Physical Qualities of Organic Potting Substrates for Containerizedand Nursery Production

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Abstract—Soil has always been used as nursery and pot substrate in horticultural industry in Kenya, but it has problems related to aeration, drainage, non-uniformity and chemical suitability.Therefore, development of alternative potting substrates with optimal physical characteristics is necessary.The objective of this study was to evaluate physical suitability of forest soil (FS), compost (C), pine bark (PB), and rice husks (RH) as alternative amendments of potting substrates. Ten different substrate formulations containing pine bark (PB), rice husks (RH), forest soil (FS) and compost (CS) [T1 (100% FS), T2 (75% CS: 25% PB), T3 (50% CS: 50% PB), T4 (25% CS: 75% PB), T5 (75% CS: 25% RH), T6 (50% CS: 50% RH), T7 (25% CS: 75% RH), T8 (100% CS), T9 (100% PB) and T10 (100% RH)] were prepared and tested for aeration porosity (AP), total porosity (TP), bulk density (BD) and water holding capacity (WHC). Results showed that WHC, BD, AP and TP of the substrate were significantly affected ($P \leq 0.05$) by the addition of the amendments. With exception of 25% CS: 75% PB, 25% CS: 75% RH, 100% PB and 100% RH, all the substrate formulations had acceptable water holding capacities.Addition of both RH and PB resulted in significantly ($P \leq 0.05$) lower BD values, and higher AP and TP of the substrate formulations. This work shows that substrate formulations containing 75% CS: 25% PB, 50% CS: 50% PB, 75% CS: 25% RH and 50% CS: 50% RH had physical qualities within the optimal ranges and are recommended as potting substrates. In conclusion, PB, RH and CS are potentially cheaper alternative potting substrate media with superior or similar chemical qualities to soil and represent better utilization of agricultural and industrial waste materials.

Keywords—Nursery production, Potted seedlings, Physical quality, Organic materials, Substrates,

1 Introduction

The development of horticulture industry in Kenya has taken place at a rapid pace [1].From 1963 and 1991 the sector realised 12 times rise in tonnage and 40 times in value[2]. By 2003,Kenya's fresh vegetable exports increased from US$23 million to US$40 million making it thefifth-largest export earner and accounting for 13 percent of gross domestic product (GDP)[3]. This development and the increase of production intensity has set new demands for high quality inputs including growing media/substrate.

Suitable plant development depends to a large extent on the substrate used[4]. A good root system is very important because it will allow the plant to adapt to the harsh conditions outside the nursery, often with minimal additional watering and fertilizing[4, 5]. It will also help the plant to overcome the transplanting shock[6].Peat is the dominant bulk material in most substrates [7]. However, it is not locally available in Kenya and has to be imported at high costs. The increased demand for peat worldwide as a substrate in recent years has also reduced its availability, quality and increase it cost [4, 7].

In Kenya, the use of peat-based substrates is confined tobig or established horticultural enterprises whose products are meant for external trade. Most horticultural enterprises use substrates made of a mixture of topsoil, organic supplements and sand in varied proportions in containers or use a bed prepared on the soil [4]. These types of growing media/substrates are limited in quality and negatively affect the development of plant roots [8, 9].Topsoil as potting substrate suffers from homogeneity, aeration and drainage problems and is often not sterile. Farmyard manure, the organic material for composting, is generallyunavailable or expensive with the quality varying depending on the age and type of animal used, the feed on which the animal is fed, handling, and the duration of composting. Due to its high bulk density, sand makes transporting the seedlings difficult and clogs the potting substrate causing of aeration, water retention and drainage problems. Soil-based growing media are prone to pests and diseases, including nematodes and weed seeds, which drastically affect the quality of the produce. The overall result is that the product has low quality, and fetches low returns to the growers.Therefore, there is an urgent need for the development of more cost effective and good quality substrates from locally available alternatives including carbonized and composted urban and agricultural wastes. However, here is limited information available on the use of local materials particularly tree by-products and their products and agricultural wastes and other materials as suitable alternatives. The objective of the study to determine the effect of pine bark (PB), rice husks (RH), forest soil (FS) and compost (CS) as potentiallyalternativepotting substrates for containerized and nursery production in Kenya.

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2 Materials and Methods

The raw materials used in the study included: Compost (CS) prepared in the demonstration farm of Department of Horticulture, Maseno University, Kenya; pine bark (PB) obtained from Webuye Paper Mills Ltd, Webuye, Kenya; rice husks (RH) obtained from Ahero rice farmers, Ahero, Kenya;andforest soil (FS) obtained from a commercial ornamental plant nursery in Kisumu, Kenya.

2.1 Media Preparation and Potting.

Farmyard manure was composted according to International Society of Horticultural Science (ISHS) standards [10]. The pine bark was cut into smaller sizes of about 2 to 3 cm sizes. The soil was sterilized by solarisation, a practice normally used by the small nurseries operators. The composted manure was mixed with the pine bark, rice husk and forest soil in different proportions using a drum and a peddle mixer. These constituted the media to be used in the study. Ten media were used (Table 1). They constituted the treatments. Forest soil treatment was used as the control. This is the standard growth media used by local nurseries operators.

Table 1. Proportions of the compost, pine bark, rice husk and forest soil as treatments used in the study.

	Substrates Composition		Composition %
T-1	Forest soil	(F.S)	100
T-2	Compost: Pine bark	(C: PB)	75: 25
T-3	Compost: Pine bark	(C: PB)	50: 50
T-4	Compost: Pine bark	(C: PB)	25: 75
T-5	Compost: Rice husk	(C: RH)	75: 25
T-6	Compost: Rice husk	(C: RH)	50: 50
T-7	Compost: Rice husk	(C: RH)	25: 75
T-8	Compost	(C)	100
T-9	Pine bark	(PB)	100
T-10	Rice husk	(RH)	100

Each of the prepared media was sampled and the samples placed in polythene paper bag and labeled for laboratory physical and chemical analyses.The ten prepared media were each placed in round plastic pot of two litres capacity in equal volumes. The pots were arranged in Completely Randomized Design (CRD) with four replications.

2.2 Substrate Analyses

The physical and chemical properties of the substrates were determined. Physical properties determined included; water retention capacity, air porosity, bulk density and total porosity. These were determined using a rapid method for the determination of physical properties of growing media as described by [11].According to this method, the drainage holes in the two litres container were sealed completely and the container filled with water and the container volume recorded as the water volume required to fill the container to the top. The sealed container was emptied of the water, dried and filled with dry substrate. With use of measured volume of water, the substrate in the container was slowly irrigated until it was saturated with water. The total pore volume was recorded as the volume of water required to reach this point. The seals on the drainage holes were then removed and the water trapped as it drained out. The water volume collected was recorded as the aeration pore volume. Therefore percentage total porosity, aeration porosity and water holding capacity were calculated as:

$$\text{Total porosity (TP)} = \text{TPV x} \frac{100}{\text{CV}}$$

$$\text{Aeration porosity (AP)} = \text{APV x} \frac{100}{\text{CV}}$$

$$\text{Water holding capacity (WHC)} = \text{TP} - \text{AP}$$

where TP- total porosity, AP- aeration porosity, WHC- water holding capacity, TPV- total pore volume, APV- aeration pore volume and CV- container volume.

2.3 Data Analysis

Data obtained were subjected to analysis of variance (ANOVA) to determine treatment effects. Duncan's multiple comparison range test procedure was employed to denote significant differences between the treatments using the GENSTAT 9 software (VSN International).

3 Results and Discussion

Container substrate in horticulture serves primarily as mechanical support for the plant in addition to affecting plant growth, root systems and plants nutritional status-fertilizing[4].In this study,physical qualities of different substrate formulations containing FS, CS, PB and RH was analyzed and results is presented in Figures 1, 2, 3 and 4.

3.1 Aeration porosity

The aeration porosity of different substrates utilized inthis study is given in Figure 1.The aeration porosity was significantly ($P \leq 0.05$) affected by the substrate formulations. Most of the substrate formulations had aeration porosities significantly ($P \leq 0.05$) higher than the control, except for substrate formulations of 100% CS and 50% CS: 50% PB which were not significantly ($P \leq 0.05$) different from the control. Substrate 100% RH and 100% PB had significantly ($P \leq 0.05$) higher aeration porosities of 53.7% and 49.6% respectively, as compared to all other substrate formulations (Figure 1). Substrate 25% CS: 75% PB was not significantly ($P > 0.05$) different from substrate 25% CS: 75% RH (Figure 1). The substrate formulations with relatively higher percentage of either the pine bark or rice husk were observed to show higher aeration porosities.

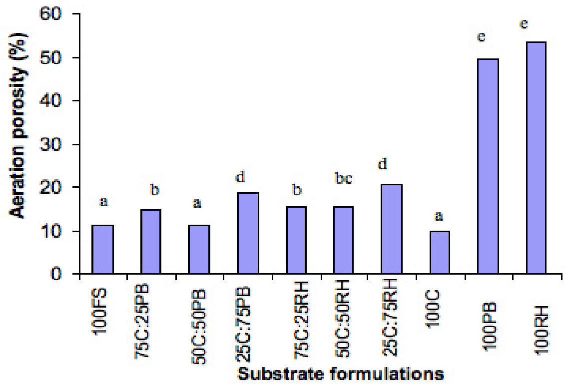


Figure 1. The effect of substrate formulations on aeration porosity

These results are in line with work done by Walker and Bragg [12]. AP values between 15% and 20% isgenerally considered optimal for containerized ornamental and nursery plants[13-15]. Substrate formulations 100% CS, 50% CS: 50% PB and 100% FS substrate formulations had lower values as compared to the recommended minimum values, while 25% CS:75% PB, 25%C:75%RH, 100% PB and 100% RH had much higher values than those recommended as optimal. The substrate formulations 75% CS: 25% PB, 75% CS: 25% RH and 50% CS: 50% RH had the aeration porosity values within the recommended range of 15% to 20%. An experiment carried out by Beeson[16],showed that minimum air porosity after drainage of 10% can be tolerated by some plants, while Russel[17], reported that, 20% air porosity was preferably required for soils used as container media. In this study the soil substrate (100% FS), as a standard container media used in majority of nurseries had an initial aeration porosity of 11.9%, which was far much below the recommended minimum value, although 100% CS and 50% CS: 50% PB had much lower values than the soil media (Figure 1).

The 100% pine bark and 100% rice husk have inherently open structures and consequently higher aeration porosity [18].The pore space is a function of the particle size distribution and owing to their relatively larger sizes; they have higher drainable pore space or higher air filled porosity.

3.2 Total Porosity

The total porosity was significantly (P≤0.05) affected the substrate formulations (Figure 2). Substrate formulations 100% PB and 100% RH were significantly (P≤0.05) higher than the rest of the other substrate formulations. Substrate formulations 50% CS: 50% PB, 25% CS: 75% PB and 100% CS were not significantly (P>0.05) different from each other. The highest total porosity values were recorded in substrate formulations 100% RH and 100% PB (850% and 85.1% respectively).

According to Nappi and Barberis[7], total porosity indicates the volume which is left free by the solid components in the substrate and is therefore available for the gaseous and liquid components. The ideal values for the total porosity of the container substrate ranges between 60% and 80% [7]. Only substrate formulations 25% CS: 75% PB, 25% CS: 75% RH and 50% CS: 50% RH had their total porosities within the optimal range while substrate formulations 100% PB and 100% RH had higher total porosities than the optimal range (Figure 2).

The results also showed that increasing CS and FS proportions led to lower total porosity. In contrast, the total porosity was observed to be higher in substrate formulations which incorporated higher volumes of PB and RH (Figure 2). Studies by Michiels*et al.*[19] and Nappi and Barberis[7]reported that fine textured substrate formulations such as compost and clay have low pore size, and as a result drainage can be very slow, leading to poor physical environment of the substrate formulations and consequently poor plant growth.

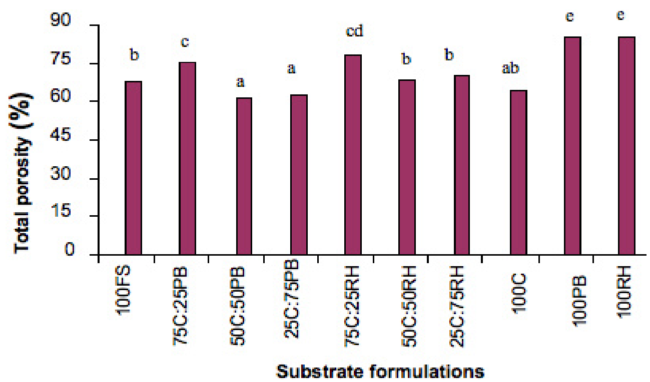


Figure 2. Variations in total porosities in the substrate formulations

3.3 Bulk density

Bulk density is an important aspect of the physical quality of any container substrate as it relates to the support of the plant. According to Nelson[20], bulk density is the mass of the substrate per unit volume. Results show that the substrate formulations had a significant (P≤0.05) effect on the bulk density (Figure 3).The bulk densities of all the substrate formulations were significantly (P≤0.05) lower than that of the substrate formulations 100% CS and the control (Figure 15). Substrate 100% RH showed the lowest bulk density of 0.13g/cm^3 as compared to the other substrate formulations.These results are in agreement with those reported byNappi and Barberis[7]and Deboodt and Verndock[21].

The bulk density is an integral physical quality of any substrate and must fall within the recommended range [7]. High bulk density is uneconomical when intensive handling of the root substrate or of the potted plants particularly transportation is required. The soil substrate, a standard nursery substrate is composed of sand, clay and silt in different proportions resulting in very high bulk densities of over 1.6g/cm^3. According to Deboodt and Verndock[21], the ideal bulk density range for any container root substrate is between 0.2 and 0.5g/cm^3.In the present study, all the substrate formulations had their bulk densities between 0.1g/cm^3 and 0.4g/ cm^3 except substrate 100% FS (control) which had higher bulk density than the recommended range.

Substrate formulations having either pine bark or rice husk components had lower bulk density values (Figure 3). This was observed to be the opposite in the control and 100% CS substrate formulations which had significantly (P≤0.05) higher bulk density values of 1.65g/cm³ and 0.73g/cm³ respectively (Figure 3).

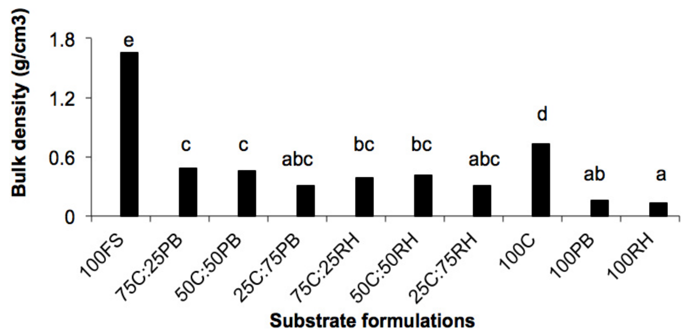


Figure 3. The effect of different substrate formulations on bulk densities

Excessively high bulk density substrate formulations have tightly packed particles [21]. This had negative implications on the plant development, particularly the root growth and development. Tightly packed growing substrate retard plant growth by reducing the supply of air to the roots by mechanically restricting the penetration and extention of the root system to all parts of the substrate. In addition, high bulk density values may imply an increase in weight and a decreasing porosity and air volume of the container substrate. In contrast, very low bulk densities causes excessive substrate aeration and consequently a drop in the available water for the plants[7, 17, 21]. High bulk density values indicates a poor physical condition of the substrate for plant growth [22]. These substrate formulations are highly compacted and contain relatively few pore spaces, therefore amendments are needed to correct substrate formulations to increase pore space of the substrate and improve the root environment.

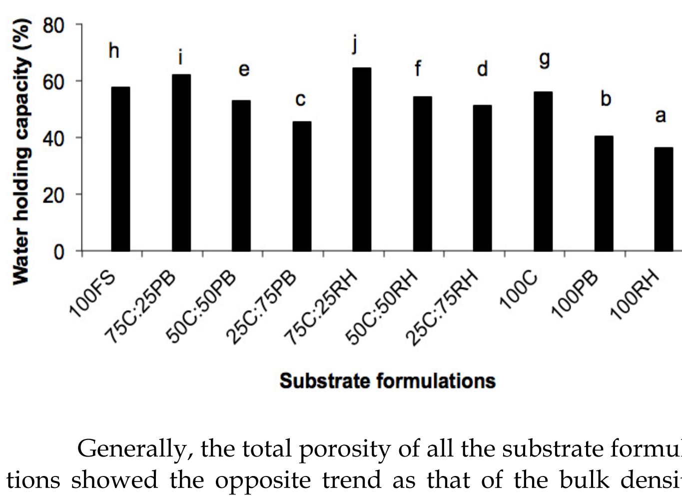
3.4 Water holding capacity

Water holding capacity (WHC) is a measure of the percentage of the water held in small pores within the substrate after drainage[23, 24]. This water is important because it is an integral part of any plant system and it is a source of essential elements, it is a solvent in biochemical reactions within the plant cells, it carries the mineral elements absorbed by the root system and the carbohydrates manufactured in the leaves to all parts of the plant and it is important in maintaining cells and tissues in a turgid condition. Plant growth probably is restricted more often by a deficiency of water than unfavorable level of any other environmental factor [25]. Water holding capacity of any container substrate is therefore very important as it determines the frequency of irrigation/watering and aeration of the substrate formulations [20]and it's a function of the size and type of the particles in the substrate formulations.

The recommended water holding capacity of any container substrate should be between 55.0% and 65.0% [21]. In this study, all the substrate formulations significantly (P≤0.05) affected the water holding capacity (Figure 4). The water holding capacities of the substrate formulations 75% CS: 25% PB and 75% CS: 25% RH were significantly (P≤0.05) higher than that of all other substrate formulations including the control (Figure 4).

In any root substrate the organic components have high water holding capacities as does peat moss, but pine bark and rice husk are coarse and hence they have poor water holding capacities. Substrate formulations containing over 75% pine bark or rice husk, generally showed lower water holding capacities.as demonstrated by substrate formulations 100% PB and 100% RH (Figures 4). Coarse materials have little surface area per unit volume as compared to the finer particles such as those in compost or peat moss [21, 24]. Since water is held on the surface of these materials, pine bark and rice husk have smaller water reserves, hence disadvantage of frequent watering need per day in the substrate containing 100% PB, 100% RH, 25%C: 75% PB, and 25% CS: 75% RH. Due to frequent watering need in these substrate formulations, leaching of nutrients is inevitable, that may lead to characteristic nutrient deficiency and little nutrient reserve thereby affecting plant growth and root development. However, excessive water holding capacity is also deleterious to plant growth and root development. Excessively higher water holding capacities as experienced in fine textured substrate formulations, have water films of the adjacent particles in close contact leaving little open space for gas exchange. As a result the carbon dioxide produced by the plants roots cannot adequately leave the substrate, leading to high carbon dioxide concentration which suppresses root respiration leading to slow growth of the plants.

Figure 4. Effect of substrate formulations on water holding capacity



Generally, the total porosity of all the substrate formulations showed the opposite trend as that of the bulk density. The soil, a standard substrate in container production and composts are too compact and therefore have little space available for either air or water. Water holding capacity and substrate aeration porosity are all related to the total porosity of the substrate and particularly to the size of the pores. Substrate formulations with relatively higher proportion of relatively large pores had rapid water drainage after irrigation. This was clearly observed in substrate formulations 100%PB and 100%RH which in spite of having higher total porosities (Figures 2) and aeration porosities (Figures 1), had very low water holding capacities (Figures 4).

This work provides evidence that substrate formulations 75% CS: 25% PB, 50% CS: 50% PB, 75% CS: 25% RH and 50% CS: 50% RH had physical qualities within the optimal ranges and are recommended as potting substrates. Therefore, PB, CS and RHhas the potential to be beneficial amendments to potting substrates when used alternative supplemental component foe peat. However, the observed physical properties of the substrates can change during plant development and can result in either growth enhancement or inhibition.It is known that physical properties of substrates considered appropriate for plant growth at planting may change over time in containers as a result of several processes [26, 27]. For example, Milks *et al*.[23]reported that the BD of the substrate is higher towards the end of the growth period as compared to the beginning of the growth period of any potted plants. Compaction occurs progressively in the substrate throughout the growth period and increases with the percentage of highly decomposible organic components in the substrate. PB and RH are resistant to decomposition due to high lignin content in the pine bark[28] and silica covering of the rice husk. PB and RH are also resistant to degradation by microorganisms[24, 28]. It is expected that substrate with PB and RH ammendments will be resistant to compaction during the growing season and can maintain higher AP and TP. However, aditional studies need to be done to prove above hypotheses.In addition, the effect of these substrate formulations on chemical properties and media fertility during plant development need further research.

4 Conclusion

The compost, pine bark and rice husk formulations for use as container substrates are highly variable in both their physical and chemical properties. However, the results of this study showed that this variability has relatively little impact on the plant performance when they are used in the proper combinations.Substrates which incorporated 75% C or 50% C with either pine bark or rice husk of the total container volume were suitable for container culture. These substrates had their physical properties within the acceptable ranges which positively influenced the growth and development of the Flame violets.The 100% pine bark and rice husk cannot be used a lone as container substrates. They require combination with compost to improve their physical as well as chemical properties for use as container substrates. Similarly compost must be formulated with either pine bark or rice husk to improve on its physical qualities, though it has potential to supply the necessary mineral nutrients required by the container plants.The compost component of the substrate can supply the mineral nutrients for a short season container production system. Prolonged container production systems require a properly regulated fertilization program to avoid salt build up in the substrates. These organic waste materials obtained from agricultural wastes, formulated with compost in correct proportions can replace soil substrates in container production.

Acknowledgment

The authors wish to thank the Late Prof Charles OwinoGerroh, Department of Horticulture, Maseno University, Kenya, for his contribution during the research. This work was supported in part by a funding from Institute of Research and Postgraduate Studies (IRPS), Maseno University.

References

[1] D.Neven, M. Odera, and T. Reardon "Horticulture farmers and domestic super-markets in Kenya," Department of Agricultural Economics Staff Paper 2006-06, Michigan State University, East Lansing, MI., 2006.
[2] N. McCulloch and M. Ota,"Export horticulture and poverty in Kenya," IDS Working Paper 174, Institute of Development Studies, Sussex, UK,2002.
[3] J.M. Lenne, D.A.C. Pink, N.J. Spence, A.F. Ward, J. Njuki, and M. Ota. "A role model for local vegetable production in Kenya,"Outlook on Agriculture,vol. 34, no. 4, pp. 225–232. 2005.
[4] H. N. P Jaenicke, "Substrates". *In Good Tree Nursery Practices Practical Guidelines for Research Nurseries ICRAF Programme 2 Nursery Manual* (ICRAF, eds) Nairobi: ICRAF. pp. 30-44, 1999.
[5] I. Biran andA. Elissaf "The effect of container size and aeration condition on growth of roots and canopy of woody plants,"*ScientiaHorticultura*,vol. 12, pp. 385-394. 1980.
[6] W.E. Reed, (1946) "The effect of plants: on the physical properties of a Dunkirk silty clay loam and the effect of soil aeration on plant growth and composition," *Journal of Environmetal Horticulture*, vol.24, pp. 181–184. 1946.
[7] P. NappiandR.Barberis, "Compost as a growing medium: chemical, physical and biological aspects,"*ActaHorticulturae,* vol.342, pp. 249-256. 1993.
[8] S.J.F.Aguila, "The present status of the substrate as an ecosystem component and its function and importance in crop productivity,"*ActaHorticulturae*, vol. 221, pp. 53-74. 1988.
[9] O. Reinkinen, "Choice of growing media for pot plants,"*ActaHorticulturae,*vol. 342, pp. 357-360. 1993.
[10] R. Gabriel, andO. Verdonck, "I.S.H.S Reference method for physical and chemical characterization of growing media,"*ActaHorticulturae,* vol. 302, pp. 169-179. 1992.
[11] R.Gabriel, V.W. Keirsbulck andH.A.HEngels, "A rapid method for the assessment of physical properties of a growing media,"*ActaHorticulturae,*vol. 342, pp. 243-247. 1993.
[12] J.A.R. Walkerand N. Bragg, "The effects of composted waste products as additives in peat based substrates on plant growth,"*ActaHorticulturae,* vol. 295, pp. 165-172. 1992.
[13] J.J. Hanan, S.C. OlympioandC. Pittas, "Bulk density, porosity, percolation and salinity control in shallow, freely draining potting soils,"*Journal of American Society of Horticultural Science,*vol. 106, pp. 742-746. 1981.
[14] O.Verdonck,M.Boodtand R. Gabriels, "Compost as a growing medium for Horticultural plants,"*Compost: Production, Quality and Use,'* M.De Bertoldi, M.P. Ferranti, P. L' Hermite, andF.Zucconi, eds,London:Elsevier Applied Science,pp. 814-817, 1986.
[15] K.A. HandreckandN.A. Black, "*Growing media for ornamental plants and turf,*"Sydney:New South Wales University Press, pp. 23 28.1984.
[16] R.C. Beeson, "Composted yard waste as a component of container substrates,"*Journal of Environmental Horticulture*. Vol. 14, pp. 15-21. 1996.
[17] M.B.Russel, "*Soil aeration and plant growth: soil physical condition and plant growth,"* New York:Academic press,1952.
[18] N.C. Bragg, J.A.R. WalkerandE. Stentford, "The use of composted refuse and sewage as a substrate additive for container grown plants,"*ActaHorticulturae*, vol. 342, pp. 155-165. 1993.

[19] P.Michielis, R. HartmannandC. Coussens, "Physical properties of peat substrates in an ebb/flood irrigation system," *ActaHorticulturae,*vol. 342, pp. 205-219.1993.

[20] P.V. Nelson,"*Greenhouse operations and management*,"London, UK:Prentice Hall International, 1991.

[21] M. DeBoodtandO.Verndonck, "The Physical Properties of Substrates in Horticulture," *ActaHorticulturae,*vol. 26, pp. 37-44. 1972.

[22] K.H. Tan, "*Soil sampling, preparation and analysis*,"New York:Marcel Dekker Inc, pp. 68-98.1996.

[23] R.R.Milks, W.C. FontenoandR.A. Larson, "Hydrology of horticultural substrates: Predicting properties of media in containers,"*Journal American Society of Horticultural Science*, vol. 114, pp 53-56.1989.

[24] B.E., Jackson, R.D. Wrightand Seiler, J.R. "Changes in Chemical and Physical Properties of Pine Tree Substrate and Pine Bark During Long-term Nursery Crop Production,"*HortScience*.vol. 44, pp. 791-799.2009.

[25] J.W. Mastalerz, "*The greenhouse environment*,"New York:John Wiley and Sons Inc, 1977.

[26] S.E.Allaire-Leung, J. CaronandL.E. Parent, "Changes in physical properties of peat substrates during plant growth,"*Canadian Journal of Soil Science,* vol. 79, pp. 137–139.1999.

[27] F. Lemaire, "Physical, chemical, and biological properties,"*ActaHorticulturae*.vol. 396, pp. 273-284.1995.

[28] R.D.Wright, J.F. Browder, andB.E. Jackson, "Ground pine chips as a substrate for container-grown woody nursery crops,"*Journal of Environmental Horticulture*,vol. 24, pp. 181-184.2006.