EVALUATING VERMICOMPOST AND RENDERED MEAT PRODUCTS AS LOCAL MEDIA COMPONENTS IN VEGETABLE SEEDLING PRODUCTION

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By
Ian B. Gurr

Thesis Committee:

Theodore Radovich, Chairperson
Robert Paull
Kent Kobayashi

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ABSTRACT

Vermicompost, coconut coir, and thermophilic compost based growing media, with and without amendment with tankage were evaluated as alternatives to peat for organic vegetable transplant production. Treatments evaluated over the course of 4 greenhouse and 1 field trial using eggplant (*Solanum melongena* var. *esculentum*) 'Purple Long' and pak choi (*Brassica rapa* var. *chinensis*) 'Bonsai' seedlings were: peat:perlite (9:1 v/v) = (P); P amended with 0.7 grams $CaCO_3$ per liter of medium = (PAM); coconut coir = (C); thermophilic compost = (TC); vermicompost = (VC); P, PAM, C with weekly applications of soluble N-P-K (19-19-19) synthetic fertilizer = (PS), (PAMS), (CS); P:VC, PAM:VC, C:VC, TC:VC at rates of (75:25, 50:50 and 25:75 v/v); P, PAM, C, TC, P:TC (50:50 v/v), TC:VC (50:50 v/v) amended with tankage at rates of 5, 10, 12, 15, 20, 25 grams per liter of medium; P with weekly applications of soluble organic fertilizer comprised of fish emulsion N-P-K (5-1-1) and seaweed extract N-P-K (0.10-0.10-1.5) = (PO). The physical and chemical properties of media were determined and the effect of treatment on seedling shoot tissue nutrient content and seedling shoot growth were evaluated. A field trial was conducted to determine if the media used in greenhouse pak choi seedling production affected crop yield.

The total pore space, water holding capacity and air-filled porosity of the peat and vermicompost used in our study were not significantly different from each other. The pH, EC, nutrient content and C/N ratio of vermicompost was more ideal for seedling growth that that of peat and amendment of peat with vermicompost improved growing media chemical properties. Amending peat, coconut coir and thermophilic compost with vermicompost increased seedling shoot tissue nitrogen content and seedling shoot dry weight, with the greatest shoot dry weights obtained from 100 % vermicompost. Media amendment with tankage up to a rate of 15 g/l of medium also increased 6 week old eggplant seedling shoot tissue nitrogen content and shoot dry weight. Amendment with tankage at 20 and 25 g/l of medium resulted in excessive tissue nitrogen content of 6 week old eggplant seedling and a decrease in shoot dry weight. The effect of transplant seedling quality (tissue nutrient content and shoot dry weight) on crop yield was evaluated in a field trial of pak choi. All treatments received identical field fertilization of 'Sustane ®' N-P-K (4-6-4) turkey manure based organic fertilizer (Sustane Natural

Fertilizers, Inc., Cannon Falls, Minnesota) at the rate of 1250 lbs fertilizer/acre or 50 lbs N/acre. At harvest, mature plants in all treatments had shoot tissue macro- and micronutrients contents that were not significantly different from each other, and plant tissue nitrogen, phosphorus and potassium contents for all treatments were within or above sufficiency ranges, yet mature plants from seedlings produced in media amended with vermicompost or with tankage up to rates of 15 g/l of medium, had significantly greater shoot dry weights than plants from seedlings produced in unamended peat.

Vermicompost, along with coconut coir and thermophilic composts are growing media which should be better utilized as alternatives to peat. They are more sustainably produced, and often locally available. Use of up to 100 % vermicompost as a substitute for peat, or the amendment of peat, coconut coir or thermophilic compost based growing media with tankage at rates between 8 and 16 grams/liter of medium can improve seedling tissue nutrient content, seedling shoot dry weight, and crop yield.

At present, there are limitations to the use of these growing media and amendments. In many areas, vermicompost is produced in limited amounts and is relatively expensive compared to peat and other growing media. In Hawai'i, thermophilic compost and tankage are both locally produced from the waste products of other industies and are relatively inexpensive as sources of growing medium and nutrients, but thermophilic composts can vary in physical, chemical and biological properties, depending upon feedstock, source and even from batch to batch. Tankage quality and consistency can also vary from batch to batch depending upon feedstock. Also, much of the nitrogen contained in tankage is in organic form and plant availability will depend upon nitrogen mineralization rates which are dependant upon media microbial population, C/N ratio, moisture content and temperature.

Research investigating thermophilic compost maturity and tankage nitrogen mineralization rates and nitrate and ammonium content changes are needed if these locally produced materials are to be better utilized in producing quality vegetable seedling media.

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Literature Review

1.1 Introduction

Hawai'i vegetable farmers commonly produce vegetable seedlings in celled trays for later transplant into the field as opposed to direct seeding into the field. This practice can improve crop establishment and yield by reducing early plant loss due to pests and diseases. Potential benefits include earlier harvest, rapid crop turnover, and reduced cost for weed, pest, and disease management (Swiader et al., 1992).

Vegetable seedling production in Hawai'i relies heavily upon sphagnum peat moss based growing media (Hensley and Yogi, 1997). Peat is used because it is light in weight, clean, of relatively consistent quality, has low bulk density resulting in high water holding and air holding qualities, and has moderately high cation exchange capacity (CEC) (Miller and Jones, 1995). Low pH values and nutrient content in peat is mitigated by amending it with lime and nutrients to produce a good medium for seedling production.

Though peat has many of the properties required for quality vegetable seedling production, it is a non-renewable resource (Bethke, 2007). The mining of peat bogs depletes a limited resource and exposes lower bog layers to aerobic conditions, disrupting a sensitive ecosystem which plays an important role as a sink for atmospheric carbon dioxide. It is estimated that peat bogs worldwide sequester 455 billion tons of carbon, equivalent to that produced by industrial emissions over 70 years (Pearce, 2001). Once mined, peat must then be transported long distances to the site of use.

To make organic vegetable production in Hawai'i more sustainable, the amount of peat used in soilless growing media can be reduced by substitution with more sustainably produced organic media such as coconut coir and locally produced composts (Yogi et al., 1997). Growing media produced from properly composted organic wastes have physical, chemical, and biological properties ideal for promoting uniform, healthy seedling growth (Epstein, 1997). The local production of composts utilizing urban wood chip-wastes from roadside and park maintenance and food-wastes from restaurants and vegetable markets as feedstock provides an attractive solution to green-waste disposal problems while producing a valuable and sustainably produced horticultural product.

1.2 Properties of an Ideal Growing Medium

An ideal growing medium for vegetable seedling transplant production will produce healthy uniform seedlings within the limited volume of a seedling tray cell. Individual cell trays are preferred to “community” seedling trays by many growers in order to minimize root disturbance and subsequent transplant shock. Because seedling tray cells hold small volumes, the medium must provide adequate nutrient levels over the period necessary to produce the seedling and have the ability to hold sufficient water between irrigation cycles for optimum plant growth (Miller and Jones, 1995). The medium should also support the high diversity and populations of microorganisms that result in the production of plant growth promoting substances, and provide disease and pest suppression (Hoitink et al., 2001). For suppression of some diseases, inoculation with specific microbial antagonists of the causal organism may be required (Hoitink et al., 2001).

Physical properties that are desirable are a low bulk density (dry) between 0.3 and 0.8 g/cc, total pore space greater than 80% by volume, water holding capacity between 40% and 50% volume after drainage, and air-filled porosity between 20% and 30% (Mahmood, 2005; Miller and Jones, 1995; Robbins and Evans, 2005). A growing medium with low bulk density will be light, allowing easy handling and transport. If the total pore space is made up of a combination of micro and macro pores, the medium will have good water holding characteristics yet allow adequate drainage resulting in good aeration (Epstein, 1997; Ingram et al., 2003).

Chemical properties desired include pH levels between 5.0 and 6.5, CEC values greater than 100 meq/liter and an electroconductivity (EC) value below 2000 uS/cm (Mahmood, 2005; Miller and Jones, 1995). Nutrients must be present in plant available forms and in concentrations necessary for optimum plant growth without causing toxicities. Appropriate pH values are necessary to allow nutrient availability and prevent the harmful effects of an excessively acidic or basic environment. High CEC allows the media to retain nutrients against the leaching effects of irrigation and prevents the loss of nutrient into surrounding soil and water supplies. Electroconductivity values identify the concentration of salts or nutrients in the media. Media with high EC values may require leaching before use (Miller and Jones, 1995).

High organic matter content improves the physical, chemical and biological properties of a growing media (Wolf and Snyder, 2003). The growing medium should be consistent in its properties and stable over time (Inbar et al., 1993).

1.3 Value of Organic Matter

The importance of soil organic matter cannot be underestimated. Organic matter affects the physical, chemical, and biological properties of a soil or growing media (Wolf and Snyder, 2003). Problems that can be prevented by adequate levels of soil organic matter include poor structure; inadequate nutrient and water content of a soil or media; pH and CEC values that limit nutrient availability; and the presence of pests, diseases, and weeds (Weil and Magdoff, 2004). Organic matter contains nutrients in organic form, which through the action of certain microorganism, are converted into plant available inorganic forms. Organic matter buffers pH, increases CEC and provides chelation, improving the retention and availability of nutrients. Microorganisms associated with organic matter also form cements essential to the formation of soil aggregates. Soil aggregates improve soil structure, water infiltration, water holding capacity, and air-filled porosity (Wolf and Snyder, 2003). The addition to soil, of large amounts of organic matter, not produced on site, is sometimes not economical (Wolf and Snyder, 2003). The addition of composted organic matter to soil in small amounts via transplant media has been shown to improve soil properties, plant growth, and yield (Granberry et al., 2001).

1.4 Deficiencies of Peat as a Growing Medium

Peat is a partially decomposed, though relatively stable source of organic matter (Bunt, 1998). Though it has good physical properties, it has deficiencies as a growing media. Peat has very low nutrient content, making the addition of fertilizers necessary for healthy transplant production. The pH and CEC values of peat can limit nutrient availability to plants and result in the loss of nutrients in leachate during irrigation. This loss of nutrients limits plant growth and is an environmental concern (Bachman and Metzger, 2007; Weil and Magdoff, 2004). Peat is a non-renewable resource, and its mining disrupts an ecosystem vital to the sequestering of carbon dioxide. Sustainably produced organic materials, such as coconut coir, thermophilic compost, and vermicompost, should be evaluated as alternatives to peat for vegetable transplant production.

1.5 Coconut Coir

Coconut coir is a renewable resource, and it provides the physical, chemical, and biological properties of a good growing medium. Coir has higher CEC and better water and air holding properties than sphagnum peat (Cresswell, 1992). It can be used to increase pH values of peat based media without the addition of lime, and it offers a source of potassium (Bethke, 2007). Coir is a stable medium, decomposing slower than peat. It provides disease suppression through association with beneficial microorganisms (Candole and Evans, 2004; Hyder et al., 2009). Although preferable to peat, coir has its limitations. The physical and chemical properties of coir can vary widely depending on source (Evans et al., 1996). Some coir based media have been shown to impair plant growth due to nitrogen immobilization caused by high carbon to nitrogen (C/N) ratios (Cresswell, 1992) and excessive chloride levels (Meerow, 1994). Availability can also be limited due to inadequate local production in some areas of the tropics.

1.6 Thermophilic Compost

Thermophilic compost is the end product of the biological decomposition and mineralization of organic matter. It is the result of a self heating, aerobic process accomplished by the activity of fungi, bacteria, actinomycetes, and protozoa (Epstein, 1997). Thermophilic composting involves three phases. A mesophilic phase, with temperatures reaching 40-50ºC, lasts only a few days. During this phase, mesophilic microorganisms, which have colonized the substrate, breakdown sugars, starches, and other easily biodegradable substances. Progression of this phase produces a change in the substrate affecting the type of microorganisms that are able to colonize and dominate it. These changes lead to the initiation of a thermophilic phase. The thermophilic phase lasts from days to weeks, and temperatures will reach 55-70ºC. During this phase, proteins, fats, and cellulosic substances are broken down by thermophilic microorganisms. Heat generated by the increasing microbial mass eventually kills seeds and most plant pathogenic and beneficial microorganisms. When most of readily biodegradeable material has been broken down and most of the microorganisms killed, temperatures begin to decline and the curing stage begins. Temperatures drop to <40ºC, and mesophilic microorganisms from surrounding areas recolonise the substrate (Hoitink et al., 1997). It is these microorganisms that produce plant growth promoting substances and provide disease and pest suppressing effects (Epstein, 1997; Hoitink et al., 1997; Hoitink et al., 2001).

Thermophilic composts are acceptable alternatives to peat as growing media for potted plant production (Chong, 2005; Ingram et al., 2003; Moore, 2005). The addition of mature compost to peat based media improves the physical, chemical, and biological qualities of the media (Bachman and Metzger, 2008; Epstein, 1997), and enhances seedling growth. Uchida et al. (1979) found that substitution of 1/3 of a peat based growing medium with composted bagasse produced healthy plant growth. Lazcano et al. (2009) found that seedlings that were grown in compost based media had better shoot and root growth, a lower shoot to root ratio, an increased number of leaves, and larger leaf area than seedlings grown in peat based media. These features of seedling morphology are indicators of potential post-transplant growth and yield. These results, along with findings by Granberry et al. (2001) suggest that substitution of peat based media with compost can improve not only seedling growth but yield following transplantation into the field.

The use of compost as growing media has been found to be effective in the control of many plant diseases (Hoitink et al., 1997; Hoitink et al., 2001; Jack, 2008; Quarles and Grossman, 1995), providing an ecologically safe method of disease management in organic production. Composts in media have been found to be as effective as fungicides in controlling root rots (Hoitink et al., 1991) and are used to suppress *Fusarium*, *Phytophthora* and *Pythium* diseases (Trillas-Gay, 1986; Zinati, 2005). The use of compost as media has replaced the use of methyl bromide for pathogen control in the ornamental industry (Quarles and Grossman, 1995). Disease suppression by compost is due to the microbial populations supported by the substrate and involves competition, antibiosis, hyperparasitism, and systemic resistance (Hoitink et al., 1997; Zinati, 2005).

1.7 Vermicompost

Vermicompost, unlike traditional compost, is the product solely of mesophilic processes (Pattnaik and Reddy, 2010) without a thermophilic phase (Atiyeh et al., 2001; Lazcano et al., 2009). Vermicompost is the result of the breakdown of organic material by the interaction of earthworms such as *Eisenia fetida* or *Perionyx excavates* and mesophilic microorganisms under aerobic conditions (Arancon et al., 2005; Edwards et al., 2010b). This interaction results in a stable material, with improved physical, chemical, and biological properties and a higher available nutrient level than the original feedstock (Arancon et al., 2003; Atiyeh et al. 2001; Azarmi et al., 2008; Shi-wei and Fu-zhen, 1991). Compared to peat or thermophilic composts, the use of vermicompost increases seed germination (Suthar, 2010), plant growth and crop yield (Arancon et al., 2004; Atiyeh et al., 2001; Diaz-Perez and Camacho-Ferre, 2010; Zaller, 2007). For example, Arancon et al. (2006) found that vermicomposting results in increased levels of NH_4^+-N, NO_3^--N and orthophosphate which improved plant growth and yield. Other research suggest that humic substances found in vermicompost cause increased seed germination (Lazcano et al., 2010) and enhanced plant growth (Arancon et al., 2003).

Because the temperatures and processes involved in thermophilic composting and vermicomposting are different, the type and numbers of microorganisms responsible for organic matter decomposition differ, resulting in different physical, chemical, and biological properties of the composts, even when the same feedstock materials are used (Lazcano et al., 2009). A comparison of the biological community of thermophilic composts and vermicomposts showed that vermicomposts produced a greater diversity, population size and functional diversity of microorganisms (Devi et al., 2009; Vivas et al., 2009). This increased mass and diversity of microorganisms associated with vermicompost results in enhanced plant growth due to the production of plant growth promoting substances, disease and pest suppression, improved physical and chemical properties, and increased nutrient content and availability (Arancon et al., 2004). Beneficial microorganisms found in vermicompost include plant pathogen antagonists (*Streptomyces*, *Bacillus*, *Pseudomonas*), nitrogen fixers (*Acetobacter*, *Wolinella*), phosphate solubilizers (Gopal et al., 2009; Riddech et al., 2002), and microorganisms associated with the production of plant growth promoting substances.

Vermicompost improves plant growth beyond the effect due to its nutrient content alone (Atiyeh et al., 2001). This enhanced growth is thought to be due to the presence of plant growth promoting substances produced by microorganisms associated with vermicomposting (Arancon et al., 2008; Suthar, 2010). Busato et al. (2010) found vermicompost contained humic substances which promoted root development. Dobbs et al. (2010) suggested that hydrophobic properties of humic substances allow bioactive compounds such as auxins to be preserved. Upon contact with organic acids exuded by plant roots, these hydrophobic forces are disrupted and the bioactive compounds are released, activating the auxin synthetic reporter gene DR5-GUS. A study by David et al. (1994) found that humic substances enhance plant growth by increasing a plants ability to accumulate nutrients even under nutrient limited conditions.

The disease and pest control options for organic farmers are limited, making vermicompost a potentially useful input for organic growers. The use of vermicompost has been found to be an environmentally safe, effective method of disease and pest control in many crops (Arancon et al., 2005; Edwards et al., 2010a). Root-knot nematode infestation in tomatos, aphids and mealy bugs on peppers, *Pythium* damping off in cucumber seedlings, *Rhizoctonia* root rot in radish, *Verticillium* wilt in strawberry plants, *Phytophthora infestans* late blight disease on tomato, and spider mite on cucumbers have all been shown to be suppressed by the use of vermicompost (Arancon et al., 2005; Chaoui et al., 2002; Edwards et al., 2010a; Edwards et al., 2010b; Jack, 2008; Serfoli et al., 2010; Szczech, 1999; Zaller, 2006). Suppression of insect pests is thought to be due to the uptake into plant tissues of soluble phenolic compounds present in the vermicompost. Phenolic compounds make plant tissues less attractive to pests and reduce their reproduction and survival rates (Edwards et al., 2010b).

The process of vermicomposting improves the physical characteristics (Bachman and Metzger, 2007; Lazcano, 2009) and enhances the plant available nutrient content of organic matter (Arancon et al., 2006). Composting of identical urban waste feedstock by thermophilic and vermicomposting methods resulted in higher levels of plant available nutrients, higher CEC, and safer pH and salinity levels in vermicompost than in thermophilic compost or the original feedstock (Ghosh et al., 1999; Pattnaik and Reddy, 2010; Shi-wei and Fu-zhen, 1991). Vermicompost, used in the proper amount, can be an effective, safe substitute to chemical fertilizers in growing media mixes (Chaoui et al., 2003).

1.8 Conclusions

Research has shown that both thermophilic and vermicompost based media provide better physical, chemical, and biological properties than peat. Results of studies on the effects of thermophilic and vermicomposts on crop yield vary. Some field trials showed that seedlings grown in compost based media increased crop yield following transplant into the field (Granberry et al., 2001), whereas other trials showed no effect on yield (Zaller, 2007). Systematic evaluation of thermophilic and vermi- compost based growing media is needed to determine if they can be used as commercially acceptable alternatives to peat for vegetable transplant production in the tropics.

1.9 References Cited

Arancon, N. Q., C. A. Edwards, A. Babanko, J. Cannon, P. Galvis, and J. D. Metzger. 2008. Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse. Appl. Soil Ecol. 39:91-99.

Arancon, N. Q., C. A. Edwards, and P. Biermman. 2006. Influences of vermicomposts on field strawberries: part 2. Effects on soil microbial and chemical properties. Bioresource Technol. 97:831-840.

Arancon, N. Q., C. A. Edwards, P. Bierman, J. D. Metzger, S. Lee, and C. Welch. 2003. Effects of vermicomposts on growth and marketable fruits of field-grown tomatoes, peppers and strawberries. Pedobiologia 47:731-735.

Arancon, N. Q., C. A. Edwards, R. Atiyeh, and J. D. Metzger. 2004. Effects of vermicomposts produced from food waste on the growth and yields of greenhouse peppers. Bioresource Technol. 93:139-144.

Arancon, N. Q., P. A. Galvis, and C. A. Edwards. 2005. Suppression of insect pest populations and damage to plants by vermicomposts. Bioresource Technol. 96:1137-1142.

Atiyeh, R. M., C. A. Edwards, S. Subler, and J. D. Metzger. 2001. Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth. Bioresource Technol. 78:11-20.

Azarmi, R., M. T. Giglou, and R. D. Taleshmikail. 2008. Influence of vermicompost on soil chemical and physical properties in tomato (Lycopersicum esculentum) field. Afr. J. Biotechnol. 7:2397-2401.

Bachman, G. R. and J. D. Metzger. 2007. Physical and chemical characteristics of a commercial potting substrate amended with vermicompost produced from two different manure sources. HortTechnology 17:336-340.

Bachman, G. R. and J. D. Metzger. 2008. Growth of bedding plants in commericial potting substrate amended with vermicompost. Bioresource Technol. 99:3155-3161.

Bethke, C. L. 2007. Influences of agrococo medium coir on pH and EC. 3 January 2011. <http://www.agrococo.com/Bethke/LIMING_PROPERTIES_OF_AGROCOIR.pdf>.

Bunt, A. C. 1988. Media and mixes for container-grown plants. Unwin Hyman Ltd., London, UK.

Busato, J. G., D. B. Zandonadi, L. B. Dobbss, A. R. Facanha, and L. P. Canellas. 2010. Humic substances isolated from residues of sugar cane industry as root growth promoter. Sci. Aric. 67:206-212.

Candole, B. and M. Evans. 2004. Suppression od soil-borne diseases caused by Pythium and Phytophthora species in coconut coir-based substrates. HortScience 39:665-666.

Chaoui, H. I., L. M. Zibilske, and T. Ohno. 2003. Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. Soil Biol. Biochem. 35:295-302.

Chaoui, H., C. A. Edwards, A. Brickner, S. S. Lee, and N. Q. Arancon. 2002. Suppression of the plant diseases, *Pythium* (damping-off), *Rhizoctonia* (root rot) and *Verticillium* (wilt) by vermicomposts. 20 August 2010. <http://www.windsweptwormfarm.com/htdocs/PDFS/Vermicompost%20and%20its%20effects%20on%20plant%20diseases.pdf>.

Chong, C. 2005. Experiences with wastes and composts in nursery substates. HortTechnology 15:739-747.

Cresswell, G. C. 1992. Coir dust - a viable alternative to peat Pg. 1-5 In: Proceedings of the Australian Potting Mix Manufacturers Conference, Sydney. 3 January 2011. <http://flrec.ifas.ufl.edu/pdfs/CoirDust.pdf>.

David, P. P., P. V. Nelson, and D. C. Sanders. 1994. A humic acid improves growth of tomato seedling in solution culture. J. Plant Nutr. 17:173-184.

Devi, S.H., K. Vijayalaksmi, K.P. Jyotsna, S.K. Shaheen, K. Jyothi, and M.S. Rani. 2009. Comparative assessment in enzyme activities and microbial populations during normal and vermicomposting. J. Env. Biol. 30:1013-1017.

Diaz-Perez, M. and F. Camacho-Ferre. 2010. Effect of composts in substrates on the growth of tomato transplants. HortTechnology 20:368-376.

Dobbs, L. B., L. P. Canellas, F. L. Olivares, N. O. Aguiar, L. E. P. Peres, M. Azevedo, R. Spaccini, A. Piccolo, and A. R. Facanha. 2010. Bioactivity of chemically transformed humic matter from vermicompost on plant root growth. J. Agric. Food Chem. 58:3681-3688.

Edwards, C. A., N. Q. Arancon, M. Vasko-Bennett, A. Askar, and G. Keeney. 2010a. Effects of aqueous extracts from vermicomposts on attacks by cucumber beetles (*Acalymna vittatum*) (fabr.) on cucumbers and hornworm (*Manduca sexta*) (L.) on tomatoes. Pedobiologia 53:141-148.

Edwards, C. A., N. Q. Arancon, M. Vasko-Bennett, A. Askar, G. Keeney, and B. Little. 2010b. Suppression of green peach aphid (*Myzus persicae*) (Sulz.), citrus mealybug (*Planococcus citrri*) (Risso), and two spotted spider mite (*Tetranychus urticae*) (Koch.) attacks on tomatoes and cucumbers by aqueous extracts from vermicomposts. Crop Prot. 29:80-93.

Epstein, E. 1997. The science of composting. CRC Press LLC. Boca Raton, Florida.

Evans, M. R., S. Konduru and R. H. Stamps. 1996. Source variation in physical and chemical properties of coconut cour dust. HortScience 31:965-967.

Ghosh, M., G. N. Chattopadhyay, and K. Baral. 1999. Transformation of phosphorus during vermicomposting. Bioresource Technol. 69:149-154.

Gopal, M., A. Gupta, E. Sunil, and G.V. Thomas. 2009. Amplification of plant beneficial microbial communities during conversion of coconut leaf substrate to vermicompost by *Eudrilus* sp. Curr. Microbiol. 59:15-20.

Granberry, D., W.T. Kelly, D.B. Langston, K.S. Rucker, and J.C. Diaz-Perez. 2001. Testing compost value on pepper transplants. BioCycle 42:60-62.

Hensley, D. and J. Yogi. 1997. Substitutions for peat in Hawaii nursery production. Cooperative extension service, College of Tropical Agriculture and Human Resources, UH-Manoa. HRN-11. 3 January 2011. <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/HRN-11.pdf>.

Hoitink, A. J., M. S. Krause, and D. Y. Han. 2001. Spectrum and mechanisms of plant disease control with composts, p 263-273. In: P. J. Stoffella and B. A. Kahn (eds.). Compost utilization in horticultural cropping systems. CRC Press LLC. Boca Raton, FL.

Hoitink, H. A. J., A. G. Stone, and D. Y. Han. 1997. Suppression of plant diseases by composts. HortScience 32:184-187.

Hoitink, H. A. J., Y. Inbar, and M. J. Boehm. 1991. Status of composted-amended potting mixes naturally suppressive to soil-borne diseases of floricultural crops. Plant Dis. 75:869-873.

Hyder, N., J. J. Sims, and S. N. Wegulo. 2009. Invitro suppression of soilborne plant pathogens by coir. HortTechnology 19:96-100.

Inbar, Y., Y. Chen, and H. A. J. Hoitink. 1993. Properties for establishing standards for utilization of composts in container media, p. 668-694. In: H.A.J. Hoitink and H. M. Keener (eds.). Science and engineering of composting: Design, microbiological and utilization aspects.Renaissance Publications Worthington, OH.

Ingram, D. L., R. W. Henley, and T. H. Yeager. 2003. Growth media for container grown ornamental plants. University of Florida, IFAS Extension, BUL241. 3 January 2011. <http://edis.ifas.ufl.edu/cn004>.

Jack, A. l. H. 2008. Suppressing plant diseases with Vermicompost. NC State Vermicomposting Workshop. 20 August 2010. <http://organic.unl.edu/Research/NCState_08_Jack.pdf>.

Lazcano, C., J. Arnold, A. Tato, J. G. Zaller, and J. Dominguez. 2009. Compost and vermicompost as nursery pot components: effects on tomato plant growth and morphology. Span. J. Agric. Res. 7:944-951.

Lazcano, C., L. Sampedro, R. Zas, J. Dominguez. 2010. Vermicompost enhances germination of the maritime pine (*Pinus pinaster* Ait.). New Forest. 39:387-400.

Mahmood, T. 2005. Properties of a good organic soilless medium. 10 August 2010. <http://www.grotek.net/planttalk/article.asp?id=22.>.

Meerow, A.W. 1994. The potential of coir: (coconut mesocarp pith) as a peat substitute in container media. HortScience 29: 452.

Miller, J. H. and N. Jones. 1995. Organic and compost-based growing media for tree seedling nurseries. World Bank Technical Paper #264. Forestry Series.

Moore, K. K. 2005. Uses of compost in potting mixes. HortTechnology 15:58-60.

Pattnaik, S. and M. V. Reddy. 2010. Nutrient status of vermicompost of urban green waste processed by three earthworm species-*Eisenia fetida, Eudrilus eugeniae*, and *Perionyx excavates*. Applied and Environ. Soil Sci. 2010:1-13. 3 January 2011. <http://downloads.hindawi.com/journals/aess/2010/967526.pdf>.

Pearce, F. 2001. Climate Key . New Scientist Website. 10 August 2010. <http://www.newscientist.com/article/dn316-climate-key.html>.

Quarles, W. and J. Grossman. 1995. Alternatives to methyl bromide in nurseries- Disease suppressive media. IPM Practitioner 17:1-13.

Riddech, N., S. Klammer, and H. Insam. 2002. Characterization of microbial communities during composting of organic wastes, p. 345-355. In: H. Insam, N. Riddech and S. Klammer (eds.). Microbiology of composting. Springer-Verlag. NY.

Robbins, J. A. and Evans, M. R. 2005. Growing media for container production in a greenhouse nursery. 10 August 2010. <http://www.uaex.edu/Other_Areas/publications/PDF/FSA-6098.pdf>.

Serfoli, P., S. Rajeshkumar, and T. Selvaraj. 2010. Management of root-knot nematode, *Meloidogyne incognita* on tomato cv Pusa Ruby. by using vermicompost, AM fungus, *Glomus aggregatum* and mycorrhiza helper bacterium, *Bacillus coagulans*. J. Agric. Technol. 6:37-45.

Shi-wei, Z., and H. Fu-zhen. 1991. The nitrogen uptake efficiency from ^{15}N labeled chemical fertilizer in the presence of earthworm manure (cast), p. 539-542. In: G. K. Veeresh, D. Rajagopal and C. A. Viraktamath (eds.). Advances in management and conservation of soil fauna. Oxford and IBH Publishing Co, New Delhi, Bombay.

Suthar, S. 2010. Evidence of plant hormone like substances in vermiwash: An ecologically safe option of synthetic chemicals for sustainable farming. Ecol. Eng. 36:1089-1092.

Swiader, J. M., G. W. Ware, and J. P. McCollum. 1992. Producing Vegetable Crops. 4th ed. Interstate Publishers, Inc., Danville, IL.

Szczech, M. M. 1999. Suppressiveness of vermicompost against Fusarium wilt of tomato. J. Phytopathol. 147:155-161.

Trillas-Gay, M. I., H. A. Hoitink, and L.V. Madden. 1986. Nature of suppression of Fusarium wilt on raddish in a container medium amended with composted hardwood bark. Plant Dis. 70:1023-1027.

Uchida, R., R. Criley, and F. Rauch. 1979. Substitution of bagasse for peat in growing mediums. Horticulture Digest No. 52. Dept. of Horticulture, University of Hawaii at Manoa, Honolulu, HI.

Vivas, A., B. Moreno, S. Garcia-Rodriguez, and E. Benitez. 2009. Assessing the impact of composting and vermicomposting on bacterial community size and structure, and microbial functional diversity of an olive-mill waste. Bioresource Technol. 100:1319-1326.

Weil, R. R., and F. Magdoff. 2004. Significance of soil organic matter to soil quality and health, p. 1-43. In: R. R. Weil and F. Magdoff (eds.). Soil organic matter in sustainable agriculture. CRC Press LLC, Boca Raton, FL.

Wolf, B., and G. H. Snyder. 2003. Sustainable soils: The place of organic matter in sustaining soils and their productivity. Haworth Press, Inc., Binghamton, NY.

Yogi. J, D. Hensley, and J. Hollyer. 1997. Substituting Hawaii composts for peat in growing media for hibiscus. 10 August 2010. <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/HRN-12.pdf>.

Zaller, J. G. 2006. Foliar spraying of vermicompost extracts: effects on fruit quality and indications of late-blight suppression on field-grown tomatoes. Biol. Agric. Hortic. 24:165-180.

Zaller, J. G. 2007. Vermicompost in seedling media can affect germination, biomass allocation, yields and fruit quality of three tomato varieties. Eur. J. Soil Biol. 43:332-336.

Zinati, G. M. 2005. Compost in the 20^{th} century: a tool to control plant diseases in nursery and vegetable crops. HortTechnology 15:61-66.

CHAPTER 2

Vermicompost, Coconut Coir, and Thermophilic Compost based Growing Media: Effects on Greenhouse Seedling Growth and post Transplant Yield

2.1 Abstract

As alternatives to peat based growing media, vermicompost, coconut coir and thermophilic compost based growing media and the use of tankage as an amendment, were evaluated on their effects on seedling growth and crop yield following transplant to the field.

The nitrogen content of vermicompost was 2.2 times greater than that of peat. Amendment of peat, with tankage at the rate of 15 g/l of medium, increased medium nitrogen content by 1.8 times. Substitution of peat, coconut coir and thermophilic compost with vermicompost, or the amendment of these media with tankage at the rate of 15 grams of tankage per liter of medium, increased seedling tissue nitrogen content and seedling shoot dry weight over that of seedlings produced in unamended peat. Seedlings with greater shoot tissue nitrogen content, that did not exceed sufficiency range values, had greater seedling shoot dry weights and produced mature plants with greater shoot dry weights following transplant. Shoot dry weights of three week old pak choi seedlings produced in 100 % vermicompost were 10 times greater than those produced in unamended peat. After transplanting, shoot dry weights of mature plants produced from seedlings grown in 100 % vermicompost were 2 times greater than those of mature plants produced from seedlings grown in unamended peat.

Substituting peat based seedling growing media with vermicompost or amending it with tankage at the rate of 15 g/l of medium increased seedling shoot tissue nitrogen content, seedling shoot dry weight, and subsequently mature plant shoot dry weight following transplant.

2.2 Introduction

The objective of this study was to evaluate the effects of media amendment with vermicompost and tankage on vegetable seedling growth and yield following transplant.

Growing media used in vegetable seedling production affects seedling quality (Miller and Jones, 1995) and potentially post transplant yield. Desirable growing media physical properties are a high total porosity made up of a combination of macro- and micropores, providing good water holding capacity and good aeration through ample drainage (Handreck and Black, 2002). Desirable chemical properties are adequate nutrient levels and CEC and pH values that allow the media to retain nutrients and make them available to the plant (Miller and Jones, 1995). These chemical properties enhance plant growth and reduce the extent of nutrient pollution due to losses in irrigation water leachate. High diverse microbial populations are desired, enhancing nutrient content and availability, producing plant growth enhancing substances and providing disease and pest suppression (Inbar et al., 1993). High organic matter content provides beneficial physical, chemical and biological properties to growing media (Wolf and Snyder, 2003).

Vegetable production in Hawai'i relies heavily upon peat based media for seedling production (Hensley and Yogi, 1997). Peat is a non-renewable resource, and its mining disrupts an ecosystem vital for carbon sequestration (Bethke, 2007). Peat has low nutrient levels, low pH values and moderate CEC, requiring amendment with nutrients and lime, often resulting in the loss of nutrients into surface and ground waters (Bachman and Metzger, 2007). The microbial diversity and populations found in peat are relatively low (Inbar et al., 1993), as are the disease and pest suppressing effects, often resulting in the need for use of chemical pesticides. For these reasons, alternatives to peat for use as growing media are needed. Vermicompost, coconut coir and thermophilic compost have been identified as potential peat substitiutes.

Coconut coir is a non composted source of organic matter. It has excellent water and air holding properties and has been shown to provide some degree of disease suppression when used as a growing media (Candole and Evans, 2004).

Thermophilic composts are an excellent form of organic matter in growing media. The composting of plant wastes and animal manures produce a horticultural product superior to the original parent material. Composting improves particle size distribution, improving media physical properties; reduces or eliminates allelopathic effects of the raw material; optimizes the C/N ratio; enhances the content and availability of plant nutrients beyond that of the raw material; eliminates weed seeds; offers disease and pest suppression; and produces plant growth enhancing substances (Chen et al., 2004; Hoitink et al., 1997; Wolf and Snyder, 2003). Limitations to the use of thermophilic composts as a growing medium are inconsistent media quality (physical, chemical and biological properties) between compost producers and even between batch to batch from the same source.

Vermicomposts, the result of the interaction of earthworms and mesophilic microorganism in the decomposition of organic matter (Edwards et al., 2010), have a higher surface area than thermophlic composts produced from of the same feedstock or the original feedstock itself. This inceased surface area offers more microsites for microbial growth and activity. The large surface area also increases the capacity of vermicompost to adsorb nutrients (Shi-wei and Fu-zhen, 1991). Edwards (1995) found that plants grown in vermicompost showed greater growth than those grown in thermophilic compost or commercial growing media. This enhanced growth is thought to be due to a combination of improved physical and chemical properties, increased levels of nutrients in plant available forms (Edwards and Burrows, 1988), and the effects of plant growth enhancing substances and disease and pest suppression (Hoitink et al., 1997). These beneficial properties of vermicompost can be linked to the large and diverse populations of mesophilic microorganisms that it supports.

Vegetable producers rely heavily on transplants to improve stand establishment and get a head start on pests and weeds. In many places, including Hawai'i and U.S. dependencies in the Pacific and the Caribbean, growers must produce their own transplants. Whether produced commercially or on-farm, the medium for seedling production is generally peat-based. As a result, there is a strong need for renewable, locally-sourced materials to replace peat as a medium for sustainable production of vegetable seedlings. A systematic evaluation of vermicompost, coconut coir and thermophilic compost based growing media, and tankage as an amendment to these media, is needed to determine how they may be optimally used as commercially acceptable alternatives to peat for vegetable transplant production in the tropics. It was found that the substitution of peat, coconut coir and thermophilic compost with vermicompost, even up to 100 % vermicompost, increased seedling shoot dry weight over that of unamended peat. Amendment of peat, coconut coir and thermophilic compost with tankage at the rate of 15 grams per liter of medium also increased 6 week old seedling shoot dry weight over that of unamended peat. Seedling dry weight affected mature plant dry weight, following transplant. Mature pak choi plants from seedlings produced in vermicompost were twice as heavy as plants from seedlings produced in unamended peat.

2.3 Material and Methods

2.3.1 Growing Media Components (all trials)

Growing media treatments for trials in this research were made up of the following components. Medium containing a peat:perlite (9:1 v/v) mix (P) was made of 'Sunshine Peat Moss, Grade Green' (Sun Gro Horticulture Canada Ltd., Alberta, Canada) and 'Natural Volcanic Perlite, Horticultural Grade' (Surpreme Perlite Co., Portland, Oregon). In trial 4, 'Sunshine Peat' was not available so 'Canadian Sphagnum Peat Moss' (Alaska Peat Inc., Edmonton, Alberta, Canada) was used. Thermophilic compost (TC) used in treatments was made from yard and tree trimmings composted in a windrow system (Hawai'ian Earth Products, Oahu, Hawai'i). Vermicompost (VC) used in treatments was produced by the processing of supermarket foodwaste by *Eisenia fetida* 'Redworm' and *Perionyx excavatus* 'Blueworm' (Waikiki Worm Co., Oahu, Hawai'i). Coconut coir (C) used in treatments was 'Organic Coco Coir Planting mix' (HydroFarm, Petaluma, California). Tankage (moisture content of 6 % by weight) consisting of the rendered, dried and ground by-products of waste meat, fish and animal carcasses was obtained from Island Commodities, Inc. (Island Commodities, Inc., Oahu, Hawai'i). Agricultural lime used to increase peat pH values was 'Tropical Aglime' $CaCO_3$ 94%, Ca 37.6% (Tileco Inc., Kapolei, Hawai'i). The soluble synthetic fertilizer was N-P-K (19-19-19) 'Gavoita 60' (BEI Hawai'i, Oahu, Hawai'i). Soluble organic fertilizers were N-P-K (5-1-1) 'Aqua-Power Fish Emulsion' (JH Biotech, Ventura, California) and N-P-K (0.10-0.10-1.5) 'Seaweed Extract' (Growmore, Gardena, California).

2.3.2 Data Collection (all trials)

Plant growth parameters

Shoots were harvested and the height and leaf number were recorded. Fresh shoot weight was measured using an 'EX-1200' electronic scale (A&D Co. Ltd., San Jose, California) and leaf area measured using a 'CI-202' portable leaf area meter (CID Bio-Science Inc., Camas, Washington). Shoot samples were dried in a forced air-circulating oven for 72 hours at 70 ºC and shoot dry weights measured using an 'Adventurer Pro AV64' electronic scale (OHAUS Corporation, Pine Brook, New Jersey).

Plant tissue nutrient levels

Shoot nutrient levels were analyzed by the Agricultural Diagnostic Services Center, University of Hawai'i at Mānoa. Total carbon and nitrogen of dried tissue samples were analyzed by dry combustion in a 'LECO CN-2000' analyzer (LECO Corp., St. Joseph, Michigan). Other nutrients in the tissue samples were measured after wet acid digestion using an inductively coupled plasma (ICP) spectrophotometer (Jarrel-Ash Division/Fisher Scientific Co., Waltham, Massachusetts).

Growing media physical and chemical properties

Dry bulk density, total porosity, water holding capacity and air-filled porosity were determined using techniques described by Bragg and Chambers (1988) and Davidson and Mecklenburg (1991). Methodologies for determining media physical properties are described in the appendix. The pH and electrical conductivity of the media were measured from a 1:1 (v/v) mixture of deionized water: medium using a 'SympHony SB80PC' pH/EC meter (VWR Scientific Products, St. Paul, Minnesota). Total carbon and nitrogen of media samples were analyzed by dry combustion in a LECO CN-2000 analyzer (LECO Corp., St. Joseph, Michigan). Other nutrients in media samples were measured after wet acid digestion using an inductively coupled plasma (ICP) spectrophotometer (Jarrel-Ash Division/Fisher Scientific Co., Waltham, Massachusetts). Ammonium-N and nitrate-N were extracted from media using 2M KCL and measured colorimetrically using a discrete analyzer 'Easy Chem Plus' (Systea Scientific, Oak Brook, Illinois).

2.3.3 Greenhouse Trial 1 (eggplant)

This trial was conducted in 9 October- 20 November, 2009 at the Magoon Facility, University of Hawai'i at Mānoa. A randomized complete block design consisting of 11 treatments with 5 replications was used. Eggplant (*Solanum melongena* var. *esculentum* 'Purple Long') seeds (Peaceful Valley Farm and Garden Supply, Grass Valley, California) were sown into 50 cell plug (5x5x6 cm) trays. Each 50 cell tray, containing one treatment, was divided into 5, 10 cell sections. Each 10 cell section represented 1 replication. Treatments were peat:perlite (9:1 v/v) = (P); vermicompost = (VC); thermophilic compost = (TC); P amended with tankage at rates of 10, 15 and 20 g/l of medium; P:VC (75:25, 50:50, 25:75 v/v); P:TC (50:50 v/v); P with weekly applications of 1 tsp/gal of soluble 'Gaviota 60' N-P-K (19-19-19) synthetic fertilizer (PS). Seeded cells were placed in a greenhouse at ambient light and temperature and were sprinkler irrigated for 5 minutes, twice a day for 6 weeks when seedlings were harvested for data collection.

2.3.4 Greenhouse Trial 2 (eggplant)

This trial was conducted on 6 April-18 May, 2010 and consisted of 22 treatments with 5 replications. The experimental design, eggplant variety, trial location, growing conditions, time to harvest and data collected were similar to trial 1. Treatments were P; PS; VC; C; TC; P amended with tankage at rates of 5, 15 and 25 g/l of medium; P amended with 0.7 grams $CaCO_3$ per liter of medium = (PAM); PAM amended with tankage at rates of 5, 15, and 25 g/l of medium; TC amended with tankage at rates of 5, 15, and 25 g/l of medium; C amended with tankage at rates of 5, 15 and 25 g/l of medium; P:TC (50:50 v/v) amended with tankage at12 g/l of medium; P:VC (75:25, 50:50, 25:75 v/v).

2.3.5 Greenhouse Trial 3 (pak choi)

This trial was conducted on 6 April-27 April, 2010 at Magoon Facility, University of Hawai'i at Mānoa. A randomized complete block design consisting of 25 treatments with 5 replications was used. Pak choi (*Brassica rapa* var. *chinensis* 'Bonsai') seeds (Johnny Selected Seeds, Winslow, Maine) were sown into 50 cell plug (5x5x6 cm) trays. Each 50 cell tray, containing one treatment, was divided into 5, 10 cell sections. Each 10 cell section represented 1 replication. Treatments were P; PAM; PS;VC; C; P, PAM and C each amended with tankage at rates of 5, 15 and 25 g/l of medium; P:VC (75:25, 50:50, 25:75 v/v); PAM:VC (75:25, 50:50, 25:75 v/v); C:VC (75:25, 50:50: 25:75 v/v); PAM with weekly applications of 1 tsp/gal of soluble 'Gaviota 60' N-P-K (19-19-19) synthetic fertilizer = (PAMS); C with weekly applications of 1 tsp/gal of soluble 'Gaviota 60' N-P-K (19-19-19) synthetic fertilizer = (CS). Seeded cells were placed in a greenhouse at ambient temperature and were sprinkler irrigated for 5 minutes, twice a day for 3 weeks when seedlings were harvested for data collection.

2.3.6 Greenhouse Trial 4. (pak choi)

This trial was conducted on 23 July-13 August, 2010 and consisted of 16 treatments with 5 replications. The experimental design, pak choi variety, trial location, growing conditions and time to harvest were similar to trial 3. Treatments were P; PAM; PS; PAMS; VC; C; CS; C:VC (75:25, 50:50 v/v); P:VC (75:25, 50:50, 25:75 v/v); PAM:VC (75:25, 50:50, 25:75 v/v). P amended with tankage at the rate of 20 g/l of medium

2.3.7 Field Trial (pak choi)

A randomized complete block design field trial consisting of 8 treatments with 4 replications was conducted on 10 August-30 September, 2010. Pak choi (*Brassica rapa* var. *chinensis* 'Bonsai') seeds were sown into each treatment in plug trays (5x5x6 cm) at the Magoon Facility. Treatments were P; VC; P:VC (50:50 v/v); P with 2 applications, prior to transplanting, of soluble organic fertilizers 'Aqua-Power Fish Emulsion' N-P-K (5-1-1) at 25 mls/gal and 'Seaweed Extract' N-P-K (0.10-0.10-1.5) at 30 mls/gal = (PO); P amended with tankage at 15 grams/liter of medium; TC amended with tankage at15 grams/liter of medium; P:TC (50:50 v/v) amended with 12 grams tankage/ liter of medium; TC:VC (50:50 v/v) amended with 12 grams tankage/ liter of medium. The treatment P amended with tankage at15 g/l of medium was excluded from the field trial due to poor germination resulting in insufficient number of seedlings. Twenty-one days after sowing, seedlings were transplanted into the organic research plots at the Waimanalo Research Station, University of Hawai'i at Mānoa. Each replication consisted of 5 plants from which data was collected surrounded by border plants for a total of 21 plants. Prior to transplanting, field plots were incorporated with 'Sustane ®'N-P-K (4-6-4) turkey manure based organic fertilizer (Sustane Natural Fertilizers, Inc., Cannon Falls, Minnesota) at the rate of 1250 lbs fertilizer/acre or 50 lbs N/acre. Plants were irrigated by drip tape and were harvested at 30 days after transplanting.

2.3.8 Statistical Analysis

Analysis of variance of seedling and mature plant growth parameters, tissue nutrient levels and growing media properties was performed on treatments using SAS 9.1 (SAS Institute Inc., Cary, NC, 2003). Means were separated using Duncan's multiple range test. Statistical significance was defined as $p \leq 0.05$ unless otherwise indicated.

2.4 RESULTS

2.4.1 Plant growth

Greenhouse trials 1 and 2 (six week old eggplant seedlings)

Amendment of P with VC significantly increased seedling growth (shoot dry weight). Growth increased as the percentage of VC in the medium increased, with the greatest growth occurring at 100% VC (Tables 4 and 5). The finding that growth was best in 100% VC conflicts with findings by Atiyeh et al. (2000) who found that plant growth was reduced in 100% VC but significantly improved at rates of 25% to 50% VC.

Amendment of P with tankage at 5, 10 and 15 g tankage/l medium resulted in increased seedling growth, with 15 g tankage/l medium resulting in the greatest increase. Seedling growth decreased at concentrations of 20 and 25 g/l medium (Tables 4 and 5). Regression analysis showed that 95% maximum yield (seedling shoot dry weight) can be obtained in peat amended with tankage at rates between 8 and 13 g/l of medium (Figures 1.2 and 2.2).

Greenhouse trials 3 and 4 (three week old pak choi seedlings)

Seedling growth was significantly greater in VC than in P. Seedling growth increased as the percentage of VC incorporated into P increased (Tables 6 and 7).

Amendment of P with tankage at rates of 5, 15 and 25 g tankage /l medium did not significantly affect seedling growth in 3 week old pak choi seedlings (Table 6). This is in contrast to the beneficial effects of tankage on 6 week old eggplant seedling growth in trials 1 and 2 (Tables 4 and 5).

In trial 3, germination of seedlings in peat amended with tankage at 5 g/l of medium (P+tank 5) was poor (Table 6). In this trial, media physical or chemical properties were not determined and the cause of this poor germination is unknown. In the field trial, germination of seedlings in peat amended with tankage at 15 g/l of medium (P+tank 15) was also extremely poor, though in trials 1, 2 and 3 germination in P+tank 15 was greater than 60%. Media nutrient analysis showed a high ammonium content (Table 3), which might have contributed to the poor germination.

Field trial (pak choi – seedlings)

Seedlings of PO treatment had relatively high tissue nitrogen content (Table 14) but low shoot dry weight (Table 8), and after transplanting to the field, mature plants of PO had shoot dry weights not significantly different from VC (Table 9) which had the highest dry weight. This inconsistency of high seedling tissue nitrogen content and low seedling shoot dry weight was most likely due to leaf damage following the initial soluble fertilizer application to seedlings. Following fertilizer application, there were signs of phytotoxicity, with leaves appearing burned and later drying up. The fertilization rate was halved, and there were no further signs of phytotoxicity, but many of the first leaves had been damaged which most likely resulted in a low seedling shoot dry weight (Table 8).

Field trial (pak choi – mature plants)

At harvest, mature plants that were produced from seedlings grown in P:VC 50:50 and VC, had shoot dry weights significantly greater than plants from seedlings grown in unamended P. Seedlings that were grown in 100% VC produced the heaviest mature plants (Table 9). Mature plants produced from seedlings grown in TC+tank 15 had shoot dry weights significantly greater that treatment P but not significantly different from treatment VC (Table 9). Mature plants produced from seedlings grown in PO had shoot dry weights significantly greater that treatment P but not significantly different from treatment VC (Table 9).

2.4.2 Media Physical Properties

Methodology for determining media total pore space (TPS), water holding capacity (WHC), air-filled porosity (AFP), and dry bulk density (DBD) are described in the appendix.

Dry bulk density (g/cc)

The dry bulk densities of P, VC, C and TC were 0.10, 0.16, 0.08, 0.34 respectively and were significantly different from each other (Table 1). Incorporation of VC into P increased media bulk density. Bachman and Metzger (2007) similarly reported an increase in bulk density of peat based media following amendment with VC.

Total pore space %

The total pore space values of P and VC were similar and significantly greater than those of TC and C which were similar to each other (Table 1). The total pore space values of P, VC, C and TC were 62.84%, 61.62%, 53.73% and 47.58% respectively.

Amendment of P with VC did not significantly change total pore space. The ideal growing medium total pore space is >80% (Miller and Jones, 1995). All media evaluated had total pore space values below 80%.

Water holding capacity %

The water holding capacity of P and VC were similar and significantly greater than that of TC and C which were similar to each other (Table 1). The water holding capacity of P, VC, C and TC were 41.09%, 39.40%, 20.39% and 23.63% respectively. Ideal water holding capacity for a growing medium is between 40% - 50% (Miller and Jones, 1995). Amendment of P with VC did not significantly change water holding capacity.

Air-filled porosity %

Peat, VC, C and TC had air-filled porosity values of 21.75%, 22.22%, 33.34% and 23.95% respectively (Table 1). The air-filled porosity of an ideal medium is between 20% -30% (Miller and Jones, 1995). There was no significant difference in the air-filled porosity of P and VC. Amendment of P with VC did not significantly change air-filled porosity.

2.4.3 Media Chemical Properties

pH

Vermicompost, PAM and C had pH values between 5 and 6.5, within or near the range for optimal plant growth (Goh and Haynes, 1977). Thermophilic compost had a pH of 7.8 and peat a pH of 4.5 (Table 2). Substitution, by volume, of 25%, 50%, 75% and 100% of P with VC increased media pH to values within the range for optimal plant growth. This increase in pH, in peat based media following amendment with VC is similar to findings by Tyler et al. (1993) but is in contrast with results of Atiyeh et al. (2001). Addition of tankage to P at rates of 5, 10, 15, 20 and 25 g/l of medium, increased pH to values within the range for optimal plant growth (Table 2). Amendment of P with lime at 0.7 g/l of medium, increased pH from 4.5 to 5.1 (Table 2).

Electrical conductivity

The electrical conductivity of P, PAM, C, VC and TC were 307, 350, 986, 2639 and 2485 uS/cm respectively (Table 2). The electrical conductivity of P increased progressively with increasing amendment with VC or tankage. Ideal EC is below 2000 uS/cm (Mahmood, 2005)

Media C/N ratio and nutrients (field trial)

The C/N ratio of P and VC were 34 and 15 respectively (Table 3). Substituting P with VC to a ratio of 1:1 by volume reduced the C/N ratio to 21. Amending P with tankage at 15 g/l of medium reduced the C/N ratio to 18. Nitrogen, phosphorus, potassium, calcium, and magnesium content were significantly greater in VC than in P (Table 3). Peat and VC had nitrogen contents of 1.20% and 2.65% respectively. Substituting P with VC to a ratio of 1:1 by volume increased the nitrogen content of the medium to 1.88%. Amending P with tankage at 15 g/l of medium increased the nitrogen content to 2.16%. Arakaki (2008) found Island Commodities, Inc. tankage to have a C/N ratio of 5.4 and nitrogen content of 8.77%. The nitrate contents of P, P:VC 50:50, VC and P+tank 15 were 411 ug/g, 3336 ug/g, 2341 ug/g and 976 ug/g respectively. The ammonium contents of P, P:VC 50:50, VC and P+tank 15 were 63.3 ug/g, 2.9 ug/g, 5.1 ug/g and 1864.7 ug/g respectively (Table 3). The ammonium content of P +tank 15 was 366 times greater than that of VC. Germination was extremely poor and the treatment was excluded from the field trial, though in previous trials (1, 2 and 3), P+tank 15 had germination between 64 and 84%. Other treatments amended with tankage in this same trial did not have excessively high ammonium contents (Table 3). Reasons for the variability are unknown, but it is important to note that users should be aware of the potential phytotoxicity caused by excessive ammonium and other unidentified factors in tankage. Peat and VC had phosphorus contents of 0.04% and 0.81% respectively (Table 3). Peat and VC had potassium contents of 0.02% and 0.42% respectively. The sodium content of P, VC, P:VC 50:50 and P+tank 15 were 0.05%, 0.12%, 0.08% and 0.13% respectively. Arakaki (2008) found the sodium content of Island Commodities, Inc. tankage to be 0.65%.

2.4.4 Plant Tissue Nitrogen Concentration

Greenhouse trials 1 and 2 (six week old eggplant seedlings)

Tissue nitrogen of P and VC grown seedlings shoot tissue in trial 1 were 1.35% and 3.01% respectively (Table 10). In trial 2, the tissue nitrogen contents of P and VC seedlings, 1.1% and 1.3% respectively (Table 11), were not significantly different.

Amendment of P with VC did not increase 6 week old eggplant seedling tissue nitrogen content significantly over that of seedlings produced in unamended P, with the exception of 75% VC and 100% VC treatment in trial 1.

Amendment of P with tankage increased seedling tissue nitrogen content. In trial 1, the shoot tissue nitrogen content of seedlings grown in P, and peat amended with tankage at rates of 10, 15 and 20 g/l of medium (P+tank 10, P+tank 15, P+tank 20) were 1.35%, 3.14%, 3.90% and 6.83% respectively (Table 10). In trial 2, the tissue nitrogen content of P, and peat amended with tankage at rates of 5, 15 and 25 g/l of medium (P+tank 5, P+tank 15, P+tank 25) were 1.1%, 2.5%, 4.3% and 4.0% respectively (Table 11). Seedlings grown in P amended with tankage showed tissue nitrogen contents greater than those grown in VC (Tables 10 and 11).

Greenhouse trials 3 and 4 (three week old pak choi seedlings)

In trial 3, seedling shoot tissue nitrogen of P, and VC were 1.21% and 2.57% respectively. Substitution, by volume, of 50% and 75% of P with VC, significantly increased 3 week old pak choi seedling tissue nitrogen content over that of unamended P (Table 12). P:VC 25:75 treatment seedlings had a tissue nitrogen content greater than that in VC seedlings.

In trial 4, due to the unavailability of ‘Sunshine Peat Moss, Grade Green’ (Sun Gro Horticulture Canada Ltd., Alberta, Canada) which was used in all other trails, ‘Canadian Sphagnum Peat Moss’ (Alaska Peat Inc., Edmonton, Alberta, Canada) was used. Germination and seedling growth in unamended P was poor (Table 7) compared to trials where ‘Sunshine Peat’ was used (Table 6). Unamended P treatment seedlings showed higher tissue nitrogen and sodium contents than P treatment seedlings from previous trials (Tables 12 and 13). Shoot tissue nitrogen content of P treatment in trial 4 was 2.16%, compared to 1.21% in trial 3. Vermicompost treatment seedlings from trials 3 and 4 had similar tissue nitrogen contents, 2.57% and 2.80% respectively. Amendment of P with VC, showed no effect on seedling tissue nitrogen in the P:VC 25:75 or P:VC 50:50 treatments, and the P:VC 75:25 treatment showed a lower tissue nitrogen content than P (Table 13). Shoot tissue sodium content of P treatment in trial 4, was 3.21%, compared to 1.54% in trial 3 (Table 13). This demonstrates the fact that there may be large difference in nutrient content of peat from different sources.

In trial 3, due to lab analysis costs and the fact that treatments involving amendment with tankage showed no beneficial effects on growth of pak choi seedling at 3 weeks, seedlings grown in tankage amended media were not analyzed for tissue nutrients (Table 12).

In trial 4, the only treatment containing tankage was P+tank 20. Analysis of seedling tissues showed P+tank 20, VC and P treatment plants to have nitrogen contents of 6.80%, 2.80% and 2.16% respectively (Table 13).

Field trial (pak choi – mature plants)

At harvest, there were no significant differences in the shoot tissue macro- or micronutrient contents of mature pak choi plants between treatments (Table 15), yet as presented earlier, there were significant differences in mature shoot dry weights between treatments (Table 9).

2.5 DISCUSSION

2.5.1 Introduction

Peat

Improving seedling quality and reducing the amount of peat used in vegetable seedling production can be accomplished by substituting peat based growing media with vermicompost or by amending with tankage.

Previous researchers have attributed increased plant growth, following substitution of peat with vermicompost, to improvement of media physical and chemical properties, increased media nutrient content and availability, the presence of plant growth enhancing compounds, and increased pest and disease resistance (Arancon et al., 2006; Atiyeh et al., 2000; Atiyeh et al., 2002). Increased plant growth following media amendment with tankage has been attributed to increased media nitrogen, phosphorus and calcium content (Jeng et al., 2004).

In this experiment, the effects of vermicompost and tankage on media physical and chemical properties, seedling shoot tissue nitrogen content, seedling growth, and crop yield following transplant into the field were evaluated.

It was found that substitution of peat based growing media with vermicompost increased seedling growth (Figures 1.1, 2.1, 3.1 and 4). Shoot dry weight of both 3 week old pak choi and 6 week old eggplant seedlings grown in 25, 50, 75 and 100%

vermicompost were significantly greater than those grown in unamended peat (Tables 4, 5, 6 and 7). Seedling shoot dry weight increased as the proportion of vermicompost increased.

Amendment of a peat based growing medium with tankage at 5, 10, and 15 g/l medium increased shoot dry weight in 6 week old eggplant seedlings. The greatest growth occurred in the 15 g/l treatment. At tankage rates of 20 and 25 g/l medium, plant growth decreased (Figures 1.2 and 2.2). Amendment of peat with tankage did not increase growth of 3 week old pak choi seedlings (Table 6). Subjective observation of 6 week old seedlings grown in peat amended with tankage, showed slow growth initially, but increased growth and greenness by the 6^{th} week. Although tankage contains relatively large amounts of nitrogen, phosphorus and calcium, much of the nitrogen is in organic form and must be mineralized to become plant available. The lack of a positive effect of tankage on the growth of 3 week old pak choi seedlings may have been due to inadequate time required for mineralization of organic nitrogen or to a sensitivity of pak choi to certain components of tankage sufficient to cause phytotoxicity. Pot experiments involving peat amended with tankage as a growing medium have shown some nitrogen immobilization. (Jeng et al., 2004).

Seedling growing media affected crop yield following transplant. Mature plants from seedlings produced in media amended with vermicompost or tankage up to rates of 15 g/l of medium, had significantly greater shoot dry weights than plants from seedlings produced in unamended peat.

Coconut coir

Seedlings grown in unamended coconut coir showed poor growth. Seedlings had low shoot tissue nitrogen and phosphorus content. Shoot tissue sodium and potassium were significantly higher than that found in seedlings produced in peat or in vermicompost (Table 11). Substituting coir with 75 % vermicompost increased seedling growth (Tables 6 and 7). Amending coir with tankage at 15 g/l of medium, increased 6 week old eggplant seedling growth (Table 5) but not 3 week old pak choi growth (Table 6). This difference in effect on 6 and 3 week old seedlings may have been due to the time required for nitrogen mineralization or sensitivity of pak choi to components of tankage.

Thermophilic compost

Seedlings grown in unamended thermophlic compost had poor growth. The pH level of unamended thermophilic compost was not ideal for seedling growth (Table 2). The maturity of the compost was also questionable. Small particles of undecomposed wood were present and heat was still being generated in the piles. Seedlings produced in unamended thermophilic compost had low tissue nitrogen and phosphorus content (Tables 10 and 11). Amendment of thermophilic compost with tankage at the rate of 15 g/l of medium improved seedling tissue nitrogen content (Table 11) and growth (Table 5) in 6 week old eggplant seedlings.

The use of coconut coir or thermophilic compost substituted with vermicompost or amended with tankage, at the appropriate rates, produced seedling growth greater that that obtained from unamended peat. These more sustainably produced growing media, often locally available in the tropics, may have value as peat alternatives if amended with vermicompost or tankage. Sufficient maturity of the thermophilic compost should be ensured, and length of time required for nitrogen mineralization should be taken into account when determining period of time between media amendment with tankage and sowing.

2.5.2 Media physical and chemical properties

The physical and chemical properties of vermicompost can vary depending upon the type and source of feedstock, processing and storage time and conditions (Lazcano et al. 2009). The physical and chemical properties and nutrient content of peat can also vary depending upon source, processing and storage time and conditions.

Several researchers have found that substitution of peat base media with vermicompost produces the greatest increase in plant growth when the percentage of vermicompost is <50%, and that at rates of >50 %, plant growth declines (Atiyeh et al., 2000; Moore, 2005; Shiralipour et al. 1992).

Findings of the present study, similar to those of Lazcano et al. (2009), were that as the proportion of substitution with vermicompost increased, so did plant growth, with 100% vermicompost producing the greatest plant growth. These differences in the percentage of vermicompost that produce optimal growth may be due to differences in the physical and chemical properties of the peat and of the vermicompost used in the different experiments.

The peat and vermicompost used in this experiment had total pore space, water holding capacity and air-filled porosity values that were not significantly different from each other. Amending peat with vermicompost did not alter these physical properties (Table 1), suggesting that increased seedling growth in our trials was likely due to factors other than media physical properties.

The electrical conductivity and pH values of peat and vermicompost were significantly different from each other, and substitution of peat with vermicompost improved these media chemical properties (Table 2). Amendment of peat with tankage also improved media pH and electrical conductivity.

The C/N ratios of peat and vermicompost were 34 and 15 respectively (Table 3), and the amendment of peat with vermicompost improved growing media C/N ratio. Amendment of peat with tankage also improved media C/N ratio.

The macro- and micronutrient content of vermicompost was significantly greater than that of unamended peat (Table 3). The nitrate content of vermicompost was 5.7 times greater than that of peat. Substitution of peat with vermicompost increased media nitrogen, phosphorus, and potassium content. Amending peat with tankage increased media nitrogen, phosphorus, potassium and ammonium content (Table 3).

2.5.3 Plant Tissue Nutrient Content

Plant tissue nutrient concentrations affect crop quality and yield (AESL; Pant et al., 2009; Paul and Metzger, 2005; Uchida, 2000). Nutrient sufficiency ranges define plant tissue nutrient levels at which growth is optimum. Nutrient levels below the sufficiency range are considered deficient and those above can result in imbalances and toxicity, both affecting plant growth (Uchida, 2000).

Eggplant

For mature eggplant, the recommended tissue nitrogen sufficiency range is 4% - 5%, from leaf tissue at the bud to small fruit stage (Uchida, 2000). The tissue nitrogen content of 6 week old eggplant seedlings shoots from trials 1 and 2, ranged from 0.51% to 6.83% (Tables 10 and 11). Seedling shoot dry weight (Table 4) was greatest when tissue nitrogen content was between 2% to 4%. Seedlings produced in treatments such as unamended P, where tissue nitrogen levels were low, had low shoot dry weights. Seedling shoot dry weight was also reduced in treatments where shoot tissue nitrogen was excessive, such as in treatment P+tank 20 in trial 1 where shoot tissue nitrogen content was 6.83% (Tables 4 and 10).

In trials 1 and 2, which involved 6 week old eggplant seedlings, even though the amendment of peat with vermicompost increased seedling shoot dry weight, the tissue nitrogen content of these seedlings was not significantly greater than those of seedlings produced in unamended peat. This is in contrast to 3 week old pak choi seedlings, where amendment of peat with vermicompost produced seedlings with shoot tissue nitrogen and shoot dry weight significantly greater than those produced in unamended peat. Subjective observation during trials 1 and 2 were that by 6 weeks, seedlings produced in vermicompost amended peat that originally appeared healthy, were beginning to show signs of chlorosis. This inconsistency of low tissue nitrogen but good seedling growth in 6 week old eggplant seedlings may have been due to the exhaustion of a limited amount of nitrogen held in the tray cells. The amount of nitrogen, from vermicompost amended peat, contained in this tray cell size may not have been adequate for 6 weeks growth of eggplant seedlings. Increased growth may also have been partially due to factors other than medium nitrogen content such as the presence of growth hormones and/or humic acid or increase in nutrients other than nitrogen.

Pak choi

For mature pak choi, the recommended tissue nitrogen sufficiency range is 2.39% - 5.51%, from fully expanded leaf tissue (Uchida, 2000). The tissue nitrogen content of 3 week old pak choi seedlings shoots from trials 3 and 4, ranged from 0.95 % to 6.80 % (Tables 12 and 13). Seedling shoot dry weight (Table 6) was greatest when tissue nitrogen content was between 2% to 5%. Seedlings produced in treatments, such as unamended P, where tissue nitrogen levels were low, had low shoot dry weights. Poor seedling growth in treatments that had adequate tissue nitrogen levels, as in PS and PAMS treatments in trial 4, may have been due to low tissue calcium content (Table 13).

2.5.4 Conclusion

Substitution of peat with vermicompost increased seedling growth. Increased growth was most likely due to a combination of improved media pH, EC, C/N ratio and nutrient content resulting in increased nutrient availability and uptake. Other factors not investigated that may have contributed to increased seedling growth may have been the presence of plant growth hormones and humic acid and their effects on nutrient uptake by the plant.

Increased seedling growth following amendment of peat with tankage at rates up to 15 g/l of medium in 6 week old seedlings is most likely due to improvement of media C/N ratio and increased nutrient content, especially nitrogen, and phosphorus. Decreased seedling growth in media amended with tankage at rates greater than 15 g/l of medium, may have been due to phytotoxicities due to ammonium, sodium, or other unidentified factors.

Either substituting peat with vermicompost or amending it with tankage, increased growing media nitrogen content, improved C/N ratio and improved media pH and EC values. The increase in media nitrogen content and improved chemical properties and mineralization rate increased the availability of nitrogen to the plant resulting in increased shoot tissue nitrogen content and seedling growth.

The field trial showed that crop yield can be affected by transplant seedling quality (tissue nutrient content and shoot dry weight). At harvest, mature plants from seedlings produced in media amended with vermicompost or with tankage up to rates of 15 g/l of medium, had significantly greater shoot dry weights than plants from seedlings produced in unamended peat. The use of vermicompost or tankage as growing media amendments, affected seedling tissue nutrient content, seedling shoot dry weight, and following transplant, mature plant shoot dry weight and crop yield.

Vermicompost and tankage, as amendments to peat, coconut coir and thermophilic compost can be used to improve transplant seedling quality and crop yield and sustainability in vegetable production systems in the tropics.

2.6 References Cited

Agricultural and Environmental Services Laboratory (AESL) - University of Georgia, College of Agricultural and Environmental Sciences. (n.d.). Plant analysis handbook, nutrient content of plant. 3 January 2011. <http://aesl.ces.uga.edu/publications/plant/Nutrient.htm>.

Arakaki, A. S. 2008. Response of corn and bean seedlings to preplant application of Island Commodities, Inc. bone meal. 3 January 2011. <http://www.ctahr.hawaii.edu/organic/downloads/Effect%20of%20Bone%20Meal%20Soil%20Amendment%20on%20Corn%20and%20Bean%20Seedlings.pdf>.

Arancon, N. Q., C. A. Edwards, and P. Biermman. 2006. Influences of vermicomposts on field strawberries: part 2. Effects on soil microbial and chemical properties. Bioresource Technol. 97:831-840.

Atiyeh, R. M., N. Arancon, C. A. Edwards, and J. D. Metzger. 2000. Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. Bioresource Technol. 75:175-180.

Atiyeh, R. M., N. Q. Arancon, C. A. Edwards, and J.D. Metzger. 2002. The influence of earthworm-processed pig manure on the growth and productivity of marigolds. Bioresource Technol. 81:103-108.

Bachman, G. R. and J. D. Metzger. 2007. Physical and chemical characteristics of a commercial potting substrate amended with vermicompost produced from two different manure sources. HortTechnology 17:336-340.

Bragg, N. C. and B. J. Chambers. 1988. Interpretation and advisory application of compost air-filled porosity (AFP) measurements. Acta Hort. 20:35-44.

Bethke, C. L. 2007. Influences of agrococo medium coir on pH and EC. 3 January 2011. <http://www.agrococo.com/Bethke/LIMING_PROPERTIES_OF_AGROCOIR.pdf>.

Candole, B. and M. Evans. 2004. Suppression of soil-borne diseases caused by Pythium and Phytophthora species in coconut coir-based substrates. HortScience 39:665-666.

Chen, Y., M. De Nobili, and T. Aviad. 2004. Stimulatory effects of humic substances on plant growth, p 103-129. In: R. R. Weil and F. Magdoff (eds.). Soil Organic Matter in Sustainable Agriculture. CRC Press LLC, Boca Raton, FL.

Davidson, H., R. Mecklenburg, and C. Peterson. 1999. Nursery management: administration and culture. 4th ed. Prentice Hall, Englewood Cliffs, N.J.

Edwards, C. A., N. Q. Arancon, M. Vasko-Bennett, A. Askar, G. Keeney, and B. Little. 2010. Suppression of green peach aphid (*Myzus persicae*) (Sulz.), citrus mealybug (*Planococcus citrri*) (Risso), and two spotted spider mite (*Tetranychus urticae*) (Koch.) attacks on tomatoes and cucumbers by aqueous extracts from vermicomposts. Crop Prot. 29:80-93.

Edwards, C.A. and I. Burrows. 1988. The potential of earthworm composts as plant growth media, p. 211-220. In: C. A. Neuhauser (ed.). Earthworms in environmental and waste management. SPB Academic Publishing, The Hague, Netherlands.
Edwards, C.A., 1995. Historical overview of vermicomposting. Biocycle 36:56-58.

Goh, K.M. and R.J. Haynes. 1977. Evaluation of potting media for commercial nursery production of container grown plants. New Zeal. J. Agr. Res. 20:363-370.

Handreck, K. and N. Black. 2002. Growing media for ornamental plants and turf. University of New South Wales Press Ltd. NSW, Australia.

Hensley, D. and J. Yogi. 1997. Substitutions for peat in Hawaii nursery production. Cooperative extension service, College of Tropical Agriculture and Human Resources, UH-Manoa. HRN-11. 3 January 2011. <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/HRN-11.pdf>.

Hoitink, H. A. J., A. G. Stone, and D. Y. Han. 1997. Suppression of plant diseases by composts. HortScience 32:184-187.

Inbar, Y., Y. Chen, and H. A. J. Hoitink. 1993. Properties for establishing standards for utilization of composts in container media, p. 668-694. In: H.A.J. Hoitink and H. M. Keener (eds.). Science and engineering of composting: Design, microbiological and utilization aspects.Renaissance Publications Worthington, OH.

Jeng, A., T. K. Haraldsen, N. Vagstad, and A. Gronlund. 2004. Meat and bone meal as nitrogen fertilizer to cereals in Norway. Agric. Food Sci. 13:268-275.

Lazcano, C., J. Arnold, A. Tato, J. G. Zaller, and J. Dominguez. 2009. Compost and vermicompost as nursery pot components: effects on tomato plant growth and morphology. Span. J. Agric. Res. 7:944-951.

Miller, J. H. and N. Jones. 1995. Organic and compost-based growing media for tree seedling nurseries. World Bank Technical Paper #264. Forestry Series.

Moore, K. K. 2005. Uses of compost in potting mixes. HortTechnology 15:58-60.

Pant, A. P., T. J. K. Radovich, N. V. Hue, S. T. Talcott, and K.A. Krenek. 2009. Vermicompost extracts influence growth, mineral nutrients, phytonutrients and antioxidant activity in pak choi (*Brassica rap* cv. Bonsai, Chinensis group) grown under vermicompost and chemical fertilizer. J. Sci. Food Agric. 89:2383-2392.

Paul, L. C. and J. D. Metzger. 2005. Impact of vermicompost on vegetable transplant quality. HortScience 40:2020-2023.

Shiralipour, A., D. B. McConnell and W. H. Smith. 1992. Uses and benefits of MSW compost: a review and assessment. Biomass Bioenerg. 3:267-279.

Tyler, H. H., S. L. Warren, T. E. Bilderback, and K. B. Perry. 1993. Composted turkey litter: 11. effect on plant growth. J. Environ. Hort. 11:137-141.

Uchida, R. 2000. Recommended plant tissue nutrient levels for some vegetable, fruit, and ornamental foliage and flowering plants in Hawai'i. 3 January 2011. <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm4.pdf>.

Wolf, B., and G. H. Snyder. 2003. Sustainable soils: The place of organic matter in sustaining soils and their productivity. Haworth Press, Inc., Binghamton, NY.

CHAPTER 3

Summary and Outlook

3.1 Project Summary

Producing vegetable seedlings for transplanting, rather than direct seedling into the field is a common practice because it improves crop establishment and yield. This practice reduces early plant loss due to pests, diseases and weeds, resulting in earlier harvest, rapid crop turnover and reduced costs for pest, disease and weed management. The quality of seedling transplants depends upon the physical, chemical and biological properties of the growing medium they are produced in. Peat based growing media have been the choice of most growers because peat is light weight, clean, of relatively consistent quality, and has physical and chemical properties that are close to ideal for seedling production (Miller and Jones, 1995). Low pH values and nutrient content in peat can be improved by amending peat with lime and nutrients. But because peat is a non-renewable resource, there is a need to evaluate locally sourced, renewable materials to replace peat as a medium for sustainable production of vegetable seedlings. In this project we evaluated vermicompost, coconut coir and thermophilic compost as alternatives to peat, and tankage as a media amendment. Media physical and chemical properties were evaluated and the effects of the different media treatments on seedling tissue nutrient content and seedling growth were evaluated. The effect of seedling media on crop yield, following transplant, was also evaluated.

3.2 Major Findings

This project was conducted in 4 greenhouse trials at Magoon Facility and 1 field trial at Waimanalo Research Station, University of Hawai'i at Mānoa from 9 October, 2009 to 30 September, 2010. The major findings were:

1. Substitution of peat with vermicompost improved media pH, EC, C/N ratio, and nitrogen content.
2. Substitution of peat with vermicompost increased seedling tissue nitrogen content and seedling dry weight, with 100 % vermicompost producing the greatest seedling growth.
3. Amendment of peat with tankage at the rate of 15 grams per liter of medium increased seedling shoot tissue nitrogen content and seedling shoot dry weight.

4. Amendment of peat with tankage at rates of 20 and 25 grams per liter of medium resulted in excessive seedling shoot tissue nitrogen content and decreased shoot dry weight.
5. Seedling tissue nitrogen content and seedling shoot dry weight affect mature plant shoot dry weight after transplanting to the field.

3.3 Management Implications

This project originated out of an effort to help make vegetable seedling production more sustainable by identifying and evaluating locally sourced growing media as alternatives to peat. Other research evaluating the substitution of peat based media with vermicompost on seedling growth, found seedling growth greatest when only a relatively small volume (20 - 40 %) of a peat based growing media was substituted with vermicompost. As the amount of vermicompost approached 100 %, plant growth suffered. This reduction in growth was thought to be due to poor aeration and high concentration of soluble salts (Atiyeh et al., 2001). In contrast, results from this project found that locally produced food waste vermicompost can be used to partially or completely substitute peat. Seedling growth increased as the substitution of peat with vermicompost increased, with 100 % vermicompost producing the greatest growth.

It was also found that the use of locally produced tankage as an amendment to peat, coconut coir or thermophilic compost at the rate of 15 grams of tankage per liter of medium increased 6 week old seedling growth. Ensuring that thermophilic compost is mature and that the time between media amendment with tankage and the time of sowing is sufficient for nitrogen mineralization is important to obtain optimum seedling growth.

3.4 Implications for Future Research

Findings of this research show that 100 % food waste vermicompost can be used as an ideal seedling media. Evaluation and comparison of other locally produced vermicomposts (rabbit, chicken and pig manure vermicompost, other sources of food waste vermicompost) should be carried out to determine if they produce similar results.

Tankage at the rate of 15 grams per liter of medium can be used as a media amendment to produce 6 week old eggplant seedlings with ideal shoot tissue nitrogen concentration and improved growth. At this rate, tankage amendment did not positively affect 3 week old pak choi seedling growth. Investigation into nitrogen mineralization rates and nitrate and ammonium content over time in various media amended with tankage should be carried out to determine optimum time for sowing after tankage amendment.

Media amended with combinations of vermicompost and tankage may provide nutrients early on and over longer periods. Evaluation of media, especially locally produced thermophilic compost, amended with combinations of vermicompost and tankage is needed.

There is a need for further evaluation of the quality and consistency of locally sourced vermicomposts, thermophilic composts and tankage produced by commercial suppliers.

3.5 References Cited

Atiyeh, R. M., C. A. Edwards, S. Subler, and J. D. Metzger. 2001. Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth. Bioresource Technol. 78:11-20.

Miller, J. H. and N. Jones. 1995. Organic and compost-based growing media for tree seedling nurseries. World Bank Technical Paper #264. Forestry Series.

Tables and Figures

Table 1. Media physical properties.

Treatment [z]	Total pore space (%)[x]	Water holding capacity (%)	Air-filled porosity (%)	Dry Bulk Density (g/cc)
P:VC 75:25	64.01a[y]	45.5a	18.5b	0.118de
P	62.84a	41.1a	21.8b	0.100e
C:VC 50:50	62.27ab	34.7ab	27.5ab	0.124cde
VC	61.62ab	39.4a	22.2b	0.156c
C:VC 75:25	60.33abc	33.9ab	26.5ab	0.098ef
P:VC 50:50	60.00abc	36.8ab	23.2ab	0.141cd
P:VC 25:75	59.26abc	37.5ab	21.8ab	0.145cd
C:VC 25:75	58.11abc	33.5ab	24.7ab	0.145cd
P:TC 50:50	53.99bcd	33.5ab	20.5b	0.248b
C	53.73cd	20.4b	33.3a	0.076f
TC	47.58d	23.6b	24.0b	0.342a

[z]P = peat:perlite ratio 9:1 by volume; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; C = coconut coir; C:VC 75:25 = C:VC ratio 3:1 by volume; C:VC 50:50 = C:VC ratio 1:1 by volume; C:VC 25:75 = C:VC ratio 1:3 by volume; TC = thermophilic compost; P:TC 50:50 = P:TC ratio 1:1 by volume.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

[x] Media physical properties were determined using methods described in appendix.

Table 2. Media pH and electrical conductivity.

Treatment[z]	pH	EC (uS/cm)
TC	7.8	2485
TC+tank 5	7.8	2881
TC+tank 25	7.7	3375
TC+tank 15	7.5	2842
C:VC 75:25	7.1	1209
C+tank 25	7.0	1577
C:VC 50:50	6.9	1557
C:VC 25:75	6.8	1779
C+tank 15	6.6	1243
PAM:VC 25:75	6.5	2648
VC	6.5	2639
P:VC 25:75	6.5	2371
C+tank 5	6.5	955
PAM+tank 25	6.4	799
P+tank 25	6.4	799
PAM:VC 50:50	6.4	1627
P:VC 75:25	6.3	1119
P:VC 50:50	6.3	1625
P+tank 20	6.3	1187
PAM:VC 75:25	6.3	1264
C	6.1	986
PAM+tank 15	6.0	612
PAM+tank 5	5.9	446
P+tank 15	5.8	627
PAM	5.0	350
P+tank 10	5.1	466
P+tank 5	5.1	411
P	4.5	307

[z]P = peat:perlite ratio 9:1 by volume; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; PAM = P amended with $CaCO_3$ at 0.7 grams/liter of medium; PAM:VC 75:25 = PAM:VC ratio 3:1 by volume; PAM:VC 50:50 = PAM:VC ratio 1:1 by volume; PAM:VC 25:75 = PAM:VC ratio 1:3 by volume; P+tank 5 = P amended with tankage at 5 grams/liter of medium; P+tank 10 = P amended with tankage at 10 grams/liter of medium; P+tank 15 = P amended with tankage at 15 grams/liter of medium; P+tank 20 = P amended with tankage at 20 grams/liter of medium; P+tank 25 = P amended with tankage at 25 grams/liter of medium; PAM+tank 5 = PAM amended with tankage at 5 grams/liter of medium; PAM+tank 15 = PAM amended with tankage at 15 grams/liter of medium; PAM+tank 25 = PAM amended with tankage at 25 grams/liter of medium; C = coconut coir; C:VC 75:25 = C:VC ratio 3:1 by volume; C:VC 50:50 = C:VC ratio 1:1 by volume; C:VC 25:75 = C:VC ratio 1:3 by volume; C+tank 5 = C amended with tankage at 5 grams/liter of medium; C+tank 15 = C amended with tankage at 15 grams/liter of medium; C+tank 25 = C amended with tankage at 25 grams/liter of medium; TC = thermophilic compost; TC+tank 5 = TC amended with tankage at 5 grams/liter of medium; TC+tank 15 = TC amended with tankage at 15 grams/liter of medium; TC+tank 25 = TC amended with tankage at 25 grams/liter of medium.

Treatment[z]	C%	N%	P%	K%	Ca%	Mg%	Na%	Fe (ug/g)	Mn (ug.g)	Zn (ug/g)	Cu (ug/g)	B (ug/g)	NO_3-N (ug/g)	NH_4-N (ug/g)
VC	40.14a[y]	2.65a	0.81a	0.42c	4.46a	0.54b	0.12b	3123c	368b	193a	68a	46a	2341ab	5.1b
P+tank 15	38.92a	2.16b	0.35c	0.11e	2.17bc	0.17d	0.13b	610d	89c	20e	2b	20de	976ab	1864.7a
P:VC 50:50	38.53a	1.88b	0.43bc	0.23d	3.83ab	0.30c	0.08c	1357cd	227bc	95c	36ab	33b	3336a	2.9b
TC:VC 50:50 +tank12	22.22b	1.56c	0.52b	0.64a	4.10a	0.74a	0.30a	25766b	819a	148b	62a	28c	307b	3.5b
TC+tank 15	16.84c	1.27cd	0.32c	0.67a	3.88ab	0.73a	0.29a	31366a	901a	106c	61a	24cd	1494ab	0.1b
P	40.30a	1.20d	0.04d	0.02f	1.62c	0.16d	0.05c	511d	94c	13e	2b	16e	411b	63.3b
P:TC 50:50 +tank12	20.45bc	1.19d	0.33c	0.56b	5.15a	0.66a	0.29a	27029b	711a	77d	68a	24cd	440b	6.8b

Table 3. Nutrient analysis of growing media used for seedling production for field trial at Waimanalo Research Station on 10 August - 30 September, 2010.

[z]P = peat:perlite ratio 9:1 by volume; VC = food waste vermicompost; P:VC 50:50 = P:VC ratio 1:1 by volume; P+tank 15 = P amended with tankage at 15 grams/liter of medium; P:TC 50:50 +tank 12 = P:thermophilic compost ratio 1:1 by volume amended with tankage at 12 grams/liter of medium; TC+tank 15 = thermophilic compost amended with tankage at 15 grams/liter of medium; TC:VC 50:50 +tank 12 = thermophilic compost:VC ratio 1:1 by volume amended with tankage at 12 grams/liter of medium.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 4. Eggplant seedling characteristics from greenhouse trial 1 at Magoon Facility on 9 October - 20 November, 2009.

Treatment[z]	**Emergence %**	**Seedling shoot fwt (g)**	**Seedling shoot dwt (g)**	**Number of leaves**	**Leaf area (cm²)**
P+tank 15	64	3.51a[y]	0.33a	4.9a	263.7a
P+tank 10	70	3.09b	0.32a	3.5ab	170.3ab
VC	42	2.20c	0.28ab	3.6ab	209.1a
P:VC 25:75	76	1.94cd	0.23bc	3.5ab	106.4bc
PS	94	1.91cd	0.23bc	3.9ab	225.9a
P:VC 50:50	84	1.71d	0.22bc	3.9ab	95.2bc
P:VC 75:25	70	1.60de	0.21c	3.3b	84.6bc
P+tank 20	54	1.27e	0.10d	3.1b	66.8bc
P	94	0.26f	0.04e	1.8c	7.8c
P:TC 50:50	88	0.13f	0.02e	1.1c	1.2c
TC	100	0.05f	0.01e	1.0c	0.3c

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; TC = thermophilic compost; P:TC 50:50 = P:TC ratio 1:1 by volume; P+tank 10 = P amended with tankage at 10 grams/liter of medium; P+tank 15 = P amended with tankage at 15 grams/liter of medium; P+tank 20 = P amended with tankage at 20 grams/liter of medium.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 5. Eggplant seedling characteristics from greenhouse trial 2 at Magoon Facility on 6 April - 18 May, 2010.

Treatment [z]	Emergence %	Seedling shoot fwt (g)	Seedling shoot dwt (g)	Seedling height (mm)	Number of leaves	Leaf area (cm^2)
PS	98	4.67a[y]	0.59a	212a	5.0a	175.0a
P:TC 50:50 +tank 12	92	2.71b	0.32b	163bc	4.0b	89.9c
P+tank 15	86	2.55b	0.21cd	177b	3.2bc	113.7b
P+tank 25	90	2.33b	0.20cd	170bc	3.6bc	122.4b
C+tank 15	60	2.30bc	0.25c	143cd	4.0b	83.0cd
PAM+tank 15	70	1.86cd	0.15def	147cd	3.8b	81.5cde
TC+tank 15	96	1.76de	0.19cde	142cd	4.0b	62.6def
VC	92	1.57def	0.24c	126de	3.4bc	55.7fg
P+tank 5	94	1.50def	0.15def	141cd	3.0bcd	63.4def
TC+tank 25	60	1.45def	0.15def	96ef	3.4bc	40.4fghi
P:VC 25:75	70	1.40defg	0.22c	118de	3.4bc	48.7fg
PAM+tank 25	52	1.31efgh	0.11fg	117de	3.4bc	56.5efg
PAM+tank 5	96	1.14fgh	0.13efg	125de	2.6cde	46.6fgh
C+tank 25	22	0.95ghi	0.10fg	48g	2.0de	17.2ijk
P:VC 50:50	74	0.89hi	0.12fg	104ef	3.0bcd	30.6ghij
C+tank 5	94	0.59ij	0.08gh	87f	3.2bc	22.9hijk
P	100	0.21jk	0.03hi	55g	2.0ed	5.2jk
P:VC 75:25	38	0.19jk	0.01i	53g	2.0ed	5.3jk
PAM	96	0.18jk	0.02hi	52g	1.8e	4.7jk
TC+tank 5	96	0.16jk	0.01i	54g	2.0de	5.4jk
TC	86	0.04k	0.01i	30g	0.2f	0.2k
C	90	0.04k	0.01i	30g	0.0f	0.0k

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; P+tank 5 = P amended with tankage at 5 grams/liter of medium; P+tank 15 = P amended with tankage at 15 grams/liter of medium; P+tank 25 = P amended with tankage at 25 grams/liter of medium; PAM = P amended with $CaCO_3$ at 0.7 grams/liter of medium; PAM+tank 5 = PAM amended with tankage at 5 grams/liter of medium; PAM+tank 15 = PAM amended with tankage at 15 grams/liter of medium; PAM+tank 25 = PAM amended with tankage at 25 grams/liter of medium; TC = thermophilic compost; TC+tank 5 = TC amended with tankage at 5 grams/liter of medium; TC+tank 15 = TC amended with tankage at 15 grams/liter of medium; TC+tank 25 = TC amended with tankage at 25 grams/liter of medium; c = coconut coir; c+tank 5 = c amended with tankage at 5 grams/liter of medium; C+tank 15 = C amended with tankage at 15 grams/liter of medium; C+tank 25 = C amended with tankage at 25 grams/liter; P:TC 50:50 +tank 12 = P:TC ratio 1:1 by volume amended with tankage at 12 grams/liter of medium.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 6. Pak choi seedling characteristics from greenhouse trial 3 at Magoon Facility on 6 April - 27 April, 2010.

Treatment [z]	Emergence %	Seedling shoot fwt (g)	Seedling shoot dwt (g)	Seedling height (mm)	Number of leaves	Leaf area (cm²)
P:VC 25:75	94	4.00a[y]	0.29a	123a	6.8a	128.7b
PAMS	92	3.89a	0.26ab	124a	6.8a	147.7b
VC	95	3.18b	0.29a	123a	6.3a	178.0a
PAM:VC 50:50	94	2.46c	0.22bcd	110ab	6.4a	84.7cd
P:VC 50:50	86	2.37c	0.23bc	105bc	6.4a	145.8b
PS	96	2.17c	0.16ef	112ab	6.0a	93.9cd
PAM:VC 25:75	90	1.97cd	0.20cd	98bc	5.6a	95.8c
C:VC 25:75	98	1.55de	0.17de	97bc	5.6a	70.52d
P:VC 75:25	80	1.02ef	0.12fg	76de	5.8a	33.0efg
PAM+tank 5	96	0.84fg	0.05hijk	90cd	4.0bc	44.9e
PAM:VC 75:25	62	0.72fgh	0.09gh	71ef	4.2b	25.8efgh
C:VC 75:25	82	0.63fghi	0.07hi	62efgh	4.0bc	23.1efgh
C+tank 5	90	0.59fghi	0.06hij	69efg	4.2b	36.4ef
PAM	100	0.38ghi	0.05hijk	59fghi	3.6bc	11.4fgh
PAM+tank 15	98	0.36ghi	0.03ijk	54ghij	3.2bcd	10.2fgh
CS	54	0.33ghi	0.03ijk	42ijk	3.4bcd	31.6efg
P+tank 15	66	0.28ghi	0.02jk	48hijk	3.0bcd	10.3fgh
P+tank 5	14	0.27ghi	0.01jk	39jk	2.2de	6.9gh
C:VC 50:50	62	0.26ghi	0.03ijk	47hijk	3.2bcd	7.2gh
P	98	0.23ghi	0.03ijk	45hijk	3.0bcd	7.9gh
C+tank 15	40	0.23ghi	0.02jk	37jk	3.0bcd	7.6gh
PAM+tank 25	72	0.22ghi	0.01jk	45hijk	2.8cd	6.9gh
P+tank 25	32	0.17hi	0.01jk	35k	2.8cd	5.6gh
C+tank 25	48	0.07hi	0.01jk	11l	1.4e	0.9h
C	98	0.04i	0.00k	15l	2.2de	0.8h

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; PAM = P amended with $CaCO_3$ at 0.7 grams/liter of medium; PAMS = PAM plus liquid synthetic fertilizer applied weekly; PAM:VC 75:25 = PAM:VC ratio 3:1 by volume; PAM:VC 50:50 = PAM:VC ratio 1:1 by volume; PAM:VC 25:75 = PAM:VC ratio 1:3 by volume; P+tank 5 = P amended with tankage at 5 grams/liter of medium; P+tank 15 = P amended with tankage at 15 grams/liter of medium; P+tank 25 = P amended with tankage at 25 grams/liter of medium; PAM+tank 5 = PAM amended with tankage at 5 grams/liter of medium; PAM+tank 15 = PAM amended with tankage at 15 grams/liter of medium; PAM+tank 25 = PAM amended with tankage at 25 grams/liter of medium; C = coconut coir; C:VC 75:25 = C:VC ratio 3:1 by volume; C:VC 50:50 = C:VC ratio 1:1 by volume; C:VC 25:75 = C:VC ratio 1:3 by volume; C+tank 5 = C amended with tankage at 5 grams/liter of medium; C+tank 15 = C amended with tankage at 15. grams/liter of medium; C+tank 25 = C amended with tankage at 25 grams/liter of medium; CS = C plus liquid synthetic (19:19:19) fertilizer applied weekly.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 7. Pak choi seedling characteristics from greenhouse trial 4 at Magoon Facility on 23 July - 13 August, 2010.

Treatment [z]	Emergence %	Seedling shoot fwt (g)	Seedling shoot dwt (g)	Seedling height (mm)	Number of leaves	Leaf area (cm^2)
VC	94	3.01a[y]	0.25a	109ab	7.0a	94.8a
P:VC 25:75	98	2.65ab	0.24a	111a	6.4ab	94.3a
PAM:VC 25:75	94	2.31b	0.20b	98bc	5.4bcd	73.2b
PAM:VC 50:50	98	1.79c	0.19bc	94cd	5.8bc	77.0b
PAM:VC 75:25	82	1.52cd	0.16cd	94cd	6.4ab	71.7b
P:VC 50:50	98	1.44cd	0.15d	87cd	5.2cde	52.4c
CS	98	1.27de	0.11e	82de	4.4def	39.6cd
PAMS	92	0.87ef	0.06fg	72ef	4.2ef	31.5d
C:VC 50:50	92	0.78f	0.09ef	66f	4.6def	33.5d
P:VC 75:25	58	0.69f	0.08fg	60f	4.4def	14.2e
C:VC 75:25	64	0.41fg	0.05g	46g	3.8f	12.1e
PS	44	0.16g	0.01h	40gh	2.8g	5.9e
PAM	68	0.10g	0.01h	33h	2.6gh	4.0e
P+tank 20	54	0.10g	0.01h	20i	1.6h	1.7e
C	100	0.06g	0.01h	13ij	1.8gh	0.8e
P	34	0.03g	0.00h	5j	0.0i	0.0e

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; PAM = P amended with $CaCO_3$ at 0.7 grams/liter of medium; PAMS = PAM plus liquid synthetic fertilizer applied weekly; PAM:VC 75:25 = PAM:VC ratio 3:1 by volume; PAM:VC 50:50 = PAM:VC ratio 1:1 by volume; PAM:VC 25:75 = PAM:VC ratio 1:3 by volume; P+tank 20 = P amended with tankage at 20 grams/liter of medium; C = coconut coir; C:VC 75:25 = C:VC ratio 3:1 by volume; C:VC 50:50 = C:VC ratio 1:1 by volume; CS = C plus liquid synthetic (19:19:19) fertilizer applied weekly.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 8. Pak choi seedling characteristics prior to transplanting to the field at Waimanalo Research Station on 10 August - 31 August, 2010.

Treatment [z]	**Seedling shoot fwt (g)**	**Seedling shoot dwt (g)**	**Seedling height (mm)**	**Number of leaves**
TC:VC 50:50 +tank 12	4.10a[y]	0.30a	118a	6.3a
VC	3.73ab	0.33a	106a	6.7a
TC+tank 15	3.10ab	0.28a	111a	6.0a
P:TC 50:50 +tank 12	2.90b	0.28a	115a	6.0a
P:VC 50:50	2.66b	0.26a	88b	6.3a
PO	1.40c	0.11b	77b	5.3a
P	0.21d	0.03b	38c	2.0b

[z]P = peat:perlite ratio 9:1 by volume; PO = P plus liquid organic fertilizer applied weekly; VC = food waste vermicompost; P:VC 50:50 = P:VC ratio 1:1 by volume; P:TC 50:50 +tank 12 = P:thermophilic compost ratio 1:1 by volume amended with tankage at 12 grams/liter of medium; TC+tank 15 = thermophilic compost amended with tankage at 15 grams/liter of medium; TC:VC 50:50 +tank 12 = thermophilic compost:VC ratio 1:1 by volume amended with tankage at 12 grams/liter of medium.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 9. Mature pak choi plant characteristics at harvest from field trial at Waimanalo Research Station on 10 August - 30 September, 2010.

Treatment [z]	**Shoot fwt (g)**	**Shoot dwt (g)**	**Number of leaves**	**leaf area (cm^2)**
VC	290.22a[y]	18.21a	25.9a	2181.0a
PO	258.04ab	15.30ab	22.5c	1732.2b
TC+tank 15	250.41ab	15.86ab	24.5abc	1809.7b
P:TC 50:50 +tank 12	247.18ab	16.79ab	23.6bc	1921.7ab
TC:VC 50:50 +tank 12	228.04b	16.00ab	24.8ab	1852.2ab
P:VC 50:50	208.80b	14.18b	24.0abc	1779.2b
P	128.86c	9.04c	18.4d	1164.2c

[z]P = peat:perlite ratio 9:1 by volume; PO = P plus liquid organic fertilizer applied weekly; VC = food waste vermicompost; P:VC 50:50 = P:VC ratio 1:1 by volume; P:TC 50:50 +tank 12 = P:thermophilic compost ratio 1:1 by volume amended with tankage at 12 grams/liter of medium; TC+tank 15 = thermophilic compost amended with tankage at 15 grams/liter of medium; TC:VC 50:50 +tank 12 = thermophilic compost:VC ratio 1:1 by volume amended with tankage at 12 grams/liter of medium.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 10. Nutrient analysis of 6 week old eggplant seedling shoot tissues. Greenhouse trial 1 at Magoon Facility on 9 October - 20 November, 2009

Treatment [z]	**N%**	**P%**	**K%**	**Ca%**	**Mg%**	**Na%**	**Fe (ug/g)**	**Mn (ug/g)**	**Zn (ug/g)**	**Cu (ug/g)**	**B (ug/g)**
P+tank 20	6.83a[y]	0.52bc	1.98bc	0.65e	0.51d	0.93de	51.2a	109.4bc	28.2d	1.79e	28.0cd
P+tank 15	3.90b	0.63a	1.05e	1.70c	1.31ab	2.09a	194.9a	114.6bc	27.9d	4.06bc	38.4a
P+tank 10	3.14bc	0.53ab	1.26de	1.74c	1.35a	1.77b	69.7a	133.9b	35.1cd	3.78bc	41.1a
VC	3.01cd	0.35d	2.40b	2.32b	0.80c	1.07cd	48.7a	24.9c	53.0abc	4.63ab	29.0c
PS	2.43cde	0.58ab	3.45a	1.37d	0.50d	0.81de	88.4a	78.6bc	25.2d	2.64de	35.9ab
P:VC 25:75	2.30de	0.41d	2.13bc	2.77a	0.96c	0.97cde	47.0a	27.2c	62.3ab	5.47a	31.5bc
P:VC 50:50	1.92ef	0.39d	1.78bcd	2.37b	0.89c	1.01cde	44.8a	29.5c	51.3abc	3.65bcd	29.6c
P:VC 75:25	1.82ef	0.43cd	1.50cde	2.43b	1.14b	1.23c	46.5a	56.3bc	44.6bcd	3.20cd	28.8c
P	1.35fg	0.07e	1.04e	1.22d	0.62d	0.77e	65.0a	278.4a	68.4a	1.71e	23.2d
TC	0.71gh										
P:TC 50:50	0.51h										

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; TC = thermophilic compost; P:TC 50:50 = P:TC ratio 1:1 by volume; P+tank 10 = P amended with tankage at 10 grams/liter of medium; P+tank 15 = P amended with tankage at 15 grams/liter of medium; P+tank 20 = P amended with tankage at 20 grams/liter of medium.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 11. Nutrient analysis of 6 week old eggplant seedling shoot tissues. Greenhouse trial 2 at Magoon Facility on 6 April - 18 May, 2010.

Treatment[z]	N%	P%	K%	Ca%	Mg%	Na%	Fe (ug/g)	Mn (ug/g)	Zn (ug/g)	Cu (ug/g)	B (ug/g)
P+tank 15	4.3a[y]	0.90a	1.2jk	2.22bc	1.32a	2.08ab	91.6b	224.9bcd	24.6c	2.2g	67.7abcde
PAM+tank 25	4.1a	0.75abc	1.3ijk	1.92cde	1.30a	2.37a	70.8b	280.8ab	52.9c	3.9efg	91.0a
P+tank 25	4.0a	0.78ab	1.1k	1.79cdef	1.20ab	2.42a	80.4b	216.0cd	23.9c	3.0fg	62.6bcdef
PAM+tank 15	3.9a	0.90a	1.3ijk	2.58ab	1.35a	2.12ab	76.8b	267.8abc	19.0c	1.8g	72.2abcd
TC+tank 25	2.9b	0.37hi	3.9a	1.67defg	0.80cd	0.93e	147.5b	127.5fg	52.3c	14.3bc	58.4cdef
C+tank 25	2.8b	0.53defgh	2.2fgh	1.01hij	0.99bc	1.86abc	53.1b	47.72hijk	19.7c	2.9fg	57.8cdef
TC+tank 15	2.7b	0.34i	3.5abc	1.47efgh	0.71cd	1.00e	74.8b	104.2fgh	55.9c	14.2bc	47.6cdef
C+tank 15	2.6b	0.58def	3.2bcd	0.69jk	0.72cd	1.65bcd	48.3b	43.7hijk	36.1c	3.1fg	47.2def
PS	2.6b	0.55defg	2.7def	1.17ghij	0.53def	0.84e	82.8b	91.5ghi	17.6c	3.0fg	47.5cdef
P+tank 5	2.5b	0.66bcd	1.1k	2.45ab	1.48a	2.32a	106.0b	196.9de	30.8c	2.6fg	83.3ab
P:TC 50:50 +tank 12	2.0c	0.43fghi	3.3bc	1.69defg	0.64de	0.76e	54.5b	81.6ghij	48.5c	10.5cd	39.2f
TC+tank 5	2.0c	0.48efghi	2.9cde	1.28fghi	0.60def	1.00e	138.3b	154.1ef	237.3a	16.7b	60.0bcdef
PAM+tank 5	1.9c	0.61cde	0.9k	2.74a	1.33a	1.67bcd	74.9b	157.6ef	27.2c	2.2g	68.3abcde
P:VC 75:25	1.5cd	0.47efghi	2.3fgh	2.10bcd	0.78cd	0.96e	111.1b	25.5jk	112.3bc	13.4bc	61.9bcdef
VC	1.3de	0.41fghi	2.2fgh	1.51efgh	0.73cd	0.72e	38.2b	16.3k	41.6c	8.9cdef	45.7ef
C+tank 5	1.3de	0.45efghi	2.6efg	0.32k	0.39ef	1.33cde	46.7b	28.5jk	24.5c	3.9efg	52.5cdef
P:VC 25:75	1.2de	0.43fghi	1.9hi	1.71cdef	0.70cd	0.80e	40.0b	18.0jk	56.1c	8.1cdefg	48.7cdef
PAM	1.2de	0.12j	1.8hij	1.75cdef	0.67de	1.15de	93.0b	137.0efg	125.0bc	4.9defg	50.0cdef
P:VC 50:50	1.2de	0.47efghi	2.1gh	1.79cdef	0.70cd	0.94e	33.5b	18.5jk	36.3c	6.3defg	49.4cdef
P	1.1de	0.14j	1.5ijk	1.60defg	0.67de	1.12de	79.0b	314.3a	47.8c	2.3g	47.3def
TC	0.9e	0.50efghi	3.1bcde	0.87ij	0.55def	1.64bcd	1079.6a	134.8fg	204.6ab	23.4a	72.7abc
C	0.9e	0.38ghi	3.6ab	0.28k	0.34f	1.94ab	108.4b	34.6ijk	31.8c	9.6cde	59.2bcdef

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; P+tank 5 = P amended with tankage at 5 grams/liter of medium; P+tank 15 = P amended with tankage at 15 grams/liter of medium; P+tank 25 = P amended with tankage at 25 grams/liter of medium; PAM = P amended with $CaCO_3$ at 0.7 grams/liter of medium; PAM+tank 5 = PAM amended with tankage at 5 grams/liter of medium; PAM+tank 15 = PAM amended with tankage at 15 grams/liter of medium; PAM+tank 25 = PAM amended with tankage at 25 grams/liter of medium; TC = thermophilic compost; TC+tank 5 = TC amended with tankage at 5 grams/liter of medium; TC+tank 15 = TC

amended with tankage at 15 grams/liter of medium; TC+tank 25 = TC amended with tankage at 25 grams/liter of medium; C = coconut coir; C+tank 5 = C amended with tankage at 5 grams/liter of medium; C+tank 15 = C amended with tankage at 15 grams/liter of medium; C+tank 25 = C amended with tankage at 25 grams/liter; P:TC 50:50 +tank 12 = P:TC ratio 1:1 by volume amended with tankage at 12 grams/liter of medium.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 12. Nutrient analysis of 3 week old pak choi seedling shoot tissues. Greenhouse trial 3 at Magoon Facility on 6 April - 27 April, 2010.

Treatment[z]	**N%**	**P%**	**K%**	**Ca%**	**Mg%**	**Na%**	**Fe (ug/g)**	**Mn (ug/g)**	**Zn (ug/g)**	**Cu (ug/g)**	**B (ug/g)**
PS	5.62a[y]	0.93a	5.06ab	1.37e	0.42cd	1.56c	420.0a	98.4c	51.2c	3.2a	38.4de
PAMS	5.16ab	0.90a	4.13c	1.89c	0.40cde	1.80b	264.2b	62.6d	53.2c	2.5a	45.7c
P:VC 25:75	4.62b	0.71cde	5.77a	1.76cd	0.64a	1.00d	55.3d	58.5d	42.5c	4.6a	60.6b
VC	2.57c	0.85ab	4.38bc	1.59de	0.63a	0.73e	49.4d	58.6d	45.5c	7.9a	72.8a
PAM:VC 50:50	2.51c	0.79bc	4.29bc	1.81cd	0.52b	0.99d	46.2d	42.5d	42.5c	4.4a	46.0c
P:VC 50:50	2.01cd	0.75cd	3.71c	1.61d	0.46c	0.81de	44.2d	33.0d	40.4c	4.2a	42.5cd
PAM:VC 25:75	1.73de	0.88a	3.60c	1.58de	0.55b	0.80de	42.7d	45.3d	50.7c	4.5a	64.2b
PAM	1.52de	0.08f	1.23f	3.12a	0.68a	2.20a	181.1c	138.1b	98.3b	2.3a	34.9e
P	1.21e	0.15f	1.62ef	2.61b	0.68a	1.54c	324.1b	337.5a	142.4a	9.0a	33.8e
P:VC 75:25	1.09e	0.66de	2.67d	1.79cd	0.39de	0.74e	53.7d	44.0d	43.6c	3.4a	36.1de
PAM:VC 75:25	1.05e	0.63e	2.32de	1.60de	0.35e	0.78de	40.1d	41.1d	39.7c	3.9a	31.9e

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; PAM = P amended with $CaCO_3$ at 0.7 grams/liter of medium; PAMS = PAM plus liquid synthetic fertilizer applied weekly; PAM:VC 75:25 = PAM:VC ratio 3:1 by volume; PAM:VC 50:50 = PAM:VC ratio 1:1 by volume; PAM:VC 25:75 = PAM:VC ratio 1:3 by volume.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 13. Nutrient analysis of 3 week old pak choi seedling shoot tissues. Greenhouse trial 4 at Magoon Facility on 23 July - 13 August, 2010.

Treatment[z]	**N%**	**P%**	**K%**	**Ca%**	**Mg%**	**Na%**	**Fe (ug/g)**	**Mn (ug/g)**	**Zn (ug/g)**	**Cu (ug/g)**	**B (ug/g)**
P+tank 20	6.80a[y]	0.95a	2.1ef	0.48h	0.39def	3.32a	108.5a	47.4c	40.5a	2.8a	29.3b
PAMS	4.05b	0.73b	2.9cde	1.07fg	0.46cde	1.18b	102.7ab	108.4a	83.0a	5.1a	64.5a
PS	3.26bc	0.69bc	2.8de	0.89g	0.65b	2.92a	97.2abc	71.7b	36.7a	3.9a	40.6ab
VC	2.80cd	0.70bc	2.3def	2.09ab	0.45cde	1.03b	47.5abc	29.3d	51.8a	5.3a	44.2ab
CS	2.50cde	0.56bc	3.7bc	0.80gh	0.53c	0.97b	50.2abc	18.0ef	37.0a	2.9a	47.0ab
PAM:VC 25:75	2.32de	0.73b	2.8de	2.12a	0.44cde	1.21b	38.5c	18.3ef	52.5a	4.4a	38.6ab
PAM	2.21def	0.40d	2.4def	1.29ef	0.69b	3.56a	72.4abc	108.3a	57.1a	2.6a	44.6ab
P	2.16def	0.61bc	4.3b	1.54de	0.65b	3.21a	66.oabc	51.0c	64.0a	6.0a	39.0ab
P:VC 25:75	2.10def	0.68bc	2.6def	2.04ab	0.42def	1.21b	38.7c	17.5ef	46.9a	3.9a	35.7ab
PAM:VC 75:25	1.82defg	0.55bc	2.4def	1.98abc	0.34f	1.07b	35.8c	12.9f	42.1a	2.5a	30.8b
P:VC 50:50	1.78efg	0.58bc	1.9f	1.62cde	0.33f	0.70b	41.3bc	12.2f	43.6a	4.9a	36.6ab
PAM:VC 50:50	1.60efg	0.63bc	2.2def	1.88abcd	0.38def	0.90b	34.6c	12.8f	44.8a	3.7a	35.9ab
C:VC 50:50	1.24fg	0.67bc	2.7def	1.83abcd	0.47cd	0.79b	34.3c	17.2ef	50.9a	4.6a	36.5ab
P:VC 75:25	1.10g	0.65bc	2.3def	1.79abcd	0.37ef	0.87b	80.2abc	20.1e	56.1a	8.6a	49.7ab
C	0.99g	0.58bc	7.0a	0.97gf	0.81a	3.34a	50.6abc	34.4d	78.5a	9.4a	40.7ab
C:VC 75:25	0.95g	0.54cd	3.1cd	1.71bcd	0.52c	1.21b	47.9abc	17.1ef	48.9a	6.3a	30.4b

[z]P = peat:perlite ratio 9:1 by volume; PS = P plus liquid synthetic fertilizer applied weekly; VC = food waste vermicompost; P:VC 75:25 = P:VC ratio 3:1 by volume; P:VC 50:50 = P:VC ratio 1:1 by volume; P:VC 25:75 = P:VC ratio 1:3 by volume; PAM = P amended with $CaCO_3$ at 0.7 grams/liter of medium; PAMS = PAM plus liquid synthetic fertilizer applied weekly; PAM:VC 75:25 = PAM:VC ratio 3:1 by volume; PAM:VC 50:50 = PAM:VC ratio 1:1 by volume; PAM:VC 25:75 = PAM:VC ratio 1:3 by volume; P+tank 20 = P amended with tankage at 20 grams/liter of medium; C = coconut coir; C:VC 75:25 = C:VC ratio 3:1 by volume; C:VC 50:50 = C:VC ratio 1:1 by volume; CS = C plus liquid synthetic (19:19:19) fertilizer applied weekly.

[y]Means within columns followed by the same letter are not significantly different ($p<0.05$).

Table 14. Nutrient analysis of pak choi seedling shoot tissues. Field trial at Waimanalo Research Station on 10 August - 31 August, 2010.

Treatment[z]	**N %**	**P %**	**K %**	**Ca %**	**Mg %**	**Na %**	**Fe (ug/g)**	**Mn (ug/g)**	**Zn (ug/g)**	**Cu (ug/g)**	**B (ug/g)**
PO	2.71	0.48	3.14	2.37	0.66	2.26	111	172	43	4	110
TC:VC 50:50 +tankage 12	2.47	0.95	5.45	1.99	0.50	1.03	314	82	81	6	55
TC+tankage 15	2.27	0.85	5.11	1.75	0.50	0.85	110	57	59	6	67
P:TC 50:50 +tankage 12	2.09	0.78	3.91	1.78	0.41	1.07	112	114	49	5	55
P:VC 50:50	1.77	0.63	2.91	2.18	0.53	1.16	245	64	74	5	47
VC	1.75	0.81	2.87	2.40	0.70	1.36	162	99	90	5	52
P	1.41	0.19	1.78	2.42	0.65	1.70	196	166	81	5	69

[z]P = peat:perlite ratio 9:1 by volume; PO = P plus liquid organic fertilizer applied weekly; VC = food waste vermicompost; P:VC 50:50 = P:VC ratio 1:1 by volume; P:TC 50:50 +tank 12 = P:thermophilic compost ratio 1:1 by volume amended with tankage at 12 grams/liter of medium; TC+tank 15 = thermophilic compost amended with tankage at 15 grams/liter of medium; TC:VC 50:50 +tank 12 = thermophilic compost:VC ratio 1:1 by volume amended with tankage at 12 grams/liter of medium.

Table 15. Nutrient analysis of mature pak choi shoot tissue. Field trial at Waimanalo Research Station on 10 August - 30 September, 2010.

Treatment [z]	**N%**	**P%**	**K%**	**Ca%**	**Mg%**	**Na%**	**Fe (ug/g)**	**Mn (ug/g)**	**Zn (ug/g)**	**Cu (ug/g)**	**B (ug/g)**
PO	3.08a [y]	0.60a	8.11a	2.27a	0.42a	0.22a	518.25a	58.25a	37.75a	6.0a	30.8a
TC+tank 15	2.93a	0.54a	7.11a	2.31a	0.41a	0.23a	348.25a	53.25a	39.00a	5.5a	33.8a
P	2.88a	0.54a	6.76a	2.06a	0.38a	0.20a	415.00a	53.75a	34.50a	5.3a	30.4a
VC	2.81a	0.57a	7.85a	2.30a	0.42a	0.22a	334.50a	51.25a	38.50a	5.3a	30.8a
P:VC 50:50	2.30a	0.49a	6.03a	2.28a	0.39a	0.16a	398.25a	51.00a	37.75a	4.8a	29.5a
TC:VC 50:50 +tank 12	2.28a	0.52a	6.45a	2.49a	0.43a	0.18a	372.00a	54.00a	39.50a	4.8a	32.5a
P:TC 50:50 +tank 12	2.25a	0.51a	6.35a	2.26a	0.37a	0.16a	390.75a	51.75a	36.50a	4.5a	29.8a

[z] P = peat:perlite ratio 9:1 by volume; PO = P plus liquid organic fertilizer applied weekly; VC = food waste vermicompost; P:VC 50:50 = P:VC ratio 1:1 by volume; P:TC 50:50 +tank 12 = P:thermophilic compost ratio 1:1 by volume amended with tankage at 12 grams/liter of medium; TC+tank 15 = thermophilic compost amended with tankage at 15 grams/liter of medium; TC:VC 50:50 +tank 12 = thermophilic compost:VC ratio 1:1 by volume amended with tankage at 12 grams/liter of medium.

[y] Means within columns followed by the same letter are not significantly different ($p<0.05$).

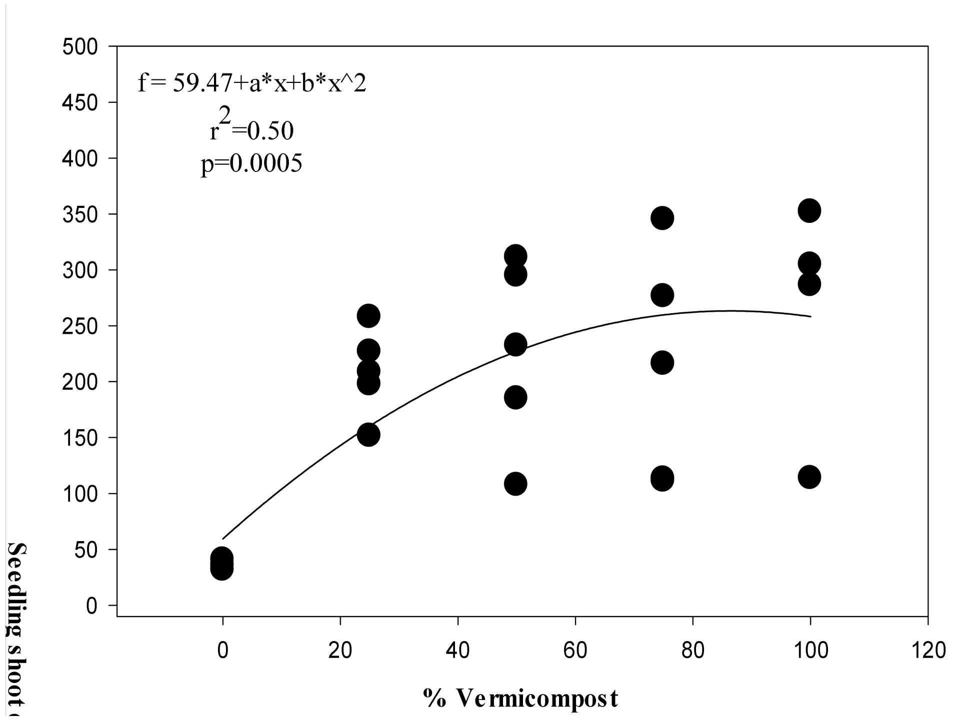

Fig. 1.1. Regression analysis between vermicompost application rate (x) and shoot dry weight (f) of 6 week old eggplant seedlings grown in peat (trial 1).

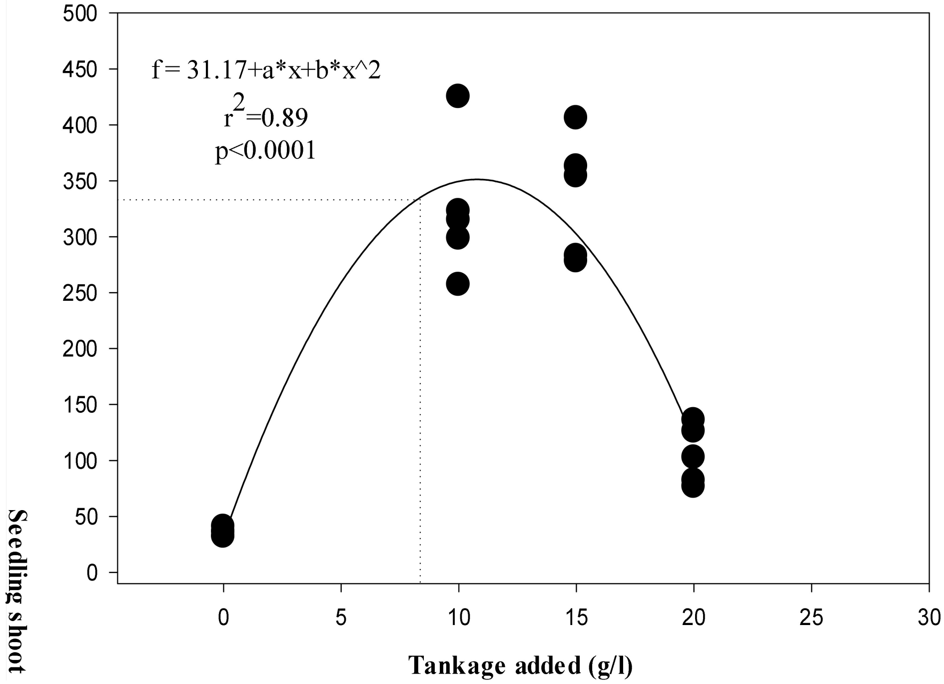

Fig. 1.2. Regression analysis between tankage application rate (x) and shoot dry weight (f) of 6 week old eggplant seedlings grown in peat. Application rate (8 g/l) at which 95 % maximum yield (shoot dry weight) is obtained is identified by dotted line (trial 1).

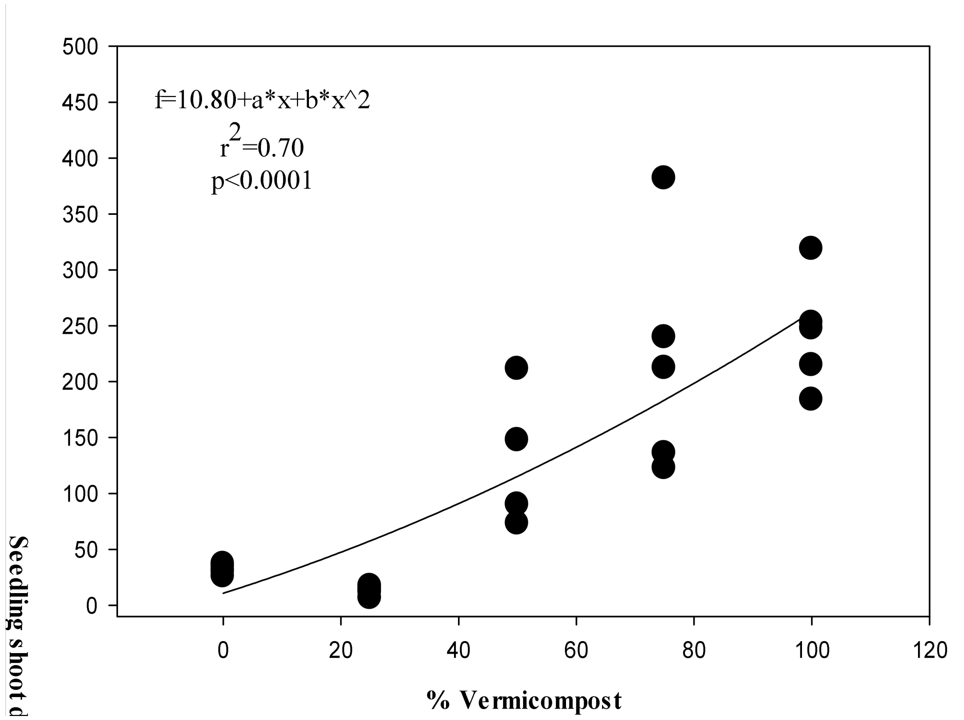

Fig. 2.1. Regression analysis between vermicompost application rate (x) and shoot dry weight (f) of 6 week old eggplant seedlings grown in peat (trial 2).

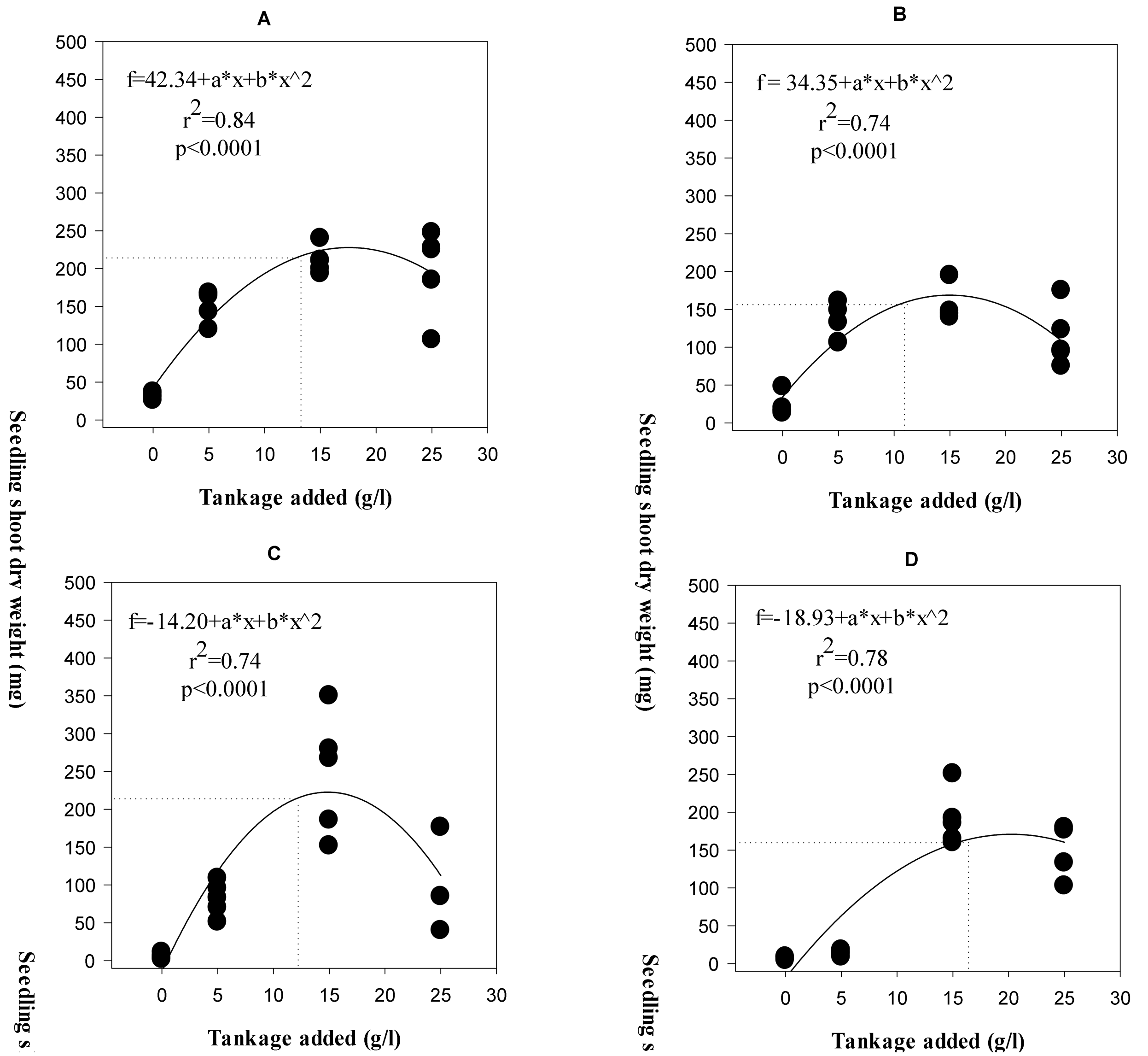

Fig. 2.2. Regression analysis between tankage application rate (x) and shoot dry weight (f) of 6 week old eggplant seedlings grown in (A) peat, (B) peat amended with $CaCO_3$ 0.7 g/l of medium, (C) coconut coir, and (D) thermophilic compost (trial 2). Application rates at which 95 % maximum yield (shoot dry weight) are obtained are identified by dotted lines, (A) 13 g/l, (B) 11 g/l, (C) 12 g/l, and (D) 16 g/l.

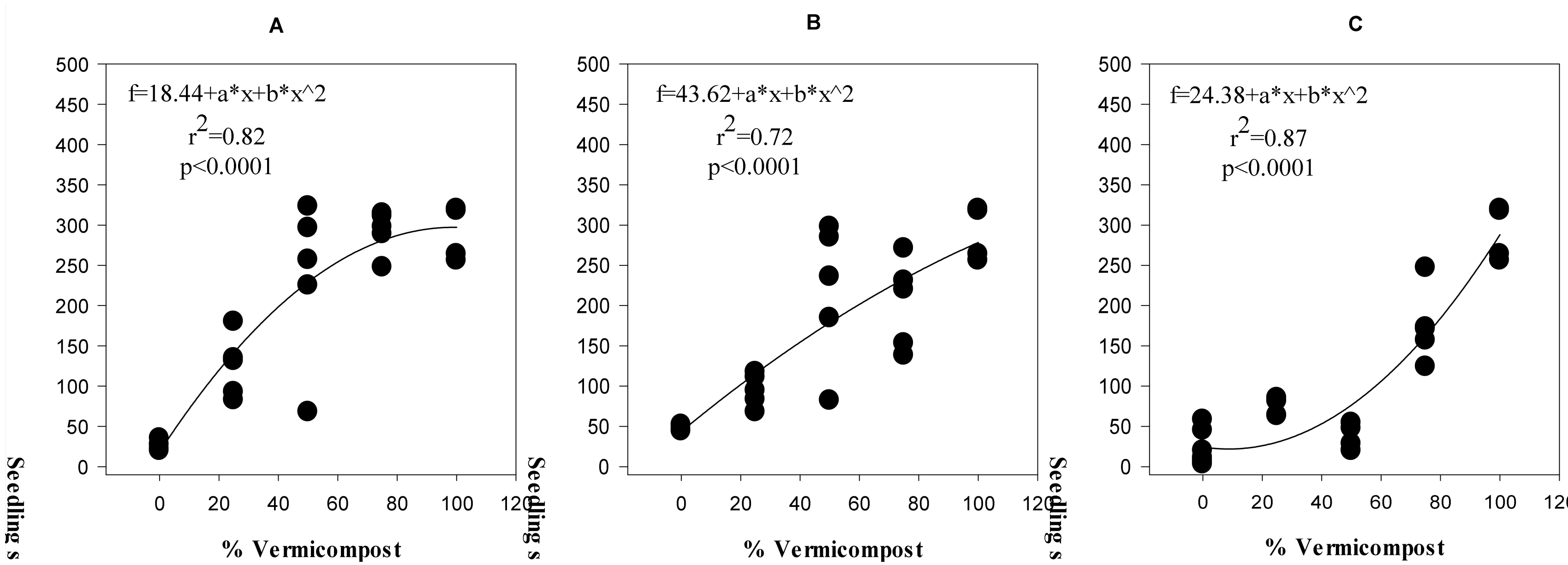

Fig. 3.1. Regression analysis between vermicompost application rate (x) and shoot dry weight (f) of 3 week old pak choi seedlings grown in (A) peat, (B) peat amended with $CaCO_3$ 0.7 g/l of medium, and (C) coconut coir (trial 3).

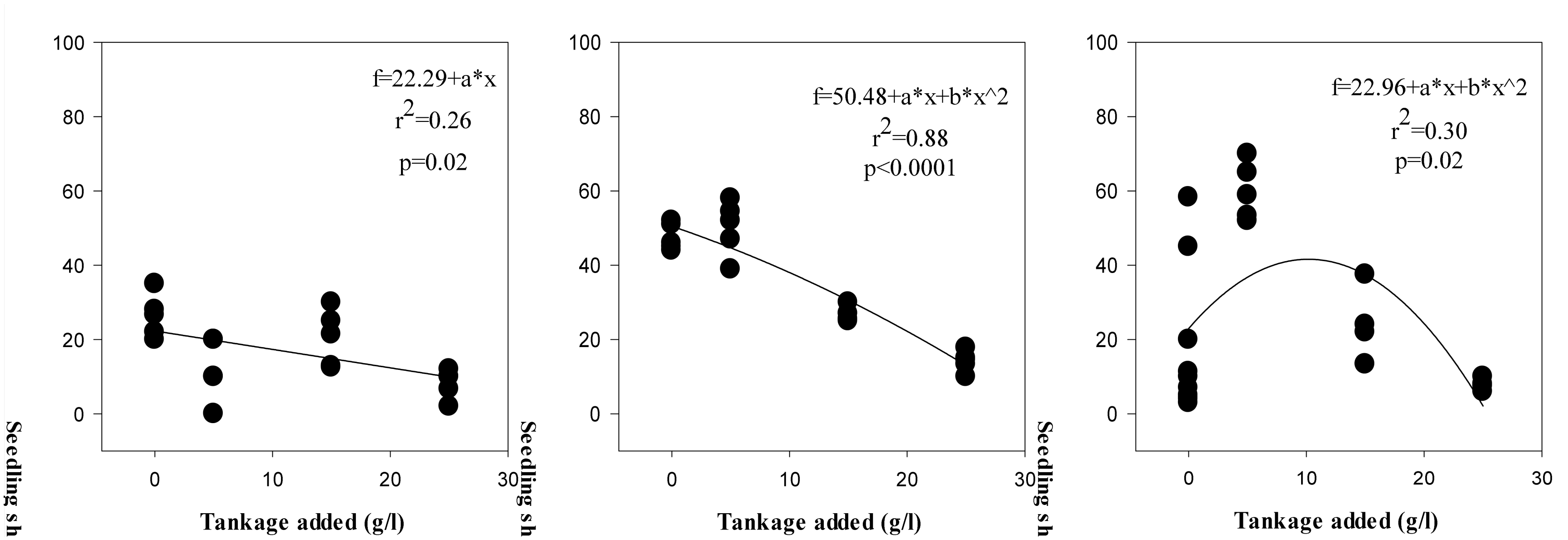

Fig. 3.2. Regression analysis between tankage application rate (x) and shoot dry weight (f) of 3 week old pak choi seedlings grown in (A) peat, (B) peat amended with $CaCO_3$ 0.7 g/l of medium, and (C) coconut coir (trial 3).

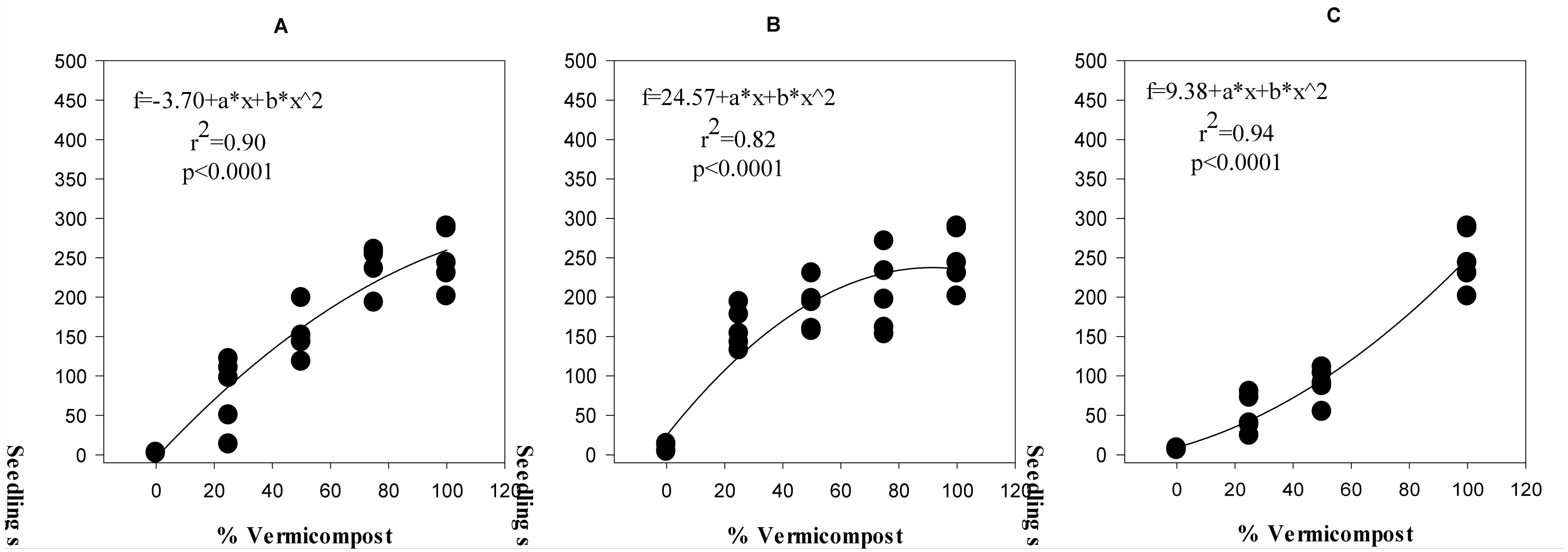

Fig. 4. Regression analysis between vermicompost application rate (x) and shoot dry weight (f) of 3 week old pak choi seedlings grown in (A) peat, (B) peat amended with $CaCO_3$ 0.7 g/l of medium, and (C) coconut coir (trial 4).

APPENDIX

Method for determining media physical properties

Physical properties of the various growing media were determined using a modified procedure described by Bragg and Chambers (1988) and Davidson and Mecklenburg (1991). Air-filled porosity % (AFP), water holding capacity % (WHC), total porosity % (TP), and dry bulk density (DBD) were determined.

1. Samples of each media were wetted thoroughly in bulk batches.
2. Containers of known weight and volume (V), with a fine mesh covering the bottom, were fitted with a 6 cm tall removable plastic collar.
3. Containers were then filled with wetted samples of media to within 2 -3 cm from the collar top.
4. Media filled containers were then placed in a water bath and slowly wet from below until the water was level with the top of the media.
5. The containers were then removed from the bath and allowed to drain for 10 minutes.
6. The collar was removed and the excess media sliced away with a flat knife, leaving the media level with the top of the container.
7. The containers were then placed on a raised tile inside the water bath and the water level was slowly raised to the level of the surface of the containers.
8. The containers were slid off the raised tile and a rubber sealing pad was used to seal the container bottom as it was removed from the bath.
9. Each container was then placed over a drainage rack and allowed to drain for 30 minutes.
10. The drained water was collected and then weighed (A).
11. Wet media from each container was then weighed (B).
12. Media from each container was then dried in a forced air drying oven at 70^{o} C until media weight did not change. This final dry media weight was then recorded (C).

1 gram of water is equal to 1 cc of water.

The weight of (A) in grams is equal to the volume of water in cubic centimeters drained from container.

[(A)/ known container volume (V)] x 100 = air-filled porosity % **(AFP)**.

(B) - (C) = weight of water retained in media after draining for 30 minutes (D).

[(D)/ known container volume (V)] x 100 = water holding capacity % **(WHC)**.

Total porosity % **(TP)** = (AFP) + (WHC)

Dry bulk density **(DBD)** (g/cc) = dry weight of the media (C) / (V)

References

Bragg, N. C. and B. J. Chambers. 1988. Interpretation and advisory application of compost air-filled porosity (AFP) measurements. Acta Hort. 20:35-44.

Davidson, H., R. Mecklenburg, and C. Peterson. 1999. Nursery management: administration and culture. 4th ed. Prentice Hall, Englewood Cliffs, N.J.