Large Scale Composting as a Means of Managing Water Hyacinth (*Eichhornia crassipes*)

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The intent of this study was to determine if composting is an effective means of managing water hyacinth while producing a quality horticultural compost product. Preliminary tests for the study included germination and seed mortality tests. Germination tests found that water hyacinth seeds germinated on filter paper media soaked in distilled water while placed in petri dishes held at a constant temperature of 27 C for 14 d. Seed mortality test results found that seeds of water hyacinth were rendered inviable at temperatures equal to or above 57 C. The study successfully developed a large-scale composting system that used water hyacinth as a primary feedstock. Eleven compost piles were derived from 10,000 kg of water hyacinth, 9,000 kg of food waste, 11,300 kg of poultry litter, and 17,200 kg of wood chips. Results indicated that the composting process reached and sustained sufficiently high enough temperatures to inactivate and fully decompose seeds and other propagules of water hyacinth. Therefore, water hyacinth can be composted without the potential danger of it spreading. Compost quality tests found that the compost produced was within acceptable to ideal ranges of accepted industry quality standards, though there was a learning curve by student workers in the preparation of the piles using the large equipment.

Nomenclature: Water hyacinth; *Eichhornia crassipes* (Mart.) Solms.

Key words: Aquatic plant management, compost quality, invasive.

Water hyacinth [*Eichhornia crassipes* (Mart.) Solms], is considered to be one of the most invasive plant species worldwide (Holm et al. 1977, Jiang and Zhang 2003, Tanaka et al. 2002). It is a native of the Amazon River, most likely from Brazil (Penfound and Earle 1948), and became a nationwide aquatic weed problem during the last century after its introduction into the United States in 1884 at the Centennial Exposition in New Orleans (Tabita and Woods 1962). There it was the featured South American horticultural display and attracted great attention (Monsod 1979). From New Orleans, the water hyacinth was transported to Florida by an attendee of the centennial expedition (Monsod 1979), where it was shared with fellow gardeners and planted in garden ponds across Florida (Monsod 1979). Presently, water hyacinth is established in the states of California, Arizona, Texas, the entire southeastern United States and up the east coast as far north as New Jersey (USGS 2009).

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The problems caused by water hyacinth include obstructing waterways, impeding drainage, destroying wildlife resources, reducing outdoor recreation opportunities, and lowering dissolved oxygen levels, resulting in reduced available oxygen for animals and other plants (Toft et al. 2003). Harvesting and using the plant for animal feed, compost, fertilizer, energy (biofuel), paper and water pollution control at wastewater treatment plants have been explored (Gopal 1987). Herbicides (2,4-D, bispyribac, diquat, glyphosate, imazapyr, imazamox, penoxsulam and triclopyr) have been used in the past to kill water hyacinth (De Marchi et al. 2009, Joyce and Haller 1984, Koschnick et al. 2004, Wersal and Madsen 2010). In many situations, biological or mechanical control may be required because of economic or environmental constraints on herbicide use.

Composting is a biological process in which microorganisms convert organic materials into a soil-like material called compost (Rynk et al. 1992). While composting, microorganisms consume oxygen and release carbon dioxide (Rynk et al. 1992). Active composting produces a large amount of heat, and releases water vapor into the air (Rynk et al. 1992). The composting process and heat produced have been found to kill plant pathogens and

Management Implications

Water hyacinth (*Eichhornia crassipes*) is one of the most invasive aquatic species worldwide. It became a nationwide aquatic weed problem during the last century after its introduction to the United States in 1884 at the Centennial Exposition in New). Different means of management have been implemented in the past including herbicides and harvesting for various reasons. The plant has been successfully composted in the past, but a large scale system had not been investigated to determine if all plant propagules are destroyed in the process. The intent of this study was to determine if composting is an effective means of managing water hyacinth while producing a quality compost product for the horticultural industry. In this study, over 10,000 kg of water hyacinth, 11,300 kg of poultry litter, and 9,000 kg of cafeteria food waste were collected and mixed with wood chips in a large scale composting system. Seed mortality tests indicated that water hyacinth seed was rendered inviable at temperatures above 57 C and, therefore, field compost piles were maintained at that temperature or above. Sampling for seed from curing piles found that no seeds survived nor were present after the composting process. Compost quality tests conducted by Pennsylvania State Agricultural Analytical Services Laboratory showed that compost produced was equal to or above quality standards. An estimated 50.5 m^3 of compost valued at $1,980 was created from materials that were otherwise considered problematic. Therefore, this study found that there is the potential to produce a valuable agricultural or horticultural product from composting invasive weeds while helping to manage populations of invasive species in the environment. Future studies should examine the economic feasibility of the project.

weed seeds (Dougherty 1999). Research found that numerous days of pile temperatures above 54 C (130 F) are required to destroy pathogens and weed seeds (Dougherty, 1999), including *E. coli* and *Salmonella* (Stoffella and Kahn 2001), and field bindweed (*Convolvulus arvensis* L.), redroot pigweed (*Amaranthus retroflexus* L.), johnsongrass (*Sorghum halepense* L.) and kochia [*Kochia scoparia* (L.) Schrad.] (Stoffella and Kahn 2001).

The volume of the finished compost is 50% or less of the volume of raw material (Rynk et al. 1992) making it an effective means of waste control (Stoffella and Kahn 2001). Preventing the loss of top soil by directly adding compost to the soil surface makes compost an effective means of erosion control (Stoffella and Kahn 2001). Compost has been used in revegetation projects and mine reclamation as a topsoil and soil amendment for disturbed landscapes (Rynk et al. 1992).

Currently, the highest demand for compost lies in the horticultural industry where it is primarily used in landscape and greenhouse operations (Stoffella and Kahn 2001). In addition, compost is utilized by horticulturists in vegetable, fruit, ornamental, nursery, and turf crop production systems (Stoffella and Kahn 2001). Compost has been found to reduce plant diseases, help with weed control, and increase the accessibility of nutrients by plants (Stoffella and Kahn 2001). In Texas, the potential industry opportunity is very high for compost, as it is used by the Texas Department of Transportation (TxDOT) for erosion control on highway right-of-ways and during construction of highways (Pearson 2003).

The purpose of this study was to determine if large scale composting is an effective means of managing water hyacinth by rendering the seeds and other propagules inviable while producing a quality compost product for the horticultural industry. Specific objectives included (1) germinating seeds of water hyacinth by implementing germination tests that have shown success in related studies, (2) compiling and analyzing data to determine the temperatures at which water hyacinth seeds were rendered inviable, (3) developing a large-scale composting system using harvested water hyacinth as a feedstock, (4) determining if the composting process renders water hyacinth seeds and propagules inviable and (5) determining the quality of the compost produced.

Materials and Methods

Germination Tests. Water hyacinth was collected from various areas of Spring Lake and the San Marcos River during the summer and fall season 2008–2009. The campus of Texas State University–San Marcos includes Spring Lake, which is fed from springs of the Edwards Aquifer and which forms the headwaters of the San Marcos River. The ecosystem of Spring Lake is critical habitat for endangered and threatened species including the fountain darter (*Etheostoma fonticola*), San Marcos salamander (*Eurycea nana*), Texas blind salamander (*Typhlomolge rathbuni*), San Marcos gambusia (*Gambusia georgei*), and Texas wild rice (*Zizania texana* Hitchc.) (Bartlett and Williamson 1995). These endangered and threatened species are dependent upon stable water quality that is rich in dissolved oxygen. Spring Lake and nearby areas of the San Marcos River are inundated by water hyacinth which depletes dissolved oxygen levels and changes the underwater ecosystem. Harvesting water hyacinth helps maintain the oxygen levels and ecosystems that are necessary for survival of the endangered and threatened species (Gopal 1987). Because of the difficulty of collecting a large number of seeds in the field, flowering water hyacinth, originally collected from various locations on Spring Lake and nearby areas, were observed in campus greenhouses and served as the source of experimental seeds.

One hundred water hyacinth seeds (50 scarified and 50 unscarified) were placed on filter paper media soaked in distilled water in petri dishes and were observed for 14 d for radicle emergence. The seeds were held in a mini-incubator that was maintained at a constant temperature of 27 C. Water hyacinth seeds were scarified by soaking the seeds in a 15% vinegar solution for 30 min (Blazich and

Evans 1999). The timespan and temperature at which seeds were held were based on previous research with the species and seed germination requirements (Barrett, 1980). Seeds, incubators, and moisture levels were monitored daily during germination tests.

Oven Seed Mortality Tests. The tests included the use of 3 ovens (Model 10AF, Quincy Lab, Chicago, IL). In total, 30 compost samples each weighing 8.1 oz (226.7 g) and holding 10 viable water hyacinth seeds were tested for 3 d in oven chambers held at temperatures of 49 C, 57 C, and 66 C for a total of 90 compost samples. Oven and sample temperatures were monitored daily (Digital Probe Thermometer, Ward's, Rochester, NY). Samples were maintained at approximately 50 to 70% moisture by using the method described by Rynk et al. (1992) whereby the sample was too wet if water could be squeezed out and too dry if the sample did not feel wet to the touch.

Of the 90 seed-containing compost samples, 45 of the samples were conducted with scarified water hyacinth seed, and 45 of the samples were conducted with unscarified water hyacinth seed. For both scarified and unscarified seeds, 15 samples were held at 49 C, 15 samples were held at 57 C and 15 samples were held at 66 C.

Once the compost samples were held for 3 d, seeds were tested using the germination procedures determined from the initial germination testing analysis. They were also tested for viability using tetrazolium tests. The tetrazolium test is a seed viability test that usually takes about 30 min to perform. Seed embryos were tested by cutting or piercing the seed coat to expose the embryo. Seeds were then imbibed by soaking them first in water, and then in the biochemical 2,3,5-triphenyl tetrazolium chloride (TTC). While TTC is initially colorless, it is converted to formazan red when living tissue is present (Lakon 1942). Therefore, seed embryos that are respirating or alive will appear stained when soaked in TTC. Dead embryos will not turn red.

Compost Pile Construction. The compost recipe was developed by a composting specialist at the Texas Commission on Environmental Quality (William Carter, personal communication). The compost piles included feedstocks at the following percentages: food waste from cafeterias (10%), poultry litter (15%), water hyacinth plants (25%) and wood chips (50%). Piles were turned every 5 d (when environmental conditions allowed) to ensure that formerly outer exposed surfaces were buried within the pile each time the pile was turned (Rynk et al. 1992). Turning was conducted with a skid-loader.

Feedstocks. For this research study, the compost operation used university cafeteria food waste as a nitrogen and moisture source within the piles. Some of the cafeteria food waste is processed through a grinder which renders all of the food into an even ''coleslaw'' consistency, while other cafeteria food waste was not processed in this manner and instead included whole food parts. The food waste material was collected in 208 L (55 gal) bins with bin liners included and was picked up in the late afternoons daily. This feedstock was utilized because the university reportedly disposes of over 272,000 kg of food waste a year, with substantial cost from trash hauling fees, and because it provides a consistent and readily available source for nitrogen-rich waste material from the campus environment.

Poultry litter was obtained from Tyson Foods in Seguin, TX and used as a primary nitrogen source. Litter consisted of soiled bedding, feathers, chicken feet, and occasionally whole chicken carcasses. By utilizing poultry litter as feedstock with water hyacinth, it was anticipated that temperatures would reach levels that were likely to render water hyacinth seeds inviable (Rynk et al. 1992). Poultry litter was collected weekly using a dump trailer.

For the study piles, water hyacinth was collected from various areas of Spring Lake and nearby areas of the San Marcos River during the months of August through December. Water hyacinth was collected in 208 L buckets by raking it from Spring Lake and nearby areas of the San Marcos River by hand in areas that were accessible with waders. Water hyacinth served as a nitrogen and moisture source for the piles. Water hyacinth was immediately added to the composting system in order to maximize the potential moisture of the material.

Tree and shrub branches that were pruned by a local tree care company were used as the primary carbon source for the composting project. Therefore, species of tree waste varied. Sizes of wood chips were relatively consistent as they were single-ground by the same grinder at the local tree care company. Wood chips were collected on an as-needed basis using a dump trailer and a skid loader.

Compost Pile Monitoring. Windrows of feedstock blends were laid out in separate areas and monitored for heat, moisture and maturity. Piles were built to be 1.5 to 1.8 m (5 to 6 ft) tall and 3 to 3.5 m wide according to the procedure described by Rynk et al.(1992).

Moisture levels were measured with a 1.5 m moisture meter with a precision level of $\pm$10% (60″ Compost Moisture Meter, Reotemp Instrument Corporation, San Diego California). Acidity and alkalinity (pH) was measured with a ''Soil pH'' sensor (Soil pH direct reading tester, Kelway, Wyckoff, NJ) with a precision level of $\pm$ 5%. Acidity and alkalinity levels for compost can vary based on feedstocks incorporated. Temperatures of the piles were monitored with a windrow thermometer at 6 randomly chosen areas (Super Duty – Fast Response Windrow Compost Thermometer, Reotemp Instrument Corporation, San Diego, CA) with a precision level of $\pm$ 1 degree. Oxygen levels of piles were controlled through

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scheduled turning of the piles and measured with an oxygen–temperature monitor (MF420-0-M, MF420-5T-100, J. Dittrich, Haueneberstein, Germany) regularly. The precision level of this instrument was ± 2%.

Once feedstocks were decomposed, and as needed, piles were moved to another designated area for curing to occur. The curing process took approximately 4 wks. Compost was determined ready for curing when the compost pile temperature decreased steadily and reached mesophilic temperatures lower than 40 C. Two long windrows adjacent to the compost production area were used as curing areas. One end of each windrow had compost that was more mature and the pile progressed to compost that was less mature. Alleyways between piles were 7 to 9 m.

Cured Compost Sampling. To observe whether water hyacinth seed survived the composting process, one hundred 3.78 L-sized pots of compost were collected. Sampling began as soon as compost piles were determined to be cured. Each sample was drawn by collecting at least five subsamples from varying depths within the pile. These five subsamples were then combined to create a composite sample.

Compost samples were taken to the Ladybird Johnson Wildflower Center Seed Lab (Austin, Texas). Each sample was screened to consist of particles less than 2 mm (0.0787 in) in size, to capture any potential water hyacinth seeds while preventing any larger particles from passing through. Samples were visually analyzed per Ladybird Johnson Wildflower Center's seed identifying procedures (Minnette Marr, personal communication) to determine if water hyacinth seeds were present in each sample.

Compost Quality. Compost from each of the 11 original compost piles were sampled again after all piles had matured. Samples were taken by collecting approximately 0.473 L of material from near the surface of each windrow, another 0.473 L of material midway to the core of the windrow, and a final 0.473 L from near the core of the windrow. Samples were placed in a clean 19 L plastic bucket and thoroughly mixed. A composite sample of approximately 1 L was then collected from the mixed material. This sampling technique was according to the procedure described by the compost quality testing standards (TMECC 2002).

Samples were sent to Pennsylvania State Agricultural Analytical Services Laboratory (University Park, Pennsylvania) which utilizes testing procedures from the U.S. Compost Council's Test Methods for the Examination of Composting and Compost (TMECC 2002) Seal of Testing Approval (STA) program. The test analyzed percent solids, organic matter, pH, soluble salts, total nitrogen, total carbon, carbon to nitrogen ratio, ammonium-nitrogen, phosphorus, potassium, calcium, magnesium, arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc, respirometry test, bioassay, and particle size (< 9.5 mm) within each compost sample.

The pH of the finished compost was measured by making a slurry of compost and deionized water and then blended to a ratio of 1 to 5. The sample was then shaken for 20 min at room temperature to allow the salts to dissolve in the deionized water and the pH was then measured with an electrometric pH meter (TMECC 2002). The soluble salts were measured by taking the electrical conductivity in a 1 to 5 (compost to water, weight ratio) slurry and was measured in units of millimhos/cm. Percent solids and moisture were measured by weighing a sample and then drying it at 70 (± 5) C and then reweighing the sample (TMECC 2002). The remaining dry solids fraction represented the total solids, and the evaporated fraction represented the percent moisture (TMECC 2002). The percent organic matter of the finished compost was measured by using the Loss-On-Ignition Organic Matter Method, which is a direct determination method that indicates organic matter content by quantifying the amount of solid material combusted relative to the original oven dried sample (TMECC 2002). The nitrogen content of the finished compost was determined by using the methodologies specified in the Test Methods for the Examination of Composting and Compost (TMECC 2002), specifically the Total Kjeldahl Nitrogen Semi-Micro Kjeldahl technique (TMECC 2002).

The total carbon content of the finished compost in this study was measured by the Combustion with CO_2 Detection method. This method uses a carbon analyzer (Leco CR-12) to determine total organic carbon in compost. The analyzer operates on the principle of total combustion of a sample in an oxygen-rich atmosphere of a 1,370 C resistance furnace (TMECC 2002). The CO_2 produced by the combustion is swept into an oxygen stream through anhydrone tubes to scrub H_2O vapor from the stream (TMECC 2002). The CO_2 stream is then fed into the infrared detector and the amount of CO_2 produced is measured.

Results and Discussion

Initial Germination Test Results. A one-way analysis of variance test indicated that there was no difference in the germination rates of unscarified versus scarified seed although 33 (66%) unscarified seeds germinated compared to 29 (58%) scarified seeds (Table 1). The successful germination of water hyacinth seeds collected from plants gathered for composting enabled researchers to continue the study to determine if the composting process kills seeds.

Initial Seed Mortality Laboratory Test Results. In germination tests conducted after seeds were exposed to

Table 1. One-way analysis of variance test comparing germination rates for 50 scarified versus 50 unscarified water hyacinth (*Eichhornia crassipes*) seed germinated on filter paper media soaked in distilled water and placed in petri dishes held at a constant temperature of 27 C for 14 d in the study of the use of composting as a means to manage the invasive species water hyacinth.

Group	Germination No.	Germination	SD	df	F	*P*
		%				
Scarified	29	58	0.499	1	0.670	0.415
Unscarified	33	66	0.479			
Total	62/100					

heat in ovens for 3 d at temperatures which could be mimicked in compost piles, no seeds germinated in the compost samples held at 49 C, 57 C and 66 C. However, using tetrazolium tests, two water hyacinth seeds were found to be viable among the unscarified seeds maintained in the compost sample held at 49 C. Therefore, water hyacinth can be safely utilized as a feedstock in the composting process even though it is an invasive species since temperatures above 57 C kill seeds and these temperatures are relatively easy to maintain in a compost pile when appropriate proportions of carbon and nitrogen-containing feedstocks are used (Rynk et al. 1992). These results were similar to those of previous studies with other plant species (Rynk et al. 1992). This method for determining the temperatures at which seeds are rendered inviable could be replicated with other invasive plant species to determine if they have the potential to be utilized as feedstocks in the composting process as well.

Initiation of Large-Scale-Composting System Results. In this study, over 9,900 kg of water hyacinth, 11,300 kg of poultry litter, and 8,100 kg of cafeteria food waste were collected and mixed with wood chips and incorporated into windrows. In the past, water hyacinth in this area of Spring Lake was typically harvested and dried on the river bank where it was a waste product. This removal process had the potential to add to the seed bank around Spring Lake. Food waste from the university cafeterias and poultry waste from the poultry producer historically were disposed in a dumpster and was a monetary expense for both entities for the both entities. This study created an estimated 50.5 m^3 (66 cubic yards) of compost valued at $1,980 from materials that were otherwise considered problematic.

Composting and Seed Mortality Field Study Results. One hundred 3.78 L compost samples were collected in this study and then screened to 2 mm to examine for seeds and other propagules. No seeds or propagules of water hyacinth were found and all the plant parts appeared to be disintegrated. This examination verified the previous seed mortality laboratory test finding that the species can be composted without the potential danger of it spreading.

Compost Quality Test Results. The results of tests conducted at the Pennsylvania State University Agricultural Analytical Services Laboratory (University Park, Pennsylvania) showed that the quality of compost created from water hyacinth was in the acceptable to ideal ranges given industry quality standards (Table 2). The pH of the finished compost ranged from 7.9 to 8.4, which is slightly alkaline, but still within the typical pH range of compost (5.0 to 8.5). The soluble salt content of the finished compost in this study ranged from 0.33 to 2.28 mmhos cm^{-1}. Compost soluble salt levels typically range from 1 to 10 mmhos cm^{-1}. Four samples were below the typical soluble salt level (Table 2) which means there is no threat of salt toxicity to plants grown in the compost.

The percent solids of the finished compost in this study ranged from 51.3% to 73.3%. An ideal percent solid value for finished compost is 50 to 60% (TMECC 2002). A total of six piles were above the ideal percent solid range (Table 2). This was due to extra solids added inadvertently by inexperienced students operating machinery and turning piles as the piles were maturing which means extra screening may be required to remove the solids.

The percent moisture level of the finished compost in this study ranged from 26.7% to 48.7%. An ideal moisture level of finished compost is 40 to 50% moisture (TMECC 2002). A total of six piles were below the ideal moisture level (Table 2). These piles were the first six constructed and likely fell out of the ideal range due to the older age of the piles which would have allowed for the piles to become drier. Additionally, drought conditions during the study period in Texas made it difficult to keep compost piles moist.

The percent organic matter of the finished compost in this study ranged from 13.4% to 43.9% (dry weight basis). Finished composts typically have an organic matter content of 30 to 70% (TMECC 2002). A total of 6 piles were below the typical range of organic matter content (Table 2). Lower organic matter content was likely due to extra solids added inadvertently by inexperienced students operating machinery and turning piles as the piles were maturing which means extra screening may be required to remove the solids.

The total nitrogen content of the finished compost in this study were in acceptable to ideal ranges: 0.6% to 1.8% (dry weight basis). Typical total nitrogen levels of finished compost range from 0.5% to 2.5% (TMECC 2002). The total carbon content of the finished compost in this study ranged from 10.4% to 24.5% (dry weight basis). Typical

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Table 2. Range and means of values for compost quality test variables for 11 compost samples sent to certified quality testing laboratory in the study of the use of composting as a means to manage the invasive species water hyacinth.

Analyte (Units)	Range of results (As is basis)	Mean (As is basis)	Range of results (Dry weight basis)	Mean (Dry Weight basis)	Normal Range (TMECC 2002)
pH	7.9–8.4	8.1	n/a	n/a	5.0–8.5
Soluble Salts (1 : 5 w : w) (mmhos/cm)	0.33–2.28	1.26	n/a	n/a	1–10
Solids (%)	51.3–73.3	62.42	n/a	n/a	50–60
Moisture (%)	26.7–48.7	37.58	n/a	n/a	40–50
Loss-On-Ignition Organic Matter (%)	9.4–25.8	16.68	13.4–43.9	27.62	30–70 (Dry weight)
Total Kjeldahl Nitrogen (%)	0.4–1.0	0.68	0.7–1.8	1.14	0.5–2.5 (Dry weight)
Organic Nitrogen (%)	0.4–1.0	0.68	0.6–1.8	1.14	0.5–2.5 (Dry weight)
Ammonium N (mg/kg)	2.6–18.9	4.87	4.9–32.1	8.00	< 0.5
Carbon Combustion with CO_2 Detection (%)	7.1–14.3	10.65	10.4–24.5	17.54	< 54 (Dry weight)
Carbon : Nitrogen Ratio	13.80–18.90	15.72	13.80–18.90	15.72	< 20 (Dry weight)
Phosphorus (%)	0.23–0.63	0.40	0.33–1.11	0.65	n/a
Potassium (%)	0.39–0.67	0.52	0.64–1.06	0.85	n/a

carbon content of compost has up to 54% total carbon (TMECC 2002), so samples were in the expected range. The carbon to nitrogen ratio of the finished compost in this study was low ranging from 13.8 to 18.9 (dry weight basis). A low carbon to nitrogen ratio (< 20) will mineralize or breakdown organic N to inorganic (plant-available) nitrogen. These values were likely due to advanced decomposition achieved from adequate curing of the piles. The curing period provides continued decomposition of large particles, organic acids, and resistant compounds and reduces the probability of immature compost being used (Rynk et al. 1992). One of the dangers of using immature compost is that the compost continues to utilize oxygen, which decreases its accessibility to the roots of plants (Rynk et al. 1992).

The samples that fell out of ideal variable ranges were some of the first piles built for the study and results were attributed to inexperienced equipment operators at the beginning of the study which was corrected in newer piles by the end of the study. Therefore, with experienced operators and improvements to the compost pad surface, compost of a more consistent and higher quality can be produced. However, the quality of the compost produced was adequate for any type of application, making it highly desirable to horticulturists and other frequent users of compost (Stoffella and Kahn 2001). It should be noted that water hyacinth absorbs water contaminants so compost produced using water hyacinth as a raw material will continually need to be quality tested (Gopal 1987). An additional study on the economics of composting water hyacinth is recommended for future research.

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