bind metals and decrease their availability for plant uptake (Brown et al. 2016, Turner 2009). In the face of soil characteristics that limit plant growth, compost amendment can continuously improve the nutrition of the soil with every crop.

Compost is a soil amendment made of aerobically decomposed vegetation and is used to introduce organic matter and growth-promoting microorganisms that improve soil structure and maintain soil nutrition over time (Pallud 2020). The process of thermophilic composting transforms food scraps and vegetative matter into stable humus by shredding organic materials, exposing them to oxygen (5-10%), and maintaining optimal moisture (40-60% by mass) and temperature in order to facilitate the breakdown of organic materials by aerobic microorganisms (Bertoldi et al. 1983). When cultivated properly, the composting process transforms carbon and nitrogen in plant tissues into plant-available carbohydrates, fats, and nitrogenous compounds (Paul 2016). This transformation is orchestrated by several stages of decomposition facilitated by a variety of microorganisms with unique capacities to decompose molecules of varying complexity (Zucconi et. al. 1981, Kallenbach et al. 2016). When incorporated into soil, these stabilized compounds adsorb to clay particles and aggregate with mineral soil, forming several pools of nutrients that plants can access over time (Paul 2016). The organisms that facilitate the decomposition process are also transferred to the soil upon amendment, and continuously supply plants with nutrients released as they consume organic residues throughout the life of the soil (Perucci 1990, Lehmann & Kleber 2015, Pallud 2020).

A number of studies have determined that MSW compost can be used as a soil conditioner and nutrient amendment to benefit plant growth, but gaps in research appear at the municipal level. It is clear that MSW compost improves the physical and biochemical ability of soil to support plant growth (Hargreaves et al. 2008). It has been established that the growth and yield of grain crops (Mishra et al. 2007, Párraga-Aguado et al. 2017) and vegetables (Hampton and Bryan 1993) are enhanced by amendment with municipal compost, often with elevated (but not harmful) levels of heavy metals like zinc, lead, and copper in plant tissues (Rodd et al. 2002). In the city of Berkley, however, there is a lack of information regarding the properties of the

MSW compost available at the Marina, which leads many gardeners to opt to purchase compost from local nurseries instead of taking the risks that they perceive are inherent to MSW compost.

This study aims to compare the growth of a crop of fava beans in an urban soil amended by MSW compost and a commercially-produced compost to better understand the quality of Berkeley's free compost program to amend urban soil for agricultural production. This research aims to answer: How do MSW compost and commercial compost affect the ability of urban soil to support plant growth? To answer that, the question fragments into the following subquestions: Do MSW and commercial compost differentially impact fava bean growth? Do they differentially impact weed growth?

METHODS

Compost sourcing

To compare plant growth in urban soil amended with MSW compost and commercial compost, respectively, I collected commercial compost from G&B organics and MSW compost from the City of Berkeley's municipal compost program and.

The "commercial compost" was made by Gardner and Bloome Organics, a trademark owned by Kellogg garden products, and was purchased from the Berkeley Horticultural Nursery. It is composed of tomato skins, almond shells, rice straw and hulls. Its product description claims to improve native soil as a plant growth medium by loosening clay and improving drainage.

On November 30th, 2019, municipal compost was deposited at the Berkeley Marina in a large uncovered heap on the asphalt. That afternoon, I shoveled the compost into black plastic buckets from several sites throughout the heap in order to represent the quality of the compost as a whole batch. Then, I transported it to Lothlorien student cooperative, where it rested in the shade of an oak tree for three days until planting.

City of Berkeley municipal composting program

The CA Integrated Waste Management Act, passed in 1989, required jurisdictions to divert 50% of their waste from landfills by 2000 (Lasin 2002). The City of Berkeley's municipal composting program began that same year (Rosenau 2011). Recology, a privately operated composting agency, oversees the collection of organic wastes from Livermore, San Francisco, San Leandro, and Berkeley and sends it to be processed into compost at the Blossom Valley processing facility in Vernalis, CA (Rosenau 2011). There, the waste is sorted by particle size; light plastics are winnowed by a blower, glass, metal, and heavier plastics are removed by a vacuum and by hand on a line; and all the remaining material is combined and shredded (Rosenau 2011). This shredded material is piled into massive outdoor windrows that are watered and turned by heavy machinery 15 times in 10 weeks. Coarse material and plastics are filtered once more from the final product, large wood chips are cleaned and sent to biomass facilities, and the remaining compost product is returned to Berkeley residents for free or sold to private soil producers who mix it with additional minerals and sell it for profit (Rosenau 2011). On the last Saturday of every month from February to October, the city of Berkeley dumps huge heaps of this compost at the Berkeley marina for residents to retrieve independently (City of Berkeley Public Works 2017). This resource is provided for free and requires no proof of residency, at a total yearly value of $42,000 (Rosenau 2011). This public service reduces the mass of waste in landfills while providing a free resource for residents to grow food organically (Rosenau 2011).

Study species: *Vicia faba*

I selected fava beans for this study to simulate the first steps in the process of growing food in an urban soil: amending the soil with compost, then cover-cropping the plot with legumes. Their large, deep root masses break apart compacted soils, retrieve mineral nutrients from deeper in the soil horizon, and form symbiotic relationships with rhizobium bacteria that make atmospheric nitrogen available to subsequent crops (Jensen et al. 2010, Coleman 2018).

The plants studied in this growth assay were grown from Broad Windsor fava beans (*Vicia faba)* harvested in September 2017 by the Sustainable Seed Company in Chico, CA.

Greenhouse growth assay

Soil preparation

On December 3rd, 2019, I excavated soil with shovels from three bare sites in the front yard of Lothlorien Student Cooperative in Berkeley, CA. That evening, I transported it in clear PVC plastic bins to the Oxford Tract greenhouse for planting.

I devised three soil amendment treatments to compare the growth of fava beans in an unamended urban soil (the control), an urban soil amended with a commercially-available compost, and an urban soil amended with the MSW compost provided by the city of Berkeley.

In each treatment, I filled black plastic pots with 10 cups each of growth medium. For each pot in either compost treatments, I mixed 9.5 cups of urban soil with half a cup of compost to yield 5% organic matter composition. I chose this composition to simulate a highly organic native soil (Pierce 2010).

Table 1. Summary of compost treatments

Treatment Type	Volume Soil	Volume Compost
Urban soil (control)	10 cups (100%)	0
Professional compost + urban soil	9.5 cups (95%)	0.5 cups (5%)
Municipal compost + urban soil	9.5 cups (95%)	0.5 cups (5%)

Planting

On December 3rd, 2019, I planted 27 fava beans at the Oxford Tract greenhouse- 9 beans in each treatment described above. At the center of each pot, I planted one fava bean 2 inches below the soil surface (Terry 2017). I then placed the planted pots in the Oxford Tract greenhouse and left them to grow for 4 months. Greenhouse employees saturated each pot with tap water whenever the soil surface was dry to the touch.

Data Collection

Weed mass

On February 3rd, 2020, after about 8 weeks of growth in the greenhouse, I trimmed all weeds present in each pot at the soil surface, then weighed their masses on a scientific scale to the nearest 0.01 g.

Stem height

On March 3rd, 2020, after 13 weeks of growth in the greenhouse, I measured the height of every fava bean stem above 6 in. with a tape measure from the base of the stem to the tip of the highest leaf, to the nearest 0.1 in.

Stem diameter

After 13 weeks of growth in the greenhouse, I used calipers to measure the diameter of each fava bean stem above 6 in. in height (to the nearest 0.1 mm) at 3 inches above the soil surface.

Vegetative mass (wet)

After 13 weeks of growth, I cut each fava bean plant at the soil surface, and weighed the mass of each plant using a scientific scale to the nearest 0.01 g.

Data analysis

I analyzed all data for normality and variance using the statistical software Rstudio. First, I analyzed the datasets for all growth response variables for normality of distribution using a Shapiro-Wilk test (Technik 2019). Then, I compared the effect of compost treatment type on stem height and vegetative mass using a parametric one-factor variance analysis (ANOVA) with pairwise comparisons made using the Tukey test; I analyzed the effect of compost treatment type on weed mass and stem diameter using a nonparametric one-factor variance analysis (Kruskall-Wallis) and made pairwise comparisons using a dunn test (Dinno 2017).

RESULTS

*P-values indicating significant differences between treatments are denoted with an asterisk.

Weed mass

Table 1. Results of a one-factor pairwise dunn test comparing the effect of treatment type on weed mass.

Treatment comparison	chi-sq	p-value
UrbanSoil & Municipal	2.072465	0.0191*
UrbanSoil & Nursery	2.571489	0.0051*
Nursery & Municipal	-0.438940	0.3304

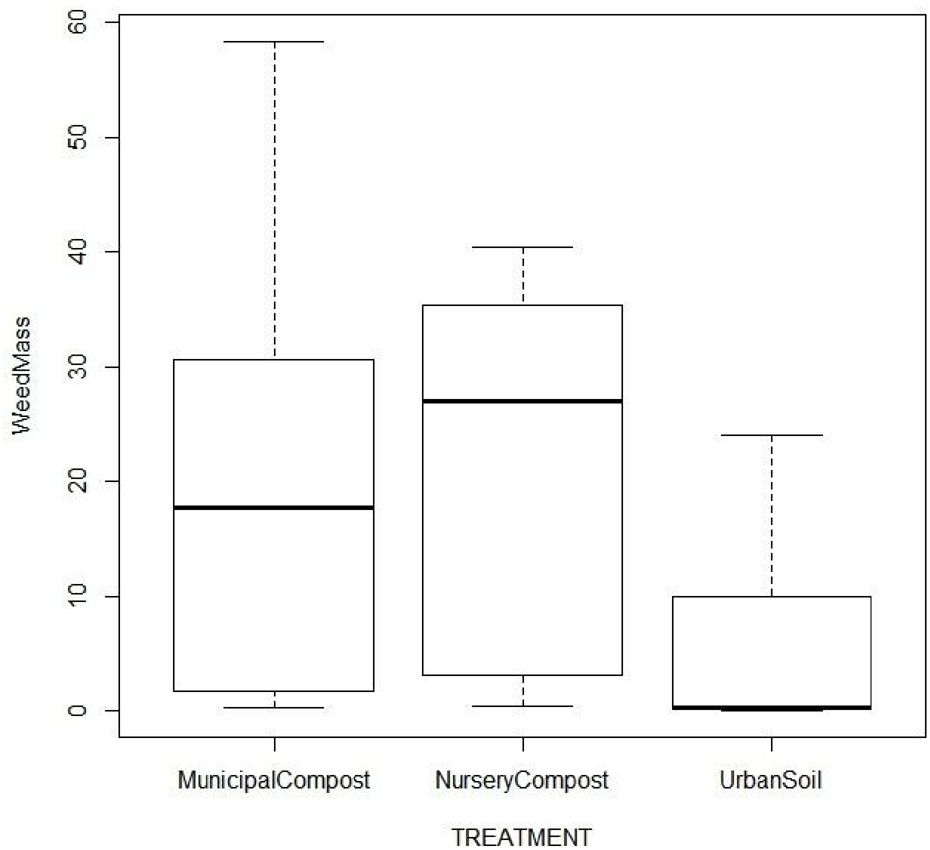

Figure 1. Box plot comparing average weed mass (g) across treatments.

Stem height

Table 2. Results of a one-way ANOVA and pairwise Tukey test comparing stem height across treatments.

	t value	Pr(>|t|)
UrbanSoil & Municipal	-0.468	0.8867
UrbanSoil & Nursery	-2.718	0.0324*
Municipal & Nursery	-2.328	0.0727

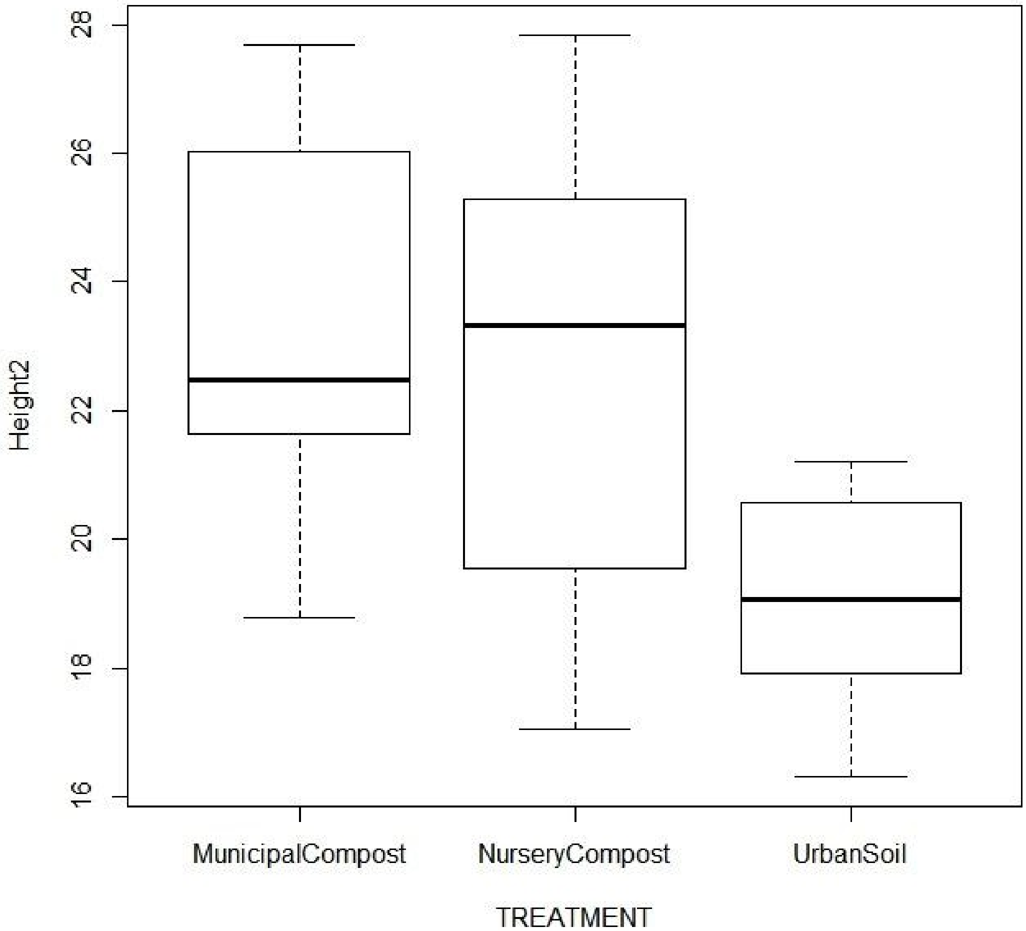

Figure 2. Box plot comparing stem height (in.) of fava plants across treatments.

Stem diameter

Table 3. Results of a one-factor pairwise dunn test comparing stem diameter by treatment type.

Treatment Comparison	chi-sq	p-value
UrbanSoil & Municipal	0.441672	0.3294
UrbanSoil & Nursery	-0.501090	0.3082
Municipal & Nursery	0.441672	0.3294

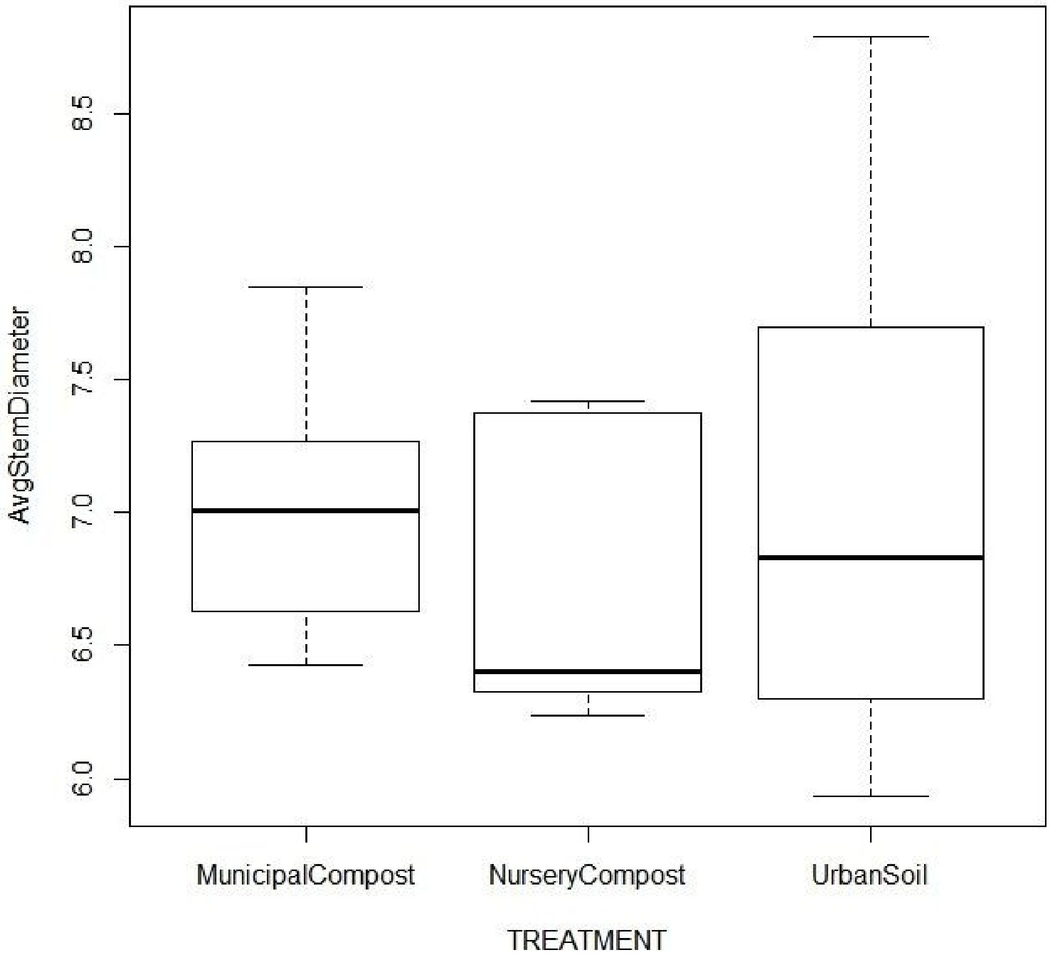

Figure 3. Box plot comparing average stem diameter(mm) across treatments.

Vegetative mass (wet)

Table 4. Results of a one-way ANOVA and pairwise Tukey test comparing vegetative mass across treatments.

Treatment Comparison	**t value**	**Pr(>|t|)**
Nursery & Municipal	-0.385	0.922
UrbanSoil & Municipal	-1.049	0.555
UrbanSoil & Nursery	-0.694	0.770

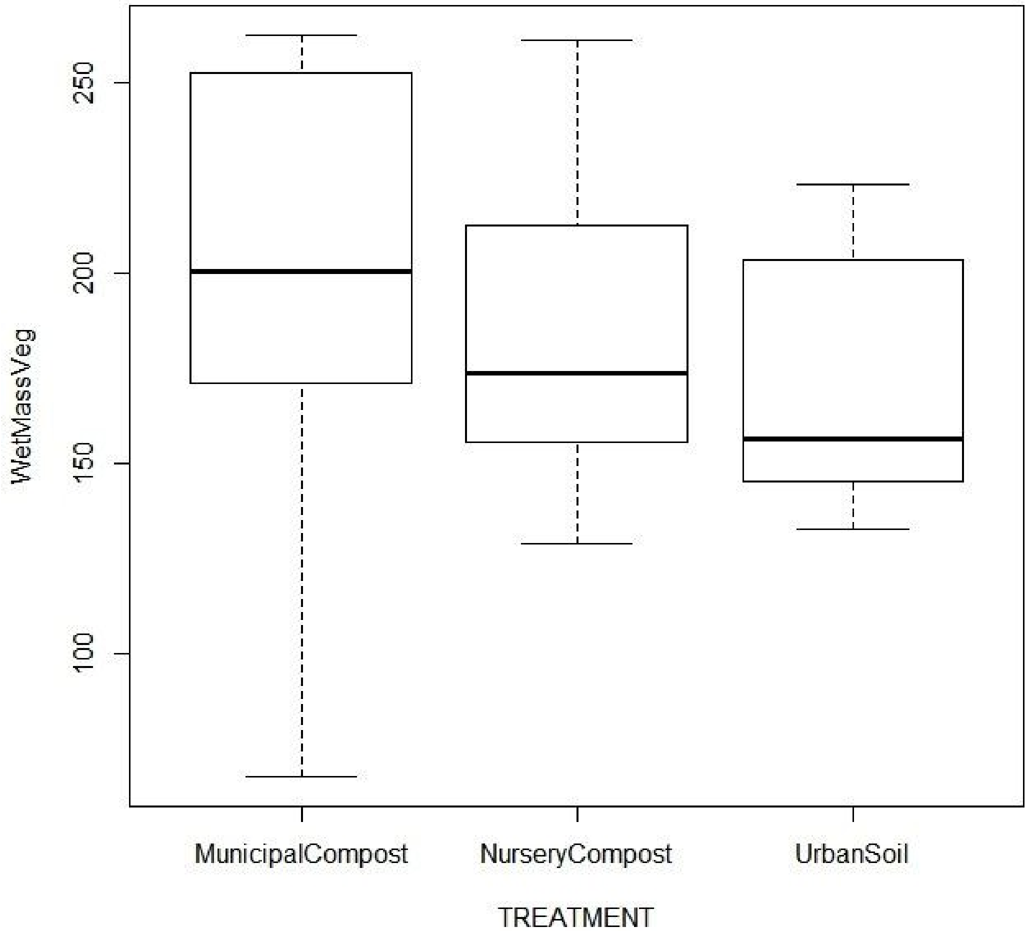

Figure 4. Box plot comparing vegetative mass (g) of fava plants across treatments.

DISCUSSION

Summary

Previous studies suggested that I would see increases in all growth variables in both composts compared to the control, and I was curious to see if there would be differences between the commercial and municipal compost treatments.

Weed growth

As expected, weed mass increased in both compost treatments compared to the control but did not vary between treatments.

Fava bean growth

Stem height increased in the nursery compost compared to the control but not in the municipal compost compared to the control. However, this difference was not significantly different between compost treatments. Surprisingly, stem diameter and vegetative mass were not affected by compost amendment. There were no significant differences in any of the measured variables (fava bean plant height, stem diameter, vegetative mass, and weed mass) between the two compost treatments, suggesting that, despite differences in inputs, municipal and commercial industrial composts did not display significant differences in their ability to support the growth of a fava bean crop and accompanying weeds after compostamendment.

These results are relevant for low-cost urban agricultural operations who are compelled by time constraints, labor availability, or land sharing to source compost from external processors. This study shows that both commercial compost and MSW compost amendment lead to increased soil nutrient availability, as displayed by the enhanced weed growth, but did not significantly differ in their ability to support plant growth. Therefore, the differences in the composition and decomposition processes between commercial and MSW processes do not prove to be functional differences. As a result, urban agriculturalists in Berkeley should feel empowered to use the MSW compost without fear that what is available for purchase is a better alternative to improve the condition of their soil and support plant growth.

Effects of industrial processing on compost quality

There are key differences between on-site composting, commercial industrial composting, and municipal solid waste processing that affect the value of the finished compost to agriculturalists. As 25% of urban gardens in Berkeley cite that they cannot produce their own compost on site due to labor restrictions and often rely on MSW compost as an organic matter amendment (Altieri et al. 2014), it is important to understand how the characteristics of this compost affect plant growth.

There are, in fact, benefits to using MSW compost instead of producing it on-site. The mechanized material shredding and pile turning at an industrial processing facility (MSW or commercial) help maintain optimal conditions for aerobic decomposition more efficiently than can be performed by hand. First, mechanically shredding organic material decreases decomposition time compared to on-site composting, as a greater surface area increases microbial access to the organic substrate (Bertoldi et al. 1983). That being said, huge piles of small particles are difficult to soak. Large-scale composting operations therefore encounter difficulties maintaining optimum moisture levels throughout the composting process, which can yield an immature product potentially toxic to plants and characterized by a potent odor (Itävaara 2002).

It is also important to note that the nutrient composition of MSW compost differs from commercial or on-site composts because its input ratios are determined by forces beyond the control of the processing facility; MSW facilities receive organic waste as it is collected while commercial operations can curate the ratio of ingredients in their compost. In a MSW compost heap, the ideal carbon to nitrogen ratio is 25:1 in order to maximize the efficiency of microbial conversions of carbon (Bertoldi et al. 1984, Paul 2016). In an on-site compost heap or commercial industrial process, this ratio is ensured by incorporating an appropriate volume of dry, woody materials, which are higher in carbon, with green vegetation, manure, or food waste, which are higher in nitrogen (Pallud 2020). During decomposition, excess carbon slows the decomposition process while microorganisms work to transform the residues into more digestible forms; excess nitrogen is released to the atmosphere as ammonia or nitrate which are unavailable to plants (Bertoldi et al. 1984, Paul 2016). In MSW compost, the C:N ratio varies with every batch as a result of hard-to-predict changes in the volume of different types of food and yard waste discarded by homes and businesses, and thus every individual pile must be managed to ensure adequate levels of plant-available N (Giannakis 2014).

Assessing the value of MSW compost

Public spending on organic waste processing is only justified if the compost proves to be a valuable resource to the residents it intends to serve (Farrell and Jones 2009). Given the perceived differences in quality from a homemade or commercial compost (from inadequate moisture or suboptimal nutrient ratios), the target audience of the Berkeley MSW compost might be agriculturalists growing food in the city at a low cost. The target audience is narrowed when considering that agriculturalists limited by transportation or concerned about consistent crop quality are likely to produce compost on-site or source from a commercial producer. With this in mind, the challenge for MSW compost processors becomes: creating a compost that is cheap to produce and can functionally and nutritionally compare to the compost that is available for purchase at nurseries (Danso et al. 2006). In order to better understand the value of the MSW compost that is available for free in Berkeley, this study shows that there are no significant differences in the growth of a crop of fava beans grown in urban soil and amended with either MSW compost or commercially-available compost.

Study Limitations

Universality

This study aims to be a replicable comparison of plant growth in MSW compost and commercial industrial compost. However, the results of this growth assay are the product of a unique interaction of the soil of one front yard, two specific batches of compost, and one crop of fava beans. Soil structure and nutrition vary with parent material and land use history (Izquierdo et al. 2015) while compost quality varies within a single pile and across batches from unique input ratios, temperature, moisture, and aeration (Bertoldi et al. 1983). Thus, this study does not seek to characterize the interactions of any urban soil with any compost amendment.

Time scale

Thirteen weeks of legume growth between compost amendment and legume harvest compose merely a moment in the lifetime of a soil. The timescale of this study does not address the long-term changes in soil structure and nutrient composition that might further enhance plant growth over several generations of crop planting and compost amendment (Diacono and Montemurro 2010).

Public health

The use of municipal compost to grow food crops overlooks research findings that MSW compost contains traces of heavy metals such as lead and chromium that can be transferred to the tissues of agricultural crops or leached into groundwater (Párraga-Aguado 2017). This issue becomes less consequential with the understanding that many urban soils likely already contain bioaccessible metals that are made less available by the addition of organic matter (Izquierdo et al. 2015). Even further, the risks associated with consuming produce grown in urban soil amended by MSW compost are complicated/diminished by the full range of health benefits generated by urban gardens through social cohesion, stress relief, and outdoor exercise (Forrest & Kearns 2001, Kingsley et al. 2009).

Broader implications

When promoting organic waste recycling, municipalities can move beyond landfill diversion and cite urban gardening as a public health benefit of organics collection and processing. The city of Berkeley's free compost program provides an example of a direct link between organic waste recycling and public health through the lens of urban gardening. For that reason, it is important to direct resources to continue to improve the distribution of this resource and information about its function and contents to empower residents to improve their environment and play a central role in the production of their produce.

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