EVALUATION OF SUBSTRATES IN CONSTRUCTED, RAISED-BEDS FOR VEGETABLE CULTURE

by

JESSICA LYNNE CUDNIK

(Under the Direction of David Berle)

ABSTRACT

With the increased interest in urban food production and community gardens, many gardeners are constructing raised beds. Constructed raised beds offer potential for better drainage and easier access to the growing area. Constructed raised beds also have the ability to increase yield. Substrates for constructed raised beds are often an afterthought, with little scientific basis for selecting materials or consideration for the broader environmental effects of materials. This study evaluates eight substrates and two crops, kale and basil, for yield and chlorophyll content. The same eight substrates were also evaluated for sustainability factors such as carbon-mineralization (C-min) over time and soil microbial biomass carbon (SMBC). Based on yield alone, the 100% compost substrate resulted in the highest yield across all three crop trials. The native soil substrate had the lowest C-min and SMBC rate. Results varied with season and crop, but yield and C-min indicate a substrate composed of compost/native soil is the best overall.

INDEX WORDS: raised beds, vegetable yields, chlorophyll leaf content, oxidation of organic matter, carbon, mineralization, substrate, soil microbial biomass

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DEDICATION

To all those before me and all those that come after, may my work be but my simple contribution to this community. I thank my family for raising me with strength, a determined work ethic, and a thirst for knowledge as well as with a healthy sense of adventure. I dedicate this accomplishment to all those who graciously offered support, time, or a simple warm meal to get me that much closer to this personal goal of mine, a Master's of Science Degree in Horticulture.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Nationwide, community gardens are on the rise. A 1998 nationwide survey reported over 6,000 community gardens (Association 1998). That number is estimated to be closer to 10,000 today (Lee 2010). In recent years, urban gardening has become increasingly popular in nearly all socioeconomic groups in the United States (Hanna and Oh 2000). Community gardens are synonymous with the local food movement, with gardeners often opting for organic or sustainable methods to grow produce (Morgan and Murdoch 2000). In step with the increased interest in locally grown is concern about the source of food and the impact agricultural practices have on the environment, the overall effect of food productions carbon footprint.

Urban gardening is often challenging due to tough soil conditions like compaction and lack of access to open ground in urban areas where concrete and asphalt can cover the majority of the outdoor spaces (Hatch 1981). Some open urban spaces are considered brownfields, with issues of possible soil contamination from heavy metals or chemicals. Excess heavy metal accumulation in soils can be toxic to humans and other animals (United States Department of Agriculture 2000). For example, lead is generally higher in urban areas with older housing stock (Finster, Gray et al. 2004). Raised beds, filled with the appropriate substrate, offer one way to address these concerns.

There are over 313,000,000 people living in the Unites States. Of that population, less than 1 percent claim farming as an occupation (Agency 2007). While according to a 2008 (Association, 2009), 31 percent of all U.S. households participated in food gardening. This estimates to be about 36 million households. Food gardening includes growing vegetables, fruit, berries, and herbs. Estimates are that 21 percent of food gardening households are new to gardening (Association 2009). Only 3 percent or about 1 million households, garden in a community garden plot with the majority having these plots at home. The scale of this experiment is in line with a recent study that showed, 57% of people that have food gardens have a size of 100 sq. feet or less. This research will help gardeners make a substrate choice that will increase yield while reducing the potential impact of C released into the atmosphere.

Raised-bed vegetable culture can provide advantages such as: remediation of difficult sites, improved drainage, higher yield per square foot, and ease of season extension using covers (Starbuck 2003). Raised beds can be free-form were the soil is simply mounded higher than the surrounding area or they can be created using constructed boxes or containers. For purposes of this thesis, the term constructed raised bed (CRB) will be employed and is defined as a wood-frame box, at least 8 inches tall, built to hold a growing substrate. A CRB could also be built using rock, cement blocks, or other suitable materials. In many situations, a CRB offers an easy way to prevent soil compaction and provide easy access for young children and the elderly. Because of these advantages, CRBs are a popular option for community and school gardens.

Typically, CRBs are filled with substrates available from garden centers in bags, such as potting soil, compost, manure, and sometimes, native soil or some combination of

these materials. The most important physical properties of any substrate, native or artificial, are good aeration and drainage, and optimum water retention capacity (Cabrera 2001). The capacity of a substrate to store water and air, as well its ability to provide them to the plant (via its hydraulic conductivity and rate of gas exchange) are determined by its total porosity (TP) and porosity characteristics (Raviv, Wallach et al. 2002).

Artificial soil substrates have been widely used in greenhouse and nursery production for many years, so it is no surprise that essentially all of the current research on soil substrates focuses on suitability for this industry. The production of greenhouse crops involves a number of cultural inputs. Among these, perhaps the most important is the type of growing substrate used and due to the relatively shallow depth and limited volume of a container, growing media must be amended to provide the appropriate physical and chemical properties necessary for plant growth (Sevgican 1997). Criteria for selecting a substrate for CRBs are similar, along with considerations of local availability and cost, especially for organizations with a limited budget.

Potential Substrates for a CRB

Pine Bark (PB)

In Georgia, pine bark (PB) is a reliable substrate in the nursery industry, suggesting possible use in a CRB. Pine bark is a by-product of the wood and paper industries in the state. Pine bark is commonly available in bags at gardens centers. Bark, when used as a container media, has been shown to increase cation exchange capacity (CEC) and water holding capacity, but decreases air porosity (Lemaire, Rivière et al. 1997). There have been some instances of plant toxicity from phenolic compounds in

fresh bark that have not been composted (Politycka, Wójcik-Wojtkowiak et al. 1985) Aging and composting is an efficient way to reduce phytotoxicity by eradicating bark toxins.

Wood Fiber Substrates (WFS)

Wood chips, or wood fiber substrates (WFS), which come from ground up trees or tree trimmings, are a renewable resource, and may serve as a good alternative to peat and/or PB. They are currently used in agriculture and landscape applications for mulch, weed control, and to add organic matter over time. Wood fiber substrates (WFS) come from trees growing locally, are reasonably priced and widely available. Wood fiber substrates (WFS) have shown promise as a substrate for greenhouse and nursery crops (Wright and Browder 2005). Fresh WFS is rarely used as a stand-alone growth substrate, and usually forms a constituent in mixtures (normally less than 50%) (Raviv, Wallach et al. 2002).

Nitrogen immobilization is a problem with substrates containing fresh WFS (Handreck 1992). Under typical nursery growing conditions, moisture, temperature and nutrient content within a growth medium are favorable to the biological decomposition of wood wastes. Unlike bark, WFS's originate from the inner part of the tree and are less resistant to decay. Their lignin content is lower and carbon: nitrogen (C:N) ratio is higher than bark. A C:N ratio of 24:1 prevents microorganisms from immobilizing soil nitrogen and ensures a gradual and stable release of nutrients (Dorais 2007). In fact, in one study, extremely high C/N ratios were found (Goh and Haynes 1977). This is important to

consider as we look at the sustainability of these substrates by measuring C-mineralization and soil microbial biomass carbon.

Peat

Peat is of value for both the greenhouse industry and gardening. Its use dates to the 18th century (Perfect 1759). Peat has a higher water holding content when compared with other container substrates (Sambo, Sannazzaro et al. 2008). It is a very common base for many commercially available potting mixes (PM), and yet questions have been raised about the sustainability and environmental impact of mining peat. (Rutherford and Juma 1992). In addition, because peat bogs are important in atmospheric CO_2 assimilation, there is a need to look for more renewable replacements (Raviv, Wallach et al. 2002).

Compost

Compost (CP), is a general term, describing organic matter that has undergone long, thermophilic, aerobic decomposition (Raviv, Wallach et al. 2002). Compost can provide many desirable qualities, such as organic matter (OM), nutrients, and offers potential for disease suppression and other physical, chemical, and biological properties (Raviv 2005) The nutritional, organic, and chemical makeup of CP varies depending on the raw materials inputs, typically based on readily available local materials. Compost is an increasingly popular component in container media. This is partly because CP is a cheaper alternative to peat (Compton 1980). Many growers now substitute part or all of the peat in their substrate mix with CP, because mature CP has been shown to suppress

soil borne pathogens and acts, to a large extent, as a slow-release fertilizer (Williams and Nelson 1992). However, non-mature CP can immobilize a significant amount of N.

Native Soil (NS)

Native soil (NS) is made up of four components: minerals, air, water, and OM. In typical soils, minerals represent approximately 45%, water and air 25% each, and OM from 2% to 5% of the total volume (Sullivan 1999). Although field soils are generally unsatisfactory for container plant production (SAHIN, ORS et al. 2006), there can a benefit to using them in a CRB, which do not have the same limitations imposed on nursery containers such as weight and portability. Native soil is economical and readily available for use in a CRB. Much of the native soil in Athens, GA (33°53'55.3"N 83°22'05.9"W) is sandy clay loam (Agriculture 2013), a soil type commonly found throughout the southeast. Generally, as clay and OM increase, CEC and soil nutrients increase. Clay soils also fix a certain amount of phosphorus (Broderson 2000) which is very insoluble to plants and generally is in the form of inorganic phosphate compounds that resist mineralization by mycorrhizal fungi in the soil (Busman, 1997) However, it makes sense to consider NS as a potential substrate in a CRB in spite of the popular belief among gardeners that clay soils are bad.

Evaluation of CRB Substrates

Yield and Chlorophyll Content

Yield was the primary means for treatment comparison. In addition to yield chlorophyll content was compared. For this experiment a SPAD 502 Plus chlorophyll

meter was used as well as a CCM (chlorophyll content meter). The SPAD 502 Plus broke after crop one. These meters provide a 'chlorophyll index' value expressed as relative chlorophyll content and can indicate overall plant health and condition. This is relevant because low chlorophyll concentration can directly limit photosynthetic potential and hence primary production (Curran, Dungan et al. 1990, Filella, Serrano et al. 1995). Chlorophyll content in leaves is an indirect measure of nutrient status and pigmentation and can be related to stress physiology as concentrations of carotenoids increase and chlorophylls generally decrease under stress and during senescence (Peñuelas and Filella 1998). These relative concentrations of pigments are known to change with abiotic factors (light, radiation, water;(Larcher 2003) In this case, different substrates could inherently affect the concentrations of pigments which can show up in a chlorophyll content reading. Quantifying these proportions can provide important information about relationships between plants and their environment (Richardson, Duigan et al. 2002).

C-mineralized and microbial biomass and impact

The Kyoto Protocol on climate change in 1992 demands fundamental understanding of carbon (C) stabilization in soils because the amount of organic matter stored in soils represents one of the largest reservoirs of organic C on a global scale (Schlesinger 1995). Consequently, any change in the size and turnover rate of soil C pools may potentially alter the atmospheric CO_2 concentration and the global climate (Lützow, Kögel-Knabner et al. 2006). Carbon dioxide (CO_2) is produced in soil and ultimately emitted into the atmosphere when microorganisms decompose organic substrates to obtain energy for their growth and functioning (Wang, Dalal et al. 2003).

Carbon is stored in soil OM; however, most agricultural soils have been depleted of C. A number of physical, management and climatic variables affect the capacity of soil to store C and its loss as CO_2. It is well known that fine-textured soils generally have higher organic C and N contents than their coarse-textured counterparts (Jenny 1941). To make a sound substrate recommendation one must look at potential environmental impacts in addition to vegetable yields in CRBs. Carbon dioxide evolution is a good indicator of carbon cycling and potential contributions to greenhouse gases. It is also well correlated with soil microbial biomass (Franzluebbers, Haney et al. 1996) and an index of and nutrient cycling. Consequently, CO_2 evolution was chosen as an indicator of potential environmental impacts of the chosen substrates.

Great efforts have also been made to quantify the readily decomposable soil organic matter, i.e. the microbial substrates, using chemical, physical or incubation methods in order to predict the rate of soil C mineralization (Davidson, Galloway et al. 1987) and (Sikora and McCoy 1990). Microbial biomass affects C cycling as well as most other nutrient cycles. Microorganisms are generally considered as the driving force behind the decomposition process and the cycling of C, N, P, and S and thus it is its magnitude that will affect the nutrient flux (Smith and Paul 1990). For example, the processes of the nitrogen cycle, carried out by microbes, transforms nitrogen from one form to another. It is 'fixed' into a plant available form (NH_3). Knowledge of the roles of microbial biomass and substrate supply and their interaction with soil matrix will help in developing management strategies to improve soil fertility and to increase C sequestration in soil (Wang, Dalal et al. 2003). Thus, in addition to a CO_2 measurement, we need a microbial biomass measurement to make sure that we choose a suitable soil

that has a low C footprint but adequate microbial activity to maintain yields over time by the breakdown of organic matter and making nutrients plant available.

Research Objectives

Though yield and carbon mineralization are common measures employed for evaluating agricultural practices, it is rare the same level scrutiny is applied to gardening practices, and yet gardening is practiced by far more people than farming. Though a square meter of production space is far less than farm scale, information gleamed from small plot work could be a starting point for making more environmentally educated choices in regard to agriculture and lifestyle practices and their effect on C release. There is strong interest in carbon footprint calculations, but academic definitions of 'carbon footprint' vary. The scientific literature is surprisingly void of clarifications, despite the fact that countless studies in energy and ecological economics measuring a 'carbon footprint' have been published.

The lack of research on suitable soil mixes for used in raised beds has left room for a lot of misinformation and misunderstanding regarding the reasons for selecting substrates and the potential benefits or problems from using each one. The purpose of this study is to evaluate locally available substrates suitable for use in CRB culture. Since soils can be a source or sink for carbon it is logical to evaluate potential substrates with equal weight to yield for c-mineralization.

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CHAPTER 2

EVALUATION OF SUBSTRATES IN CONSTRUCTED, RAISED-BEDS FOR VEGETABLE CULTURE

[1] Cudnik, J.L., D.C. Berle, G.E. Boyhan, and J.W. Gaskin. To be submitted to *HortTechlology*.

Abstract

With the increased interest in urban food production and community gardens, many gardeners are constructing raised beds. Constructed raised beds offer potential for better drainage and easier access to the growing area. Constructed raised beds also have the ability to increase yield. Substrates for constructed raised beds are often an afterthought, with little scientific basis for selecting materials or consideration for the broader environmental effects of materials. This study evaluates eight substrates and two crops, kale and basil, for yield and chlorophyll content. The same eight substrates were also evaluated for sustainability factors such as carbon-mineralization (C-min) over time and soil microbial biomass carbon (SMBC). Based on yield alone, the 100% compost substrate resulted in the highest yield across all three crop trials. The native soil substrate had the lowest C-min and SMBC rate. Results varied with season and crop, but yield and C-min indicate a substrate composed of compost/native soil is the best overall.

Introduction

One critical consideration for community garden programs and urban farming is soil or substrate for growing fruits and vegetables. The decision to work with existing soil or import substrate materials is one that is often made without knowledge of horticulture practices or understanding of broader environmental implications. Plant growth and yield are practical measures of success of substrate selected, but equally important are considerations of CO_2 footprint over time as the substrate respires and oxidizes. Oxidation of substrate may, at first, seem beyond the realm of small gardens, however, it

possess the very real problem of substrate settling and requires re-filling of constructed raised beds, costing both time and money.

Materials and Methods

All growth experiments were conducted at UGArden Learning and Demonstration Farm in Athens, GA (lat. 33°53'55.3"N, long. 83°22'05.9"W). The CRBs were placed on an existing concrete pad and arranged in a complete randomized design. The respiration incubation experiment was conducted at J. Phil Campbell Sr. Research and Education Center in Watkinsville, GA (lat. 33°52'24.1"N 83°25'32.0"W).

Substrate Evaluation

Eight substrates were evaluated to determine the most suitable for use in CRB vegetable culture. Substrates were selected based on local availability and historical use in the nursery/greenhouse industry. The substrates chosen for this study are locally available, inexpensive and/or commonly used in the nursery or greenhouse industry. The substrates evaluated were potting mix (PM), native soil (NS), pine bark (PB), wood fiber substrates (WFS), compost (CP) and 50%/50% mixes of the aforementioned materials (Table 1). There were three replications of each treatment for a total of 24 CRBs, built of untreated 61cm x 25cm pine boards measuring 91cm wide x 122cm long. Landscape fabric was stapled to the bottom to prevent the loss of substrates from the CRBs. The CRBs were arranged in a complete randomized design (Fig. 1.)

All CRB boxes were filled uniformly, lightly tamped down, and filled to the top. Each CRB required 0.25 cubic meters of substrate. Soil samples were taken prior to

fertilization and pH adjusted according to the results by adding the recommended amount of lime 1.13 kg per treatment area. Lime was added only to the PB treatment.

Symphony (5-4-3, + 0.09 Ca) granular fertilizer was incorporated at a rate of 0.32kg per treatment to provide nitrogen at the rate of 145kg/hectare[1].

Kale (*Brassica oleracea* 'Toscano') was the first crop grown and planted on 30.5 cm x 30.5 cm spacing in spring on March 30, 2013. The second crop was sweet mammoth basil (*Ocimum basilicum)* planted on 30.5 cm x 30.5 cm spacing in summer on June 14, 2013. The third crop was kale (*Brassica oleracea* 'Toscano') planted on 30.5 cm x 30.5 cm spacing in fall on September 13, 2013. All crops were irrigated uniformly with overhead mini-sprinklers on an as-needed basis. Weeds were removed by hand and insects were either removed by hand or sprayed with pesticides approved by the USDA National Organic Program guidelines.

Kale was harvested every two weeks after an initial four week growth period over a 66 day period. On the day of harvest SPAD (chlorophyll content) meter readings were taken of all twenty-four beds. (The SPAD meter died after the first crop season and was replaced with a Chlorophyll Content Meter (CCM) which gives the same between treatment index.)

Prior to planting the second crop, CRBs were cleaned of plant debris and measured for substrate drop from top of bed. Symphony fertilizer (5-4-3 + 0.09 Ca) was broadcast and incorporated at the rate of 0.32 kg per treatment which is 145 kg/hectare. This is at the lower end of the recommended rates which provides adequate plant growth yet allows the substrate characteristics to evolve. Basil was grown for the second crop

[1] Symphony is composted poultry manure and comes from a USDA organic egg laying operation.

trial during the summer months. At maturity, basil was harvested every two weeks after an initial four week growth period. At each harvest, WET and CCM readings were taken.

After the final basil harvest the CRBs were cleaned of any plant debris and measured to determine the amount of settling and/or respiration. The CRBs were re-tilled, Symphony fertilizer (5-4-3 + 0.09 Ca) was incorporated at of 0.32 kg per treatment and planted with six kale plants for the fall season. An early frost ended the kale harvest earlier than anticipated on November 13, 2013.

2.2 Laboratory respiration following rewetting of dried substrates

A companion laboratory respiration experiment evaluated the C-mineralized and microbial biomass of the substrates, mimicking the crop cycle of 66 days of trial one kale (*Brassica oleracea*, 'Toscano'). Thirty grams of each substrate were air-dried and sieved through a 4.75 mm sieve and then moistened to 55% of water-filled pore space (WFP) in a Pyrex beaker (Fig. 10). This was accomplished by determining the volume occupied by soil in the beaker by packing and leveling the soil and determining the amount of water needed with these equations: mL H_2O = 0.55 x porosity x volume occupied by soil; and porosity = 1-(bulk density/2.65) bulk density = (g of soil/mL of soil). The beaker, together with a scintillation vial with deionized (DI) water and a scintillation vial with 10 mL of NaOH, was placed in a 1 L wide-mouth mason jar and capped. There were eight substrates used and four repetitions of each for a total of thirty-two jars arranged in a randomized complete block design.

Fresh NaOH vials were changed out at previously determined intervals of 3 days, 7 days, 14 days, another 14 days and then 28 days to total 66 days, mimicking the kale

crop cycle. Franzluebbers et al. (1996) showed the initial flush of CO_2 in the first 3 days of rewetted soil is well correlated with soil microbial biomass; consequently our first interval was designed to capture this initial flush. Carbon dioxide mineralization typically increases initially then tapers off with time. The next 7- day interval was expected to capture the CO_2 peak. After the first 10 days, the CO_2 slowly declines and therefore two, 2 week intervals and a final 4 week interval were chosen with the expectation that soil microbial biomass carbon activity would be low enough not to exceed absorption abilities of the NaOH vial .

At the end of each interval, the jars were taken out of the incubator, and the traps rapidly removed and sealed (to avoid CO_2 contamination). Each NaOH vial was removed from the jar, immediately capped for later titration, and a fresh NaOH scintillation vial was placed back in the jar to capture CO_2 for another interval. The jars were placed in an incubator at 25 °C for the duration of the experiment.

Carbon dioxide evolution was measured by titration. Barium chloride ($BaCl_2$) was added to the NaOH to form a barium carbonate ($BaCO_3$) precipitate containing the absorbed CO_2 (Fig. 11). Three drops of phenolphthalein indicator were added to the vials that were titrated with hydrochloric acid (HCl) until no color was observed. The amount of acid used to force the color change represented unconsumed NaOH. The following equations were used to calculate the quantity of C-mineralized (CMIN) CMIN (mg * kg^{-1} AD soil) = (mL BLANK – mL SAMPLE) x *N* HCl x 6 x 1000/ (g AD soil); where AD represent air dried soil. To calculate the concentration of soil microbial biomass carbon (SMBC) from the titration use SMBC (mg * kg^{-1} AD soil) = (mL BLANK – mL SAMPLE) x *N* HCl x 6 x 1000/((g AD soil)/k_c) where, 6 = equivalent weight of C and k_c

= 0.41 (efficiency factor). (Jenkinson and Powlson 1976, Voroney and Paul 1984, Franzluebbers, Haney et al. 1996).

Statistical Analysis

For the CRB study, yield was analyzed using one-way ANOVA. Mean separation was determined using Fisher's LSD method. Carbon-mineralization was analyzed using a general linear model. Soil microbial biomass carbon was analyzed using Fisher's test. Chlorophyll content data was analyzed using repeated measures ANOVA to identify significant interactions.

Results

Kale yield differed significantly as a function of substrate. In the first kale crop trial, the highest yielders were PM, CP, CP/PM, and CP/NS (Table 3). Basil yield also was significantly different as a function of substrate. In the second crop trial, basil yields were highest in CP, followed by CP/NS, CP/PM, and CP/PB (Table 4). Differences were smaller for the third trial of kale, with highest yield in CP, CP/PM, CP/PB, and NS (Table 5). There was disease in one of the beds with CP/NS reducing the total yield in this treatment.

SPAD meter chlorophyll readings followed a similar trend in crop one kale with CP/ NS having the highest reading indicating the highest chlorophyll content (Fig. 2). Crop one kale chlorophyll content differed significantly between treatments as a function of substrate. In crop two basil NS had the highest chlorophyll reading followed closely by CP/NS (Fig. 3). Crop two basil chlorophyll content differed significantly between

substrates. In crop three the substrates chlorophyll content differed slightly between substrates as a function of treatment (Fig. 4). There were only two CCM measurements taken because an early frost killed the crop on Nov. 13, 2013. It was expected that over time the CCM measurements would have shown greater significant had there been a longer crop time.

C-mineralization results showed that NS had the lowest rate followed by the next least substrate, CP/NS (Table 7). Total C-min differed significantly as a function of substrate. All substrates were significantly different in their SMBC. The highest was CP/WC with a mean of 222.2 mg per kg $^{-1}$ AD soil and the lowest was NS with a mean of 16 mg per kg $^{-1}$ AD soil (Table 8).

Conclusion

Compost was the top yielding substrate in all three cropping trials, while NS had the lowest C mineralization. When selected for optimal yield with lowest respiration rate, the compost/native soil is best compromise of the two measures (Fig. 6).

Table 1. The eight substrates, their constituents and source used in the evaluation for constructed raised beds.

Substrate	Code	Constituents	Source
Potting Mix	PM	Traditional potting mix for USDA certified organic w/o fertilizer starter	Jolly Gardener
Compost	CP	Vegetation waste composted in large-scale, active, aerobic program	UGA Physical Plant
Native Soil	NS	Sandy clay loam scrapped from nearby construction site	UGArden Farm
Pine Bark	PB	Standard nursery-grade, aged pine bark	Jolly Gardener
Compost/Potting Mix	PM+CP	50/50 Mix	Jolly Gardener + UGA Physical Plant
Compost/Wood Chips	WFS+CP	50/50 Mix	New Urban Forestry+ UGA Physical Plant
Compost/Native Soil	NS+CP	50/50 Mix	UGArden Farm+ UGA Physical Plant
Compost/Pine Bark	PB+CP	50/50 Mix	Jolly Gardener + UGA Physical Plant

Table 2. The pH, soluble salt, and available nutrients (Mehlich I) in the substrate used in the evaluation

		mmhos/cm	mg/kg							
Sample	**pH**	**SS**	**Ca**	**K**	**Mg**	**Mn**	**NH_4-N**	**NO_3-N**	**P**	**Zn**
Potting Mix	6.4	0.88	19.31	89.4	23.36	0.25	31.93	6.63	9.42	0.95
Compost	7.5	3.19	48.90	562.0	16.46	0.16	5.81	80.71	9.38	0.67
Native Soil	6.4	0.29	10.39	30.3	4.60	0.24	1.89	16.92	0.67	0.41
Pine Bark	5.1	0.12	<0.1	21.3	0.22	<0.05	0.34	0.16	8.13	0.39
Compost /Potting Mix	6.9	1.66	33.65	335.3	16.37	0.20	14.64	36.01	12.54	1.29
Compost/Woodchips	6.7	2.77	77.37	572.5	30.81	1.44	7.91	0.62	26.58	1.17
Compost/Native Soil	6.9	0.62	18.24	109.5	7.02	<0.05	1.90	29.92	4.15	0.58
Compost/Pine Bark	6.1	0.82	27.57	180.1	8.54	0.15	2.85	30.84	34.25	0.64

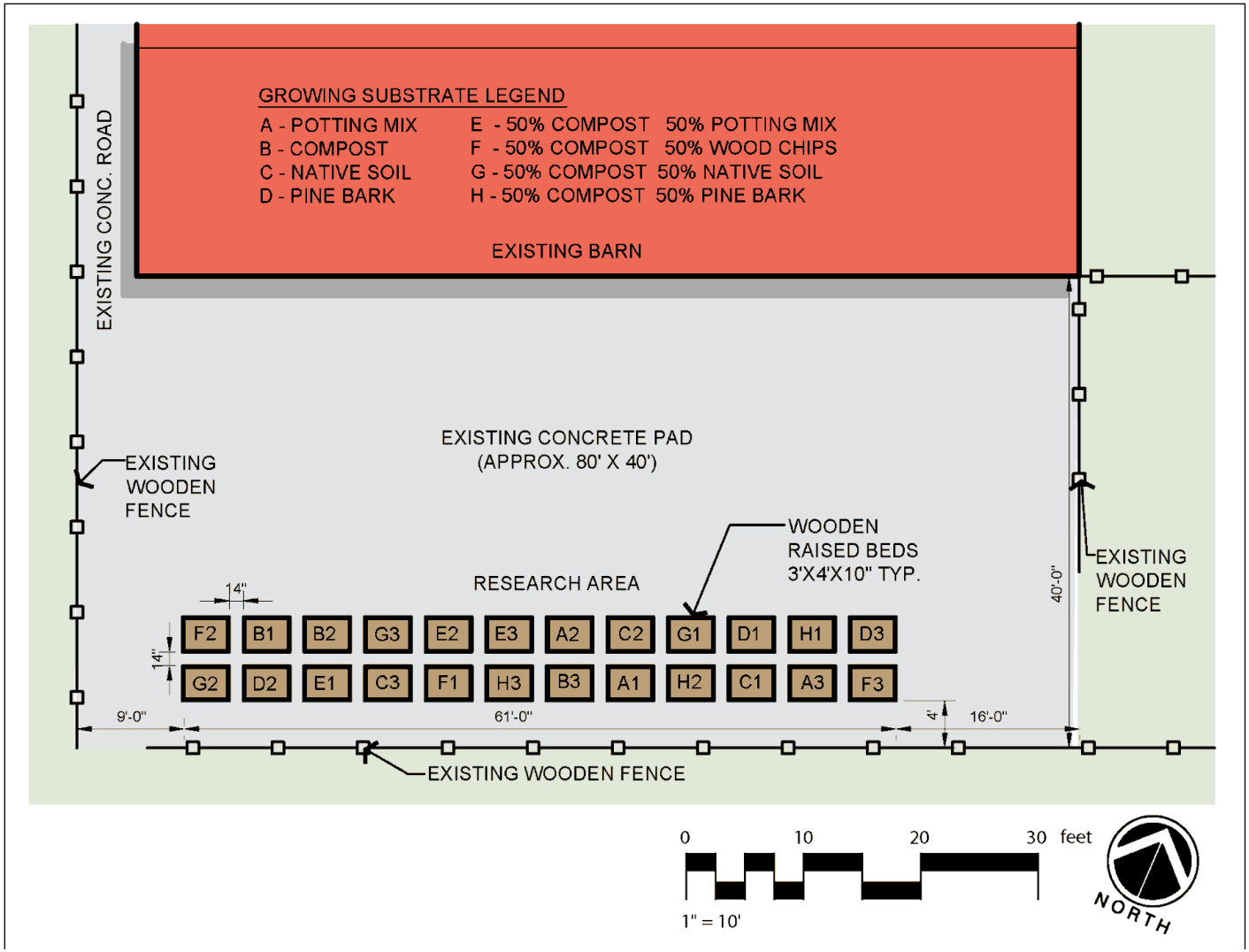


Figure 1. Research area used for the substrate evaluation of constructed raised beds with 24 beds in a complete randomized design.

Table 3. Mean kale yields and standard error from crop one of the substrate evaluations in constructed raised beds. Means that do not share a letter are significantly different p=0.05

Treatment	Mean	SE Mean	Grouping			
Potting Mix	3.3	0.13	a			
Compost	2.9	0.19	a			
Native Soil	1.9	0.09		b		
Pine Bark Fines	0.3	0.02			c	
Compost/Potting Mix	3.0	0.21	a			
Compost/Woodchips	0.2	0.03				d
Compost/Native Soil	2.8	0.16	a			
Compost/Pine Bark Fines	1.9	0.15		b		

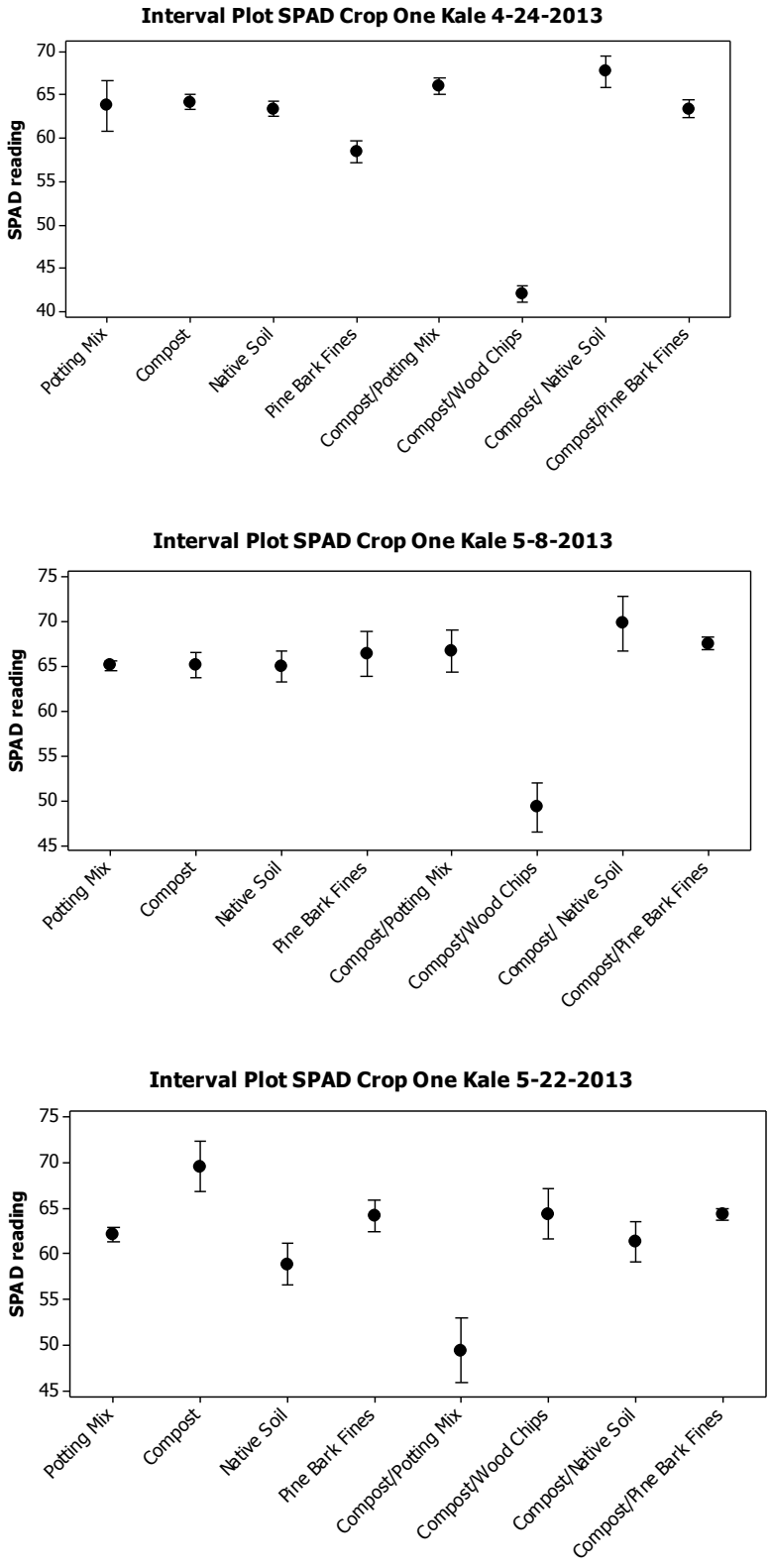
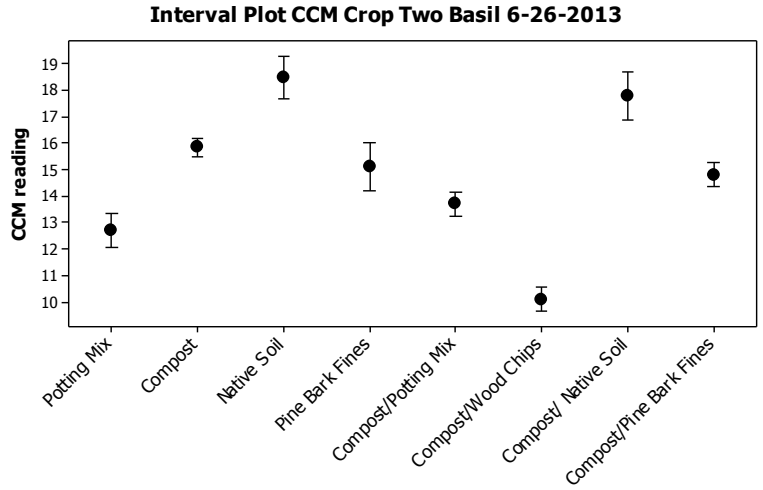
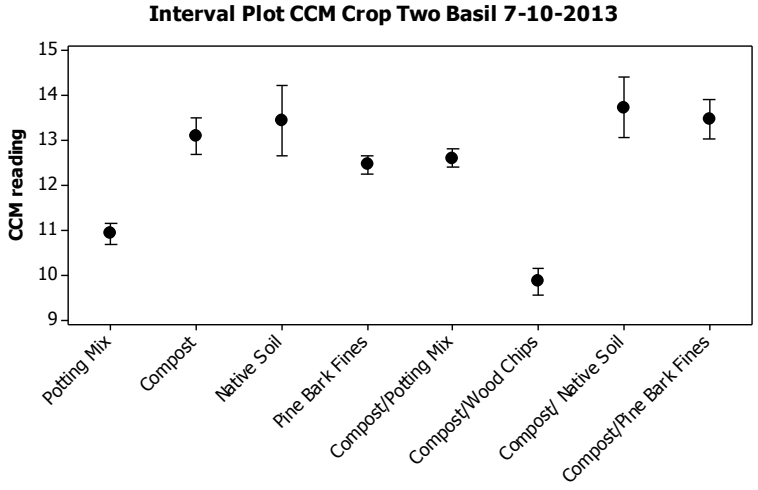


Figure 2. Mean chlorophyll content index with standard error bars one standard error from the mean by date.

Table 4. Crop two mean basil yields and standard error from crop two of the substrate evaluations in constructed raised beds. Means that do not share a letter are significantly different p=0.05

Treatment	Mean kg	SE	Grouping				
Potting Mix	1.5	0.09				d	
Compost	3.7	0.16	a				
Native Soil	2.1	0.16			c		
Pine Bark Fines	1.0	0.07					e
Compost/Potting Mix	3.1	0.05		b			
Compost/Woodchips	1.6	0.00				d	
Compost/Native Soil	3.2	0.12		b			
Compost/Pine Bark Fines	2.8	0.11		b			





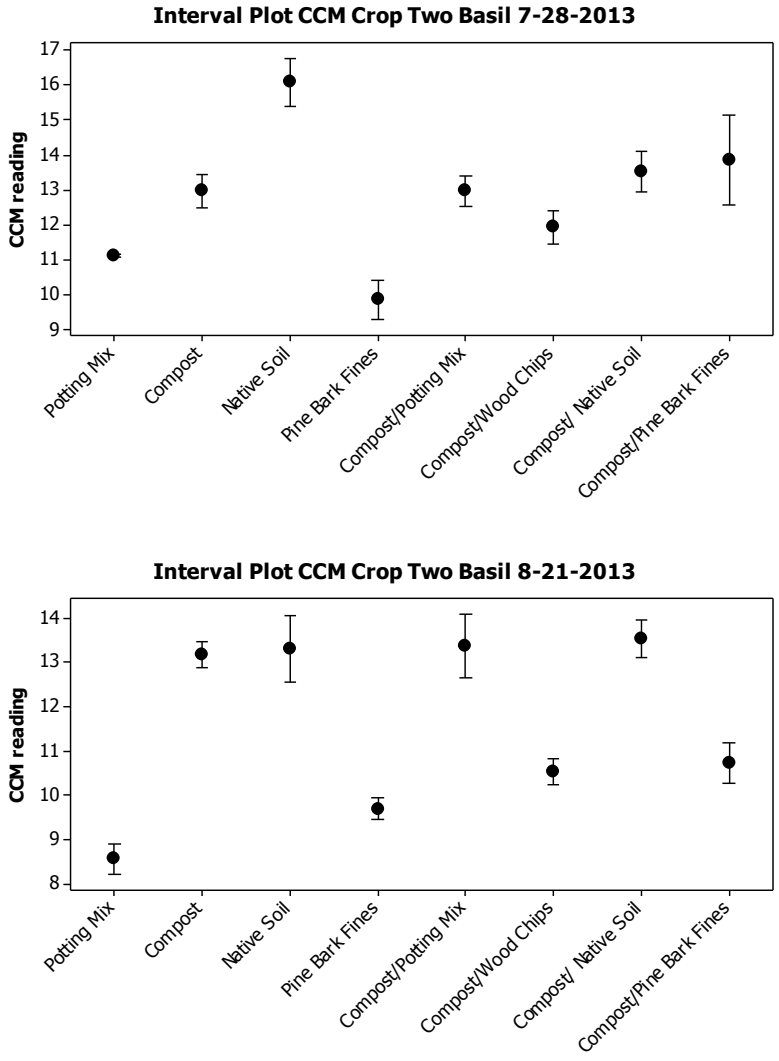


Figure 3. Mean chlorophyll content index with standard error bars one standard error from the mean by date.

Table 5. Crop three mean kale yields and standard error from crop one of the substrate evaluations in constructed raised beds. Means that do not share a letter are significantly different p=0.05

Treatment	Mean kg	SE	Grouping				
Potting Mix	0.8	0.05			c	d	
Compost	2.3	0.04	a				
Native Soil	1.5	0.06	a	b	c		
Pine Bark Fines	0.4	0.07					e
Compost/Potting Mix	1.8	0.08	a	b			
Compost/Woodchips	0.7	0.06				d	
Compost/Native Soil	1.4	0.57		b	c	d	
Compost/Pine Bark Fines	1.5	0.07	a	b	c		

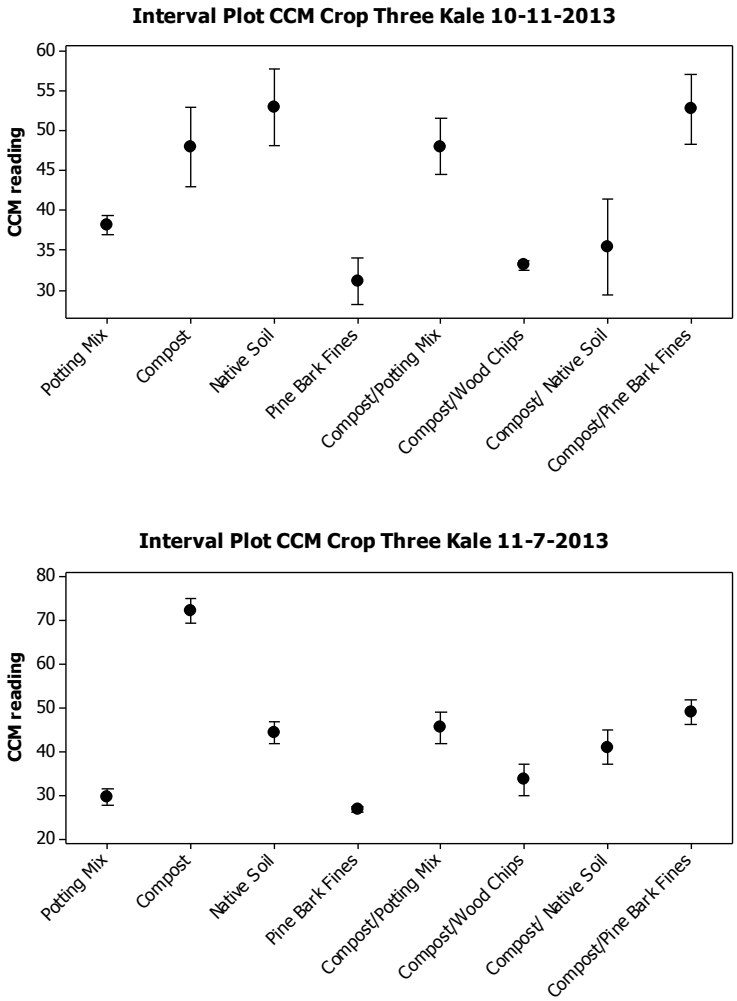


Figure 4. Mean chlorophyll content index with standard error bars one standard error from the mean.

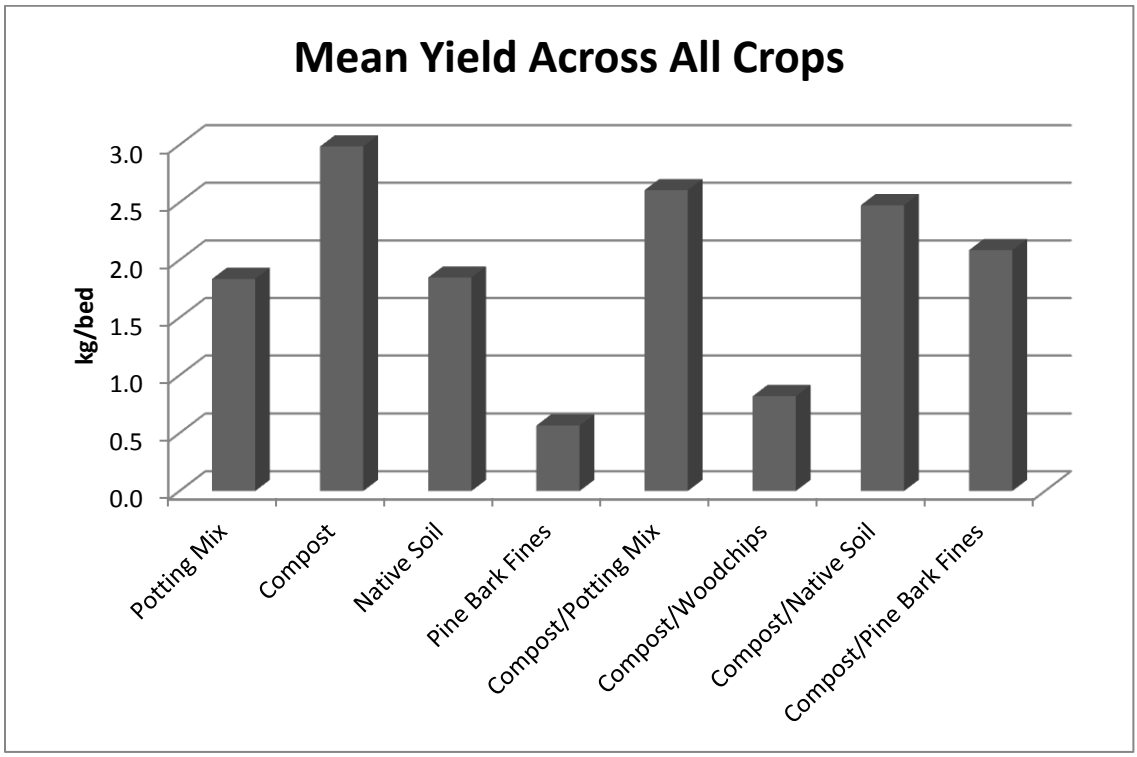


Figure 5. Mean cumulative yield across all three crop trials.

Table 6. C mineralized over time per day. Sum is cumulative.

Treatment	Days					Sum
	3	10	24	38	66	mg CO_2/g soil
Potting Mix	442	187	104	104	59	896
Compost	318	155	119	110	70	772
Native Soil	39	11	9	8	9	77
Pine Bark	179	89	79	77	57	481
Compost/Potting Mix	388	162	111	112	70	843
Compost/Wood Chips	542	248	121	110	70	1090
Compost/ Native Soil	102	41	32	26	3	203
Compost/Pine Bark	261	118	86	81	62	608

Table 7. Mean cumulative C mineralized and standard error. Means that do not share a letter are significantly different p=0.05

Treatment	Mean	SE	Grouping				
	mg C/kg soil						
Potting Mix	7326	68.90		b			
Compost	7202	79.70		b			
Native Soil	701	30.00					f
Pine Bark Fines	4931	68.90				d	
Compost/Potting Mix	7374	33.60		b			
Compost/Wood Chips	8539	37.10	a				
Compost/ Native Soil	1487	488.00				e	
Compost/Pine Bark Fines	5679	53.40			c		

Table 8. Mean soil microbial biomass carbon and standard error. Means that do not share a letter are significantly different p=0.05

Treatment	Mean	SE	Grouping						
	mg C/kg soil								
Potting Mix	181	0.06		b					
Compost	130	0.01				d			
Native Soil	16	0.01							h
Pine Bark Fines	73	0.00					f		
Compost/Potting Mix	159	0.03			c				
Compost/Wood Chips	222	0.01	a						
Compost/ Native Soil	42	0.06						g	
Compost/Pine Bark Fines	107	0.03				e			

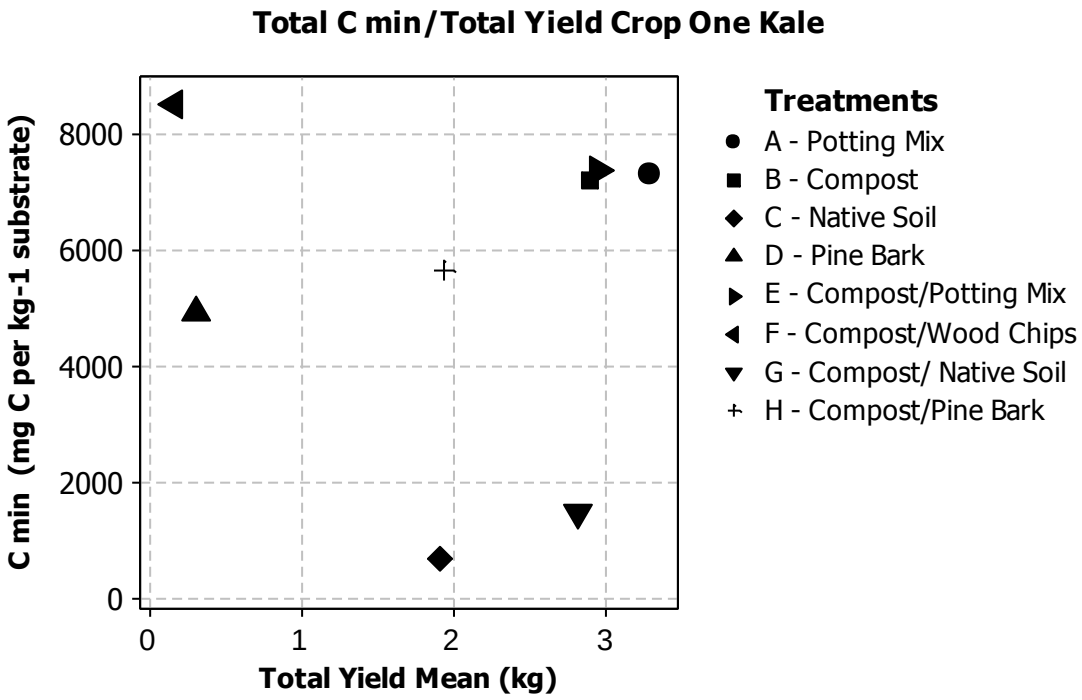


Figure 6: Integration of c-min and yield to see ideal substrate in lower right quadrant where high yield and low c-min meet at compost/native soil.

Figure 7. Constructed raised bed design with substrates and kale crop

Figure 8. Planting kale transplants at 30.5 x 30.5 cm spacing.

Figure 9. Re-tilling beds for next crop.

Figure 10. Incubation experiment, respiration of re-wetted substrates.

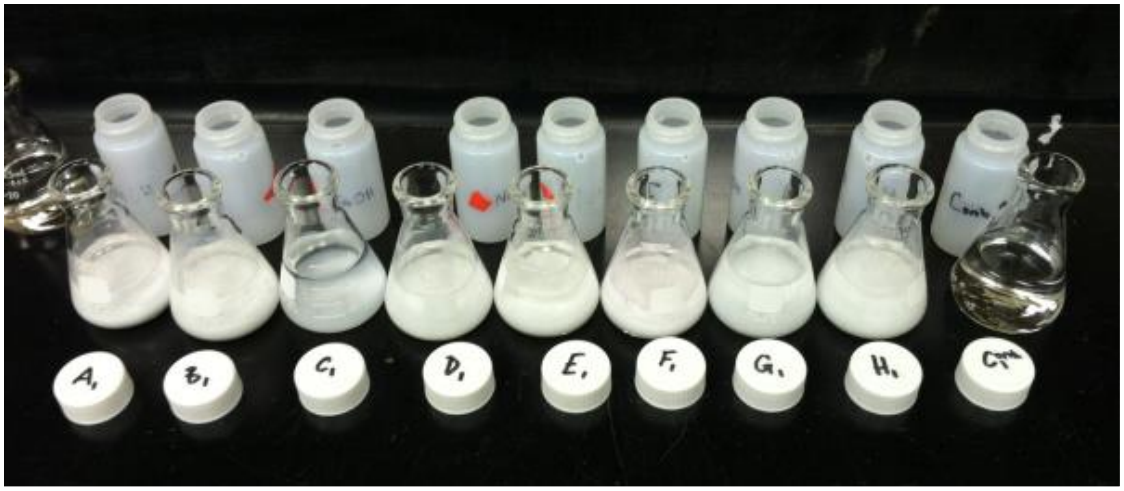


Figure 11. Barium chloride ($BaCl_2$) was added to the sodium hydroxide (NaOH) to form barium carbonate ($BaCO_3$) precipitate, the absorbed CO_2.

Figure 12. Using the CCM to take a chlorophyll measurement from crop three kale.

CHAPTER 3

ADDITIONAL DATA AND ANALYSIS

During the course of this research there were other important data taken to support the outcome and eventual recommendation of the ideal substrate but were secondary to yield and C-mineralization. Other measurements included: 1.) settling of the substrates; 2.) electrical conductivity (EC) and; 3.) root weight with photos to show visual differences.

Substrate Settling

After each crop trial the substrates were measured for the substrate settling by measuring from the top of the leveled soil at the top of the bed at the start of this experiment. The substrates were screed level at the beginning of this experiment. After the third crop trial the measurement was measured from the top of the bed to the inside level of substrate. The beds all started out at 25.4 cm in depth. After running Fisher's protected LSD on the data the substrate that settled the least after three crop trials was pine bark which remained at a depth of 22.8 cm and the substrate that dropped the most was compost/wood chips which ended at a depth of 19.6 cm (Fig 13). Pine bark is the natural protective outer layer of a tree and thus resists breakdown while the wood chips come from the inside of the tree and do not resist breakdown like pine bark. This is consistent with our C-mineralization results as we showed that the compost/wood chip

mix had the highest C-min (Table 7). The practical consideration of substrate settling must be taken into consideration because it will add time and cost to re-fill beds with high organic matter. It has also been shown that the net loss of carbon can be diminished by the addition of the organic materials (Bingeman, 1953).

EC Readings

On the day of the last harvest of each crop trial a WET meter (from Delta-T Devices) was used to take readings of electrical conductivity (EC, in $mS.cm^{-1}$). The three pronged instrument was inserted at the proper depth into the center of each bed to capture the reading. At the end of crop one kale compost and compost/potting mix had the highest and pine bark fines had the lowest EC reading (Table 10). EC was then taken at the end of crop two basil and compost/native soil had the highest while interestingly potting mix joined pine bark fines in having the lowest at the end of the cropping season (Table 11). Crop three kale showed that compost and compost/native soil retained the highest EC and potting mix and pine bark fines had the lowest EC reading after the third cropping season (Table 12).

Root Weight and Photographs

Other plant physiology measurements could be taken to fully support a holistic substrate choice. Roots from crop one of kale were carefully dug up, washed and photographed to capture any differences (Figure 14). Clearly there are differences in root formation, based on treatments; however, since yield is of primary concern, root development was not measured but weights were taken. Crop one kale had potting mix

with the most weight in roots and compost/wood chips had the least weight in roots (Table 13). This trend in roots is the same as the yield mean results with potting mix having the highest yields and compost/wood chips having the lowest yield (Table 3). When the roots were photographed for crop two basil there was less evidence of differences and after running the statistics on the root weights we could see that there are in fact no statistical differences between treatments as far as root weight (Fig. 15 and Table 14). This could be because basil is not an ideal indicator crop because it so adaptable to different environments. There were no photographs or root weights taken for crop three kale.

There may be something to the way the roots form that would be worth exploring in future studies, particularly with crops with a longer growth cycle, like tomatoes. It would be expected that those plants with well-developed root systems would fare better in drought conditions. It also is crop dependent which we saw in the basil's ability to adapt and grow equal root masses despite the different substrates.

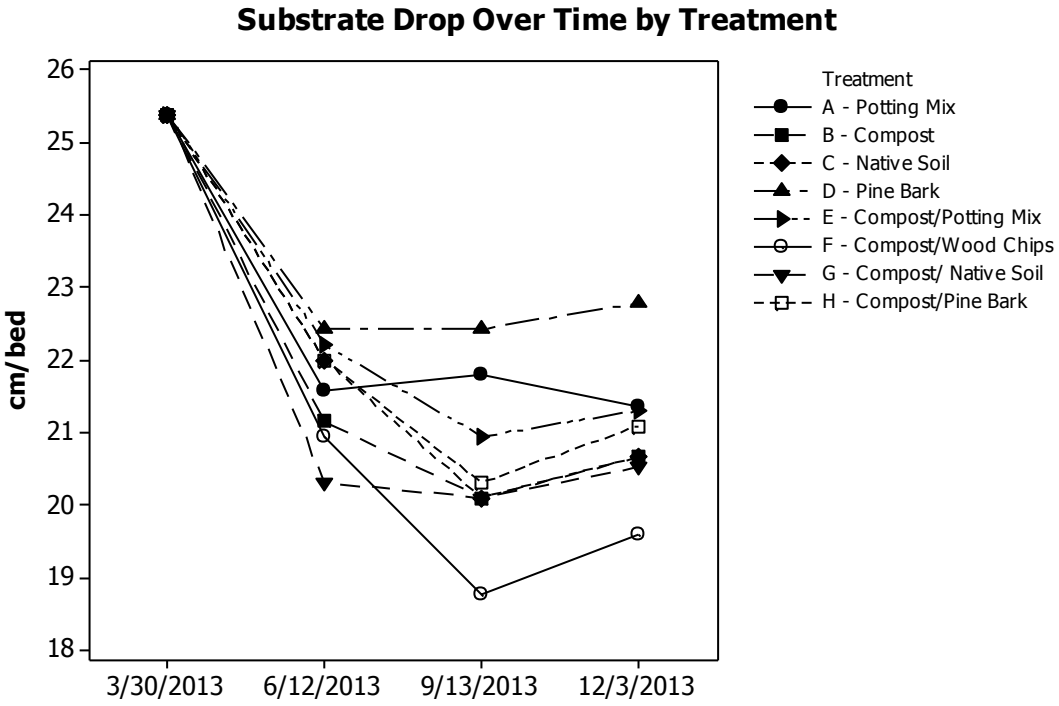


Figure 13. Graph of substrate drop by treatment starting from 25.4 cm representative of respiration of organic matter in the substrate.

Table 9. Substrate drop in cm at the end of third crop trial. Means that do not share a letter are significantly different p=0.05

Treatment	Mean cm	SE	Grouping		
Potting Mix	21.38	0.60	a	b	
Compost	20.67	0.20		b	c
Native Soil	20.67	0.55		b	c
Pine Bark Fines	22.79	0.18	a		
Compost/Potting Mix	21.31	0.09	a	b	
Compost/Wood Chips	19.61	0.60			c
Compost/ Native Soil	20.53	0.64		b	c
Compost/Pine Bark Fines	21.10	0.87		b	c

Table 10. EC readings of crop one kale trial at end of harvest. Means that do not share a letter are significantly different p=0.05

Treatment	Mean $mS.cm^{-1}$	SE	Grouping					
Potting Mix	0.72	0.00				d		
Compost	1.49	0.07	a					
Native Soil	0.54	0.00					e	
Pine Bark Fines	0.37	0.00						f
Compost/Potting Mix	1.36	0.00	a					
Compost/Wood Chips	1.09	0.08		b				
Compost/ Native Soil	1.14	0.05		b				
Compost/Pine Bark Fines	0.95	0.07			c			

Table 11. EC readings of crop two basil trial at end of harvest. Means that do not share a letter are significantly different p=0.05

Treatment	Mean $mS.cm^{-1}$	SE	Grouping			
Potting Mix	0.39	0.01				d
Compost	0.68	0.03	a	b		
Native Soil	0.62	0.02		b	c	
Pine Bark Fines	0.32	0.02				d
Compost/Potting Mix	0.59	0.05			c	
Compost/Wood Chips	0.58	0.01			c	
Compost/ Native Soil	0.73	0.02	a			
Compost/Pine Bark Fines	0.54	0.03			c	

Table 12. EC readings of crop three kale trial at end of harvest. Means that do not share a letter are significantly different p=0.05

Treatment	Mean $mS.cm^{-1}$	SE	Grouping			
Potting Mix	0.46	0.02				c
Compost	0.84	0.09	a			
Native Soil	0.65	0.02		b		
Pine Bark Fines	0.45	0.04				c
Compost/Potting Mix	0.64	0.05		b		
Compost/Wood Chips	0.57	0.03		b	c	
Compost/ Native Soil	0.80	0.00	a			
Compost/Pine Bark Fines	0.60	0.06		b		

Figure 14. A representative root sample from crop one kale. Each treatment was carefully excavated, washed, and then photographed to capture differences for crop one kale plants. Treatments are A to H, left to right.

Table 13. Root weights in kg of crop one kale trial at end of harvest. Means that do not share a letter are significantly different p=0.05

Treatment	Mean kg	SE	Grouping		
Potting Mix	1.28	0.18	a		
Compost	0.84	0.13		b	
Native Soil	0.51	0.04		b	c
Pine Bark Fines	0.29	0.08			c d
Compost/Potting Mix	0.78	0.03		b	
Compost/Wood Chips	0.07	0.01			d
Compost/ Native Soil	0.73	0.21		b	
Compost/Pine Bark Fines	0.80	0.19		b	

Figure 15. A representative root sample from crop two basil. Each treatment was carefully excavated, washed, and then photographed to capture differences for crop one kale plants. Treatments are A to H, left to right.

Table 14. Root weights in kg of crop two basil trial at end of harvest. Means that do not share a letter are significantly different p=0.05

Treatment	Mean kg	SE	Grouping
Potting Mix	0.33	0.03	a
Compost	0.32	0.02	a
Native Soil	0.27	0.05	a
Pine Bark Fines	0.29	0.02	a
Compost/Potting Mix	0.35	0.04	a
Compost/Wood Chips	0.26	0.03	a
Compost/ Native Soil	0.33	0.03	a
Compost/Pine Bark Fines	0.32	0.01	a

CHAPTER 4

DISCUSSION AND CONCLUSIONS

Consideration of soil substrates for constructed raised beds (CRB) leads to different conclusions each based on evaluation factors. Plant growth and yield are practical measures of success of substrate selected, but equally important are considerations of CO_2 footprint over time as the substrate respires and oxidizes. Oxidation of substrate may, at first, seem beyond the realm of small gardens, however, it possess the very real problem of substrate settling and requires re-filling of constructed raised beds, costing both time and money.

Peat based potting mixes (PM) are a common choice because of availability at garden centers. Though the PM had a high yield in the first crop trial of this study, over the last two cropping trials, yield decreased to second from last in the basil crop trial, just above pine bark fines (PB) (Table 4) and in the third crop trial with kale the yield was third to last just above compost/woodchips and PB (Table 5). In addition, PM was the second highest in C-min and SMBC (Tables 7 and 8), suggesting a greater CO_2 footprint and greater settling over time. Depending on availability and cost of the other substrates compared in this study, PM would likely be the most expensive.

Compost (CP) was a high yielder over all three cropping trials, however beds filled with 100% CP had high C-mineralization (Table 7) and ‘shrunk’ the most of all

substrates evaluated. The plants grown in CP had high chlorophyll content measurements across all three crop trials (Figs. 2, 3, and 4). Compost is a highly variable product that changes depending on raw material inputs, decomposition method and time. Using large quantities of CP can be costly, depending on source and availability. From an environmental perspective, CP as a substrate can perform as well as peat moss, while avoiding concerns of peat bog harvesting and sustainability (Raviv, 2002).

Native Soil (NS) alone was a moderate yielder in crop one and two, and a top yielder in crop three. In crop one, the best performing group for yield (group one) consisted of PM, CP/PM. CP, and CP/NS (Table 3). In crop two basil, NS was the only substrate in the third statistical group which was lower than CP, CP/NS, CP/PM, and CP/PB (Table 4). In crop three, kale, NS was a top yielder, statistically the same as CP, CP/PM, and CP/PB (Table 5). NS had the lowest C-min (Table 7) as well as the lowest SMBC (Table 8) However, when mixed 50/50 with CP, it was a top yielder in the crop trial one (Table 3) and had the second highest yield in crop trials two and three (Table 4 and Table 5). Plants in the CP/NS beds had high chlorophyll content across all three crops (Figs. 2, 3, and 4). NS had moderate C-min and SMBC rates (Table 7 and Table 8) suggesting a lower environmental impact. It is worth noting that topsoil is relatively scarce in some regions and digging up large volumes of soil is laborious and there are potential negative consequences on the soil environment (Baiyeri and Mbah 2006). Source and cost are important consideration with NS as with other substrates considered in this study.

Pine bark (PB) is a common component for container mixes in the southeast. This study demonstrated that growing in 100% PB resulted in low yield across all three crop

trials (Tables 3, 4, and 5) and moderate-low in C-min. The plants grown in PB appeared malnourished or stunted, suggesting N immobilization. The lower initial pH of 5.1 of PB required the addition of lime and may have been a contributing factor in the first crop trial. Low yield of PB could also be a result of the slow break down of organic matter because tree bark developed as a protective layer to desiccation and phytopathogenic organisms and this layer is very resistant to microbial decomposition (Raviv, 2002). The lack of microbial activity could also affect the nutrient cycling for crops grown in PB. The nursery industry successfully uses PB through managed fertilization. PB in CRB's could be possible if the plants nutritional needs are met.

Adding CP to any of the pure substrates greatly improved the yield and chlorophyll content readings but again there could be an opportunity to trial different rates of CP to fine tune this researches recommendation.

Future Work

While this research showed that the ideal substrate is one that is a compost/native soil mix the rates used in this experiment were 50% compost and 50% native soil. More work is needed to determine the ideal ratio of CP/NS, as it might be possible to further reduce C-min while maintaining yield. This study also demonstrated its possible to grow in 100% CP, though typically a grower would use a blend of CP and either PM or native soil (NS), more often, amounts are in the range of 10% to 20% (Chong 2005).

Future research could expand the sustainability component by measuring leachate. It is imperative to look into water use and leachate of each of the substrates because Nitrogen (N) fertilizers comprise almost 60% of the global reactive N load attributable to

human activities; especially in China (UNEP 2007). Concerns about the environmental impact of intensive agricultural systems require an improvement in production technologies to maximize resource-use efficiencies, and to minimize the environmental impact (Spiertz 2010). There already exists information for N fertilizers making it a logical comparison gathering this information from these substrates.

Additionally, alternative sites, such as placing CRBs on bare ground and different irrigation methods could be tested. There are also other substrates to consider such as mushroom compost or vermicompost. Further considerations to fine tune this research would include different fertilizers and amounts. An investigation into the true cost of filling the CRBs with the different substrates would also help in choosing the ideal substrate. Details about the water holding capacity could lead us to a substrate mix that efficiently absorbs and holds water for plant uptake making the recommended substrate choice for CRB's even more environmentally considerate. Water conservation in addition to CO_2 can play a potentially critical role as resources become limited or costly.

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