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Hydro-Physical Characterization of Media Used in Agricultural Systems to Develop the Best Management Practices for operation of an Environmentally Sustainable Agricultural Enterprise

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

HYDRO-PHYSICAL CHARACTERIZATION OF MEDIA USED IN
AGRICULTURAL SYSTEMS TO DEVELOP THE BEST MANAGEMENT
PRACTICES FOR OPERATION OF AN ENVIRONMENTALLY SUSTAINABLE
AGRICULTURAL ENTERPRISE

A dissertation submitted in partial fulfillment of the
requirements for the degree of
DOCTOR OF PHILOSOPHY

in

CIVIL ENGINEERING

by

Vivek Kumar

2012

To: Dean Amir Mirmiran
College of Engineering and Computing

This dissertation, written by Vivek Kumar, and entitled Hydro-Physical characterization of media used in agricultural systems to develop the best management practices for operation of an environmentally sustainable agricultural enterprise, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Date of Defense: November 9, 2012

The dissertation of Vivek Kumar is approved.

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Florida International University, 2012

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DEDICATION

I dedicate this dissertation to my wonderful family, especially my mother for encouraging me to pursue my dreams, my father for instilling the importance of higher education and my brother for supporting me all these years. Thank you for all of your love, patience and sacrifice.

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ABSTRACT OF THE DISSERTATION

HYDRO-PHYSICAL CHARACTERIZATION OF MEDIA USED IN

AGRICULTURAL SYSTEMS TO DEVELOP THE BEST MANAGEMENT

PRACTICES FOR OPERATION OF AN ENVIRONMENTALLY SUSTAINABLE

AGRICULTURAL ENTERPRISE

by

Vivek Kumar

Florida International University, 2012

Miami, Florida

Professor Berrin Tansel, Major Professor

Florida is the second leading horticulture state in the United States with a total annual industry sale of over \$12 Billion. Due to its competitive nature, agricultural plant production represents an extremely intensive practice with large amounts of water and fertilizer usage. Agrochemical and water management are vital for efficient functioning of any agricultural enterprise, and the subsequent nutrient loading from such agricultural practices has been a concern for environmentalists. A thorough understanding of the agrochemical and the soil amendments used in these agricultural systems is of special interest as contamination of soils can cause surface and groundwater pollution leading to ecosystem toxicity. The presence of fragile ecosystems such as the Everglades, Biscayne Bay and Big Cypress near enterprises that use such agricultural systems makes the whole issue even more imminent.

Although significant research has been conducted with soils and soil mix, there is no acceptable method for determining the hydraulic properties of mixtures that have been

subjected to organic and inorganic soil amendments. Hydro-physical characterization of such mixtures can facilitate the understanding of water retention and permeation characteristics of the commonly used mix which can further allow modeling of soil water interactions.

The objective of this study was to characterize some of the locally and commercially available plant growth mixtures for their hydro-physical properties and develop mathematical models to correlate these acquired basic properties to the hydraulic conductivity of the mixture. The objective was also to model the response patterns of soil amendments present in those mixtures to different water and fertilizer use scenarios using the characterized hydro-physical properties with the help of Everglades-Agro-Hydrology Model.

The presence of organic amendments helps the mixtures retain more water while the inorganic amendments tend to adsorb more nutrients due to their high surface area. The results of these types of characterization can provide a scientific basis for understanding the non-point source water pollution from horticulture production systems and assist in the development of the best management practices for the operation of environmentally sustainable agricultural enterprise.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
BM	Bulk Mix
CH	Constant Head
EAHM	Everglades Agro Hydrology Model
EDS	Energy Dispersive Spectrometer
ET	Evapotranspiration
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Department of Environmental Protection
FFCR	Florida Fertilizer Consumption Reports
FH	Falling Head
LOI	Loss on Ignition
NASA	National Aeronautics and Space Administration
PM	Potting Mix
SEMS	Scanning Electron Microscope
USACE	US Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

I. INTRODUCTION

Florida is the second leading horticulture state in the United States, with a total industry sale of \$12.33 billion for the year 2010, which includes \$6.04 billion for landscape services and \$4.27 billion for wholesale nurseries (Hodges et al., 2011). Agricultural plant production represents an extremely intensive agricultural practice with large amounts of water and chemical fertilizer usage. Non-point source pollutants resulting from agricultural areas have been implicated as a source of water quality degradation in southern Biscayne Bay (USACE, 1999). It is a major challenge to develop effective practices that combine maximizing crop production while protecting the environment. The presence of fragile ecosystems such as the Everglades, Biscayne Bay and Big Cypress national preserve near farms and nurseries where such agricultural systems are used makes the whole issue even more complicated.

1.1 Objective

The objective of this study is to thoroughly examine the unique mixtures used in agricultural plant production, how they alter the hydraulic properties, and how they enhance the nutrient capability of the mix.

The objective was pursued through:

- The hydro-physical characterization of the mix
- The development of mathematical models correlating these physical and hydrological characteristics.
- Modeling the various interactions between the plant, soil and the environment.

- Characterizing the organic and inorganic soil amendments used in the mix.

1.2 Contributions

The characterization and in depth knowledge of the mixes can result in the optimized use of agrochemicals and water, which will lower the chemical stress on the environment, while simultaneously reducing the running cost of the agricultural enterprises. This study can further provide a scientific basis for understanding the non-point source water pollution from horticulture production systems in order to assist in the development of an environmentally sustainable agricultural enterprise. The understanding and control over the basic hydro-physical parameters can be a vital tool for the nursery growers. Individuals will be able to understand and manipulate the infiltration rate to some extent to suit their specific needs or requirements.

1.3 Background and Related Works

Permeability of soils is the most important feature in understanding the hydrological behavior of any soil and is often used for modeling the water flow in the saturated and unsaturated zones, as well as for modeling transport of water-soluble pollutants. There are several methods to determine the saturated hydraulic conductivity of soils (Danielson and Sutherland, 1986; Rawls et al., 1982; Rupp et al., 2004; Savabi, 2001). Soil scientists and engineers have tried to correlate the soil saturated hydraulic conductivity with soil survey data and soil physical parameters which include soil texture, soil organic matter, soil bulk density, etc. (Flanagan and Nearing, 1995; Williams et al., 1984; Duan et al., 2012; Saxton and Rawls, 2006). Many studies have focused on

the effects of management and tillage on hydraulic conductivity and water retention; however, only a few studies address the consequences of agricultural practices on water infiltration in soils (Ndiaye et al., 2007; Sepaskhah and Tafteh, 2012).

Saturated hydraulic conductivity of soils and soil water retention can be estimated from sand, clay, organic content of the soils as well as the clay type (Flanagan and Nearing, 1995; Williams et al., 1984). The best approach to estimate soil saturated hydraulic conductivity has been on the basis of soil texture data (Duan et al., 2012). In normal soil, the soil texture can be well defined and the soil can be classified as sand, silt, clay, or one of the numerous combinations.

But all that fails when the soil texture data becomes complicated, such as in the case of the agricultural mixes. The new soil amendments redefine the soil used in the agricultural systems by adding very high organic content, porous rock pieces, Styrofoam chunks, polyethylene pieces and several other unique materials.

The presence of 2 to 6 % organic matter in any soil sample decreases the bulk density and degree of compactness by increasing resistance to deformation and/or by increasing elasticity (Arvidsson, 1998; Soane, 1990). Subsequent drying and wetting results in chemical breakdown of organic matter, which increases the availability of the stored nutrient (Nguyen and Marschner, 2005; Onweremadu et al., 2007). If the mere presence of 2 to 6 % organic matter can causes such hydro-physical variations, imagine how agricultural mixes containing more that 50 % organic matter will affect the hydro-physical behavior of the system.

These agricultural mixes are new to soil science and much research and characterization has to be done to have a thorough understanding of its effect on agricultural entities and environment alike.

1.4 Scope of the Dissertation

The study will focus on the comprehensive characterization of the nursery mixtures. The first part of the study will involve techniques to optimize the use of resources such as water and fertilizers by nursery growers for the maximum possible yield, while minimizing environmental impacts from agrochemical leaching. The second part will focus on the sorption and fate of agrochemicals in the system.

Both experimental and theoretical analyses will be conducted to achieve the project goals set as follows:

- a. Acquisition of samples: Samples of plant growth mix will be acquired from various different nurseries in and around Miami-Dade County as well as commercially available mixes, so as to have a nearly complete representation of mix used in South Florida.
- b. Experimental work: Experiments will be performed to hydro-physically characterize the plant growth mixtures in terms of:
 - Hydraulic conductivity using three methods:
 1. Constant head permeability test,
 2. Falling head permeability test, and
 3. Tension infiltrometer test.
 - Particle size distribution

- Dry bulk density,
- Organic matter,
- pH,
- Air space, and
- Total water holding capacity.

c. Modeling:

- Develop mathematical models for characterizing hydraulic conductivity as a function of the basic hydro-physical parameters, such as particle size distribution dry bulk density, Organic matter, pH, Air space, and Total water holding capacity,
- Model of the response patterns in terms of yield, percolation, leachate, soil moisture, evapotranspiration and etc. of soil amendments present in readily available mix to different water and fertilizer use scenarios using data acquired through lab experiments.

d. Nutrient fate: Experimental and theoretical analyses will be interpreted using the sorption data of elements on the surface of organic and inorganic amendments present in the mixes.

The Projected goals of the study are elaborated in detail in the subsequent brief summary of the following six chapters.

Chapter II, entitled “Hydro-Physical Characteristics of Selected Mix Used for Agriculture Systems and Nurseries”, identifies and characterizes the hydro-physical properties of plant growth mix that are commonly used by nurseries in South Florida. This section deals with the experimental analyses that were performed to characterize the plant growth mixtures in terms of particle size distribution, pH, dry bulk density, water

saturation, organic matter, percent air space, total water holding capacity and hydraulic conductivity using three different methods (i.e., constant head permeability, falling head permeability test, and tension infiltrometer test). Ten samples were characterized in this study, and the effect of particle size on hydraulic conductivity was analyzed after separating each sample into three different particle size ranges. The hydraulic conductivity measurements varied significantly between different test methods. The results of these types of characterization can be vital in understanding the needs of plants and soils to increase yield while minimizing pollution.

Chapter III, entitled “Saturated Hydraulic Conductivity of Containerized Plant Growing Mix: Constant Head vs. Falling Head Method and Estimation Using Common Mix Properties”, deals with the saturated hydraulic conductivity and its correlation with basic hydro-physical properties of the mix. Saturated hydraulic conductivity is an important parameter for the development of best management practices in nurseries where high amounts of fertilizer and pesticides are used. Although significant research has been conducted with soils and soil mix, there is no acceptable method for agriculture systems. The hydro-physical properties (dry bulk density, water saturation, total organic matter, air space, and total water holding capacity) of the plant growing mix samples were correlated with the saturated hydraulic conductivity of the samples using two different methods (constant head and falling head). In this section predictive equations were developed to estimate the hydraulic conductivity of plant growing mixes that are commonly used by nurseries in South Florida based on readily available hydro-physical properties. The results showed that the saturated hydraulic conductivities of the samples appeared to be significantly different depending on the method used.

Chapter IV, entitled “Modeling Soil Water Balance, Yield and Nutrient Behavior of Soil Amendments Used for Plant Growth”, deals with the simulations of the response patterns of soil amendments present in mix under varying scenarios. Field experiments and monitoring studies usually represent only one specific condition or just a single set of scenarios, whereas computer simulation models provide a mechanism to evaluate the interactions between chemicals and the environment with many what if scenarios. The Everglades Agro Hydrology Model (EAHM) which has been developed to evaluate the impact of agricultural practices on the water quantity and quality, will simulate the water balance, water redistribution and agro-chemical movement from mixes for any given irrigation event.

The model was calibrated using the data acquired through lab experiments on the readily available mix. The objective of this study was to evaluate and model response patterns in terms of yield and hydrological behavior of soil amendments present in readily available mixes to different water and fertilizer use scenarios and develop strategies to reduce loss of chemicals with excessive water use. The simulations indicate quite a diverse behavior of the soils which were subjected to the same set of management and climatic conditions. The amendments in the mix do enhance the desired properties, where yield from the mixes is significantly higher than the traditional soil yield. The yield falls short of the sophisticated greenhouse farming techniques yield as some of the parameters are not controlled. With these understanding nurseries can develop better management strategies and common growers can make informed mix selection to suit their requirements.

Chapter V, entitled “Tension Infiltrometer Based Study of Soil Amendments Used by Nurseries to Optimize Soil Water Balance and Yield”, deals with the simulations of the response patterns in terms of yield and hydrological behavior of soil amendments present in mix under varying scenarios accounting for macropore effects. The tension infiltrometer method of estimating infiltration properties is preferred in this section as it best imitates the nursery conditions where water is release in small quantities with high frequency over the surface thus the macropores near the surface play the primary role.

The fate of applied fertilizers and pesticides depends on the management practices combined with interactions between soil chemistry and soil’s hydro-physical properties. The objective of this study was to model and evaluate the effect of agricultural practices on the water balance in readily available mix using the data acquired through lab experiments based on tension infiltrometer. The yield values of the commercially available samples in study are significantly higher than the common fresh field tomato farming under common growth practices.

Chapter VI, entitled “SEM-EDS Analysis of Soil Amendments Used in Nurseries before and after Fertilizer Application”, incorporated the adsorption behavior of the soil amendments used in mix by the nurseries. Some of the commercially available samples that were characterized in this study where subjected to plant food which is a combination of required fertilizer to imitate the nursery growth condition. Then the unique fractions which were part of the amendments were investigated for nutrient sorption with the help of Scanning electron microscope and energy dispersive X-ray microanalysis (SEM-EDS). This section deals with the presence and distribution of

nutrient elements at the surface of the unique material found in mix and the effects of common fertilizer on soil Amendments used in agriculture systems.

II. HYDRO-PHYSICAL CHARACTERISTICS OF SELECTED MIX USED FOR AGRICULTURE SYSTEMS AND NURSERIES

This Chapter consists of the experimental analyses that were performed to characterize the plant growth mixtures in terms of particle size distribution, pH, dry bulk density, water saturation, total organic content, percent air space, total water holding capacity and saturated hydraulic conductivity using three different methods (i.e., constant head permeability, falling head permeability test, and tension infiltrometer test). These characterizations of the plant growing mix can allow modeling of soil–water interactions for optimized use of water and agrochemicals by nurseries. A total of ten mix samples were characterized in this study.

2.1 Introduction

Florida is the second leading horticulture state in the United States with greenhouse and nursery sales of approximately \$4.27 billion every year (Hodges et al., 2011). Containerized plant production represents an extremely intensive agricultural practice with large amounts of water and chemical fertilizer use. Considering that three national parks (Everglades, Biscayne Bay and Big Cypress) in south Florida surround the agricultural areas where containerized agricultural systems are used, there exists a major challenge for development of effective practices that combine maximizing crop production while protecting the environmental. Non-point source pollutants (i.e., nutrients, pesticides, and other chemicals) resulting from agricultural areas have been implicated as a source of water quality degradation in southern Biscayne Bay (USACE,

1999). The nutrient loads from agricultural and urban areas have significantly increased nutrient concentrations, particularly phosphorus in surface waters (USEPA, 1996). In addition, discharging phosphorus at the current control target of 50 µg/L would continue to allow eutrophication of over 95% of the Everglades marshes.

Farming methods can alter soil properties such as soil structure, porosity, as well as the hydraulic conductivity and water retention. In south Florida, transition to containerized agricultural practices is driven by market demands and production advantages including higher production per acre, faster plant growth, higher plant quality, and lack of dependence on arable land (Colangelo and Brand, 2001). In agriculture systems, environmental conditions affect the longevity of fertilizer availability and its release. Because environmental conditions fluctuate, regular monitoring of the nutrient levels is essential to ensure fast plant growth and plant quality. Lack of essential elements will result in slow and aesthetically unacceptable products. Conversely, excessive nutrient concentrations result in root injury, hindering the plant's ability to absorb water and nutrients; which also increases the potential for environmental contamination (Water Quality Handbook for Nurseries, 1998). Leaching of nutrients is a major concern in agricultural areas. The ability of soils to hold the nutrients depends on the mechanics and dynamics of soil-water interactions which affect the nutrient transport as illustrated in Figure 1. Extent of leaching depends directly on the hydro-physical properties of the plant growing mix (i.e., soil or plant mix). The leaching is substantially reduced when the hydraulic conductivity of mix is lowered for a stabilized soil and substantially increases when the hydraulic conductivity is increased (Rao And Mathew, 1995). In fine grained soils, the hydraulic conductivity under saturated conditions is controlled by the

microstructure of the soil matrix which in turn depends on the type of the fine material (e.g., clay mineral) present in the soil, the composition of the exchangeable cations, and the electrolyte concentration in the pore water system (Rao and Mathew, 1995; Ruth, 1946). The measured permeability coefficient at a given porosity is significantly dependent upon the nature of the permeating medium. For example, clays are much more permeable to gases and most organic liquids than to water.

Figure 1. Important soil-water interactions which affect the water and nutrient management practices.

It has long been recognized that hydraulic conductivity is related to the grain-size distribution of granular porous mix (Freeze and Cherry, 1979; Rawls et al. 1982; Savabi 2001). Knowledge of saturated hydraulic conductivity of soil is necessary for modeling the water flow in the soil mix (both in the saturated and unsaturated zones) and for modeling transport of water-soluble pollutants. Permeability is the ease with which the water flows through a soil medium. There are several methods to determine saturated

hydraulic conductivities of soils (Savabi, 2001; Nearing et al., 1986; Rawls et al., 1982). The two commonly used methods include falling head permeability test and falling head permeability test. For the case of unsaturated soils, tension infiltrometer can be used to measure the unsaturated hydraulic properties of a soil sample using different tension conditions. During the tension infiltrometer tests, water is allowed to infiltrate the soil at a rate which is lower than the free fall rate of water through a column, which is accomplished by maintaining a negative pressure on the water. When similar infiltration experiments involving two different negative pressures are performed, the saturated hydraulic properties of the soil can be estimated (Wahl et al., 2004).

The objectives of this study were to characterize the selected hydro-physical properties of plant growth mix that are commonly used by the nurseries in South Florida. Characterization of the plant growing mix can allow modeling of soil-water interactions and development of best management practices for more efficient use of water and agrochemicals by nurseries. Experimental analyses were performed to characterize the plant growth mixtures in terms of particle size distribution and hydraulic conductivity using three different methods (i.e., constant head permeability, falling head permeability test, and tension infiltrometer test). The results were analyzed in relation to particle size distribution characteristics of the samples.

2.2 Materials and Methods

The samples of plant growth mix were obtained from different nurseries in Miami-Dade County in South Florida and a few were acquired from Home Depot. Greenhouse mix and Nursery mix were obtained from USDA Agricultural Research

Service, Miami, Florida. Pine Island mix, Costa Farms mix, Redland potting mixes (PM) and Redland bulk mix (BM) were obtained from nurseries around South Florida. While Miracle grow potting mix (PM), Miracle grow garden soil (GS) and Scotts mix were purchased from Home Depot (Miami, Florida) and the biosolids sample was obtained from the south district wastewater treatment plant in Miami, Florida. The source and diversity of the mixes is shown in Figure 2.

Figure 2 Schematic of the source of the sample mixes used in this study.

The general characteristics of the known samples provided by the nursery growers are presented in Table 1. The uncommon amendments present in the study mixes illustrated in Table 1 are:

- Talstar: It is an insecticide composed of the active ingredient bifenthrin.
- Dolomite: It is a carbonate mineral composed of calcium magnesium carbonate.

- Coir pith: It is made from coconut husks and is a byproduct of industries using coconuts.
- Perlite: It is an amorphous volcanic glass that has relatively high water content and expands upon being heated.
- Micro-Mix: It is a nutrient fertilizer that contains complexed zinc, iron, manganese, boron and copper.

Table 1. Materials used for preparation of nursery mixtures.

Pine Island mix	Nursery mix	Greenhouse mix	Costa Farms mix
Hardwood Fines	Pine Bark (50%)	Pine Bark (37.5%)	Pine Bark
Pine Bark Fines	Sand (10%)	Sand (7.5%)	Sand
Eco-Soil	Coir Pith (40%)	Coir Pith (30%)	Coir Pith
Dolomite	Dolomite	Perlite (25%)	Dolomite
Talstar	Micro mix	Dolomite	Styrofoam

The specifics of the other mixture compositions were not available due to proprietary nature of the plant growth mix used by the commercial nurseries. The plant growth mixes also have high organic content which is in contrast to regional soils which contain high percentages of clay, sand, loam and silt. The high organic content of the nursery mixtures is due to the efforts of the nursery operators to increase the moisture retention capacity of the plant growing mix. Some other unique materials found large numbers in some of the mixes are Rock in Miracle grow mix, Fertilizer pellet in Scotts mix, white pellet in Redland mixes (Figure 3).

Figure 3 Unique amendments present in the mix and their microstructure, a) Rock in Miracle grow mix, b) Fertilizer pellet in Scotts mix, c) White pellet in Redland mix.

Specific procedures followed for the characterization of the hydro-physical properties of the mixtures are provided below.

2.2.1 Sieve Analyses

Particle size distributions of the mixtures were characterized using Fisher Scientific US Standard Sieve Series (Figure 4). Samples were oven dried at 105 °C for 24 hours and cooled to room temperature, then each oven dried sample was sieved through a stack of 13 sieves for 15 minutes using sieve sizes ranging from 38.1 mm to 0.075 mm (Figure 5). After 15 minutes at the shaker, the sieves were removed and material retained at each sieve was weighted. The percent of material retained and passing through the sieves as well as the weight gain of the samples during sieve analysis were determined.

Figure 4 Fisher Scientific US Standard Sieve Series which was used to characterize the particle size distribution.

The uniformity coefficient (C_u) is used to evaluate the gradation of soils. The uniformity coefficient is defined as the ratio of the grain diameter corresponding to 60

percent passing (i.e., 60 percent is finer) on the size distribution curve (D_{60}) to the diameter corresponding to the 10 percent (D_{10}) passing (i.e., 10 percent is finer) as follows.

$$C_u = D_{60}/D_{10} \quad 1$$

where,

D : is the grain size (i.e., apparent diameter) of the particles and subscripts 10 and 60 denote the percentage that is smaller than the specific size.

A well-graded soil is defined as having a good representation of all particle sizes from the largest to the smallest. For example, well-graded sands typically have C_u values over 6. The coefficient of curvature is another parameter that is used to judge the gradation of soils. The coefficient of curvature, C_c , can be calculated as follows:

$$C_c = (D_{30})^2 / (D_{60} D_{10}) \quad 2$$

where,

D : is the grain size (i.e., apparent diameter) of the particles and subscripts 10, 30 and 60 denote the percentage that is smaller than the specific size.

2.2.2 Hydraulic Conductivity Experiments

To characterize the hydraulic conductivity profile of the mixtures, each sample was divided into 3 different particle size ranges as shown in Figure 5. The fractions in small sieve (0.425mm - Pan), medium sieve (2mm - 0.6mm) and large sieve (38.1mm-

4.75mm) ranges as well as the entire mix were used to determine hydraulic conductivity profile of the samples.

Large sieve range (38.10 mm - 4.75 mm)	38.100
	25.400
	4.750
Medium sieve range (4.75 mm - 0.60 mm)	2.380
	0.841
	0.600
Small sieve range (0.60 mm - Pan)	0.425
	0.297
	0.178
	0.150
	0.124
	0.104
	0.075
	0.000

Figure 5. Sieve sized corresponding to large, medium, and small particle size ranges in samples used for permeability experiments.

2.2.2.1 Constant Head Permeability Test

The constant head permeability tests were conducted using an ELE International Permeameter Model EI25-0623 (Loveland, Colorado). This instrument consists of a transparent acrylic cylinder which holds the soil sample (Figure 6). The permeameter has two openings, one at the top and the other at the bottom for continuous movement of fluid. To distribute the flow over the entire cross-sectional area of the permeameter, two porous stones were used at either end of the cylinder. Since the flow of water through the

mix may cause actual movement of the soil particle or even the soil fragments, a spring was placed on the top porous stone to pack/contain the soil mix movement. The constant head permeability test requires a constant flow of water through the medium; hence, a constant-head supply device consisting of a large funnel with an overflow was placed over the permeameter.

Figure 6. Experimental setup to estimate the saturated hydraulic conductivity using a permeameter.

The sample was placed to about two-thirds full inside the permeameter sample compartment. The spring packing of the sample allows the calculation of the dry bulk density as follows:

$$\rho_d = \frac{W}{AL}$$

where,

W : weight of the specimen in the permeameter (g);

L : length of specimen (cm); and

A : area of specimen (cm²) calculated as: $A = (\pi/4) D^2$; and

D : diameter of specimen compartment (cm).

The hydraulic conductivity of the particular sample can be calculated by measuring the time and the constant head using the following equation (For detailed derivations see Appendix A):

$$K = \frac{QL}{Ah}$$

where,

Q : Flow (cm³/sec); and

h : head difference (cm).

2.2.2.2 Falling Head Permeability Test

The falling head permeability tests were conducted using the ELE International Permeameter, Model EI25-0623 (Loveland, Colorado). The equipment and assembly is similar to the constant head permeability; however, unlike the constant-head supply

device, the head was allowed to fall using a burette instead of the funnel assembly (Figure 7).

Figure 7. Permeameter equipped with a burette for the falling head permeability tests.

The hydraulic conductivity of the sample can be calculated by the following equation (For detailed derivations see Appendix A):

5

$$K = \frac{aL \ln \frac{h_1}{h_2}}{At}$$

where,

a : area of falling head test tube (cm²);

L: final length of sample (cm);

A : area of sample chamber (cm²);

t : falling head time from h_1 to h_2 (seconds);

h_1 : initial height (cm); and

h_2 : final height (cm).

2.2.2.3 Infiltration Test

Tension infiltrometer measures the unsaturated hydraulic properties of the soil samples. Infiltration tests were conducted using a tension infiltrometer by Soil Measurement Systems (SMS), Model SW-080B with a 20 cm base plate (Figure 8).

Figure 8. Experimental setup for tension infiltrometer.

During the infiltrometer tests, water was allowed to infiltrate the sample at a rate which is lower than the free fall rate of water through a column, which was accomplished

by maintaining a negative pressure on the water. The tension infiltrometer measures the unsaturated hydraulic properties and the infiltration rate decreases as the sample becomes saturated until it attains a stabilized rate. The range of tensions attainable in the infiltrometer was between 0 and –30 cm water, and each cm corresponds to 1 mbar pressure. Therefore, at tensions close to zero, the infiltration rate is approximately equal to saturated hydraulic conductivity of the soil.

The saturated hydraulic properties of the soil can be calculated when similar infiltration experiments are performed at two different negative pressures (Gardner, 1958; Hussen and Warrick, 1993; Wooding, 1968). Experiments performed at different negative pressures (h) provide different volumes of water entering the soil per unit time (Q). This variation can be corrected using the following correction factor (For detailed derivations see Appendix A):

6

$$\alpha = \frac{\ln \left[\frac{Q(h_2)}{Q(h_1)} \right]}{h_2 - h_1}$$

where,

α : correction coefficient (cm^{-1});

$Q(h_1)$: volume of water entering the soil per unit time (cm^3/hr) at tension h_1 ,

$Q(h_2)$: volume of water entering the soil per unit time (cm^3/hr) at tension h_2 .

The hydraulic conductivity can be calculated as:

7

$$K(h) = K_{sat} \exp (\alpha h)$$

where, $K(h)$ is the hydraulic conductivity. The volume of water entering the soil per unit time can be calculated as:

8

$$Q(h_x) = K(h) A$$

The volume of water entering the sample per unit time (cm^3/hr) after correction can be calculated by the following equation:

9

$$Q(h_x) = \pi^2 K_{sat} \exp(\alpha h_x) \left[1 + \frac{4}{\pi \alpha} \right]$$

where,

$Q(h_x)$: volume of water entering the soil per unit time (cm^3/hr);

r : inside radius of sample chamber (cm);

K_{sat} : hydraulic conductivity (cm/hr);

h_x : tension (cm).

The α constant can be considered a soil pore parameter as the value of α increases when flow is driven by gravity, and decreases when flow is driven by soil capillarity. Numerous other procedures have been developed for estimating soil hydraulic conductivity from tension infiltrometer data, including Ankeny et al (1991), Smettem and Clothier (1989), White (1992), White and Perroux (1989) and etc. All these methods have their advantages and limitations with varying capabilities and complexities.

2.2.3 Organic Matter

Organic matter content may be estimated by loss on ignition (LOI) method, which is based on the weight loss measurements for samples subjected to heating (Dean 1974; Heiri et al. 2001). As organic matter oxidizes to carbon dioxide and ash generally at temperatures above 200°C, but a temperature of 550°C is preferred to have thorough ignition (Figure 9). Weight losses associated with soil moisture and organic matter can be estimated by analyzing before and after sample weights under controlled heating; that is heating the sample at 110 °C for soil moisture and ignition of sample at 550 °C for organic matter.

Figure 9. Furnace used for the loss on ignition experiment.

The organic matter is estimated using the equation:

10

$$OM = \frac{W_{550^{\circ}\text{C ash}}}{W_{110^{\circ}\text{C dry sample}}} \times 100$$

where,

OM: organic matter (%)

$W_{550^{\circ}\text{C ash}}$: weight of post 550°C ash (g).

$W_{110^{\circ}\text{C dry}}$: weight of post 110°C dry sample (g).

2.2.4 pH

For sample with high organic matter, a ratio of 1:5 of water to sample is recommended. Thus 5 grams of mix is added to 25 mL of distilled water and Stirred vigorously, and then it is allowed to stand for 2 hours before measuring with the help of pH meter.

2.2.5 Moisture Retention Capacity

The saturated water retention capacities of the samples were estimated using two different procedures. The first procedure consisted of adding water to the sample until it was saturated. For the second method, the sample was submerged in water until it was saturated. The amount of oven dry sample used for each experiment was 50 grams. To prevent the intermixing and loss of the soil mix, cheese cloth was used. The moisture retention capacity of the mix was computed by accounting for the error due to the absorption of water by the cheese cloth as follows:

11

$$\text{Saturation Water Content (\%)} = \frac{W - S - E}{S} \times 100$$

where,

W: total weight of the saturated specimen (gram);

S: weight of the soil sample (gram); and

E: weight of cheese cloth (gram).

2.2.6 Air Space

Air space of the mix is the total volume of pores filled with air after irrigation and drainage. When a medium is allowed to drain for a period of 2 hours, air space replaces the volume of water drained. Air space or pore space can be estimated by the following equation (FDACS 2007).

12

$$A = (V_d / V_c) \times 100$$

where,

A: air space (% v/v);

V_d: volume of water drained (cm³); and

V_c: container volume (cm³).

Container dimensions may affect air space and container capacity.

2.2.7 Water Holding Capacity

Water holding capacity is the percentage of the total volume of substrate that is filled with water after irrigation and drainage. The water holding capacity of the samples was determined by the following equation (FDACS 2007):

13

$$W_h = (V_p - V_d) / V_c \times 100$$

where,

W_h : total water holding capacity (% v/v); and

V_p : pore volume (cm^3).

A plant cannot take up the total volume of water from the container; this unavailable water is the portion of the total water holding capacity the plant cannot use and the portion of water holding capacity volume taken up by the plant is termed as available water.

2.3 Results

The plant growing mixes used by the nurseries contain amendments to satisfy the needs of the nurseries depending on their needs. One important need for nurseries is to increase moisture retention of the mixtures as much as possible. Hence, organic amendments (i.e., pine bark, manure) are used in addition to a small fraction of sand in preparation of the mixtures. Figure 10 presents the particle size distribution of the nursery mixtures studied (For log probability plot of particle size distribution see Appendix B).

All ten mixtures had similar particle size distribution characteristics (For comprehensive experimental data see Appendix C). However, the uniformity coefficient of the mixtures ranged from 0.170 to 8.276 as presented in Table 2. Unlike the natural soils which tend to lose some mass during the sieving experiments, the nursery mixtures gain some increase in weight during the course of the experiments which was about 20 minutes from the time of coming out of the oven to the final step of measuring the individual sieve weight.

Figure 10. Particle size distribution of the nursery mixtures.

The moisture retention capacities of the nursery mixtures were relatively high in comparison to that of natural soils. The water saturation characteristics of the nursery mixtures are presented in Table 2.

Table 2. Hydro-physical characteristics of the nursery mixtures.

Sample	pH	Organic matter (%)	Uniformity coefficient (Cu)	Gradation coefficient (Cc)	Dry bulk density (g/cm ³)	Water Saturation (% v/v)
Pine Island mix	4.26	72.1	7.26	0.63	0.277 ± 0.033	59.6 ± 4.6
Greenhouse mix	5.18	43.8	3.39	0.82	0.313 ± 0.031	73.5 ± 1.3
Nursery mix	6.48	69.7	2.74	0.72	0.281 ± 0.018	64.4 ± 6.1
Costa Farms mix	6.55	60.5	8.28	0.92	0.223 ± 0.002	71.0 ± 2.0
Redland PM	5.86	32.2	2.92	1.16	0.436 ± 0.026	55.6 ± 4.2
Miracle grow PM	6.03	38.2	0.17	0.59	0.268 ± 0.022	45.6 ± 3.4
Miracle grow GS	4.75	42.6	4.27	0.64	0.530 ± 0.064	45.9 ± 3.5
Redland BM	5.6	22.4	5.00	0.64	0.311 ± 0.006	73.1 ± 5.5
Biosolids	7.00	35.4	6.73	0.49	0.269 ± 0.004	68.6 ± 5.1
Scotts mix	5.74	43.0	3.71	0.93	0.344 ± 0.025	63.9 ± 4.8

The pH of any media is the medium on the basis of which the nutrient is exchanged between plant, water and soil. Thus the goal of pH management is to maintain an optimum pH level so that the availability of nutrients is at its maximum and the presence of toxic metals in solution is at the minimum. The general pH range for plant growth is between 5.5 and 6.8 but few acid loving plants prefer lower pH environment in the range 4 to 5. Nitrogen form of nitrate is readily available to plants above a pH of 5.5 while Phosphorus is most available when the soil pH is between 6.0 and 7.0. Plant growth may be limited in alkaline conditions as the solubility of minerals decrease upon increase in basicity. Decrease in Solubility of minerals results in the deficiencies of iron,

manganese, zinc, copper and boron which hampers the plant growth significantly. Table 3 illustrates the pH preferred by plants commonly grown in Florida as per Biospheric Sciences Research (NASA, 2012).

Table 3. pH preferred by plants commonly grown in Florida.

Plant	Soil pH
Orchid	4.0-5.0
Azalea	4.5-5.0
Blueberry, Cranberry	4.0-5.0
Potato	4.8-6.5
Strawberry	5.0-6.5
Carrot	5.5-7.0
Cauliflower, Cucumber, Tomato	5.5-7.5
Celery, Onion, Broccoli, Lettuce	5.8-7.0
Spinach	6.0-7.5

Table 2 presents the dry bulk density of the nursery mixtures which ranged between 0.223 and 0.530 g/cm³. The variation of dry bulk density and the estimated hydraulic conductivity in relation to particle size for each of the ten mixtures is shown in Figure 11 to figure 20. Decrease in particle size results in an increase in dry bulk density and decrease in hydraulic conductivity. The hydraulic conductivity of the mixture follows the particle size behavior which is prominent in the mix. For example the Pine Island

sample had larger particle size; hence, the hydraulic conductivity is similar to the hydraulic conductivity of the sample corresponding to larger sieve range.

Figure 11. Variation of dry bulk density and hydraulic conductivity in relation to particle size in Pine Island mix measured by constant head method.

Figure 12. Variation of dry bulk density and hydraulic conductivity in relation to particle size in Greenhouse mix measured by constant head method.

Figure 13. Variation of dry bulk density and hydraulic conductivity in relation to particle size in Nursery mix measured by constant head method.

Figure 14. Variation of dry bulk density and hydraulic conductivity in relation to particle size in Costa Farm mix measured by constant head method.

Figure 15. Variation of dry bulk density and hydraulic conductivity in relation to particle size in Redland PM measured by constant head method.

Figure 16. Variation of dry bulk density and hydraulic conductivity in relation to particle size in Scotts mix measured by constant head method.

Figure 17. Variation of dry bulk density and the hydraulic conductivity in relation to particle size in Miracle grow PM measured by constant head method.

Figure 18. Variation of dry bulk density and the hydraulic conductivity in relation to particle size in Miracle grow GS measured by constant head method.

Figure 19. Variation of dry bulk density and the hydraulic conductivity in relation to particle size in Redland BM measured by constant head method.

Figure 20. Variation of dry bulk density and the hydraulic conductivity in relation to particle size in Biosolids measured by constant head method.

The saturated and unsaturated hydraulic properties of the mixtures were measured using the tension infiltrometer at two different negative pressures shown in Table 4.

Table 4. Tension Infiltrometer parameters and observations

Sample	Negative pressure (cm)		Infiltration Rate (cm/hr)		Saturated Hydraulic Conductivity (cm/hr)
	h1	h2	h1	h2	
Pine Island	154	40	6.1	32	0.180 ± 0.010
Greenhouse	153	40	23.6	36.4	0.399 ± 0.008
Nursery	181	50	24.4	33.6	0.194 ± 0.039
Costa Farms	135	40	22.8	28.8	0.018 ± 0.003
Redland PM	118	37	11.4	22.8	0.063 ± 0.003
Miracle grow PM	105	43	100.6	152.8	0.33 ± 0.017
Miracle grow GS	114	40	44.4	77.4	0.187 ± 0.009
Redland BM	110	38	31.8	37.2	0.022 ± 0.001
Biosolids	115	35	5.4	14.4	0.109 ± 0.005
Scotts	108	55	69.6	76.8	0.04 ± 0.002

Table 5 presents the corresponding best equation fit between linear and logarithmic which suited the cumulative infiltration curves presented in Figure 21.

Table 5. Equations fitted to the infiltrometer data (infiltration volume vs. time).

Sample	Equation	R ²
Pine Island	$y = 12.796 \ln(x) + 154.69$	0.915
Green house	$y = 43.856 \ln(x) - 44.61$	0.985
Nursery	$y = 61.091 \ln(x) - 189.07$	0.994
Costa Farms	$y = 33.689 \ln(x) - 34.38$	0.982
Redland PM	$y = 47.646 \ln(x) - 78.10$	0.967
Miracle grow PM	$y = 0.707 x + 41.15$	0.987
Miracle grow GS	$y = 59.206 \ln(x) - 184.43$	0.997
Redland BM	$y = 44.679 \ln(x) - 137.48$	0.945
Biosolids	$y = 25.31 \ln(x) + 36.78$	0.778
Scotts	$y = 0.306 x - 19.42$	0.995

y: cumulative volume (cm³); x: time (seconds)

The hydraulic conductivity of a saturated mix as measured in the laboratory may vary with time, among the factors responsible for the variation have been cited the progressive deterioration of soil aggregation in the cations interaction between the soil and the flowing solution, and also the effects of the soil microorganisms and the changes in the volume of entrapped air (Poulovassilis, 1972).

Figure 21. Results from tension infiltrometer tests.

The hydraulic conductivity for a soil mixture depends on size and shape of the particles, void ratio, arrangement of the pores and soil particles, shape of the particles composing the bed, specific surface area of the solid particles, particle orientation, properties of the pore fluid and the amount of undissolved gas in the pore water. These correlations appear to apply with considerable accuracy to porous masses composed of rigid particles with relatively large sizes; however, fail significantly when used to describe the permeability characteristics of mix composed of small particles (of the order of 1 micron or less) (Michaels and Lin, 1954; Lambe 1954).

2.3.1 Reynolds Number Estimation

The saturated hydraulic conductivity estimated using the constant head and falling head methods is based on Darcy's Law, and since Darcy's Law applies to laminar flow through media, it is essential to quantify the Reynolds number as it is an important parameter to characterize the flow through a system. The Reynolds number can be estimated as:

14

$$R = \frac{q d}{\nu}$$

where,

q: Discharge (m/sec),

ν : Kinematic viscosity of fluid (m²/sec),

Kinematic viscosity of water at 20°C is 1.004x 10⁻⁶ m²/sec.

d: Mean particle diameter (m).

The geometric mean particle diameter can be calculated on a weight basis using the equation (ASABE, 2006; Pfost and Headley, 1976):

15

$$X_{gm} = \log^{-1} \left[\frac{\sum (M_i \log d_i)}{\sum M_i} \right]$$

where,

d_i = Diameter of ith sieve in the stack,

M_i = Mass of the sample on the ith sieve.

The standard deviation can be calculated as follows:

16

$$S_{gm} = \log^{-1} \left[\frac{\sum M_i (\log d_i - \log X_{gm})^2}{\sum M_i} \right]^{0.5}$$

where,

X_{gm} = Geometric mean particle diameter.

The calculated Mean particle diameter of the mixes is listed in Table 6.

Table 6. Mean particle diameter of the mixes under study.

Sample	Mean particle diameter (μm)	Standard deviation
Pine Island	641.84	3.19
Greenhouse	746.84	2.51
Nursery	805.88	2.47
Costa Farms	984.38	2.86
Redland PM	561.74	2.24
Miracle Grow PM	578.06	3.28
Miracle Grow GS	621.65	4.14
Redland BM	573.55	2.90
Biosolids	410.34	3.54
Scotts Mix	386.12	2.85

Darcy's Law is valid if the Reynolds number is lower than 10 (Bear, 1972).

Sample Reynolds number calculation for Pine Island:

For Reynolds number to be less than or equal 1,

$$\frac{qd}{v} \leq 1$$

Assuming Reynolds number to be 1,

$$\frac{qd}{v} = 1$$

Upon inserting the available values in the given equation with $R = 1$ and solving for the limit q and Q :

$$v = 1.004 \times 10^{-6} \text{ m}^2/\text{sec at } 20^\circ\text{C}$$

$$d = 641.84 \text{ } \mu\text{m}$$

$$q = \frac{v}{d} = \frac{1.004 \times 10^{-6} \frac{\text{m}^2}{\text{sec}}}{641.84 \times 10^{-6} \text{m}} = 0.00156 \frac{\text{m}}{\text{sec}}$$

$$q = 5.63 \frac{\text{m}}{\text{hr}} \text{ or } 563.14 \text{ cm/hr}$$

$$\text{Area of permeameter} = 30.18 \text{ cm}^2$$

$$\text{Area of burette in falling head setup} = 1.56 \text{ cm}^2$$

$$Q = 563.14 \text{ cm/hr} \times 30.18 \text{ cm}^2 = 16,995.42 \text{ cm}^3/\text{hr}$$

$$Q = 16,995.42 \text{ cm}^3/\text{hr}$$

For the experimental measurements and as per Darcy velocity and flow:

Constant head:

$$q = \frac{500 \text{ cm}^3}{55 \text{ sec}} \times \frac{3600 \text{ sec}}{\text{hr}} \times \frac{1}{30.18 \text{ cm}^2} = 1084.40 \frac{\text{cm}}{\text{hr}}$$

$$q = 1084.40 \text{ cm/hr}$$

$$Q = \frac{500 \text{ cm}^3}{55 \text{ sec}} \times \frac{3600 \text{ sec}}{\text{hr}} = 32727.27 \frac{\text{cm}^3}{\text{hr}}$$

$$Q = 32727.27 \text{ cm}^3/\text{hr}$$

Falling head:

$$q = \frac{\text{Head Difference (cm)}}{\text{Time (sec)}} \times \frac{\text{Area of burette in falling head setup (cm}^2\text{)}}{\text{Area of permeameter (cm}^2\text{)}}$$

$$q = \frac{80 \text{ cm}}{8.5 \text{ sec}} \times \frac{3600 \text{ sec}}{\text{hr}} \times \frac{1.56 \text{ cm}^2}{30.18 \text{ cm}^2} = 1751.37 \frac{\text{cm}}{\text{hr}}$$

$$q = 1751.37 \text{ cm/hr}$$

$$Q = \frac{(100 - 20)}{8.5 \text{ sec}} \times \frac{3600 \text{ sec}}{\text{hr}} \times 1.56 \text{ cm}^2 = 52856.47 \frac{\text{cm}^3}{\text{hr}}$$

$$Q = 52856.47 \text{ cm}^3/\text{hr}$$

As per the Reynolds number computed for the nursery mixes (Table 7), it can be assumed that flow through the permeameter column containing the mix is laminar in nature and Darcy's law is applicable for constant head as well as falling head experiments.

Table 7. Reynolds number for flow of water through the mixes under study.

Sample	For R = 1	From experiment		Reynolds number	
		Constant head	Falling head	Constant head	Falling head
	q (cm/hr)	q (cm/hr)	q (cm/hr)		
Pine Island	563.14	1084.40	1751.37	1.93	3.11
Greenhouse	483.96	1061.25	1302.58	2.19	2.69
Nursery	448.50	1037.25	1528.62	2.31	3.41
Costa Farms	367.18	747.86	1774.64	2.04	4.83
Redland PM	643.43	472.10	1365.01	0.73	2.12
Miracle Grow PM	625.26	568.02	1232.34	0.91	1.97
Miracle Grow GS	581.42	535.71	1069.45	0.92	1.84
Redland BM	630.18	1016.74	2138.89	1.61	3.39
Biosolids	880.82	482.28	1394.63	0.55	1.58
Scotts Mix	936.09	350.84	1022.44	0.37	1.09

The hydraulic conductivity of the nursery mixtures measured by constant head and falling head methods and saturated hydraulic conductivity measured by tension infiltrometer are presented in Table 8. The hydraulic conductivity of the mixtures measured by constant head method ranged from 57.6 to 159.12 cm/hr and by falling head method ranged from 280.8 to 600.3 cm/hr. The saturated hydraulic conductivity of the mixtures measured by tension infiltrometer ranged from 0.018 to 0.399 cm/hr.

Table 8. Saturated hydraulic conductivity of nursery mixtures measured by three different test methods.

Sample	Constant Head (cm/hr)	Falling Head (cm/hr)	Tension Infiltrometer (cm/hr)
Pine Island	136.8 ± 21.6	381.6 ± 43.2	0.180 ± 0.010
Greenhouse	151.2 ± 18	280.8 ± 36	0.399 ± 0.008
Nursery	144 ± 7.2	334.8 ± 21.6	0.194 ± 0.039
Costa Farms	104.4 ± 7.2	403.2 ± 18	0.018 ± 0.003
Redland PM	68.4 ± 10.2	393.9 ± 41.2	0.063 ± 0.003
Miracle grow PM	75.6 ± 15.3	331.9 ± 43.7	0.33 ± 0.017
Miracle grow GS	79.2 ± 10.2	320.1 ± 31.2	0.187 ± 0.009
Redland BM	159.1 ± 6.1	600.3 ± 46.5	0.022 ± 0.001
Biosolids	68.4 ± 3.1	354.1 ± 6.4	0.109 ± 0.005
Scotts	57.6 ± 2.0	296.3 ± 121.2	0.04 ± 0.002
All average of 3 tests			

2.4 Conclusions

Hydro-physical characteristics such as water retention and hydraulic conductivity of ten different nursery mixtures were characterized by laboratory experiments. Effect of particle size on hydraulic conductivity was analyzed after separating each sample by using three 3 different size sieve sizes. The results of the hydraulic conductivity measurements varied significantly between different test methods and the reasons for this remain unknown. Additional research is needed to determine why these differences were observed. The results of these types of characterization can vital in deciding the type of irrigation required with respect to the mix used for the system.

III. SATURATED HYDRAULIC CONDUCTIVITY OF CONTAINERIZED PLANT GROWING MIX: CONSTANT HEAD VS FALLING HEAD METHOD AND ESTIMATION USING COMMON MIX PROPERTIES

Saturated hydraulic conductivity is major factor in understanding the soil water behaviors in any mix used in nurseries where high amounts of fertilizer and pesticides are used. In spite of major research and breakthroughs in soil mechanics there is no acceptable method for determining the saturated hydraulic conductivity of the highly organic mix used in various agriculture systems. In this chapter predictive equations were developed to estimate the hydraulic conductivity of plant growing mix that are commonly used by nurseries in South Florida based on basic hydro-physical properties (dry bulk density, water saturation, total organic content, percent air space, and total water holding capacity).

3.1. Introduction

Development of effective water and agrochemical management practices to maximize plant growth while protecting the environment is a major challenge for containerized agriculture systems (Kumar et al., 2010). Non-point source pollutants (e.g., nutrients, pesticides) resulting from agricultural areas have been implicated for causing degradation of water quality in southern areas of Biscayne Bay (USACE, 1999). In south Florida, there is an increasing concern for the potential impacts on water quality due to leaching of agrochemicals due to the fragile natural habitat of the three national parks

(Everglades, Biscayne Bay and Big Cypress) surrounding the agricultural areas where containerized agriculture systems are used.

The ability of soils to hold onto the nutrients depends on the complex mass balance occurring in the system involving numerous parameters as shown in Figure 22. Plant nurseries have a tendency to blend soil amendments to accelerate plant growth by maximizing the desired soil property along with the occasional soil conditioners. Synthetic soil conditioners have shown to improve water availability to plants by increasing the retention pores and by decreasing the drainage pores thus reducing the saturated hydraulic conductivity, hence they have potential to restore soil productivity even under limited irrigation. (Abedi-Koupai et al., 2008; Narjary et al., 2012).

Figure 22. Soil-water interactions affecting the water and nutrient management practices at nurseries.

Hydraulic conductivity is correlated to the grain-size distribution of the granular porous mix (Williams et al., 1984; Rawls et al., 1982; Freeze and Cherry, 1979; Rawls et al., 1990; Savabi, 2001; Wu et al., 1990). In either field or laboratory conditions, the size of the individual soil sample has been known to influence measurement of soil's hydrodynamic parameters (Bagarello et al., 2012; Lai et al., 2010). The extent of leaching significantly increases when the hydraulic conductivity of the soil mix increases (Rao And Mathew, 1995). In fine grained soils, the hydraulic conductivity under saturated conditions is controlled by the microstructure of the soil matrix which in turn depends on the type of the fine material (e.g., clay mineral) present in the soil, composition of the exchangeable cations, and electrolyte concentration in the pore water (Rao and Mathew, 1995; Ruth, 1946). Soil under stress or weight can have a significant impact on the hydraulic conductivity due to the soil packing or compaction. Soil compaction reduces the total soil porosity, root growth and also impacts the proportion of elongated pores which are useful for water movement. Further compaction has been shown to destroy the granular, spongy and sub-angular blocky aggregates, changing the soil structure into massive micro-structure, which results in reduction in water in-filtration increasing soil erosion risk (Bagheri et al., 2012). The most important properties of the porous beds which appear to correlate with the bed permeability are porosity, particle size, and particle orientation (Michaels and Lin, 1954; Nimmo, 1997). The measured permeability coefficient at a given porosity significantly depends on the nature of the mix. For example, clays are relatively more permeable to gases and most organic liquids than to water.

Saturated hydraulic conductivity of soils is often used for modeling the water flow in the saturated and unsaturated zones as well as for modeling transport of water-soluble pollutants. Permeability relates to the ease with which the water flows through a soil medium. There are several methods to determine the saturated hydraulic conductivities of soils (Danielson and Sutherland, 1986; Rawls et al., 1982; Rupp et al., 2004; Savabi, 2001). The two commonly used methods include falling head and constant head permeability tests. Determinations of saturated hydraulic conductivity based on readily available soil physical properties have been reported primarily for application of the hydrologic models on a watershed or farm scale (Flanagan and Nearing, 1995; Williams et al., 1984). Soil scientists and engineers have tried to develop models to estimate soil saturated hydraulic conductivity with readily available soil survey data and soil physical parameters which include soil texture, soil organic matter, and soil bulk density (Duan et al., 2012; Saxton and Rawls, 2006). The known simple and fastest approach to estimate soil saturated hydraulic conductivity is on the basis of soil texture data (Duan et al., 2012). Saturated hydraulic conductivity of soils and soil water retention can be estimated based on sand, clay, organic content of the soils as well as the clay type (Flanagan and Nearing, 1995; Williams et al., 1984). Some studies report that soil surface crusting should be considered for calculating saturated hydraulic conductivity and for hydrologic model (Rawls et al., 1990; Zhang et al., 1995). Many studies have focused on the effects of management and tillage on hydraulic conductivity and water retention; however, only a few studies address the consequences of agricultural practices on water infiltration in soils (Ndiaye et al., 2007; Sepaskhah and Tafteh, 2012). To account for the variability of most field soils, extensive measurements might be required to have reliable estimate of

the soil conductivity for any area of interest (Bagarello et al., 2006). There are many ways to estimate the hydraulic conductivity and other hydro-physical parameters in the laboratory but most of them tend to be expensive or tedious or both. For modeling studies that require characteristics of numerous soil types and layers for regional studies or scenario studies, it may be impossible to measure all the necessary characteristics (Hackten Broeke and Hegmans, 1996).

Although significant research has been conducted on soils and soil mix, there is no accepted method for determining saturated hydraulic conductivity of the plant growing mix used in containerized agriculture systems (Kumar et al., 2010). The objective of this study was to develop a model to estimate hydraulic conductivity of plant growing mix that are commonly used by the nurseries in South Florida based on the readily available hydro-physical properties. The hydro-physical properties used for the estimation of hydraulic conductivity included dry bulk density, water saturation, total organic content, percent air space, and total water holding capacity.

3.2. Materials and Methods

Experimental analyses were performed to characterize the plant growth mixtures in terms of particle size distribution and hydraulic conductivity using two different methods (constant head and falling head). These plant growing mix samples tested included Redland PM, Redland BM, Miracle grow PM, Miracle grow GS, biosolids and Scotts mix.

The plant growth mixes have high organic content which is in contrast to regional soils that contain high fractions of clay, sand, loam and silt. The high organic content of

the nursery mixtures is due to the efforts of the nursery operators to increase the moisture retention capacity of the plant growing mix. The hydro-physical properties of the mixtures were characterized for: hydraulic conductivity (constant head and falling head), air space, moisture retention capacity, water holding capacity, and pH. The procedures followed for these tests are provided in section 2.2.

3.3. Results

The plant growing mixes used by the nurseries are prepared by blending soil amendments to satisfy the needs of the nurseries to accelerate plant growth. One important consideration in preparation of the mixtures is to increase the moisture retention as much as possible. Hence, organic amendments (e.g., pine bark, manure) in addition to a small fraction of sand are used in preparation of the mixtures. Unlike the natural soils which tend to lose some mass during the sieving tests, the nursery mixtures exhibited some increase in weight during the experiments which was about 20 minutes from the time of coming out of the oven to the final step of measuring the individual sieve weight. This increase is due to the high organic content of the samples which resulted in between 0.025 and 2.36 percent weight increase due to absorption of moisture during sieve analyses as presented in Table 9. The moisture retention capacities of the nursery mixtures were relatively high in comparison to that of natural soils. Dry bulk density of the mixtures determined by the experiments ranged between 0.268 and 0.530 g/cm³. The variation of air space and water holding capacity among the plant growing mix is presented in Figure 23 and Figure 24 respectively.

Table 9. Hydro-physical characteristics of the plant growing mix.

Sample	pH	Organic content (% w/w)	Dry Density ^b (g/cm ³)	Water saturation ^b (% w/w)	Water holding capacity (% v/v)	Air space (% v/v)
Redland PM	5.86	32.2	0.44± 0.03 ^A	55.6 ± 4.2 ^C	44.7 ± 6.3	8.5 ± 3.5
Miracle grow PM	6.03	38.2	0.27 ± 0.02 ^B	45.6 ± 3.4 ^C	44.3 ± 3.5	0.9 ± 0.4
Miracle grow GS	4.75	42.6	0.53 ± 0.06 ^C	45.9 ± 3.5 ^C	45.4 ± 5.6	1.8 ± 0.8
Redland BM	5.60	22.4	0.31± 0.01 ^B	73.1 ± 5.5 ^D	57.0 ± 11.1	11.6 ± 2.6
Biosolids	7.00	35.4	0.27 ± 0.01 ^B	68.6 ± 5.1 ^D	50.5 ± 9.8	7.8 ± 2.8
Scotts mix	5.74	43.0	0.34 ± 0.03 ^B	63.9 ± 4.8 ^D	54.6 ± 3.2	5.3 ± 2.1

All average of 3 tests

^bParameters with the same superscript (A, B, C or D) are not statistically different at p=0.05.

Figure 23. Air space characteristics of the plant growing mix.

Figure 24. Water holding characteristics of the plant growing mix.

The hydraulic conductivity of the mixtures estimated by constant head method ranged from 57.6 to 159.12 cm/hr and by falling head method ranged from 296.3 to 600.3 cm/hr.

Table 10. Saturated hydraulic conductivity of plant growing mix measured by two different test methods.

Sample	Saturated hydraulic conductivity ^a (cm/hr)	
	Constant head ^b	Falling head ^b
Redland PM	68.4 ± 10.2 ^{AB}	393.9 ± 41.2 ^A
Miracle Grow PM	75.6 ± 15.3 ^{AB}	331.9 ± 43.7 ^A
Miracle Grow GS	79.2 ± 10.2 ^B	320.1 ± 31.2 ^A
Redland BM	159.1 ± 6.1 ^C	600.3 ± 46.5 ^B
Biosolids	68.4 ± 3.1 ^{AB}	354.1 ± 6.4 ^A
Scotts Mix	57.6 ± 2.0 ^A	296.3 ± 40.9 ^A
Sand	77.78 ± 0.6	52.24 ± 0.2

^a Average of 4 tests.

^b Parameters with the same superscript (A, B, or C) are not statistically different at p=0.05.

As presented in Table 10, the saturated hydraulic conductivity of the nursery mixtures measured by constant head and falling head methods has significant differences (Figure 25). The variation of saturated hydraulic conductivity for sand measured by constant head and falling head methods was not as drastic but followed opposite trend compared to the common nursery mixes.

Figure 25. Saturated hydraulic conductivity of plant growing mix as per constant head and falling head method methods.

The values determined by the falling head were between 4 to 5 times of the values determined by the constant head method. Other researchers have observed that the hydraulic conductivity of soils can vary by a factor of two to three between different methods and reported that this variation is considered acceptable for practical purposes (Elrick and Reynolds, 1992; Reynolds and Zebchuk, 1996). For example, the estimate of hydraulic conductivity by falling head method for undisturbed soil cores with silty clay loam texture was reported to be 1.82 times more than the value determined by the constant head method (Bagarello et al., 2004). The hydraulic conductivity can vary

significantly for mixtures when the mix is not as well defined as those for soils. The tendency of the falling head technique to produce higher values of hydraulic conductivity in comparison to constant head technique has been reported by several researchers (Bagarello et al., 2004; Elrick and Reynolds, 1992; Reynolds and Zebchuk, 1996). Simplified falling head and pressure infiltrometer techniques have shown relative variability of several hundred or even thousands percent for saturated soil hydraulic conductivity (Bagarello et al., 2012). This behavior can be attributed to the short-term surface soil structure degradation which contributes to the reduction of hydraulic conductivity or the closure of macropores as the soil water content increases (Bagarello et al., 2000).

Saturated hydraulic conductivity exhibits scale dependency with regards to the volume of soil investigated (Lai and Ren, 2007; Mallants et al., 1997; Schulze-Makuch et al., 1999). The variability of saturated hydraulic conductivity may be due to the heterogeneity of the soil (Fodor et al., 2009; Fodor et al., 2011; Schulz and Huwe, 1999).

Among the factors responsible for the variation in the hydraulic conductivity include the progressive deterioration due to soil aggregation, interactions between the soil and the flowing solution, and also the effects of the microorganisms that could change the volume of entrapped air (Poulovassilis, 1972). The hydraulic conductivity of soil mixtures also depend on the size, shape and orientation of the particles, void ratio, arrangement of the pores and soil particles, specific surface area of the solid particles, properties of the pore fluid and the amount of undissolved gas in the pore water. These factors appear to apply with considerable accuracy to porous masses composed of rigid particles with relatively large sizes; however, they fail significantly when used to

describe the permeability characteristics of mix composed of small particles (of the order of 1 micron or less) (Lambe, 1954; Michaels and Lin, 1954). In the case of mixtures used by nurseries, the variety of materials used to prepare the mixtures and their highly organic nature contribute to significant variation in the tests. The natural organic mix particles used as amendments contain internal micro pores in addition to the pores between the particles. Hence, test duration can have significant effect on the results due to swelling of the particles over time.

Analysis of variance (ANOVA) and Tukey tests ($P = 0.05$) were conducted to determine the differences between the measured values for the mix characteristics presented in Tables 10 and 11 using Minitab statistics software (Minitab, 2010). There were no typical correlations between the similarities observed with different mixtures. For example, based on the statistical analysis of the dry bulk density measurements, mix tested presented three distinct groups (A, B, C) which were (i.e., statistically different at $p=0.05$). However, based on water saturation volume, the mixtures had two distinct groups (C, D).

Multiple regression analysis was used to analyze the hydraulic conductivity data in relation to the parameters tested to characterize the mix. Table 11 presents the regression analysis results between the saturated hydraulic conductivity (as dependent variable) and soil physical properties. The R^2 values adjusted for the degrees of freedom are significant for all three methods. Figure 26 presents the predicted versus measured saturated hydraulic conductivity values for each test methods.

Figure 26. Predicted and measures values of saturated hydraulic conductivity with different measurement methods: (a) Constant head, (b) Falling head.

Similar observations were reported by other researchers (Bagarello et al., 2000; Elrick and Reynolds, 1992). The physical characteristics of the plant growing mix that

affect the saturated hydraulic conductivity are similar to those reported for natural soils (Freeze and Cheery, 1979; Rawls et al., 1990; Savabi, 2001).

Table 11. Regression equations for estimating the hydraulic conductivity of the plant growing mix in relation to mix characteristics.

Regression equation ^{a,b}	R ²
CH = 228.66 D + 0.21 S _w + 11.85 pH - 8.37 OC - 12.77 A + 6.0 W _h	0.995
FH = 642.72 D - 1.76 S _w + 61.36 pH - 21.32 OC - 20.44 A + 15.0 W _h	0.985

^a CH: Constant head (cm/hr), FH: Falling head (cm/hr), ^b D: Dry bulk density (g/cm³), S_w: Water saturation (% w/w), OC: Organic content (% w/w), A: Air space (% v/v), W_h: Total water holding capacity (% v/v)

3.4. Conclusions

Hydro-physical characteristics and hydraulic conductivity of ten plant growing mixes were experimentally determined. The mix characterization can provide a scientific basis for better understanding of the water movement within the mix used. Nurseries can develop best management strategies to optimize the use of water and agrochemical, thus minimizing water pollution from commercial horticultural and floricultural production.

IV. MODELING SOIL WATER BALANCE, YIELD AND NUTRIENT BEHAVIOR OF SOIL AMENDMENTS USED FOR PLANT GROWTH.

This chapter incorporates the modeling of the response patterns of soil amendments present in readily available mix to different water and fertilizer use scenarios to develop strategies to reduce loss of chemicals with excessive water use. The EAHM will simulate the water balance, water redistribution and agro-chemical movement from soil mixture containers for any given soil mixtures and irrigation event using data acquired through lab experiments based on constant head saturated hydraulic conductivity.

4.1 Introduction

Water and nutrient management are an integral part of any agricultural enterprise. Reducing production costs and minimizing environmental impacts of mineral fertilizers and pesticides has been the major driving force among researchers and farmers (Lin et al., 2011; Gilbert et al., 2009). The fate of pesticides and nutrients applied in the environment depends on several factors and their interactions, such as climatic conditions, management practices, soil chemistry, soil's hydrologic behavior etc. In intensive agricultural systems N fertilizers do increase crop yield but some discrepancies in its use often results in low efficiency and N loss with potential risks of leaching to groundwater (Campiglia et al., 2011). Agricultural management practices have incorporated techniques that minimize nutrient losses by identifying and separately addressing key sources such as surface runoff, erosion and fertilizer management (Kim et al., 2011).

A major difference between usual soil based agricultural production and production in containers is the finite substrate volume imposed by containers and that has implications for relating canopy evapotranspiration with water uptake (Million et al., 2011). Temperatures in container tend to exceed usual soil temperatures due to adsorption of radiation by container walls as well as the surrounding environment (Martin and Ingram, 1993). Field experiments and monitoring studies usually only represent one specific environmental condition or just a single set of scenario, whereas computer simulation models provide a mechanism to evaluate the interactions between chemicals and the environment, and simulate the movement of chemicals within as well as between various mediums with changes in climate, soil, vegetation, and management practices.

It is nearly impossible to measure all the required characteristics to fit modeling studies that need detailed soil type and layer characteristics for regional or scenario based studies (Broeke and Hegmans, 1996; Stevenson et al., 2001; Wang et al., 2008). Modeling allows examination of a wide variety of factors which may influence the extent and severity of possible water pollution problems, chemical application rates, artificial drainage, etc.

The USDA-EAHM will simulate the water balance, water redistribution and agro-chemical movement from soil mixture containers for any given soil mixtures and irrigation event (Savabi and Shinde, 2003; Savabi et al., 2007). The EAHM is an event-based model that assesses the impacts of different water management systems on agricultural production, hydrologic conditions, and water quality for farms (Savabi et al., 2001; Savabi et al., 2005). The model's parameterization and evaluation can lead to the better selection of the Best Management Practices for nurseries and large scale farms

alike. The EAHM can help in the conservation efforts by quantifying water quality improvements in areas which infuse large quantities of nutrients and pesticides in the aquifer.

The objective of this study was to evaluate and model response patterns of soil amendments present in readily available mix to different water and fertilizer use scenarios and develop strategies to reduce loss of chemicals with excessive water use. Results of model simulations can be used for selection of best management practices for maintaining or improving water quality, for identification of critically threatened areas, and for determination of soil management plus chemical application combinations, which pose a significant threat to water quality.

4.2 Methodology

4.2.1 Model Description

The EAHM is described as a distributed parameter, continuous simulation, and water balance prediction model, implemented as a set of computer programs (Savabi and Shinde, 2003). The distributed input parameters include precipitation quantity and intensity, soil properties and effects of tillage on its properties and plant growth parameters; etc. Continuous simulation means that the simulations run with climate data on daily basis. The limits of application for EAHM include a size restriction to 640 acres for basins with slope to 2000 acres for rangelands.

The EAHM has various components which when coupled together bring about the complete results of a crop growth event. The climate component is generated using the CLIGEN model which creates climate files that contain daily values for rainfall (amount,

duration and intensity), temperatures, solar radiation, wind speed, wind direction, and dew point temperature. Inaccurate prediction of storm intensity and patterns results in considerable errors in estimating runoff and soil loss. (Zhang and Garbrecht, 2003). The hydrology component computes infiltration, runoff, soil evaporation, plant transpiration, soil water percolation and effective hydraulic conductivity. The model takes into account various factors that might affect the values of the parameters under study such as tillage activity which decrease the soil bulk density, increase the soil porosity and increase infiltration parameters.

The EAHM requires four input data files to perform the simulations. The CLIGEN program is used to generate a climate file that includes daily values for precipitation, temperatures, solar radiation, and wind information. The model requires a slope input file which defines the slope orientation, slope length, and slope steepness. The soil input file characterizes the soil's hydro-physical properties with input parameters including bulk density, porosity, CEC, hydraulic conductivity, etc. Finally the management file contains the input parameters that describe the different plants, tillage implements, tillage sequences, nutrient application, management practices, etc.

4.2.2 Model Theory

The EAHM water balance uses many of the algorithms developed for the Simulator for Water Resources in rural basins model by Williams (Williams et al., 1985). The water balance in the EAHM is maintained using the following equation (Savabi et al., 1995):

$$\Theta = \Theta_{in} + (P - I) \pm S - Q - ET - D - Q_d \quad 17$$

where,

Θ : is the soil water content (mm),

Θ_{in} : is the initial soil water (mm),

P: is the cumulative precipitation (mm),

I: is the precipitation intercepted by vegetation (mm),

Q: is the cumulative surface runoff (mm),

ET: is the cumulative evapotranspiration (mm),

D: is the cumulative percolation loss (mm), and

Q_d : is subsurface lateral flow (mm).

4.2.2.1 Evapotranspiration

The EAHM uses the Penman equation with the wind function method in scenarios where radiation, temperature, wind and dew point temperature are available or if they are generated by the CLIGEN program. (Penman, 1963; and Jensen 1974):

18

$$E_u = \frac{\delta}{\delta + \gamma} (R_n - G) + \frac{\gamma}{\delta + \gamma} 6.43 (1 + 0.53 U_z)(e_z^0 - e_z)$$

where,

E_u : is the daily potential evapotranspiration (MJ/m²d),

δ : is the slope of the saturated vapor pressure curve at mean air temperature,

γ : is the psychrometric constant,

G: is the soil heat flux (MJ/m²d),

R_n : is the net radiation (MJ/m²d),

U_z : is the wind speed (m/s),

e_z^0 : is the saturated vapor pressure (KPa),

e_z : is the vapor pressure (KPa).

The model uses the Priestly-Taylor (1972) method in the case where data is limited to temperature and solar radiation:

$$E_u = 0.00128 \frac{R_n}{58.3} \frac{\delta}{\delta + \gamma} \quad 19$$

where,

R_n : daily net solar radiation.

And δ is estimated using the equation:

$$\delta = \frac{5304}{T_k^2} e^{\left[21.25 - \frac{5304}{T_k}\right]} \quad 20$$

where,

T_k : is the daily average air temperature (k).

Also saturated vapor pressure is estimated using the equation:

$$e_z^0 = \frac{e^{\left[\frac{16.78 T - 116.9}{T + 237.3}\right]}}{2.7} \quad 21$$

where,

T : is the average daily temperature in °C.

Potential soil evaporation (E_{sp}) and plant transpiration (E_{tp}) are predicted with the equations (Ritchie, 1972):

$$E_{sp} = E_u e^{(-0.4 L)} \quad 22$$

23

$$E_{tp} = \left(1 - \frac{E_{smp}}{E_{sp}}\right) * E_{sp}$$

where,

L : is the leaf area index.

Evaporation from the soil continues until a stage where no more water can be evaporated from the bare soil. The actual soil evaporation is estimated using the equation:

24

$$E_s = E_{sb} e^{(-0.000064 C_r)}$$

where,

E_s : is the actual soil evaporation (m/d),

E_{sb} : is the bare soil evaporation (m/d),

C_r : is the plant residue on soil (kg/ha).

Whereas the Adjusted potential plant transpiration is estimated as:

25

$$E_{tp} = \frac{E_{smp} L}{3} \quad L \leq 3$$

where,

E_{tp} : is the daily-adjusted potential plant transpiration, (m/d).

The potential plant transpiration is not adjusted for leaf area index with values over 3.

4.2.2.2 Percolation

Water content exceeding the corresponding field capacity in any layer is subjected to percolation through the succeeding layer. Flow through soil layers are hindered by

coarse fragments in the layer and saturated or nearly saturated lower layer. Percolation of water is computed using the equation (Savabi, 1993):

26

$$p_i = (\theta_i - FC_i) \left[1 - \left(\frac{-\Delta t}{t_i} \right) \right] \quad \theta_i > FC_i$$

$$p_i = 0 \quad \theta_i \leq FC_i$$

where,

p_i : is the percolation rate through layer i (m/d),

FC_i : is the field capacity water content for layer i (m),

Δt : is the travel interval (s), and

t_i : is the travel time through layer i (s).

The travel time through a particular layer is computed using the equation:

27

$$t_i = \frac{\theta_i - FC_i}{K_{sai}}$$

where,

K_{sai} : is the adjusted hydraulic conductivity of layer i (m/s).

The hydraulic conductivity varies from values ranging from the saturated hydraulic conductivity (K_s), to near zero at field capacity.

28

$$K_{sai} = K_{si} \left[\frac{\theta_i}{UL_i} \right]^{B_i}$$

where,

K_{si} : is the saturated hydraulic conductivity for layer i (m/s),

UL_i : is the upper limit soil water content for layer i, (m).

B_i : is a parameter that causes K_{sai} to approach zero as Θ_i approaches FC_i .

29

$$\theta_r = \frac{-2.655}{\log \frac{\theta_r}{\theta_{fc}}}$$

4.2.2.3 Soil Water Content

The residual water content of the soil is predicted from (Alberts et al., 1995)

30

$$\theta_r = (0.000002 + 0.0001 \text{ OM} + 0.00025 \text{ clay CEC}_r^{0.45}) \rho_t$$

where,

θ_r : is the residual volumetric water content of the soil (m^3/m^3),

ρ_t : is the bulk density (kg/m^3).

The volumetric water content at 0.033 MPa of tension (field capacity), θ_{fc} , is predicted from:

31

$$\theta_{r_{fc}} = 0.2391 - 2.1 \text{ orgmat} + 0.19 \text{ sand} + 0.72 \theta_d$$

where,

θ_d : is the volumetric water content at 1.5 MPa of tension (wilting point) is predicted from:

32

$$\theta_d = 0.002 + 0.393 \text{ orgmat} - 0.5 \text{ orgmat}^2 + 0.265 \text{ sand}^2 - (0.06 \text{ orgmat}^2 + 0.108 \text{ sand}) \left[\frac{\theta_d}{1000} \right]^2$$

4.2.2.4 Nutrient Fate

A fraction of the water's energy in any surface runoff flow elevates and transports soil particles and smaller particles are more easily transported than coarser particles due to their lower weight. Therefore the nutrients which favor adhering to smaller particles such as clay are more likely to be carried away as runoff. Since Organic nitrogen is attached primarily to colloidal particles in the soil, the sediment load will have a higher concentration of organic nitrogen compared to soil surface layer. Most such studies have assumed sediments to be soil-derived and moving in surface runoff, although only few studies have considered subsurface transport by macropore flow (McGechan and Hooda, 2010). The common available negatively charged soil particles attract and absorb the plant-essential nutrients which are generally positively charged. Nitrate being an anion is not as easily absorbed by the soil particles and its retention by mix is minimal, it is very prone to leaching. Water carrying dissolved nutrients in the lower layers will move towards the surface in response to the gradient created as a result of water evaporation at the soil surface.

4.2.2.5 Crop Yield

Crops have a variety of mechanisms which ensures it has a perfect balance for survival as a species and enough production to be supported by the vegetation. Thus the harvest index which is the ratio of yield to above-ground biomass remains relatively uniform over a range of environmental conditions for unstressed crops. The harvest index which is adjusted to water stress constraints (Montieth, 1977; Arnold et al., 1995) throughout the season is used to estimate the Crop yield as per the following equation:

$$Y_p = (Y_c) (HIA)$$

where,

Y_c : is crop yield (kg/m²),

HIA: is adjusted harvest index at harvest, and

B_{AG} : is cumulative above-ground biomass (kg/m²).

The harvest index varies with water stress using the following equation:

$$HIA = \frac{HI}{1 + 0.01 (FHU)(0.9 - WS)}$$

where,

HIA: is the adjusted harvest index,

0.01: denotes the crop parameter expressing drought sensitivity,

FHU: is a function of crop stage, and

WS: is the water stress.

The crop growth model does not account for biomass and yield variation due management factors.

4.2.2.6 Experimental Analyses

The reliability of the modeling simulation on its application depends on the accuracy of the soil hydraulic parameters used in the model (Connolly, 1998; Mermoud and Xu, 2006). Experimental analyses were performed to acquire the mix hydraulic parameters for Greenhouse mix, Miracle grow PM, Nursery and Scotts mix. The

Saturated Hydraulic Conductivity values were acquired through experiments using an ELE International Permeameter Model EI25-0623 (Loveland, Colorado) (Section 2.2.2.1). The methods to characterize the hydro-physical parameters are illustrated in section 2.2.

4.2.3 Model Setup

Most of the initial model conditions were default conditions in the EAHM as per south Florida scenarios. This modeling scenario is based on the tomato cultivation which is harvested annually for a period of 20 years. The field or farm length for each model run is 100 m (328.08 ft.) having a slope profile of 0.2 %. For the climate input file CLIGEN version 4.3 is used which provides input of precipitation, temperatures, solar radiation, and wind speed as well orientation. The water balance in the model takes into account soil depth of 0.305 m (1 ft.) with an initial saturation value of 28 % and a constant albedo fraction of 0.23. The Mean tillage depth is 15 cm over the entire field with a random roughness value of 2 cm post tillage. Plant Growth and Harvest Parameters include that the in row plant spacing be 7.6 cm and the initial soil NO_3 , organic N and organic P is set at 15 mg/kg.

Simulations were performed to model response patterns of soil amendments present in readily available mix to different water and fertilizer use based upon the soil hydraulic parameters acquired through lab experiments.

4.3 Results

4.3.1 Experimental Results

The plant growth mixes have extremely high organic content (Table 12) as expected which is in contrast to regional soils that contain high fractions of clay, sand, loam and silt (Kumar et al., 2010). The high organic content is to increase the water holding capacity of the mix which is preferred by nurseries, gardeners and farmers by using organic amendments such as pine bark, manure etc. Nursery mix consists of pine bark (50%), sand (10%), and coir pith (40 %) with traces of dolomite and micro mix. The Greenhouse mix consists of pine bark (37.5%), sand (7.5 %), coir pith (30 %), and perlite (25%) with traces of dolomite and micro mix.

Table 12. Measured hydro-physical characteristics of the growing mix.

Sample	pH	Organic Content (%)	Uniformity coefficient (C_u)	Dry bulk density (g/cm^3)	Water Saturation (% w/w)
Greenhouse	5.18	43.8	3.39	0.313 ± 0.031	73.5 ± 1.3
Miracle grow PM	6.03	38.2	0.17	0.268 ± 0.022	45.6 ± 3.4
Nursery	6.48	69.7	2.74	0.281 ± 0.018	64.4 ± 6.1
Scotts	5.74	43.0	3.71	0.344 ± 0.025	63.9 ± 4.8

All average of 3 tests

The moisture retention capacities of the nursery mixtures were relatively high in comparison to that of natural soils (Kumar et al., 2010). A pH range of 6 to 7 is preferred as it enhances the availability of nutrients to plants and most of the mix under study are

moderately acidic but Greenhouse mix is considered to be strongly acidic with a pH of 5.18 (Table 12). Dry bulk density of the mixtures ranged between 0.268 and 0.344 g/cm³ which are extremely low compared to usual soils which can be due to the presence of organic material and other perforated amendments added to hold water. Water saturation values which represent the amount of water the mix can hold ranged from 45.6 to 73.5 percentages by weight. Greenhouse mix holds the most water among all the samples while Scotts retains the most water among commercial mix. Miracle grow PM due to its low organic content is unable to hold similar water quantities under similar condition as compared to other mix. The constant head saturated hydraulic conductivity values were at par with the values of generally available soils with values ranging from 57.6 cm/ hr to 151.2 cm/hr. (Table 13).

Table 13. Measured saturated hydraulic conductivity of mix.

Sample	Saturated Hydraulic Conductivity (cm/hr)
Greenhouse	144.0 ± 7.2
Miracle grow PM	75.6 ± 15.3
Nursery	151.2 ± 18.0
Scotts	57.6 ± 2.0
Average of 4 tests	

4.3.2 Modeling Results

The parameters investigated to compare the mixes, include yield, plant transpiration, soil evaporation, deep percolation, soil moisture, pesticide fate and nutrient

leached. As the climate data is generated using the CLIGEN, the precipitation values are same for each mix simulation for the entire duration of 20 years. The total annual precipitation for the 20 years fluctuates between 1000 mm to 2000 mm (40 – 80 inch) with a major event at the end on the 20th year with cumulative precipitation values as high as 2600 mm (102 inch) as shown in Figure 27.

Figure 27. Annual precipitation for the 20 years.

The major source of water to the environment is the losses through evapotranspiration and percolation. Soil evaporation accounts for the major share of water loss with values averaging between 300 mm to 800 mm per year for all mix samples but Scotts mix annual loss exceed the values of 800mm up to 1000 mm per year (Figure 28). Plant transpiration accounts for a significantly lower value ranging between 15 mm to 50 mm per year, Scotts mix losing the most as well as the other mix exhibit nearly the same profile in terms of plant transpiration and soil evaporation (Figure 28).

Figure 28. Annual plant transpiration and soil evaporation of the growth mix.

The soil moisture follows the same pattern as the precipitations as expected with some mix holding on to more moisture than other which might be as a result of the higher organic content in Greenhouse, Nursery, and Scotts mixes as compared to Miracle grow PM (Figure 29). Due to the high value of hydraulic conductivity and the simulation zone being just 1 ft., it was expected that the Deep percolation would be significantly high. Again most of the mixes follow the same profile but the Scotts mix with water as much as 450 mm to 1200 mm per year moves down through the soil profile below the root zone and is unutilized by plants (Figure 29).

Figure 29. Annual soil moisture and deep percolation of the growth mix.

In normal pesticides application in an enclosed farming, it has been observed that only $\frac{2}{3}$ of the total applied pesticides reaches the crop while $\frac{1}{4}$ of it goes to the soil (Katsoulas et al., 2012). Under large scale open farming the amount of pesticides reaching the ground would be significantly higher due to other unforeseen conditions. The fate and transport of a pesticide are governed by properties such as solubility in water, volatility and ease of degradation (Savabi and Shinde, 2003). Degradation is the conversion of a compound into less complex forms and can occur in several ways including photo degradation, chemical degradation and biodegradation. The majority of

pesticides in use today are organic compounds which are susceptible to microbial degradation, In contrast to the inorganic pesticides which are immune to microbial degradation. The first order Kinetics governs the degradation and removal of the Pesticide in all soil layers under study. The pesticide behavior in the mix in terms of its availability in soil and degradation follows identical patterns. The presence of pesticide in the soil starts at 4kg/ha to at the time of application and drops steadily for the next 150 days to 1% of its initial value (Figure 30). The same phenomenon is observed where the pesticides decay as per the first order kinetics to near negligible of 0.004 kg/ha of pesticides remaining at the end of 6 months (Figure 30).

Figure 30. Annual quantity of pesticides available in soil and degraded.

Figure 31. Annual loss of N as leachate.

Leaching of any chemical is governed by the water present in the layer above it, depending on the hydraulic conductivity coupled with the interaction of the soils hydrologic and chemical behavior. Greenhouse and nursery mix have approximately the same characteristics and composition but quite different organic content and that can be a major contributor to the lag observed in the N leachate profile which are almost identical (Figure 31). Scotts mix follows the precipitation owing to its low hydraulic conductivity and high dry bulk density which create a packing effect. Miracle grow PM yield surprisingly a different profile and seems to lose the least N as leachate.

The yield for the entire period of 20 years varies between 13 kg/m^2 and 30 kg/m^2 . The yield profile has similar characteristics which might be due to the high rate of hydraulic conductivity and percolation. Miracle grow PM has the least yield over most of the years while nursery and greenhouse mix leading the tight comparison (Figure 32).

Figure 32. Annual yield of the growth mix.

4.4 Discussions

Scotts mix tends to lose the most water to Evapotranspiration which can be attributed to the low hydraulic conductivity which tends to keep the water at the surface for a longer span of time (Figure 28). Scotts mix has a high dry bulk density and moderate organic content meaning it takes more effort on its part to retain water under drainage compared to other mix which it loses most to percolation. Miracle grow PM has the least soil moisture throughout the simulation which might be due to its lower organic content among the mix under study (Figure 29). Due to the high hydraulic conductivities of the mix it is expected for the runoff to be negligible under normal scenarios. As per the constant head simulation it is observed that most of the water is lost due to percolation which leaves no room for runoff.

The yield is more or less uniform when considered over the 20 years with values varying between 21.5 kg/m^2 to 22.5 kg/m^2 for the simulations (Figure 33).

Figure 33. Average yield of 20 harvests of the growth mix.

Greenhouse cultivation is a sophisticated form of farming where every aspect of the system is monitored and controlled using hydroponics for water and nutrient management (Cook and Calvin, 2005). Yields can be extremely high in such systems, in some cases as much as 15 to 20 times greater than average field production (Cook and Calvin, 2005). In United States the average yield of tomato via the greenhouse farming techniques is astonishingly high as 48.4 kg/m^2 while the Average fresh field tomato yield stands at about 3.2 kg/m^2 . While the average yield for the whole country irrespective of farming technique is 8.1 kg/m^2 which is among the top in the world and considerable higher than the world average of 3.4 kg/m^2 (Table 14).

Miracle grow PM which has the lowest organic content, lowest dry bulk density, lowest water saturation, and high hydraulic conductivity ends up having the least yield in comparison to other mix (Figure 33). While Nursery and greenhouse mix having identical characteristics such as an average organic content, average dry bulk density, high water saturation and the highest hydraulic conductivity have the most yields (Figure 33).

Table 14. Average yield of tomato across countries and entities.

Entities	Average Yield (kg/m ²)
China	5.1
Europe	3.9
India	2.0
Spain	7.4
United States	8.1
World	3.4

(FAOSTAT, 2010)

The yield values acquired through the simulation (21.5-22.5 kg/m²) exceed the expectations for common fresh field tomato farming by a factor of 5 but still have to do far better to compete with the sophisticated farming techniques.

4.5 Conclusions

The amendments present in the mixes under study do enhance the desired properties, making the average yield significantly higher than the traditional yield. The yield falls short of the sophisticated greenhouse farming techniques yield as some of the parameters are not controlled. With these understanding nurseries can develop better management strategies and common growers can make informed selection of mixes to suit their requirements.

V. TENSION INFILTROMETER-BASED STUDY OF SOIL AMENDMENTS USED BY NURSERIES TO OPTIMIZE SOIL WATER BALANCE AND YIELD.

This chapter incorporates the modeling of the response patterns of soil amendments present in readily available mix to different water and fertilizer use scenarios using data acquired through lab experiments based on saturated hydraulic conductivity estimated using tension infiltrometer. The tension infiltrometer is preferred as it imitates the nursery conditions which use water sprinkler which releases water in small amount at high frequency.

5.1 Introduction

Effective water and agrochemical management to maximize yield while protecting the environment is a major challenge for nursery growers using agriculture systems and farmers alike (Kumar et al., 2010). The ability of soils to hold water and nutrients depends on the soil-water interactions, which is considerable manipulated in commonly available mix. Hydraulic conductivity is correlated to the grain-size distribution of the granular porous mix, as well as the organic content in conditioned mix (Rawls et al., 1990; Savabi, 2001; Vaz et al., 2011; Wu et al., 1990). Increases in hydraulic conductivity of the soil mix leads to significant increase in leaching of nutrients depending on the partitioning coefficient (Rao And Mathew, 1995). Porosity, particle size, and particle orientation are primary factors that determine the properties of any porous beds and subsequently dictate the soil water interactions (Nimmo, 1997; Vaz et al., 2011; Whalley et al., 2007; Whitmore et al., 2011)

There are several methods to determine the infiltration rates and saturated hydraulic conductivities of soils using equipment such as constant head permeameter, falling head permeameter, tension infiltrometer etc. (Savabi, 2001; Danielson and Sutherland, 1986; Rupp et al., 2004). Tension infiltrometers are useful while quantifying the effects of macropores and flow paths upon infiltration in the field as well as in the laboratory. Tension infiltrometer is used to measure the hydraulic and transport properties of a soil sample and under different tension conditions the saturated hydraulic properties can be estimated.

Effective saturated hydraulic conductivity of soils and other basic soil water properties can be estimated based on sand, clay and organic content of the soils (Kutilek, 2004; Williams et al., 1984, Flanagan and Nearing, 1995; Zhuang et al., 2001). Many available studies focus on the effects of management and tillage on the hydro-physical properties with only a few addressing the consequences of agricultural practices on the same (Ndiaye et al., 2007; Stevenson et al., 2001; Yoon et al., 2007). Common methods to estimate the hydraulic conductivity and other hydro-physical characteristics in laboratory are either costly or tedious or both. It is impossible to measure all the necessary characteristics to suit modeling studies that require numerous soil type and layer characteristics for regional or scenario based studies (Broeke and Hegmans, 1996; Stevenson et al., 2001; Wang et al., 2008). Field experiments and monitoring studies usually represent one specific environmental condition or just a single scenario, whereas computer simulation models can provide a mechanism to evaluate the interactions and simulate the movement of water along with chemicals within as well as between various mediums with variations in climate, soil, vegetation, and management practices. The

complexity of water balance and behavior due to the interactive nature of the multiple processes involved in such agricultural mix soils requires using a complex computer models (Richards and Peth, 2009).

The USDA-EAHM model simulates water balance, water redistribution and agro-chemical movement in mix for any given irrigation event (Savabi and Shinde, 2003; Savabi et al., 2007). The model is an event-based model that assesses the impacts of different water management systems on agricultural production, hydrologic conditions, and water quality for farms; it predicts the complete results of a crop growth event (Savabi et al., 2001; Savabi et al., 2005). The reliability of the modeling simulation for its application depends majorly on the accuracy of the soil hydraulic parameters appearing in the model (Connolly, 1998; Mermoud and Xu, 2006).

The objective of this study was to hydro-physically characterize some of the readily available plant growth mix and to model response patterns of soil amendments present in those mixes to different water and fertilizer use scenarios and develop strategies to reduce loss of chemicals with excessive water use. Results of model simulations can be used for selection of best management practices for maintaining or improving water quality.

5.2 Materials and Methods

5.2.1 Sample and Experimental Setup.

Experimental analyses were performed to hydro-physically characterize the readily available plant growth mix, which included Redland PM, Miracle grow PM, Greenhouse mix, Nursery mix and Scotts mix (Chapter II). A tension infiltrometer is

typically used to measure the unsaturated hydraulic properties of the soils. Infiltration tests were conducted using the tension infiltrometer and methodologies followed were similar to the one illustrated in section 2.2.5. The experiment was set up to simulate conditions similar to the containerized agricultural process as well as field process (Figure 34). Since the tension infiltrometer measures the unsaturated hydraulic properties, the infiltration rate decreases as the sample becomes saturated until the infiltration rate stabilizes. When similar infiltration experiments involving two different negative pressures are performed, the saturated hydraulic properties of the soil can be estimated (Wahl et al., 2004). The range of tension attainable in the infiltrometer was between 0 and -30 cm water.

Figure 34. Experimental setup for tension infiltrometer.

The hydro-physical properties of the mixtures were characterized for: hydraulic conductivity using tension infiltrometer, air space, moisture retention capacity, water holding capacity, and pH. The procedures followed for these tests are provided in section 2.2.

5.2.2 Modeling Setup

The model setup and model theory are similar to section 4.2.2. Most of the initial model setup was default conditions in the EAH model to suit the south Florida scenarios. The modeling scenario is based on the tomato cultivation which is harvested annually for a period of 20 years. As it is seasonal cultivation, the first year is discarded for the sake of uniformity and to avoid any bias for the subsequent years. The field length for each model runs is 328.08 ft. (100 m) with a slope profile of 0.2 %. The water balance in the model is done over a soil depth of 1 ft. (0.305 m) with an initial saturation value of 28 % and a constant albedo fraction of 0.23. The Mean tillage depth is 15 cm with a random roughness value of 2 cm post tillage for the entire field. Plant Growth and Harvest Parameters include that the in row plant spacing be 7.6 cm and the initial soil NO₃, organic N and organic P concentration is 15 mg/kg.

The various factors that might affect the values of the parameters under study are accounted for such as tillage activity which decrease the soil bulk density, increase the soil porosity and increase infiltration parameters. The crop growth model does not account yield variation due to nutrient, pest and other management factors.

5.3 Results

5.3.1 Experimental Results

The mixes used by the nurseries are prepared by blending soil amendments to accelerate plant growth to have that competitive edge over other available growth mix. Solubility of minerals or nutrients significantly depend on the pH of the soil and most minerals and nutrients are easily soluble and available to plants in slightly acidic soils compared to neutral or slightly alkaline soils. A pH range of 6 to 7 enhances the availability of nutrients to plants and most of the mixes under study are considered moderately acidic but Greenhouse mix with a pH of 5.18 is considered to be strongly acidic (Table 15).

Table 15. Measured hydro-physical characteristics of the plant growing mix.

Sample	pH	Organic Content (% w/w)	Uniformity coefficient (Cu)	Dry bulk density (g/cm ³)	Water Saturation by (% v/v)
Greenhouse mix	5.18	43.80	3.39	0.313 ± 0.031	73.5 ± 1.3
Miracle grow PM	6.03	38.20	0.17	0.268 ± 0.022	45.6 ± 3.4
Nursery mix	6.48	69.70	2.74	0.281 ± 0.018	64.4 ± 6.1
Redland PM	5.86	32.20	2.92	0.436 ± 0.026	55.6 ± 4.2
Scotts mix	5.74	43.00	3.71	0.344 ± 0.025	63.9 ± 4.8

All average of 3 tests

The plant growth mixes have extremely high organic content (Table 15) as expected which is in contrast to regional soils that contain high fractions of clay, sand, loam and silt (Kumar et al., 2010). The high organic content is to increase the water

holding capacity of the mix which is preferred by nurseries, gardeners and farmers by using organic amendments such as pine bark, manure etc. The amendments are unique and vary for the different mixes such as Miracle grow PM has porous rocks (Figure 35 a) and pine bark, while the Scotts mix has fertilizer pellets with smooth surface (Figure 35 b) and rough wood chips (Figure 35 d). Styrofoam is observed in Redland PM as (Figure 35 c).

Figure 35. Microstructure of unique amendments in soil a) Rock in Miracle grow mix, b) Fertilizer pellet in Scotts mix, c) White pellet in Redland mix and d) Wood chip in Scotts mix.

Dry bulk density of the mixtures ranged between 0.268 and 0.530 g/cm³ which are low compared to usual soils. Water saturation values which represent how much

water the mix can hold range from 45.6 to 73.1 percentages by weight that indicates that the mix can hold approximately half its weight in water under normal circumstances (Table 15). Greenhouse mix holds the most water among all the samples while Scotts mix retains the most water among commercial mix. Miracle grow PM hold the least water under similar condition as compared to other mix.

The saturated hydraulic conductivity of the mixtures measured by tension infiltrometer ranged from 0.040 to 0.399 cm/hr which is low compared to other methods and even for other soil types (Table 16). This behavior can be attributed to the short-term surface soil structure degradation which contributes to the reduction of hydraulic conductivity or the closure of macro pores as the soil water content increases or to other, unknown factors. (Bagarello et al., 2000; Gebhardt et al., 2012).

Table 16. Saturated hydraulic conductivity and Infiltration rate of plant growing mix.

Sample	Saturated hydraulic conductivity ^a (cm/hr)	Infiltration rate ^b (cm/hr)	
		Suction pressure 110 mm water	Suction pressure 40 mm water
Greenhouse mix	0.399 ± 0.008	23.6	36.4
Miracle grow PM	0.330 ± 0.017	100.6	152.8
Nursery mix	0.194 ± 0.039	24.4	33.6
Redland PM	0.063 ± 0.003	11.4	22.8
Scotts mix	0.040 ± 0.002	69.6	76.8

^a Average of 4 tests

^b Average of 2 tests

The hydraulic conductivity of a saturated mix as measured in the laboratory tend to vary with time especially in mix with high organic content due to its decaying nature and compaction as a result of compression. Among the factors responsible for the variation in the hydraulic conductivity include the interactions between the soil and the flowing solution and also the effects of the microorganisms that could changes the volume of entrapped air.

Figure 36. Cumulative water infiltration rates of the mix over time at a negative pressure of 40 mm water.

While most of the mixes follow approximately the same cumulative infiltration profile but Miracle grow PM which has significantly different profile and requires a lot of water to attain a stable condition (Figure 36). The corresponding best equation fit

between linear and logarithmic is shown in Table 17. It is observed that the commercially available mixes follow more of a uniform infiltration behavior while the other nursery mixes prefer logarithmic profile.

Table 17. Equations fitted to the infiltrometer test data (infiltration volume vs. time).

Sample	Equation ^a	R ²
Greenhouse mix	$y = 43.856 \ln(x) - 44.61$	0.985
Miracle grow PM	$y = 0.707 x + 41.15$	0.987
Nursery mix	$y = 61.091 \ln(x) - 189.07$	0.994
Redland PM	$y = 47.646 \ln(x) - 78.10$	0.967
Scotts mix	$y = 0.306 x - 19.42$	0.995

^a y: cumulative infiltration volume (cm³), x: time (sec).

The natural organic mix particles used as amendments contain internal micro pores in addition to the pores between the particles which might have significant effect on the results due to swelling of the particles over time.

5.3.2 Modeling Results

In the modeling aspect the climate data is generated using CLIGEN program, thus the precipitation values for the entire duration of 20 years are identical for each mix simulation. The Cumulative annual precipitation for the 20 years varies between 40 to 80 in per year (1000 mm to 2000 mm) with a major event in the 20th year with high cumulative annual precipitation of 102 in (2600 mm) (Figure 37).

Figure 37. Cumulative annual precipitation for the 20 years.

All mix exhibit nearly the same profile pattern for both plant transpiration as well as deep percolation (Figure 38). The annual plant transpiration accounts for a significantly lower value ranging between 20 mm to 50 mm per year with an anomaly observed in the 18th year with all time high value of 55mm for all the mix samples. The annual cumulative average soil moisture in the infiltration scenario follows the same pattern as the precipitations with much delayed and corrected responses. It is observed that the mix holds on to more moisture in the 6, 8, 18 and 20th year than other years (Figure 38), while still being in the same range of almost 40 mm to 55 mm per year. The annual percolation accounts for the major share of water loss averaging between 300 mm to 900 mm per year for all mix samples.

Figure 38. Annual evapotranspiration, soil moisture and deep percolation of the growth mix.

Due to the low hydraulic conductivities of the mix it is expected for the runoff to be high. Most of the mixes follow the identical profile while being slightly apart but Scotts deviates slightly of delayed response. Greenhouse and Scotts mix lose the most water; 500 mm/year as runoff compared to 200 mm/year for Miracle grow PM, 350 mm/year for Nursery mix, 450 mm/year for Redland PM (Figure 39).

Smaller particles are easier to transport than coarser particles due to their lower weight, thus the nutrients which favor adhering to smaller particles are more likely to be carried away as runoff. Enrichment ratio is based on the amount of runoff that occurs over the surface and the low hydraulic conductivities of the mix leads to relatively high runoff, resulting in high concentration of nutrient being transported with the sediment. No-tillage systems have been considered an effective practice for erosion control in some areas with no significant loss in yield (Fu et al., 2006). The enrichment ratio is defined as the ratio of the concentration of nutrient transported with the sediment to the concentration in the soil surface layer. The daily average of enrichment ratio for mix samples illustrates values with significant variation. Greenhouse and Scotts mix seem to lose the most nutrient to the environment with a 20 year average of 0.8 (Figure 39). Redland PM and Nursery mix follow with a 20 year average of 0.6 and Miracle grow PM is observed to be the most nutrient retaining mix with a 20 year average of 0.45 (Figure 39). The yield for the entire period of 20 years follows approximately the same trend with different values which varies between 17 kg/m^2 to 33 kg/m^2 for the simulations with a major yield occurrence in year 13 (Figure 39). Miracle grow PM leads the mix in terms of yield throughout the years while Greenhouse mix is simply unable to match up and lags significantly in the later years.

Figure 39. Annual runoff, enrichment ratio and yield of the growth mix.

5.4 Discussions

The macro-pores at the soil surface can be obstructed by the contact material such as cheese cloth causing substantial and variable discrepancies between the pressure head set on the tension infiltrometer membrane and that at the soil surface (Bagarello et al., 2001). As the infiltrometer operates in the macro-pore range, where water transmission properties changes significantly with even small changes in pressure head (Reynolds and Zebchuk, 1996), this might have a significant impact on the tension infiltrometer results. Macro-pores issues coupled with the negative pressure and extremely high organic matter makes the mix buffer to change which can lead to lower hydraulic conductivity. Other unknown factors could also be responsible for the unexpected results.

Table 18. Additional hydro-physical characteristics of the readily available growing mix

Sample	Air space (% v/v)	Water holding capacity (% v/v)
Miracle grow PM	0.90 ± 0.41	44.25 ± 3.48
Redland PM	8.55 ± 3.49	44.72 ± 6.31
Scotts mix	5.30 ± 2.13	54.59 ± 3.15

All average of 3 tests

The following are the Regression equations for estimating the hydraulic conductivity of readily available plant growing mix in relation to the basic physical characteristics of the mix (Table 15, Table 18) for tension infiltrometer with an R^2 of 0.994.

Hydraulic conductivity = 0.506 Dry bulk density - 0.003 Water saturation by volume +
 0.125 pH - 0.019 Total organic content - 0.057 Air space + 0.008
 Total water holding capacity.

It is observed that the water saturation has negligible effect on the saturated hydraulic conductivity based on the regressing equations for estimating the hydraulic conductivity. This may be attributed to two factors: first, under saturated conditions, the micro pores are already clogged and there is no additional room for water to flow in the vertical direction; second being the intrinsic property of the tension infiltrometer which prevents the free fall of water as it is subjected to negative pressure and when the soil is already saturated it has no capacity to attract more water, hence, water saturation has no significant impact on the regression equation of tension infiltrometer. The predicted versus measured saturated hydraulic conductivity values for tension infiltrometer method is shown in Figure 40.

Figure 40. Predicted and measures values of saturated hydraulic conductivity as per Eq. 36.

Scotts mix tends to lose the most water to Evapotranspiration which can be attributed to the low infiltration rate which even leads to high runoff (Figure 38). Scotts mix has a high water holding capacity and moderate percentage air space, meaning it is easy on taking water but hard on releasing it hence it takes some time and effort to absorb more water. Redland PM has the least soil moisture throughout the simulation which might be due to its lower organic content among the mix under study (Figure 38). The water saturation value is high in Redland PM though most of its water is replaced by air when subjected to drainage. Deep percolation majorly depends on the infiltration rate and higher the saturated hydraulic conductivity higher is the percolation rate (Figure 38). Miracle grow PM has the highest infiltration rate which can be attributed to its high percolation. Runoff which basically depends on the infiltration and percolation follows

trends as expected with Miracle grow PM having the least runoff as it has the highest infiltration rate and highest percolation while Greenhouse and Scotts mix have the most runoff due to its low infiltration rate (Figure 39).

Greenhouse cultivation is used by sophisticated growers who monitor and control light, temperature, humidity, water, nutrients, and carbon dioxide of the whole system using hydroponics for water and nutrient management (Cook and Calvin, 2005). Yields can be extremely high in such systems, in some cases as much as 15 to 20 times greater than average field production as in Table 19 (Cook and Calvin, 2005).

Table 19. Average yield of greenhouse and fresh field farming techniques.

Type of cultivation	United States	Canada	Mexico
	Kg/m ²		
Average greenhouse tomato yield	48.4	49.4	15.6
Average fresh field tomato yield	3.2	1.5	2.8

Figure 41. The average yield for 20 years.

The average yield for 20 year varies between 21.5 kg/m² to 24.5 kg/m² for the infiltrometer based simulations. Redland PM which has the lowest organic content, above average dry bulk density, very high water saturation, air space and water holding capacity with above average infiltration rate ends up having below average yield (Figure 41) Miracle grow PM with an average organic content, lowest dry bulk density, water saturation, air space and water holding capacity has the highest infiltration rate and is the best mix in terms of yield (Figure 41). The yield values acquired through the simulation fall in the range of the highly sophisticated greenhouse farming (48.2 Kg/m²) and common fresh field tomato farming (3.2 Kg/m²) which is due to the use of some basic farming techniques along with appropriate nutrients.

5.5 Conclusions

Tension infiltrometer method of estimating infiltration properties is preferred in containerized agricultural cultivation as these use sprinkler systems which irrigate with high frequency on the surface hence the percolation is not observed and mix along with other amendments play primary role. The same applies for farms and other cultivation which are not subjected to tillage or disturbances and over time result in compaction of soil. With these understanding nurseries can develop best management strategies in containerized systems to optimize the use of water and agrochemical, thus minimizing water pollution from commercial horticultural and floricultural production.

VI. SEM-EDS ANALYSIS OF SOIL AMENDMENTS USED IN NURSERIES BEFORE AND AFTER FERTILIZER APPLICATION.

This chapter incorporated the surface adsorption that takes place on the unique material present in the readily available mix. The presence of elements on the surface of the organic material and other unique material is evaluated. Further the effects of common fertilizer on soil amendments used in agriculture systems are investigated with the help of SEM-EDS analysis.

6.1. Introduction

Florida is the second leading horticulture state in the United States with a total industry sale of \$12.33 billion for the year 2010, which include \$6.04 billion for landscape services and \$4.27 billion for wholesale nurseries (Hodges et al., 2011). Agricultural plant production represents an extremely intensive agricultural practice with large amounts of water and chemical fertilizer use. A thorough understanding of the agrochemical and the soil amendments used is of special interest as contamination of soils can cause surface and groundwater pollution and further resulting in ecosystem toxicity. The agrochemical fate in the environment is directly related to the retention capacity of soils which involves the adsorption on minerals and organic matter surface, cation exchange or precipitation of secondary minerals (Sayen et al., 2009). Upon application of fertilizer the fraction of chemical that evades the target site is subjected to runoff, leaching, adsorption and ultimately degradation. Runoff and leaching results in contamination of surface and ground water, the subsequent degradation of chemicals

generates toxic pollutants such as inorganic anions, metal ions, and synthetic organic chemicals (Carrizosa et al., 2003; Bhardwaja et al., 2012).

The extensive canal system coupled with Climate and soil conditions in South Florida facilitate the movement of agrochemicals. The most important indicator of surface waters health is the changing trends in water quality. As per the Florida Department of Environmental Protection (FDEP), of the 823 water bodies (rivers/streams, lakes, estuaries, and coastal waters) monitored between 1997 and 2007, about half are stable, a quarter were improving and a quarter were degrading as shown in Figure 42. Most of the degrading water bodies were in close vicinity of agricultural areas or farms (FDEP, 2008).

Figure 42. Changing trends in water quality of water bodies monitored by FDEP in Florida.

Nitrogen is concerned to be the limiting factor for any production in Florida's sandy soils and relatively larger quantities of nitrogen rich fertilizer are required to maximize yields. Nitrogen as ammonium ions and Phosphorus as phosphate ions are the

major ingredient of any fertilizer widely used in agriculture systems (Ma et al., 2011). Leaching of P has been a major concern in highly organic sandy soils with shallow water tables such as Florida due to rapid soil water flow and low P adsorption capacity (Kang et al., 2011; Nelson et al., 2005). Private Wells around the agricultural areas in Florida have regularly recorded nitrate-nitrogen or nitrate-nitrite-nitrogen concentrations exceeding the set MCL (FDEP, 2008). The most familiar health risks associated with consumption of water contaminated with nitrates is methemoglobinemia which occurs when bacteria found in the digestive tract reduces the nitrate (NO_3) to nitrite (NO_2) (Follet and Follet 2001). The nitrite then oxidizes the ferrous iron (Fe^{2+}) in hemoglobin to ferric iron (Fe^{3+}), forming methemoglobin, which hampers the oxygen transport capability of hemoglobin, and can be fatal if the oxygen deficiency persists (Pierzynski et al. 1994). The pesticides most frequently detected in the canals and in Biscayne Bay were Atrazine (16 ng/L), Chlorpyrifos (2.6 ng/L) found majorly near corn production, while Endosulfan (11 ng/L), Chlorothalonil (6.0 ng/L) and Metolachlor (9.0 ng/L) found around vegetable plantations (Harman Fetcho et al, 2005)

Many techniques are available to alleviate this leaching problem such as the development of slow release fertilizers which try to bridge the imbalance between the rate at which the nutrient is released from fertilizers to the rates at which the plants uptake the nutrient (Bhardwaja et al., 2012; Ni et al., 2010; Solihin et al., 2010; Zhang et al., 2009). Also delayed applications of P fertilizer does not account for any reduction in yields if timed precisely, relative to conventional applications of P (Lundy et al., 2012).

Total amount of fertilizers sold in Florida from 2010 to 2011 was 2.1×10^9 kg as per FDACS's Florida Fertilizer Consumption Reports (FFCR, 2012), with 144.1×10^6 kg

being nitrogen and 2.98×10^6 kg being phosphorus. The total quantity of pesticide used in 2007 was 19.1×10^6 kg (42×10^6 lbs) (FDACS, 2010). Sulfur (S) and chloride (Cl) are other nutrition elements that are required for crop growths, which are available as soluble SO_4^{2-} and Cl^- for plant uptake (Pu et al., 2011).

Soil Amendments are used to improve poor soils or just have soil representing a desired feature suiting the crop to be grown. Numerous ingredients from conventional materials such as peat, coir, manure, straw, vermiculite, blood meal, to uncommon ones such as Styrofoam, enhanced perforated rocks etc. are used as amendments all across the globe. Organic amendments currently used in agricultural soils do enhance their physical and chemical properties, but still it is not evident as to which part of the soil organic matter is modified upon being subjected to such amendments (Sebastia et al., 2007). The primary function of soil amendments is to improve soil structure. They also improve water retention in dry, coarse soils and the addition of organic material improves the water retention abilities of any soils.

Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectrometer (EDS) have been used by soil scientists and researchers to analyze the physical and mechanical characteristics of soils along with the elemental composition at the surface.

The study investigates the soil elements and the effects of readily available fertilizer on soil Amendments used in containerized agriculture systems. SEM-EDS were performed to quantify the scale and distribution of elements and fertilizer absorbance on the unique amendments present in the readily available soil.

6.2. Materials and Methods

6.2.1. Sample and Experimental Setup.

Experimental analyses were performed on the amendments material procured from commercially available mix including Miracle grow PM, Scotts mix and Redland PM (Section 2.2). The plant growth mixes have extremely high organic content which is to increase the water holding capacity of the mix which is preferred by nurseries, gardeners and farmers by subjecting the mix to organic amendments such as pine bark, manure etc.

Miracle-Grow liquid all-purpose plant food was used as the nutrient source for the mix. The composition of the Miracle-Grow Liquid All Purpose Plant Food applied consisted of 12% Total nitrogen (12 % as urea nitrogen), 4% available phosphate, 8% soluble potash, 0.1 % chelated iron and 0.05 % of each chelated manganese and chelated zinc. The suggested administration quantity was 30 ml per gallon of water.

The soil sample preparation was similar to the containerized agricultural systems where adequate packing is performed and the soil is allowed to settle in the container. Water along with the nutrient was administered imitating the irrigation technique for normal horticulture cultivation. After 24 hours, fraction of the major organic material and the unique amendments such as perforated rock or Styrofoam was selected and subjected to drying for a period of 2 hours. Then those treated material were introduced to gold sputtering to provide an electrically conductive thin film over the specimen for better representation since the material under study are organic or nonconductive in nature.

Further SEM- EDS analysis on the coated material was performed using JSM 5900 LV SEM.

6.3. Results

6.3.1. Elements on Organic Matter

Organic matter is vital for any mixes used for agricultural practices due to the immense benefits it brings to the mix. Organic matter Enhances aggregate stability, which improving water infiltration and soil aeration. It is known to elevate the soil's CEC and its ability to supply essential nutrients over time. While in farming conditions the subsequent drying and wetting results in chemical breakdown of organic matter, which increases the availability of the stored nutrient.

Apart from Carbon being the major constituent in all material surfaces, Nitrogen (N), sodium (Na), Magnesium (Mg), aluminum (Al), Silicon (Si), Phosphorus (P), Chlorine (Cl), Potassium (K), Iron (Fe), Calcium (Ca), and Sulfur (S) were investigated at the mix surface. The weight fraction of the elements on the surface of the organic material in mix excluding C in the initial state before being treated by the fertilizer is shown in Table 20.

Table 20. Elemental compositions at the surface of organic matter under initial state.

Element	Element weight (% w/w)		
	Miracle grow PM	Redland PM	Scotts
N	14.44	9.11	9.86
Na	0.72	0.10	0.57
Mg	0.12	0.56	0.14
Al	1.29	0.16	0.31
Si	7.47	0.60	0.84
P	0.00	0.00	1.18
Cl	1.58	0.00	0.29
K	7.52	0.89	0.00
Fe	0.00	0.00	0.45
Ca	1.55	12.48	0.00
S	0.00	8.27	0.00

It is observed that the organic particle in Miracle grow PM has the most N and K available and negligible P on its surface corresponding to region shown in Figure 45 a. Redland PM (Figure 46 a) and Scotts mix (Figure 47 a) having similar weight fraction for N and Si while having very low amount of K compared to Miracle grow PM. The weight percentage comparison of elements on the organic matter in different mix before fertilizer treatment is illustrated in Figure 43.

Figure 43. Elemental compositions on the organic surface in the mixes under initial state.

The weight fraction of the elements on the surface of the organic material in mix excluding C post fertilizer treatment is shown in Table 21. It is observed that the organic particle in Miracle grow PM (Figure 45 a) has almost the same weight percentage of N, with decrease in K weight percent and but has a significant P gain on its surface corresponding to region shown in Figure 45 b. Redland PM (Figure 46 b) and Scotts mix (Figure 47 b) having similar low weight fraction for P of approximately 4%. Redland's organic matter seems to acquire the most K compared to Miracle grow PM and Scotts. The weight percentage comparison of elements on the organic matter in different mix post fertilizer treatment is illustrated in Figure 44.

Table 21. Elemental compositions at the surface of the organic matter post fertilizer treatment.

Element	Element weight (% w/w)		
	Miracle grow PM	Redland PM	Scotts
N	13.82	14.73	23.39
Na	0.32	1.22	0.91
Mg	0.14	0.16	0.06
Al	0.18	0.65	0.53
Si	0.00	1.64	0.84
P	31.04	3.45	4.13
Cl	0.97	1.82	5.91
K	4.03	12.09	2.11
Fe	2.69	0.00	0.85
Ca	0.00	0.36	0.00
S	0.00	0.00	0.00

Figure 44. Elemental compositions on the organic surface in the mixes post fertilizer treatment.

Figure 45. Organic surface in Miracle grow PM, (a) Under initial and (b) Post fertilizer treatment condition

Figure 46. Organic surface in Redland PM, (a) Under initial and (b) Post fertilizer treatment condition.

Figure 47. Organic surface in Scotts Mix, (a) Under initial and (b) Post fertilizer treatment condition.

NPK fertilizers are very important for any plant production system, as Nitrogen in soils boosts the growth of plants, while its absence causes smaller than normal plant size with weak structure. Phosphorous is essential for root growth to overcome the growth conditions and Potassium helps the plants with richer fruit and vegetable production. In general Nitrogen uptake by the plants occurs as a result of mass flow which is the movement of nutrients toward the root when nearby water is taken up, while phosphorus uptake occurs as diffusion of the nutrients present on soil surfaces (Badruzzaman et al., 2012).

The weight fraction of the elements at the surface in clean (fertilizer not applied) and treated (fertilizer applied) condition for C, N, P and K is shown in Figure 48. It is expected for an organic matter surface to show high weight fractions of C compared to other elements (Figure 48 C), but after the nutrient application, it is observed that the weight fraction goes down to accommodate the other nutrients. Since all the mixes have N (Figure 48 N) imbedded in since forming them, the increase in N value is not that drastic as the ones observed for P (Figure 48 P) and to some extent for K (Figure 48 K).

Figure 48. C, N, P and K compositions on the organic surface in the mixes under initial and post fertilizer treatment condition.

6.3.2. Elements on Inorganic Matter

The amendments are unique and vary for the different mixes such as Miracle grow PM has porous rocks (Figure 49 a, b) and pine bark, while the Scotts mix has fertilizer pellets with smooth surface and smooth white pellet is observed in Redland PM (Figure 50 a, b). The weight fraction of the elements on the surface of the inorganic material in mix excluding C in the initial state before being treated by the fertilizer for Miracle grow PM' rock, Scotts fertilizer pellets and Redland PM's white pellet are shown in Figure 51, 52 and 53 respectively. It is observed that the inorganic particle in Miracle

grow PM absorbs the most N, O and P along with fractions of K while replacing Si in the system (Figure 51) from its surfaces corresponding to regions shown in Figure 49. Redland PM inorganic particle has a contrasting nature to that of from Miracle grow PM as its replaces N, O and k with Si from its surfaces (Figure 52) corresponding to regions shown in Figure 50.

Figure 49. Rock surface in Miracle grow PM, (a) Under initial and (b) post fertilizer treatment condition.

Figure 50. White pellet in Redland PM, (a) Under initial and (b) Post fertilizer treatment condition.

Figure 51. Elemental compositions at the surface of the rock in Miracle grow PM, (a) Under initial and (b) Post fertilizer treatment condition.

Figure 52. Elemental compositions at the surface of the white pellet in Redland PM, (a) Under initial and (b) Post fertilizer treatment condition.

Scotts mix's fertilizer pellets is mostly organic in nature and has the tendency to burst under stress and disturbance to make way for the nutrients to come in contact with the surrounding soil. Post cracking of shell and leaching the nutrient the fertilizer pellet becomes dormant in nature with minimum affinity to NPK or other chemical (Figure 53).

Figure 53. Elemental compositions at the surface of the fertilizer pellet in Scotts, (a) Under initial and (b) Post fertilizer treatment condition.

6.4. Discussions

Soil Amendments are well known to improve the water retention abilities of any soils. The organic fraction of mix under study does increase the retention for the vital NPK nutrient (Figure 48). Owing to the fact that Florida sandy soil requires nitrogen rich fertilizer, it is desired to have amendments that could hold on to the N which is lost to the environment. The average fertilizer application rates were as shown in Table 22 (Cohen et al., 2007).

Table 22. Fertilizer application rates for Florida.

Type of Application	N application rate (g N/m ² /yr)
Residential lawns	8-24
Landscape plants	8-16
Athletic fields	20-28
Vegetable	18-20

Approximately 80% of the nitrogen uptake by the plants occurs as a result of mass flow which is the movement of nutrients toward the root when nearby water is taken up. While phosphorus uptake occurs as diffusion of the nutrients that are adsorbed onto soil surfaces (Badruzzaman et al., 2012). In the year 2010, 144.1×10^6 kg of nitrogen and 2.98×10^6 kg of phosphorus was sold in Florida for agricultural purposes (FFCR, 2012). The average leaching loss from any fertilizer application is assumed to be 6 % of the total fertilizer applied (Addiscott, 2007), thus the amount of nitrogen leached as per the amount of nitrogen sold would be 8.64×10^6 kg.

Pesticide Sorption is largely affected by the solubility of the pesticide and the amount of water percolating through soil. The most useful indices for quantifying pesticide sorption on soil are the of sorption index and partition coefficient (Wolf, 1996).

36

$$K_p = (K_{oc}) (OM) (0.0058)$$

Where,

K_p : index of sorption for a given pesticide on a particular soil.

K_{oc} : partition coefficient.

OM: percent organic matter in the soil (%).

The partition coefficient can be normalized in terms of soil organic matter as follows (Dragun, 1988):

37

$$K_{oc} = 1.724 K_{om}$$

Where,

1.724: conversion factor from organic matter to organic carbon,

K_{om} : partition coefficient normalized to organic matter (L/kg), and

f_{om} : fraction organic matter (g/g).

The pesticide sorption (Equation 36, 37) coupled with the already characterized values for hydraulic conductivity and organic matter (Table 23) can be very useful while comparing the media in terms of pesticide sensitivity.

Table 23. Saturated hydraulic conductivity and organic matter of the mixes.

Sample	Constant head saturated hydraulic conductivity (cm/hr)	Organic matter (%)
Pine Island	136.8 ± 21.6	72.1
Greenhouse	151.2 ± 18	43.8
Nursery	144 ± 7.2	69.7
Costa Farms	104.4 ± 7.2	60.5
Redland PM	68.4 ± 10.2	32.2
Miracle grow PM	75.6 ± 15.3	38.2
Miracle grow GS	79.2 ± 10.2	42.6
Redland BM	159.1 ± 6.1	22.4
Biosolids	68.4 ± 3.1	35.4
Scotts	57.6 ± 2.0	43.0

Pesticides with large K_{oc} and long half-life tend to remain near ground surface and therefore more prone to runoff loss while small K_{oc} values and long half-life pesticides and more prone to leaching. Pesticides with same K_{oc} and half-life will then depend on

the fraction of organic matter presents in the mixes then follow the trend of the hydraulic conductivity for leaching and runoff behavior.

6.5. Conclusions

The presence of organic amendments does helps in retaining the water which are generally rich with nutrients under containerized systems. The fact that organic matter interact with the plant better in terms of chemical transport makes this amendments even more promising. The inorganic amendments have extremely high surface area due to their porous nature which can be a major source of nutrient absorption as opposed to leaching.

VII. CONCLUSIONS AND FUTURE WORKS

Each chapter included in this dissertation attempts to cover the hypotheses and objectives proposed in this study. This basic idea of this study was to understand the mixes and characterize them in terms of methods normally used for common soil. After characterizing and analyzing the results, the following facts and assumptions are noteworthy:

- Standard laboratory methods of measuring hydraulic conductivity may not apply to these mixes based on the variability and/or uncertainty observed while comparing the constant head and falling head measurements
- Saturated hydraulic conductivity should be a unique property of a medium provided that the medium does not change significantly and given the differences between the constant head and falling head measurements, it would be appropriate to regard the results as tentative. Further research is needed to address this discrepancy.
- The EAHM was developed for normal soils usually available in Florida with emphasis given to sand, silt, clay and organic matter for soil compositions. Since the media is so different from the common soil, it would be safe to say that the model was not developed for the mixes under study, nevertheless provides a basic idea of the hydrological behavior assuming conditions similar to soil.
- This study does not endorse any of the mixes investigated [Commercial (Miracle grow PM , Miracle grow BM, Scotts mix) or local (Redland PM, Redland BM, Pine island mix and costa farms mix)] irrespective of the unbiased results indicating some mixes to be better than other regarding yield, leachate, nutrient sorption.

7.1 Conclusions

A brief summary of the outcome of the study already illustrated in the previous chapters is outlines as follows:

1. The mixes acquired locally as well as commercially are so much similar in nature and particle size distribution yet they tend to show extremely varying hydro-physical characteristics.
2. The hydraulic conductivity which is a unique property of the media is very sensitive to changes in measuring techniques and scenarios. Due to the variability and/or uncertainty of saturated hydraulic conductivity, just referring to the applied measuring device is not enough; a detailed description of the method and parameters used for evaluation should be outlined and discrepancies between different measuring techniques should be resolved or adequately explained.
3. The understanding of which and to what extent the basic hydro-physical parameters affects the hydraulic conductivity can be a vital tool for the nursery growers. With the suggested generalized hydraulic conductivity equation any one can manipulate the hydrologic properties to suit its need to some extent for such mixes.
4. The mixes characterized in this study may be assumed to be better than the traditional soil from an economical and environmental point of view, as they weigh less for the same volume, and the amendments do enhance the desired properties to suit horticulture needs.
5. The average yield of these mixes is significantly higher than the traditional farming technique yield, and is even competitive compared to the sophisticated greenhouse

farming techniques without the hassle of intensive monitoring and controlling all the parameters.

6. The pollution due to the excessive use of water and agrochemical is a major concern and depends on the type of cultivation and the extent to which the system is controlled.
 - Closed systems: when the type of cultivation is closed system and water is provided in form of irrigation in controlled amount then leaching of the applied chemical is the major point source. Since the hydraulic conductivity is extremely low as evaluated by the tension infiltrometer this form of production would be preferred in terms preventing nutrient pollution.
 - Open system: In open system the water is provided in the form of irrigation as well as natural precipitation which makes it difficult to contain the water and the agrochemical in it. Since the hydraulic conductivity is relatively high as evaluated by the constant head and falling head techniques, this form of production would lead to leaching of the agrochemical as well as the nutrient in surface runoff.
7. The presence of organic amendments in the mix enhances its water retaining capacity, which means that the system requires less water thus losing less water rich with nutrients.
8. Inorganic amendments have extremely high surface area due to their porous nature which provides stability by allowing the right amount packing of the mix and preventing unnecessary compaction. The macropores provide pathways for water and nutrient exchange, while the surface sites can be a major source of nutrient absorption which would otherwise leach.

7.2 Future Study Recommendations

7.2.1 Experimental Recommendations

- Acquisition and characterization of more mixes to have a better representation of mix used in Florida.
- Characterize the plant growth mixtures in terms of even more hydro-physical parameters to have a better and robust mathematical model to predict hydraulic conductivity as a function of the basic hydro-physical parameters.
- Perform lab experiments to test the evaluated results for leaching of agrochemicals from the mixes.

7.2.2 Modeling Recommendations

- Expand the grid and model the response patterns of better defined soil amendments present in readily available mix to different water and fertilizer use scenarios.

7.3 Future work

- Test the evaluated results in the field for the hydro-physical characteristics of the mix to account for all those change over time which include compaction, decaying, erosion, etc.
- Perform field experiments to test the accuracy of the suggested mathematical model for estimating the hydraulic conductivity of the mix.
- Test the evaluated results in the field for yield and leaching of agrochemicals from the mixes.

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APPENDICES

Appendix A

Constant Head Hydraulic Conductivity:

The hydraulic conductivity of the sample can be calculated by measuring the time and the constant head using the following equation (Darcy's law):

$$Q = q t = K A i$$

where,

Q: total quantity of flow (cm³);

q: flow rate (cm³/sec)

A: area of specimen (cm²) calculated as: $A = (\pi/4) D^2$; and

i: hydraulic head gradient , $i = h/L$.

h: head difference (cm).

L: length of specimen (cm); and

Rewriting in terms of hydraulic conductivity:

$$k = \frac{Q L}{A t h} \text{ or } \frac{q L}{A h}$$

Falling Head Hydraulic Conductivity:

The initial head difference h_1 at time $t = t_1$ is recorded, and

Final head difference h_2 at time $t = t_2$, when water is allowed to flow through the soil.

Velocity of fall of water level in the burette:

$$v = -\frac{dh}{dt}$$

Flow of water into the sample:

$$q_{in} = -a \frac{dh}{dt}$$

where,

a: area of burette in falling head setup (cm²) calculated as: $A = (\pi/4) D^2$.

From Darcy's law, flow out of the sample is:

$$q_{out} = kiA = k \frac{h}{L} A$$

For continuity,

$$q_{in} = q_{out}$$

$$-a \frac{dh}{dt} = k \frac{h}{L} A$$

Separating the variables and integrating over the limits,

$$a \int_{h_2}^{h_1} \frac{dh}{h} = k \frac{A}{L} \int_{t_2}^{t_1} dt$$

$$a \ln\left(\frac{h_1}{h_2}\right) = k \frac{A}{L} (t_1 - t_2)$$

$$k = \frac{aL}{At} \ln \left(\frac{h_1}{h_2} \right)$$

Also,

$$k = 2.303 \frac{aL}{At} \log_{10} \left(\frac{h_1}{h_2} \right)$$

Thus measuring h_1 and h_2 over time t , k can be computed.

Tension Infiltrometer-Based Hydraulic Conductivity:

Steady state flux from a shallow circular pond is given by (Wooding, 1968):

$$Q = K_h [1 + 4\lambda_c/(\pi r_0)] \quad (1)$$

where,

Q : steady state flux from a shallow circular pond (m/s),

r_0 : radius of shallow circular pond (m),

h : supply tension, (m), and

λ_c : macroscopic capillary length (m), $\lambda_c = 1/\alpha$

K_h is the exponential hydraulic conductivity function (Gardner, 1958):

$$K_h = K_s \exp(\alpha h) \quad (2)$$

Combining Eq. (1) and (2) we have:

$$Q = K_s \exp(\alpha h) \left[1 + \frac{4}{(\alpha \pi r_0)} \right] \quad (3)$$

If only two tensions were used, α can be estimated as (Hussen and Warrick, 1993):

$$\alpha = \frac{\ln \left[\frac{Q_2}{Q_1} \right]}{(h_2 - h_1)} \quad (4)$$

where,

h_1 and h_2 are the two tensions and the corresponding steady state fluxes.

Appendix B

Appendix C

Constant head:

Sample	Column height	Volume of water collected	Time (sec)				Water temp	Head	Kch
Sieve range (mm)	cm	L	1	2	3	Avg	°F	cm	cm/hr
Pine Island mix									
38.1- 4.75	9.8	1	117	115	116.0	116.0	77.6	75.7	132.9
2 - 0.6	9.8	1	122	127	124.5	124.5	78.6	75.6	124.7
0.425 - Pan	9.7	1	168	170	169.0	169.0	77.2	75.8	90.4
Mix	10.5	1	109	111	110.0	110.0	77.1	75.5	150.5
Greenhouse mix									
38.1- 2.36	11.8	1	98	97	97.5	97.5	75.5	76.4	188.2
2 - 0.5	10.6	1	103	102	102.5	102.5	75.9	76.3	162.3
0.425-Pan	8.9	1	143	138	140.5	140.5	76.0	76.1	99.3
Mix	10.5	1	100	99	99.50	99.5	75.9	75.6	147.6
Nursery mix									
38.1- 2.36	11.4	1	101	96	98.5	98.5	75.5	75.8	182.6
2 - 0.5	10.8	1	110	109	109.5	109.5	75.8	75.9	154.9
0.425 - Pan	12.4	1	155	151	153.0	153.0	75.7	75.9	127.1
Mix	11.6	1	116	114	115.0	115.0	76.1	75.9	158.3
Costa Farms mix									
38.1- 2.36	11.4	1	133	134	133.5	133.5	74.5	75.8	134.7
2 - 0.5	11.3	1	142	147	144.5	144.5	73.6	75.8	122.7
0.425 - Pan	12.4	1	175	172	173.5	173.5	72.9	75.8	112.3
Mix	11.1	1	154	153	153.5	153.5	72.7	75.8	108.0
Redland PM									
38.1- 2.36	12.1	0.5	66	67	66	66.5	81.5	74.9	144.5
2 - 0.5	11.7	0.5	68	69	70	68.5	82.9	75.4	135.1
0.425 - Pan	12.7	0.5	115	131	143	123.0	81.6	75.4	81.7
Mix	11.7	0.5	144	109	126	126.5	80.5	74.9	73.6
Miracle grow PM									
38.1- 2.36	10.8	0.5	81	83	82	82.0	82.9	76.2	103.1
2 - 0.5	12.2	0.5	71	71	77	71.0	83.9	76.2	134.5
0.425 - Pan	13.3	0.5	129	146	163	137.5	86.0	76.2	75.9
Mix	10.8	0.5	90	113	112	101.5	81.6	76.2	79.2
Miracle grow GS									
38.1- 2.36	12.1	0.5	65	66	66	65.5	84.2	76.2	144.2
2 - 0.5	11.7	0.5	82	83	82	82.5	83.6	76.2	111.0
0.425 - Pan	11.7	0.5	116	118	126	117.0	82.9	76.2	78.3

Mix	12.7	0.5	130	99	105	114.5	82.4	76.2	90.0
Redland BM									
38.1- 4.75	12.1	0.5	59	60	60	59.5	77.5	74.8	161.7
2 - 0.6	12.2	0.5	78	75	79	76.5	77.2	75.3	126.2
0.425 - Pan	12.5	0.5	82	77	77	79.5	78.2	75.1	124.4
Mix	12.5	0.5	58	57	57	57.5	78.0	74.6	169.2
Biosolids	0.0								
38.1- 2.36	12.5	0.5	75	75	79	75.0	77.4	74.6	132.7
2 - 0.5	12.1	0.5	60	61	63	60.5	77.0	73.6	161.7
0.425 - Pan	13.1	0.5	101	99	101	100.0	76.2	73.6	106.0
Mix	11.4	0.5	122	121	125	121.5	76.8	75.6	72.0
Scotts mix									
38.1- 2.36	12.7	0.5	58	55	56	56.5	79.0	72.5	184.9
2 - 0.5	12.5	0.5	65	64	65	64.5	79.2	72.5	158.8
0.425 - Pan	13.0	0.5	139	138	144	138.5	81.1	72.5	76.9
Mix	12.7	0.5	170	169	171	169.5	82.4	72.5	61.6

Falling head:

Pine Island mix

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/hr	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	11.43	4.84	30	90	0.48	482.24	513.29	44.09
38.1- 2.36	1.56	30.18	11.43	3.62	30	80	0.43	575.64		
38.1- 2.36	1.56	30.18	11.43	6.63	20	90	0.65	481.97		
2 - 0.6	1.56	30.18	12.38	5.74	20	90	0.65	602.97	693.89	187.11
2 - 0.6	1.56	30.18	12.38	3.72	30	70	0.37	524.12		
2 - 0.6	1.56	30.18	12.38	3.02	20	70	0.54	954.56		
0.425 - Pan	1.56	30.18	11.43	14.1	20	90	0.65	226.63	241.29	13.29
0.425 - Pan	1.56	30.18	11.43	7.55	30	70	0.37	238.43		
0.425 - Pan	1.56	30.18	11.43	11.38	20	80	0.60	258.81		
Mix	1.56	30.18	11.43	8.5	20	100	0.70	402.27	381.12	34.07
Mix	1.56	30.18	11.43	8.38	20	100	0.70	408.03		
Mix	1.56	30.18	11.43	7.68	30	100	0.52	333.06		

Greenhouse mix

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/hr	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	12.07	4.93	30	90	0.48	499.95	577.68	71.08
38.1- 2.36	1.56	30.18	12.07	4.63	20	80	0.60	671.74		
38.1- 2.36	1.56	30.18	12.07	3.92	30	80	0.43	561.35		
2 - 0.6	1.56	30.18	12.22	6.14	20	90	0.65	556.41	510.27	40.07
2 - 0.6	1.56	30.18	12.22	5.44	30	90	0.48	458.71		
2 - 0.6	1.56	30.18	12.22	4.32	30	80	0.43	515.70		
0.425 - Pan	1.56	30.18	12.38	9.97	20	70	0.54	289.14	286.55	52.94
0.425 - Pan	1.56	30.18	12.38	5.57	30	70	0.37	350.04		
0.425 - Pan	1.56	30.18	12.38	15.7	20	90	0.65	220.45		
Mix	1.56	30.18	11.75	10	30	100	0.52	262.89	280.35	29.89
Mix	1.56	30.18	11.75	10.28	30	100	0.52	255.73		
Mix	1.56	30.18	11.75	10.9	20	100	0.70	322.41		

Nursery mix

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/hr	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	12.07	5.53	20	90	0.65	610.20	646.08	77.34
38.1- 2.36	1.56	30.18	12.07	3.83	30	80	0.43	574.54		
38.1- 2.36	1.56	30.18	12.07	3.73	20	70	0.54	753.51		
2 - 0.6	1.56	30.18	12.38	5.24	20	80	0.60	608.91	655.85	133.17
2 - 0.6	1.56	30.18	12.38	4.33	30	80	0.43	521.36		
2 - 0.6	1.56	30.18	12.38	3.02	20	60	0.48	837.27		
0.425 - Pan	1.56	30.18	12.38	10.57	40	80	0.30	150.93	208.57	70.99
0.425 - Pan	1.56	30.18	12.38	15.51	10	80	0.90	308.58		
0.425 - Pan	1.56	30.18	12.38	7.75	40	70	0.24	166.19		
Mix	1.56	30.18	11.75	9.13	25	100	0.60	331.62	334.00	23.80
Mix	1.56	30.18	11.75	9.65	20	100	0.70	364.25		
Mix	1.56	30.18	11.75	8.59	30	100	0.52	306.11		

Costa Farms mix

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/hr	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	11.11	5.23	30	90	0.48	433.79		
38.1- 2.36	1.56	30.18	11.11	5.59	20	90	0.65	555.64		
38.1- 2.36	1.56	30.18	11.11	3.22	30	70	0.37	543.39	510.94	54.78
2 - 0.6	1.56	30.18	11.43	5.34	30	90	0.48	437.09		
2 - 0.6	1.56	30.18	11.43	6.15	20	90	0.65	519.59		
2 - 0.6	1.56	30.18	11.43	3.32	30	70	0.37	542.21	499.63	45.18
0.425 - Pan	1.56	30.18	9.53	8.77	20	90	0.65	303.80		
0.425 - Pan	1.56	30.18	9.53	7.56	30	90	0.48	257.42		
0.425 - Pan	1.56	30.18	9.53	5.74	20	70	0.54	386.61	315.94	53.44
Mix	1.56	30.18	12.065	8.1	20	100	0.70	445.59		
Mix	1.56	30.18	12.065	7.34	30	100	0.52	367.85		
Mix	1.56	30.18	12.065	7.91	25	100	0.60	393.03	402.16	32.39

Redland PM

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/sec	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	12.07	5.64	20	96	0.68	623.97		
38.1- 2.36	1.56	30.18	12.07	2.82	30	70	0.37	674.08		
38.1- 2.36	1.56	30.18	12.07	3.52	20	70	0.54	798.46	698.84	73.35
2 - 0.6	1.56	30.18	11.7	5.83	20	88	0.64	552.67		
2 - 0.6	1.56	30.18	11.7	3.92	20	70	0.54	695.01		
2 - 0.6	1.56	30.18	11.7	2.42	30	60	0.30	622.90	623.53	58.11
0.425 - Pan	1.56	30.18	12.7	9.46	40	80	0.30	172.96		
0.425 - Pan	1.56	30.18	12.7	13.19	20	80	0.60	248.10		
0.425 - Pan	1.56	30.18	12.7	11.38	30	80	0.43	203.46	208.18	30.86
Mix	1.56	30.18	11.7	9.27	20	88	0.64	347.58		
Mix	1.56	30.18	11.7	6.35	20	70	0.54	429.04		
Mix	1.56	30.18	11.7	3.72	30	60	0.30	405.22	393.95	41.88

Miracle grow PM

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/sec	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	10.8	5.64	40	90	0.35	288.63		
38.1- 2.36	1.56	30.18	10.8	5.54	30	80	0.43	355.41		
38.1- 2.36	1.56	30.18	10.8	7.45	20	90	0.65	405.28	349.77	58.53
2 - 0.6	1.56	30.18	12.2	5.83	20	90	0.65	585.03		
2 - 0.6	1.56	30.18	12.2	3.93	30	80	0.43	565.95		
2 - 0.6	1.56	30.18	12.2	2.41	30	60	0.30	652.21	601.07	45.31
0.425 - Pan	1.56	30.18	13.34	20.56	20	90	0.65	181.39		
0.425 - Pan	1.56	30.18	13.34	11.09	30	70	0.37	189.44		
0.425 - Pan	1.56	30.18	13.34	7.95	30	60	0.30	216.19	195.68	18.22
Mix	1.56	30.18	10.8	10.57	20	90	0.65	285.65		
Mix	1.56	30.18	10.8	6.75	20	70	0.54	372.57		
Mix	1.56	30.18	10.8	4.12	30	60	0.30	337.73	331.99	43.74

Miracle grow GS

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/sec	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	12.07	4.94	20	90	0.65	683.08		
38.1- 2.36	1.56	30.18	12.07	4.23	20	80	0.60	735.26		
38.1- 2.36	1.56	30.18	12.07	2.01	30	60	0.30	773.67	730.67	37.13
2 - 0.6	1.56	30.18	11.7	7.96	20	90	0.65	410.93		
2 - 0.6	1.56	30.18	11.7	6.85	30	90	0.48	348.79		
2 - 0.6	1.56	30.18	11.7	4.83	40	80	0.30	312.09	357.27	40.79
0.425 - Pan	1.56	30.18	11.7	11.17	20	90	0.65	292.83		
0.425 - Pan	1.56	30.18	11.7	7.46	20	70	0.54	365.20		
0.425 - Pan	1.56	30.18	11.7	4.32	30	60	0.30	348.94	335.66	31.00
Mix	1.56	30.18	12.7	12.18	20	90	0.65	291.51		
Mix	1.56	30.18	12.7	9.66	22	80	0.56	315.48		
Mix	1.56	30.18	12.7	4.63	30	60	0.30	353.40	320.13	25.48

Redland BM

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/sec	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	12.07	3	30	70	0.37	633.64		
38.1- 2.36	1.56	30.18	12.07	5	20	90	0.65	674.88		
38.1- 2.36	1.56	30.18	12.07	3	30	80	0.43	733.50	680.67	40.97
2 - 0.6	1.56	30.18	12.19	4	30	70	0.37	479.95		
2 - 0.6	1.56	30.18	12.19	8	20	90	0.65	425.99		
2 - 0.6	1.56	30.18	12.19	6	30	80	0.43	370.40	425.45	44.73
0.425 - Pan	1.56	30.18	12.45	7	30	70	0.37	280.11		
0.425 - Pan	1.56	30.18	12.45	13	20	90	0.65	267.74		
0.425 - Pan	1.56	30.18	12.45	9	30	80	0.43	252.20	266.68	11.42
Mix	1.56	30.18	12.45	3	30	70	0.37	653.59		
Mix	1.56	30.18	12.45	6	20	90	0.65	580.11		
Mix	1.56	30.18	12.45	4	30	80	0.43	567.44	600.38	37.98

Biosolids

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm		cm/sec	cm/hr	cm/hr
38.1- 2.36	1.56	30.18	12.45	7	20	90	0.65	497.23		
38.1- 2.36	1.56	30.18	12.45	4	30	70	0.37	490.19		
38.1- 2.36	1.56	30.18	12.45	5	30	80	0.43	453.95	480.46	18.96
2 - 0.6	1.56	30.18	12.07	4	30	80	0.43	550.12		
2 - 0.6	1.56	30.18	12.07	5	20	90	0.65	674.88		
2 - 0.6	1.56	30.18	12.07	3	30	70	0.37	633.64	619.55	51.90
0.425 - Pan	1.56	30.18	13.08	9	30	80	0.43	264.96		
0.425 - Pan	1.56	30.18	13.08	12	20	70	0.54	253.81		
0.425 - Pan	1.56	30.18	13.08	7	30	70	0.37	294.28	271.02	17.07
Mix	1.56	30.18	11.43	5	30	70	0.37	360.02		
Mix	1.56	30.18	11.43	9	20	90	0.65	355.05		
Mix	1.56	30.18	11.43	6	30	80	0.43	347.30	354.13	5.23

Scotts mix

Sieve range	a	A	L	t	h ₁	h ₀	Log(h ₀ /h ₁)	Kfh	Avg Kfh	std
mm	cm ²	cm ²	cm	sec	cm	cm			cm/hr	cm/hr
38.1- 2.36	1.56	30.18	12.7	3	20	70	0.544	985.760		
38.1- 2.36	1.56	30.18	12.7	5	20	90	0.653	710.107		
38.1- 2.36	1.56	30.18	12.7	4	20	80	0.602	818.124	838.00	113.41
2 - 0.6	1.56	30.18	12.45	5	30	80	0.426	453.955		
2 - 0.6	1.56	30.18	12.45	7	20	90	0.653	497.235		
2 - 0.6	1.56	30.18	12.45	6	30	70	0.368	326.794	425.99	72.34
0.425 - Pan	1.56	30.18	12.95	15	30	70	0.368	135.967		
0.425 - Pan	1.56	30.18	12.95	18	20	90	0.653	201.135		
0.425 - Pan	1.56	30.18	12.95	10	30	60	0.301	166.846	167.98	26.62
Mix	1.56	30.18	12.7	9	30	80	0.426	257.261		
Mix	1.56	30.18	12.7	6	20	60	0.477	432.232		
Mix	1.56	30.18	12.7	13	30	90	0.477	199.492	296.33	98.95

Tension infiltrometer

Pine Island mix

Time	Head (154)	Head difference	Volume	Cumulative volume	Head (40)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	42				128			
10	72	30	46.65	46.65	138	10	15.55	15.55
20	105	33	51.315	97.965	151	13	20.215	35.765
30	125	20	31.1	129.065	163	12	18.66	54.425
40	140	15	23.325	152.39	176	13	20.215	74.64
50	151	11	17.105	169.495	191	15	23.325	97.965
60	161	10	15.55	185.045	200	9	13.995	111.96
70	167	6	9.33	194.375	210	10	15.55	127.51
80	173	6	9.33	203.705	219	9	13.995	141.505
90	177	4	6.22	209.925	224	5	7.775	149.28
100	181	4	6.22	216.145	230	6	9.33	158.61
110	182	1	1.555	217.7	236	6	9.33	167.94
120	183	1	1.555	219.255	241	5	7.775	175.715
130	184	1	1.555	220.81	243	2	3.11	178.825
140	184	0	0	220.81	248	5	7.775	186.6
150	185	1	1.555	222.365	250	2	3.11	189.71
160	185	0	0	222.365	251	1	1.555	191.265
170	186	1	1.555	223.92	253	2	3.11	194.375
180	186	0	0	223.92	254	1	1.555	195.93
210	187	1	1.555	225.475	256	2	3.11	199.04
240	188	1	1.555	227.03	258	2	3.11	202.15
270	188	0	0	227.03	262	4	6.22	208.37
300	189	1	1.555	228.585	264	2	3.11	211.48
360	190	1	1.555	230.14	269	5	7.775	219.255
420	191	1	1.555	231.695	274	5	7.775	227.03
480	192	1	1.555	233.25	278	4	6.22	233.25
540	193	1	1.555	234.805	283	5	7.775	241.025
600	194	1	1.555	236.36	288	5	7.775	248.8
660	194	0	0	236.36	293	5	7.775	256.575
720	195	1	1.555	237.915	297	4	6.22	262.795
780	196	1	1.555	239.47	303	6	9.33	272.125
840	196	0	0	239.47	307	4	6.22	278.345
900	197	1	1.555	241.025	312	5	7.775	286.12
960	197	0	0	241.025	316	4	6.22	292.34

Greenhouse mix

Time	Head (153)	Head difference	Volume	Cumulative volume	Head (40)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	79				113			
10	99	20	31.1	31.1	116	3	4.665	4.665
20	118	19	29.545	60.645	120	4	6.22	10.885
30	135	17	26.435	87.08	125	5	7.775	18.66
40	143	8	12.44	99.52	129	4	6.22	24.88
50	150	7	10.885	110.405	133	4	6.22	31.1
60	156	6	9.33	119.735	137	4	6.22	37.32
70	165	9	13.995	133.73	142	5	7.775	45.095
80	169	4	6.22	139.95	146	4	6.22	51.315
90	172	3	4.665	144.615	151	5	7.775	59.09
100	176	4	6.22	150.835	156	5	7.775	66.865
110	180	4	6.22	157.055	159	3	4.665	71.53
120	184	4	6.22	163.275	162	3	4.665	76.195
130	187	3	4.665	167.94	167	5	7.775	83.97
140	191	4	6.22	174.16	170	3	4.665	88.635
150	194	3	4.665	178.825	173	3	4.665	93.3
160	196	2	3.11	181.935	176	3	4.665	97.965
170	200	4	6.22	188.155	179	3	4.665	102.63
180	202	2	3.11	191.265	183	4	6.22	108.85
210	207	5	7.775	199.04	190	7	10.885	119.735
240	210	3	4.665	203.705	198	8	12.44	132.175
270	213	3	4.665	208.37	206	8	12.44	144.615
300	216	3	4.665	213.035	211	5	7.775	152.39
360	219	3	4.665	217.7	219	8	12.44	164.83
420	221	2	3.11	220.81	225	6	9.33	174.16
480	223	2	3.11	223.92	231	6	9.33	183.49
540	227	4	6.22	230.14	235	4	6.22	189.71
600	231	4	6.22	236.36	238	3	4.665	194.375
660	233	2	3.11	239.47	241	3	4.665	199.04
720	235	2	3.11	242.58	243	2	3.11	202.15
780	237	2	3.11	245.69	246	3	4.665	206.815
840	239	2	3.11	248.8	247	1	1.555	208.37
900	240	1	1.555	250.355	249	2	3.11	211.48
960	241	1	1.555	251.91	251	2	3.11	214.59

Nursery mix

Time	Head (181)	Head difference	Volume	Cumulative volume	Head (50)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	45				72			
10	51	6	9.33	9.33	76	4	6.22	6.22
20	54	3	4.665	13.995	85	9	13.995	20.215
30	59	5	7.775	21.77	94	9	13.995	34.21
40	64	5	7.775	29.545	102	8	12.44	46.65
50	71	7	10.885	40.43	108	6	9.33	55.98
60	79	8	12.44	52.87	115	7	10.885	66.865
70	87	8	12.44	65.31	120	5	7.775	74.64
80	92	5	7.775	73.085	123	3	4.665	79.305
90	96	4	6.22	79.305	125	2	3.11	82.415
100	102	6	9.33	88.635	129	4	6.22	88.635
110	107	5	7.775	96.41	132	3	4.665	93.3
120	113	6	9.33	105.74	137	5	7.775	101.075
130	117	4	6.22	111.96	141	4	6.22	107.295
140	120	3	4.665	116.625	143	2	3.11	110.405
150	123	3	4.665	121.29	144	1	1.555	111.96
160	125	2	3.11	124.4	147	3	4.665	116.625
170	128	3	4.665	129.065	150	3	4.665	121.29
180	131	3	4.665	133.73	151	1	1.555	122.845
210	137	6	9.33	143.06	159	8	12.44	135.285
240	142	5	7.775	150.835	163	4	6.22	141.505
270	146	4	6.22	157.055	167	4	6.22	147.725
300	148	2	3.11	160.165	171	4	6.22	153.945
360	155	7	10.885	171.05	176	5	7.775	161.72
420	159	4	6.22	177.27	182	6	9.33	171.05
480	163	4	6.22	183.49	185	3	4.665	175.715
540	168	5	7.775	191.265	188	3	4.665	180.38
600	171	3	4.665	195.93	190	2	3.11	183.49
660	174	3	4.665	200.595	192	2	3.11	186.6
720	179	5	7.775	208.37	193	1	1.555	188.155
780	183	4	6.22	214.59	194	1	1.555	189.71
840	186	3	4.665	219.255	195	1	1.555	191.265
900	190	4	6.22	225.475	196	1	1.555	192.82
960	193	3	4.665	230.14	197	1	1.555	194.375

Costa Farms mix

Time	Head (135)	Head difference	Volume	Cumulative volume	Head (40)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	86				61			
10	96	10	15.55	15.55	73	12	18.66	18.66
20	112	16	24.88	40.43	94	21	32.655	51.315
30	124	12	18.66	59.09	112	18	27.99	79.305
40	134	10	15.55	74.64	129	17	26.435	105.74
50	141	7	10.885	85.525	142	13	20.215	125.955
60	147	6	9.33	94.855	150	8	12.44	138.395
70	151	4	6.22	101.075	157	7	10.885	149.28
80	156	5	7.775	108.85	163	6	9.33	158.61
90	158	2	3.11	111.96	167	4	6.22	164.83
100	162	4	6.22	118.18	171	4	6.22	171.05
110	165	3	4.665	122.845	174	3	4.665	175.715
120	167	2	3.11	125.955	176	2	3.11	178.825
130	169	2	3.11	129.065	179	3	4.665	183.49
140	172	3	4.665	133.73	181	2	3.11	186.6
150	174	2	3.11	136.84	182	1	1.555	188.155
160	176	2	3.11	139.95	184	2	3.11	191.265
170	178	2	3.11	143.06	186	2	3.11	194.375
180	179	1	1.555	144.615	187	1	1.555	195.93
210	182	3	4.665	149.28	191	4	6.22	202.15
240	186	4	6.22	155.5	195	4	6.22	208.37
270	188	2	3.11	158.61	199	4	6.22	214.59
300	191	3	4.665	163.275	201	2	3.11	217.7
360	194	3	4.665	167.94	205	4	6.22	223.92
420	196	2	3.11	171.05	209	4	6.22	230.14
480	198	2	3.11	174.16	211	2	3.11	233.25
540	200	2	3.11	177.27	212	1	1.555	234.805
600	202	2	3.11	180.38	213	1	1.555	236.36
660	203	1	1.555	181.935	215	2	3.11	239.47
720	205	2	3.11	185.045	216	1	1.555	241.025
780	206	1	1.555	186.6	217	1	1.555	242.58
840	207	1	1.555	188.155	217	0	0	242.58
900	208	1	1.555	189.71	217	0	0	242.58

Redland PM

Time	Head (118)	Head difference	Volume	Cumulative volume	Head (37)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	54				73			
10	67	13	20.215	20.215	121	48	74.64	74.64
20	86	19	29.545	49.76	160	39	60.645	135.285
30	101	15	23.325	73.085	184	24	37.32	172.605
40	112	11	17.105	90.19	203	19	29.545	202.15
50	120	8	12.44	102.63	220	17	26.435	228.585
60	129	9	13.995	116.625	227	7	10.885	239.47
70	134	5	7.775	124.4	228	1	1.555	241.025
80	140	6	9.33	133.73	229	1	1.555	242.58
90	145	5	7.775	141.505	230	1	1.555	244.135
100	149	4	6.22	147.725	230	0	0	244.135
110	153	4	6.22	153.945	231	1	1.555	245.69
120	156	3	4.665	158.61	232	1	1.555	247.245
130	160	4	6.22	164.83	232	0	0	247.245
140	162	2	3.11	167.94	232	0	0	247.245
150	164	2	3.11	171.05	233	1	1.555	248.8
160	166	2	3.11	174.16	233	0	0	248.8
170	168	2	3.11	177.27	234	1	1.555	250.355
180	170	2	3.11	180.38	234	0	0	250.355
210	173	3	4.665	185.045	235	1	1.555	251.91
240	177	4	6.22	191.265	236	1	1.555	253.465
270	179	2	3.11	194.375	237	1	1.555	255.02
300	180	1	1.555	195.93	238	1	1.555	256.575
330	182	2	3.11	199.04	240	2	3.11	259.685
360	183	1	1.555	200.595	241	1	1.555	261.24
420	186	3	4.665	205.26	242	1	1.555	262.795
480	188	2	3.11	208.37	244	2	3.11	265.905
540	190	2	3.11	211.48	246	2	3.11	269.015
600	191	1	1.555	213.035	247	1	1.555	270.57
660	193	2	3.11	216.145	249	2	3.11	273.68
720	194	1	1.555	217.7	251	2	3.11	276.79

Miracle grow PM

Time	Head (105)	Head difference	Volume	Cumulative volume	Head (43)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	181				80			
10	190	9	13.995	13.995	87	7	10.885	10.885
20	200	10	15.55	29.545	95	8	12.44	23.325
30	209	9	13.995	43.54	104	9	13.995	37.32
40	216	7	10.885	54.425	110	6	9.33	46.65
50	221	5	7.775	62.2	117	7	10.885	57.535
60	230	9	13.995	76.195	124	7	10.885	68.42
70	234	4	6.22	82.415	130	6	9.33	77.75
80	238	4	6.22	88.635	137	7	10.885	88.635
90	244	6	9.33	97.965	143	6	9.33	97.965
100	249	5	7.775	105.74	149	6	9.33	107.295
110	252	3	4.665	110.405	155	6	9.33	116.625
120	256	4	6.22	116.625	160	5	7.775	124.4
130	260	4	6.22	122.845	167	7	10.885	135.285
140	265	5	7.775	130.62	172	5	7.775	143.06
150	269	4	6.22	136.84	178	6	9.33	152.39
160	273	4	6.22	143.06	184	6	9.33	161.72
170	277	4	6.22	149.28	191	7	10.885	172.605
180	280	3	4.665	153.945	197	6	9.33	181.935
210	291	11	17.105	171.05	216	19	29.545	211.48
240	301	10	15.55	186.6	232	16	24.88	236.36
270	312	11	17.105	203.705	249	17	26.435	262.795
300	331	19	29.545	233.25	264	15	23.325	286.12
330	339	8	12.44	245.69	278	14	21.77	307.89
360	350	11	17.105	262.795	291	13	20.215	328.105
420	357	7	10.885	273.68	315	24	37.32	365.425
480	374	17	26.435	300.115	341	26	40.43	405.855
540	388	14	21.77	321.885	361	20	31.1	436.955
600	406	18	27.99	349.875	384	23	35.765	472.72
660	421	15	23.325	373.2	404	20	31.1	503.82
720	435	14	21.77	394.97	428	24	37.32	541.14
780	446	11	17.105	412.075	449	21	32.655	573.795
840	461	15	23.325	435.4	468	19	29.545	603.34
900	474	13	20.215	455.615	491	23	35.765	639.105

Miracle grow GS

Time	Head (40)	Head difference	Volume	Cumulative volume	Head (114)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	50				111			
10	62	12			118	7		
20	73	11	17.105	17.105	126	8	12.44	12.44
30	81	8	12.44	29.545	133	7	10.885	23.325
40	90	9	13.995	43.54	140	7	10.885	34.21
50	97	7	10.885	54.425	146	6	9.33	43.54
60	104	7	10.885	65.31	152	6	9.33	52.87
70	111	7	10.885	76.195	158	6	9.33	62.2
80	115	4	6.22	82.415	163	5	7.775	69.975
90	118	3	4.665	87.08	168	5	7.775	77.75
100	122	4	6.22	93.3	172	4	6.22	83.97
110	126	4	6.22	99.52	176	4	6.22	90.19
120	129	3	4.665	104.185	179	3	4.665	94.855
130	132	3	4.665	108.85	183	4	6.22	101.075
140	135	3	4.665	113.515	186	3	4.665	105.74
150	138	3	4.665	118.18	188	2	3.11	108.85
160	140	2	3.11	121.29	192	4	6.22	115.07
170	143	3	4.665	125.955	194	2	3.11	118.18
180	146	3	4.665	130.62	197	3	4.665	122.845
210	153	7	10.885	141.505	202	5	7.775	130.62
240	161	8	12.44	153.945	208	6	9.33	139.95
270	168	7	10.885	164.83	212	4	6.22	146.17
300	174	6	9.33	174.16	217	5	7.775	153.945
330	181	7	10.885	185.045	221	4	6.22	160.165
360	187	6	9.33	194.375	224	3	4.665	164.83
420	200	13	20.215	214.59	231	7	10.885	175.715
480	211	11	17.105	231.695	236	5	7.775	183.49
540	222	11	17.105	248.8	241	5	7.775	191.265
600	233	11	17.105	265.905	245	4	6.22	197.485
660	245	12	18.66	284.565	249	4	6.22	203.705
720	258	13	20.215	304.78	253	4	6.22	209.925

Redland BM

Time	Head (110)	Head difference	Volume	Cumulative volume	Head (38)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	35				53			
10	40	5	7.775	7.775	57	4	6.22	6.22
20	47	7	10.885	18.66	60	3	4.665	10.885
30	53	6	9.33	27.99	64	4	6.22	17.105
40	57	4	6.22	34.21	67	3	4.665	21.77
50	62	5	7.775	41.985	71	4	6.22	27.99
60	65	3	4.665	46.65	74	3	4.665	32.655
70	70	5	7.775	54.425	77	3	4.665	37.32
80	72	2	3.11	57.535	81	4	6.22	43.54
90	74	2	3.11	60.645	85	4	6.22	49.76
100	77	3	4.665	65.31	90	5	7.775	57.535
110	79	2	3.11	68.42	93	3	4.665	62.2
120	82	3	4.665	73.085	96	3	4.665	66.865
130	84	2	3.11	76.195	99	3	4.665	71.53
140	87	3	4.665	80.86	102	3	4.665	76.195
150	89	2	3.11	83.97	105	3	4.665	80.86
160	90	1	1.555	85.525	108	3	4.665	85.525
170	93	3	4.665	90.19	110	2	3.11	88.635
180	95	2	3.11	93.3	113	3	4.665	93.3
210	101	6	9.33	102.63	121	8	12.44	105.74
240	104	3	4.665	107.295	126	5	7.775	113.515
270	108	4	6.22	113.515	129	3	4.665	118.18
300	112	4	6.22	119.735	132	3	4.665	122.845
330	115	3	4.665	124.4	134	2	3.11	125.955
360	117	2	3.11	127.51	136	2	3.11	129.065
420	121	4	6.22	133.73	142	6	9.33	138.395
480	125	4	6.22	139.95	147	5	7.775	146.17
540	128	3	4.665	144.615	150	3	4.665	150.835
600	130	2	3.11	147.725	154	4	6.22	157.055
660	133	3	4.665	152.39	156	2	3.11	160.165
720	135	2	3.11	155.5	158	2	3.11	163.275

Biosolids

Time	Head (115)	Head difference	Volume	Cumulative volume	Head (38)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	49				218			
10	63	14	21.77	21.77	250	32	49.76	49.76
20	81	18	27.99	49.76	278	28	43.54	93.3
30	95	14	21.77	71.53	290	12	18.66	111.96
40	106	11	17.105	88.635	301	11	17.105	129.065
50	112	6	9.33	97.965	310	9	13.995	143.06
60	118	6	9.33	107.295	315	5	7.775	150.835
70	122	4	6.22	113.515	320	5	7.775	158.61
80	127	5	7.775	121.29	323	3	4.665	163.275
90	133	6	9.33	130.62	325	2	3.11	166.385
100	138	5	7.775	138.395	327	2	3.11	169.495
110	142	4	6.22	144.615	328	1	1.555	171.05
120	145	3	4.665	149.28	329	1	1.555	172.605
130	149	4	6.22	155.5	329	0	0	172.605
140	151	2	3.11	158.61	330	1	1.555	174.16
150	153	2	3.11	161.72	330	0	0	174.16
160	155	2	3.11	164.83	330	0	0	174.16
170	156	1	1.555	166.385	330	0	0	174.16
180	157	1	1.555	167.94	330	0	0	174.16
210	160	3	4.665	172.605	331	1	1.555	175.715
240	161	1	1.555	174.16	332	1	1.555	177.27
270	162	1	1.555	175.715	332	0	0	177.27
300	163	1	1.555	177.27	333	1	1.555	178.825
330	164	1	1.555	178.825	333	0	0	178.825
360	165	1	1.555	180.38	333	0	0	178.825
420	166	1	1.555	181.935	334	1	1.555	180.38
480	167	1	1.555	183.49	335	1	1.555	181.935
540	168	1	1.555	185.045	336	1	1.555	183.49
600	168	0	0	185.045	336	0	0	183.49
660	169	1	1.555	186.6	337	1	1.555	185.045
720	169	0	0	186.6	338	1	1.555	186.6

Scotts mix

Time	Head (108)	Head difference	Volume	Cumulative volume	Head (55)	Head difference	Volume	Cumulative volume
sec	mm	mm	cm ³	cm ³	mm	mm	cm ³	cm ³
0	150				55			
10	151	1	1.555	1.555	56	1	1.555	1.555
20	152	1	1.555	3.11	56	0	0	1.555
30	153	1	1.555	4.665	56	0	0	1.555
40	154	1	1.555	6.22	57	1	1.555	3.11
50	155	1	1.555	7.775	57	0	0	3.11
60	156	1	1.555	9.33	58	1	1.555	4.665
70	157	1	1.555	10.885	58	0	0	4.665
80	158	1	1.555	12.44	59	1	1.555	6.22
90	159	1	1.555	13.995	60	1	1.555	7.775
100	160	1	1.555	15.55	61	1	1.555	9.33
110	162	2	3.11	18.66	63	2	3.11	12.44
120	164	2	3.11	21.77	64	1	1.555	13.995
130	165	1	1.555	23.325	66	2	3.11	17.105
140	168	3	4.665	27.99	68	2	3.11	20.215
150	170	2	3.11	31.1	69	1	1.555	21.77
160	172	2	3.11	34.21	72	3	4.665	26.435
170	174	2	3.11	37.32	74	2	3.11	29.545
180	175	1	1.555	38.875	76	2	3.11	32.655
210	182	7	10.885	49.76	84	8	12.44	45.095
240	189	7	10.885	60.645	91	7	10.885	55.98
270	197	8	12.44	73.085	97	6	9.33	65.31
300	204	7	10.885	83.97	105	8	12.44	77.75
330	210	6	9.33	93.3	111	6	9.33	87.08
360	216	6	9.33	102.63	117	6	9.33	96.41
420	232	16	24.88	127.51	129	12	18.66	115.07
480	245	13	20.215	147.725	139	10	15.55	130.62
540	258	13	20.215	167.94	150	11	17.105	147.725
600	269	11	17.105	185.045	159	9	13.995	161.72
660	281	12	18.66	203.705	169	10	15.55	177.27
720	292	11	17.105	220.81	180	11	17.105	194.375

Particle size distribution: Sieve analyses

Pine Island mix

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0.1	0.03	0.03	99.97
	1	25400	0	0	0.03	99.97
4	0.187	4749.8	43.6	12.13	12.16	87.84
8	0.0937	2379.98	51.9	14.44	26.59	73.41
20	0.0331	840.74	77.8	21.64	48.23	51.77
30	0.0236	600	41.5	11.54	59.78	40.22
40	0.0167	425	26.1	7.26	67.04	32.96
50	0.0117	297.18	27.6	7.68	74.71	25.29
80	0.007	177.8	49.6	13.8	88.51	11.49
100	0.0059	149.86	15.8	4.39	92.91	7.09
120	0.0049	124.46	8.7	2.42	95.33	4.67
140	0.0041	104.14	11.4	3.17	98.5	1.5
200	0.003	75	3.4	0.95	99.44	0.56
Pan			2	0.56	100	0
Total			359.5	100		

Greenhouse mix

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0.1	0.04	0.04	99.96
	1	25400	0.2	0.09	0.13	99.87
4	0.187	4749.8	20.4	8.96	9.09	90.91
8	0.0937	2379.98	31.4	13.79	22.88	77.12
20	0.0331	840.74	53.5	23.5	46.38	53.62
30	0.0236	600	36.7	16.12	62.49	37.51
40	0.0167	425	51.7	22.71	85.2	14.8
50	0.0117	297.18	12.8	5.62	90.82	9.18
80	0.007	177.8	15.7	6.9	97.72	2.28
100	0.0059	149.86	2.7	1.19	98.9	1.1
120	0.0049	124.46	1.3	0.57	99.47	0.53
140	0.0041	104.14	0.7	0.31	99.78	0.22
200	0.003	75	0.3	0.13	99.91	0.09
Pan			0.2	0.09	100	0
Total			227.7	100		

Nursery mix

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0.1	0.03	0.03	99.97
	1	25400	0.2	0.07	0.1	99.9
4	0.187	4749.8	33	10.92	11.02	88.98
8	0.0937	2379.98	38.8	12.84	23.86	76.14
20	0.0331	840.74	68.7	22.73	46.59	53.41
30	0.0236	600	68.4	22.63	69.23	30.77
40	0.0167	425	60.4	19.99	89.21	10.79
50	0.0117	297.18	12.8	4.24	93.45	6.55
80	0.007	177.8	14.4	4.77	98.21	1.79
100	0.0059	149.86	3	0.99	99.21	0.79
120	0.0049	124.46	1.3	0.43	99.64	0.36
140	0.0041	104.14	0.6	0.2	99.83	0.17
200	0.003	75	0.2	0.07	99.9	0.1
Pan			0.3	0.1	100	0
Total			302.2	100		

Costa Farms mix

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0.1	0.05	0.05	99.95
	1	25400	0	0	0.05	99.95
4	0.187	4749.8	33.8	16.77	16.82	83.18
8	0.0937	2379.98	44.3	21.97	38.79	61.21
20	0.0331	840.74	58.7	29.12	67.91	32.09
30	0.0236	600	17.5	8.68	76.59	23.41
40	0.0167	425	17.1	8.48	85.07	14.93
50	0.0117	297.18	8.5	4.22	89.29	10.71
80	0.007	177.8	10.3	5.11	94.39	5.61
100	0.0059	149.86	3.8	1.88	96.28	3.72
120	0.0049	124.46	2.1	1.04	97.32	2.68
140	0.0041	104.14	1.8	0.89	98.21	1.79
200	0.003	75	1.8	0.89	99.11	0.89
Pan			1.8	0.89	100	0
Total			201.6	100		

Redland PM

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0	0.00	0.00	100.00
	1	25400	0	0.00	0.00	100.00
4	0.187	4749.8	9	2.25	2.25	97.75
8	0.0937	2379.98	45.5	11.37	13.62	86.38
20	0.0331	840.74	81.6	20.39	34.02	65.98
30	0.0236	600	86.2	21.54	55.56	44.44
40	0.0167	425	72.9	18.22	73.78	26.22
50	0.0117	297.18	44.3	11.07	84.85	15.15
80	0.007	177.8	49.8	12.45	97.30	2.70
100	0.0059	149.86	5.8	1.45	98.75	1.25
120	0.0049	124.46	2.7	0.67	99.43	0.57
140	0.0041	104.14	1.3	0.32	99.75	0.25
200	0.003	75	0.6	0.15	99.90	0.10
Pan			0.4	0.10	100.00	0.00
Total			400.1	100		

Miracle grow PM

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0	0	0	100
	1	25400	0	0	0	100
4	0.187	4749.8	31.2	12.19	12.19	87.81
8	0.0937	2379.98	39.8	15.55	27.75	72.25
20	0.0331	840.74	45.8	17.9	45.64	54.36
30	0.0236	600	25	9.77	55.41	44.59
40	0.0167	425	22.7	8.87	64.28	35.72
50	0.0117	297.18	23.7	9.26	73.54	26.46
80	0.007	177.8	35.3	13.79	87.34	12.66
100	0.0059	149.86	9	3.52	90.86	9.14
120	0.0049	124.46	7.3	2.85	93.71	6.29
140	0.0041	104.14	5	1.95	95.66	4.34
200	0.003	75	6.2	2.42	98.09	1.91
Pan			4.9	1.91	100	0
Total			255.9	100		

Miracle grow GS

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0	0	0	100
	1	25400	29.7	5.93	5.93	94.07
4	0.187	4749.8	43	8.59	14.53	85.47
8	0.0937	2379.98	53.8	10.75	25.27	74.73
20	0.0331	840.74	66.5	13.29	38.56	61.44
30	0.0236	600	43.4	8.67	47.23	52.77
40	0.0167	425	52	10.39	57.62	42.38
50	0.0117	297.18	67.1	13.41	71.03	28.97
80	0.007	177.8	96.3	19.24	90.27	9.73
100	0.0059	149.86	17.2	3.44	93.71	6.29
120	0.0049	124.46	12.6	2.52	96.22	3.78
140	0.0041	104.14	7.8	1.56	97.78	2.22
200	0.003	75	7.3	1.46	99.24	0.76
Pan			3.8	0.76	100	0
Total			500.5	100		

Redland BM

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0.0	0.00	0.00	100.00
	1	25400	0.0	0.00	0.00	100.00
4	0.187	4749.8	19.1	7.63	7.63	92.37
8	0.0937	2379.98	39.3	15.69	23.32	76.68
20	0.0331	840.74	48.2	19.25	42.57	57.43
30	0.0236	600	30.6	12.22	54.79	45.21
40	0.0167	425	29.6	11.82	66.61	33.39
50	0.0117	297.18	27.1	10.82	77.44	22.56
80	0.007	177.8	33.0	13.18	90.62	9.38
100	0.0059	149.86	7.4	2.96	93.57	6.43
120	0.0049	124.46	5.7	2.28	95.85	4.15
140	0.0041	104.14	4.7	1.88	97.72	2.28
200	0.003	75	2.8	1.12	98.84	1.16
Pan			2.9	1.16	100.00	0.00
Total			250.4	100		

Biosolids

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0	0	0	100
	1	25400	0.2	0.1	0.1	99.9
4	0.187	4749.8	16.7	8.23	8.33	91.67
8	0.0937	2379.98	28.4	14	22.33	77.67
20	0.0331	840.74	30.2	14.88	37.21	62.79
30	0.0236	600	16.7	8.23	45.44	54.56
40	0.0167	425	14.9	7.34	52.78	47.22
50	0.0117	297.18	16	7.89	60.67	39.33
80	0.007	177.8	25.5	12.57	73.24	26.76
100	0.0059	149.86	8.9	4.39	77.62	22.38
120	0.0049	124.46	10.9	5.37	83	17
140	0.0041	104.14	16.7	8.23	91.23	8.77
200	0.003	75	13.5	6.65	97.88	2.12
Pan			4.3	2.12	100	0
Total			202.9	100		

Scotts mix

Sieve No	Sieve Size		Mass of soil retained	Percentage on each sieve	Cumulative percent retained	Percent finer
	inch	um	g	%	%	%
	1.5	38100	0	0	0	100
	1	25400	0	0	0	100
4	0.187	4749.8	8.3	3.27	3.27	96.73
8	0.0937	2379.98	33.4	13.14	16.4	83.6
20	0.0331	840.74	41.5	16.33	32.73	67.27
30	0.0236	600	20.2	7.95	40.68	59.32
40	0.0167	425	29.3	11.53	52.2	47.8
50	0.0117	297.18	29.1	11.45	63.65	36.35
80	0.007	177.8	51.2	20.14	83.79	16.21
100	0.0059	149.86	10.4	4.09	87.88	12.12
120	0.0049	124.46	8.7	3.42	91.31	8.69
140	0.0041	104.14	9.5	3.74	95.04	4.96
200	0.003	75	6.7	2.64	97.68	2.32
Pan			5.9	2.32	100	0
Total			254.2	100		

Dry bulk density

Sample	Sieve range	Initial weight	final weight	Sample weight	Column height	Column area	Dry density
	mm	g	g	g	cm	cm ²	g/cm ³
Pine Island	38.1- 4.75	3055.6	3114.9	59.3	9.8	30.18	0.201
	2 - 0.6	3068.1	3128.5	60.4	9.8	30.18	0.203
	0.425 - Pan	3053.8	3265.2	211.4	9.7	30.18	0.721
	Mix	3052.0	3129.3	77.3	10.5	30.18	0.244
Greenhouse	38.1- 2.36	3051.8	3116.9	65.1	11.8	30.18	0.184
	2 - 0.5	3052.4	3157.8	105.4	10.6	30.18	0.328
	0.425-Pan	3053.7	3193.5	139.8	8.9	30.18	0.520
	Mix	3051.3	3140.2	88.9	10.5	30.18	0.281
Nursery mix	38.1- 2.36	3053.8	3133.2	79.4	11.4	30.18	0.230
	2 - 0.5	3052.9	3126.5	73.6	10.8	30.18	0.226
	0.425 - Pan	3054.4	3179.8	125.4	12.4	30.18	0.336
	Mix	3052.4	3144.5	92.1	11.6	30.18	0.263
Costa Farms	38.1- 2.36	3048.8	3111.3	62.5	11.4	30.18	0.181
	2 - 0.5	3044.4	3110.4	66.0	11.3	30.18	0.194
	0.425 - Pan	3054.5	3144.6	90.1	12.4	30.18	0.241
	Mix	3050.4	3125.6	75.2	11.1	30.18	0.224
Redland PM	38.1- 2.36	3047.1	3114.5	67.4	12.1	30.18	0.185
	2 - 0.5	3057.7	3228.2	170.5	11.7	30.18	0.483
	0.425 - Pan	3057.1	3346.2	289.1	12.7	30.18	0.754
	Mix	3047.6	3201.4	153.8	11.7	30.18	0.436
Miracle grow PM	38.1- 2.36	3055.6	3148.9	93.3	10.8	30.18	0.286
	2 - 0.5	3054.9	3124.0	69.1	12.2	30.18	0.188
	0.425 - Pan	3056.2	3191.2	135.0	13.3	30.18	0.335
	Mix	3051.4	3138.9	87.5	10.8	30.18	0.268
Miracle grow GS	38.1- 2.36	3061.1	3230.2	169.1	12.1	30.18	0.464
	2 - 0.5	3062.3	3192.5	130.2	11.7	30.18	0.369
	0.425 - Pan	3057.5	3265.1	207.6	11.7	30.18	0.588
	Mix	3059.8	3262.9	203.1	12.7	30.18	0.530
Redland BM	38.1- 4.75	3057.8	3133.3	75.5	12.1	30.18	0.207
	2 - 0.6	3055.7	3161.4	105.7	12.2	30.18	0.287
	0.425 - Pan	3055.8	3244.6	188.8	12.5	30.18	0.502
	Mix	3055.3	3172.3	117.0	12.5	30.18	0.311
Biosolids	38.1- 2.36	3054.1	3156.9	102.8	12.5	30.18	0.274
	2 - 0.5	3055.4	3161.1	105.7	12.1	30.18	0.290
	0.425 - Pan	3053.3	3171.5	118.2	13.1	30.18	0.299
	Mix	3044.1	3136.9	92.8	11.4	30.18	0.269
Scotts mix	38.1- 2.36	3051.8	3163.5	111.7	12.7	30.18	0.291
	2 - 0.5	3052.8	3157.0	104.2	12.5	30.18	0.277
	0.425 - Pan	3262.9	3438.2	175.3	13.0	30.18	0.449
	Mix	3050.8	3182.5	131.7	12.7	30.18	0.344

Organic matter

Sample	Sieve range	Dish weight	Total Weight	Sample weight	Final weight	Ash weight of the sample	Organic matter
	mm	g	g	g	g	g	%
Pine Island mix	38.1- 4.75	71.5	74.5	3	74.3	2.8	93.3
	2 - 0.6	22.5	25.5	3	23.1	0.6	20.0
	0.425 - Pan	66.9	69.9	3	68.4	1.5	50.0
	Mix	80.5	85.5	5	84.1	3.6	72.14
Greenhouse mix	38.1- 2.36	67.6	70.6	3	70.5	2.9	96.7
	2 - 0.5	73.4	76.4	3	75.3	1.9	63.3
	0.425-Pan	69.2	72.2	3	69.9	0.7	23.3
	Mix	68.53	73.53	5	70.7	2.2	43.79
Nursery mix	38.1- 2.36	21.1	24.1	3	23.4	2.3	76.7
	2 - 0.5	80.5	83.5	3	81.2	0.7	23.3
	0.425 - Pan	22.8	25.8	3	23.5	0.7	23.3
	Mix	80.5	85.5	5	84.0	3.5	69.70
Costa Farms mix	38.1- 2.36	69.9	72.9	3	70.3	0.4	13.3
	2 - 0.5	23.6	26.6	3	24.0	0.4	13.3
	0.425 - Pan	23	26	3	25.1	2.1	70.0
	Mix	75.7	80.7	5	78.7	3.0	60.54
Redland PM	38.1- 2.36	20.8	23.8	3	21.9	1.1	36.7
	2 - 0.5	21.3	24.3	3	23.9	2.6	86.7
	0.425 - Pan	82.1	85.1	3	83.4	1.3	43.3
	Mix	85.09	90.09	5	86.7	1.61	32.2
Miracle grow PM	38.1- 2.36	93.4	96.4	3	94.4	1	33.3
	2 - 0.5	74.3	77.3	3	75.2	0.9	30.0
	0.425 - Pan	22.5	25.5	3	24.1	1.6	53.3
	Mix	75.39	80.39	5	77.3	1.91	38.2
Miracle grow GS	38.1- 2.36	74.2	77.2	3	75.6	1.4	46.7
	2 - 0.5	93.6	96.6	3	95.7	2.1	70.0
	0.425 - Pan	92.8	95.8	3	93.4	0.6	20.0
	Mix	81.27	86.27	5	83.4	2.13	42.6
Redland BM	38.1- 4.75	23.6	26.6	3	24.8	1.2	40.0
	2 - 0.6	70.6	73.6	3	71.8	1.2	40.0
	0.425 - Pan	23.4	26.4	3	25.7	2.3	76.7
	Mix	83.58	88.58	5	84.7	1.12	22.4
Biosolids	38.1- 2.36	81.2	84.2	3	82.4	1.2	40.0
	2 - 0.5	75.6	78.6	3	76.3	0.7	23.3
	0.425 - Pan	22	25	3	23.4	1.4	46.7
	Mix	68.53	73.53	5	70.3	1.77	35.4
Scotts mix	38.1- 2.36	21.1	24.1	3	23.5	2.4	80.0
	2 - 0.5	20.5	23.5	3	22.6	2.1	70.0
	0.425 - Pan	71.3	74.3	3	73.1	1.8	60.0
	Mix	74.45	79.45	5	76.6	2.15	43.0

Water holding capacity and air space

Sample	Dry weight	Total weight	2 hour leaching weight	Total pore space	water retained after 2 hrs	Volume of water drained	Air space	Total water holding capacity
Sieve Range (mm)	g	g	g	cm ³	g	cm ³	%	%
Redland PM								
38.1- 2.36	60.75	185	170	109.0	103.65	5.4	2.4	46.07
2 - 0.5	124.92	260	245	118.2	113.87	4.3	1.9	50.61
0.425 - Pan	96.17	210	190	81.7	79.99	1.7	0.8	35.55
Mix	110.19	255	220	119.9	100.63	19.2	8.5	44.72
Miracle grow PM								
38.1- 2.36	79.34	235	205	125.7	114.63	11.1	4.9	50.95
2 - 0.5	62.55	215	180	109.1	101.5	7.6	3.4	45.11
0.425 - Pan	87.39	240	195	124.0	97.08	26.9	12.0	43.15
Mix	92.88	215	200	101.6	99.57	2.0	0.9	44.25
Miracle grow GS								
38.1- 2.36	115.24	250	225	106.0	99.19	6.8	3.0	44.08
2 - 0.5	97.6	245	230	123.1	122.17	0.9	0.4	54.30
0.425 - Pan	173.68	245	220	37.4	33.84	3.6	1.6	15.04
Mix	161.56	285	270	106.0	102.04	4.0	1.8	45.35
Redland BM								
38.1- 4.75	63.66	250	200	161.4	127.16	34.2	15.2	56.52
2 - 0.6	80.37	255	175	146.8	84.4	62.4	27.7	37.51
0.425 - Pan	135.82	185	175	33.1	32.97	0.1	0.0	14.65
Mix	85.77	270	225	154.3	128.2	26.1	11.6	56.98
Biosolids								
38.1- 2.36	78.44	255	235	156.0	149.01	7.0	3.1	66.23
2 - 0.5	60.85	240	225	163.9	158.55	5.4	2.4	70.47
0.425 - Pan	79.7	220	205	122.9	118.9	4.0	1.8	52.84
Mix	70.49	245	200	131.2	113.56	17.6	7.8	50.47
Scotts mix								
38.1- 2.36	84.38	235	205	121.9	110.05	11.8	5.3	48.91
2 - 0.5	80.78	240	215	125.3	121.74	3.6	1.6	54.11
0.425 - Pan	135.82	190	165	16.6	15.34	1.2	0.5	6.82
Mix	101.64	265	235	134.7	122.83	11.9	5.3	54.59

pH

Sample	pH			
	1	2	3	Avg
Pine Island mix	4.35	4.23	4.2	4.26
Greenhouse mix	5.23	5.19	5.12	5.18
Nursery mix	6.45	6.59	6.4	6.48
Costa Farms mix	6.43	6.45	6.77	6.55
Redland PM	5.9	5.85	5.83	5.86
Miracle grow PM	5.9	5.99	6.2	6.03
Miracle grow GS	4.9	4.66	4.69	4.75
Redland BM	5.62	5.68	5.5	5.6
Biosolids	6.98	7	7	7
Scotts mix	5.78	5.71	5.73	5.74

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EDUCATION

- 2009- Present Doctoral Candidate,
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- 2006 B.E. Chemical Engineering,
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PROFESSIONAL EXPERIENCE

- 2011-2012 Research Assistant, Department of Civil and Environmental Engineering,
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- 2010-2011 Lab Instructor, Department of Civil and Environmental Engineering,
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- 2007-2010 Teaching Assistant, Department of Civil and Environmental Engineering,
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PUBLICATIONS

Journals Publications:

B. Sizerici, B. Tansel, V. Kumar “Knowledge Based Ranking Algorithm for Comparative Assessment of Post Closure Care Needs of Closed Landfills”, Waste Management, Vol. 31, No. 6, pp. 1232-1238, 2011.

V. Kumar, F. M. Guerrero, B. Tansel, M. R. Savabi, “Hydro-physical characteristics of selected mix used for containerized agriculture systems”, Agricultural Water Management, Vol. 98, No. 2, pp. 314-320, 2010.

Conference Publications:

B. Tansel, V. Kumar, M. R. Savabi, "Modeling effects of soil amendments used in containerized agricultural systems on its water capitalization, nutrient leaching and product yield". World Environmental & Water Resources Congress. Albuquerque, NM, May 20-24, 2012.

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V. Kumar, B. Sizerici, B. Tansel, L. Prieto-Portar , "Knowledge Based Ranking Algorithm for Comparative Assessment of Post Closure Care Needs of Landfills." International Conference on Solid Waste Technology and Management. Philadelphia, PA, March 15-18, 2009.

V. Kumar, M. R. Savabi, F. M. Guerrero, B. Tansel, "Water Retention and Hydraulic Conductivity of Different Mix Used for Containerized Agriculture Systems" World Environmental & Water Resources Congress. Kansas City, Missouri, May 17-21, 2009.

B. Sizerici, V. Kumar , B. Tansel, L. Prieto-Portar, D. Reinhart, A. Joshi, "Assessment of Health Risks from a Closed Landfill with FRAMES Model Using Groundwater and Leachate Monitoring Data." International Conference on Solid Waste Technology and Management. Philadelphia, PA, March 15-18, 2009.

Workshop Publications:

V. Kumar, F.M. Guerrero, B. Tansel, M. R. Savabi, "Hydro-physical characteristics of selected mix used for containerized agriculture systems" NSF CMMI Research and Innovation Conference . Atlanta, Georgia, January 4-7, 2011.

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Technical Reports:

Performance Based Decision System for Determining Post-Closure Care (PCC) Period in Florida Landfills, Hinkley Center for Solid and Hazardous Waste Management. <http://www.floridacenter.org/publications/byauthor.htm>, Dec 2008.

GRANTS AND AWARDS

2012	Dissertation Year Fellowship,
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