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Water Lettuce (*Pistia stratiotes* L.) as Base Material for Composting

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Abstract

This research aims to study the quality of derived compost using water lettuce (*Pistia stratiotes* L.), a nuisance aquatic plant causing severe damage to waterways in Thailand and other tropical regions, as a major composting material together with dry leaves and pig manure. Three sets of the compost consisting of water lettuce, dry leaves, and pig manure at the ratio of 7:4:0 (T1), 7:4:1 (T2) and 7:4:3 (T3) by wet weight, respectively were composted for 21 days. All treatments used water lettuce as base material fermented in a composter for seven days and cured in a perforated plastic black bag for fourteen days. Among all treatments, the optimum ratio of raw materials in producing quality compost was determined as T3 (water lettuce, dry leaves and pig manure at a ratio of (7:4:3). Pig manure addition was found to hasten the compost process. The ratio of T3 product with decomposition maturity from 21 days of treatment yielded quality compost that met all Thai Agricultural Commodity and Food Standards ($\geq$ 1%N and $\geq$ 0.5%P). This T3 treatment produced the best quality compost comparing plant nutrients, nitrogen (3.0%) and phosphorus (2.6%) to the other treatment scenarios investigated. Thus, water lettuce, an often-problematic weed found in rivers and canals, can rather be used as a base material for composting to enhance crop growth and for environmental benefits like reducing water pollution, use of chemical fertilizers and greenhouse gas emissions.

Keywords: Compost; Water lettuce; Germination index

1. Introduction

Water lettuce (*Pistia stratiotes* L.) is an aquatic plant which is present in large areas in waterways around the world, including Thailand (Walsh and Maestro, 2014). This plant can propagate quickly and generates subsequent problems. Its growth increases the evaporation rate of open water areas resulting in lower than normal water levels. Therefore, many areas of canals become shoals and the aquatic ecosystem is adversely affected due to its overwhelming abundance. This propagation of water lettuce and the need for subsequent control presents problems for its disposal as well. Chemical herbicides have been widely used for removal of water lettuce but may significantly pollute the water environment.

Therefore, studying alternative uses for the overabundance of water lettuce including animal foods, bio extract, compost or fertilizer is needed and mutually beneficial. Water lettuce as a nuisance aquatic weed has been studied in many locations throughout the world (Cilliers *et al.,* 1996). The United States National Academy of Science published a book in 1976 which surveyed losses due to aquatic weeds like water hyacinth and lettuce in Ghana, Sudan, Zambia, Thailand, Guyana and the US. It encouraged these countries to "convert such… plants to useful purposes so the cost of mechanical control methods and herbicides can be avoided. (National Research Council, 1976)

The 2014 Food and Agriculture Organization's Handbook compares five aquatic plants including water lettuce for nutrients including nitrogen, phosphorous and potassium. It shows that water lettuce has nutrient levels adequate for producing compost fertilizer based on studies in India. (FAO, 2014). Some research shows that this plant can be used to remove nutrients and improve eutrophic stormwaters by absorbing nitrogen and phosphorous (Lu *et al.,* 2010).

Water lettuce has high nutrient content, particularly potassium, which is necessary for the growth of plants. Generating compost from water lettuce therefore poses a promising way to improve the physical and chemical properties of the soil useful for plant growth. Water lettuce in composting has been shown useful in preparing phosphorous enriched organic manure. Hence, farmers may be able to reduce the use of chemical fertilizer which leads to less environmental and health hazards and improved crop yield (Kanwal *et al.,* 2011). In 2016, the European Commission established new environmental regulations to boost the use of organic and waste-based fertilizers to replace chemical fertilizers (European Commission, 2016). Projections of demand by the Food and Agriculture Organization of the United Nations indicate a growing need for vegetation and animal waste fertilizers in Asia and many other food producing areas worldwide (FAO, 2019). Kanwal found that composting can contribute to the production of organic manure and that "the use of organic manure is the ultimate alternate to avoid the hazards of chemical fertilizers and pesticides on humans". In Thailand, rice grown organically resulted in five-times lower green- house gas emissions than rice grown with conventional agricultural fertilizers and chemicals. (Yodkhum *et al.,* 2017)

Our aim is to assess the use of water lettuce as a bio fertilizer through composting three different compost mixtures with water lettuce to determine if they meet agricultural standards worldwide and in Thailand. We also describe the composting process used and the quality of the resulting bio fertilizer produced. Finally, we discuss the increasing demand for organic compost fertilizer and the several advantages of plant-based compost to produce fertilizer versus using chemical fertilizers.

2. Materials and Methods

2.1 Composting materials and processes

Materials employed for composting in this study included fresh water lettuce (*Pistia stratiotes* L.) used as a base material; dry leaves like Teak *(Tectona grandis* L.f.*)*, Broad Leaf Mahogany *(Swietenia macrophylla* King*)*, Byttneria *(Buddleja paniculata* Wall*);* and dry pig manure. The physical and chemical characteristics of these composting materials were analyzed for moisture content, organic carbon, organic matter, total nitrogen, total phosphorus, total potassium and C/N ratio. The results are shown in Table 1.

Three sets of treatments (T1, T2, T3) were investigated using the ratio of water lettuce: dry leaves: pig manure of T1 = 7:4:0, T2 = 7:4:1, T3 = 7:4:3 by wet weight. Each treatment was run with three replications. Water lettuce and dry leaves were minced into about 2-3 centimeter size before being added to the composter with the addition of small quantities of dry pig manure according to the study ratio selected. Each type of composting material is shown in Figure 1.

Table 1. Physical and chemical characteristics of composting materials

Parameters	**Mean ± S.D.**		
	Water lettuce (n=3)	**Dry leaves** (n=3)	**Pig manure** (n=3)
Moisture content (%)	95.3 ± 0.6	4.7 ± 0.5	10.9 ± 0.3
Organic carbon (%)	49.3 ± 0.7	36.9 ± 0.6	55.6 ± 0.8
Organic matter (%)	85.0 ± 1.1	63.4 ± 0.9	95.7 ± 1.4
Total nitrogen (%)	2.5 ± 0.2	1.7 ± 0.1	3.7 ± 0.1
Total phosphorus (%)	1.0 ± 0.04	0.05 ± 0.01	5.3 ± 0.1
Total potassium (%)	3.2 ± 0.2	0.3 ± 0.01	0.7 ± 0.02
C/N ratio	25.2 ± 1.8	21.0 ± 0.3	14.7 ± 0.2

(a) (b) (c)

Figure 1. Compost materials: (a) water lettuce (b) dry leaves (c) pig manure

A composter with the mixing equipment was used to compost materials over a 7 day period (Benjawan *et al.,* 2012). The reactor size was 0.4 m in width, 0.6 m in length, and 0.4 m in height, having a capacity of 96 L. (Figure 2). The composter is convenient for limited spaces. It uses electrical power with a control automatic timer system in order to co-mingle the raw material and air into the compost pile. An initial C/N ratio of 20-40 and initial moisture content of 40-60% composting conditions were applied. After the composting was completed the resultant mixtures were removed and placed into black plastic bags (55x75 cm) with 48 holes of 0.7 centimeter diameter for open curing over 14 days (Vijuksungsith *et al.,* 2015). The total composting period was 21 days. Temperatures were measured daily using a thermometer during the composting 21 day process.

2.2 Analyses of compost

Several parameters were analyzed for the finished compost. These parameters include: pH, measured by a pH meter (S220; Mettler Toledo); electrical conductivity (EC) measured by a conductivity meter (S30-k; Mettler Toledo); and moisture content determined by incubation at 105 ºC for 3 hours according to the official methods of the Association of Official Analytical Chemists. Organic matter (OM) was analyzed using the wet oxidation method (Synder, 1984). Organic carbon (OC) was calculated by multiplying 1.72 to the value of OM. Total nitrogen (N) content was analyzed by the Kjeldahl method. Total phosphorus (P) was determined by colorimetric method using a spectrophotometer (UV 160A; Shimadzu Corp.); and total potassium (K) was analyzed using mixed acid digestion and atomic absorption spectrophotometer (AA-6300; Shimadzu Corp.). The ratio of C/N was calculated by dividing the value of OC by total nitrogen (N). The percentage of germination index (% GI) using mung beans was performed using the testing protocol from the study of Tiquia *et al.* (1996). Samples of 50 g were manually collected from 6 different locations for chemical analyses as in the study by Kasamsuk (2013).

Statistical analysis is descriptive with median, mean and standard deviation using MS-Excel (version 2013; Microsoft Inc., Redmond, WA, USA). Comparative analysis was not included in the experimental design which focused on determining if the compost mixtures meet the required standard for compost fertilizer products. In addition, the small sample size does not enable meaningful analytic statistical analysis.

3. Results and Discussion

3.1 Temperature changes during the composting process

Results of daily simultaneous monitoring of composting temperature compared to the ambient conditions are shown in Figure 3. As indicated, after 24 hours the temperatures of the composting mixtures increased up to 42, 49 and 60 °C for T1, T2 and T3, respectively. The initial temperature in the composting piles was higher than the temperature of ambient air due to the microbial degradation activity causing thermal energy generated within the pile (Benjawan *et al.,* 2012). Thereafter, microbial activities were enhanced by placing the compost into the black plastic bags with 48 ventilating holes for curing (Vijuksungsith *et al.,* 2015). The temperature of composting gradually decreased and reached 33, 33 and 32 °C for T1, T2 and T3 at the conclusion of composting, respectively. The temperature of the final compost was ambient temperature. This indicates that the microbial degradation activity was complete. Results are similar to the study of Zang *et al.* (2016) which reported that temperatures were highly increased to 70 °C during the first 1–2 days, and slightly lower through the 10^{th} day, then gradually decreased to the level of ambient temperature. Graphic illustrations of temperature profiles over the composting period (21 days) are presented in Figure 3.

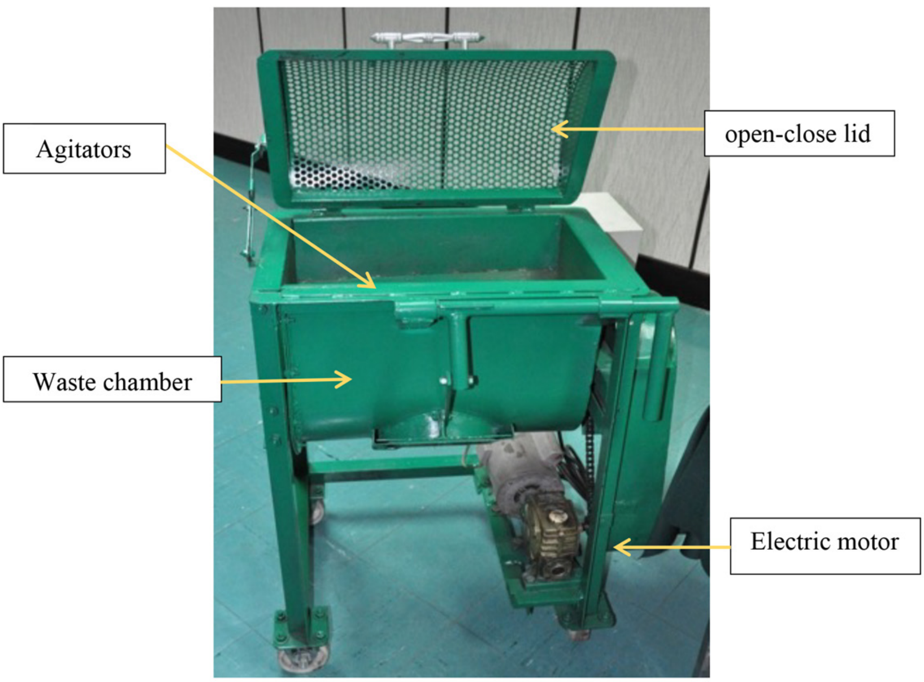

Figure 2. Composter with the mixing equipment used in the study.

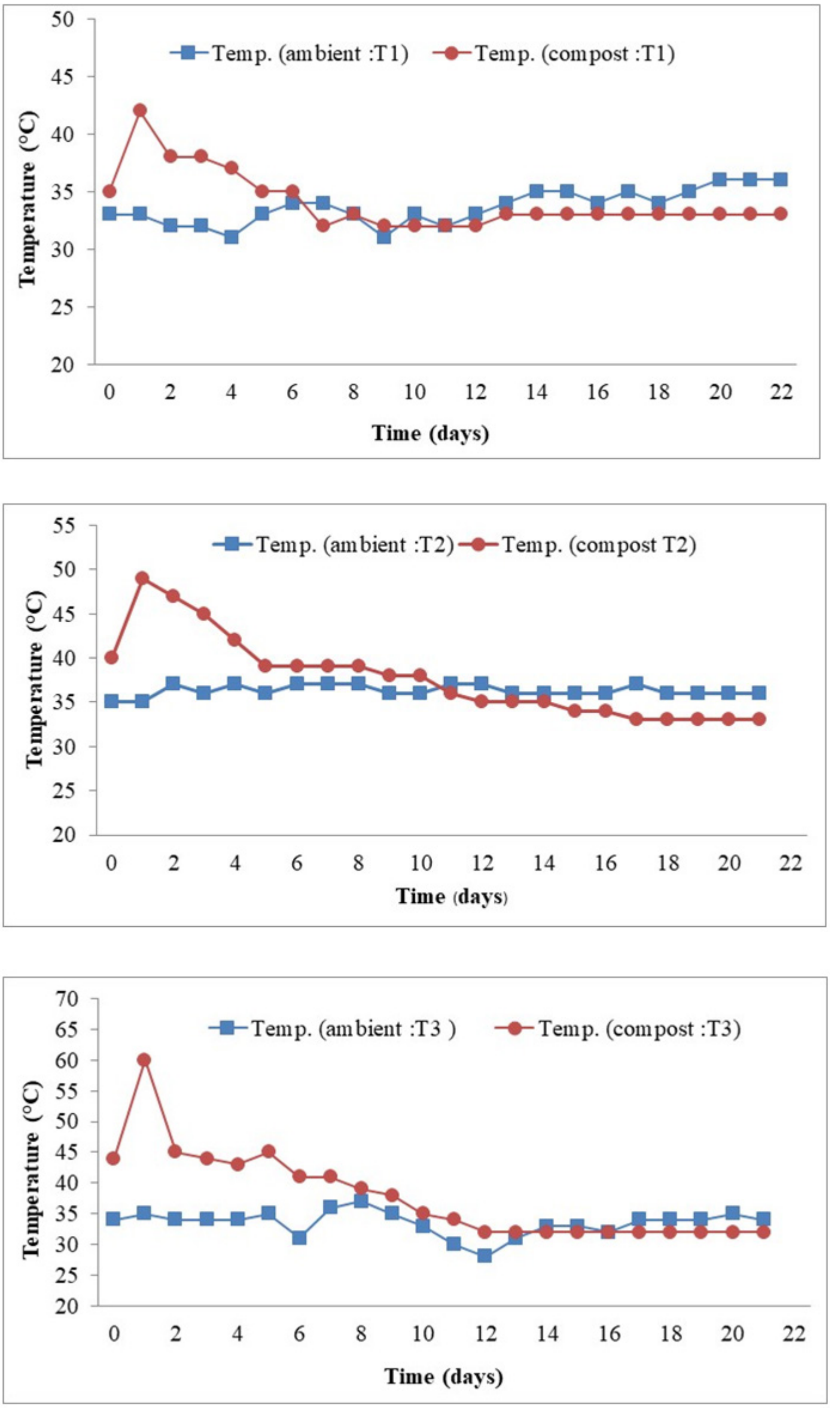

Figure 3. Changing pattern of temperature during composting period for scenarios T1, T2, T3

3.2 Compost characteristics

The physical characteristics of the derived compost product for all treatments (T1, T2, and T3) exhibited a brown or black brown color, similar to that of soil and had no odor. Figure 4 depicts the appearance of the T1, T2, and T3 composts. Table 2 compares the chemical characteristics of derived compost with those recommended by the Thai Agricultural Commodity and Food Standards (2005).

As shown in Table 2, the characteristics of derived compost in mean and median values are presented. Both mean and median results are similar for all parameters; hence, only mean values are used for discussion.

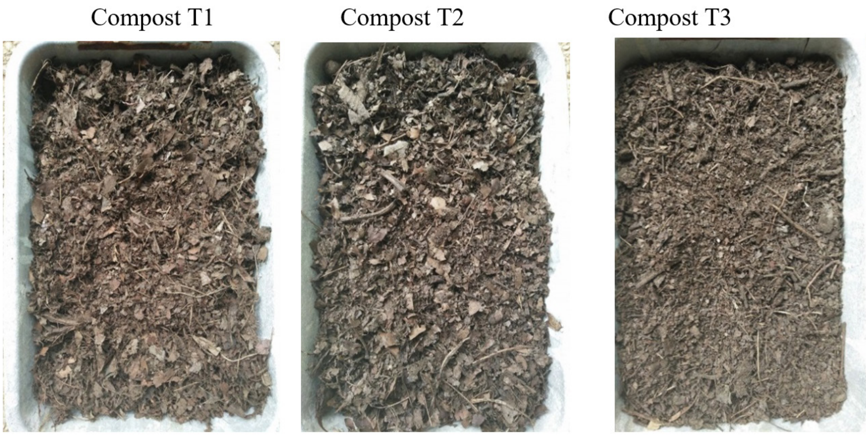

Figure 4. Appearance of derived compost from T1, T2, and T3

Table 2. Characteristics of the final T1, T2 and T3 compost

Parameters	**Mean ± S.D. [Median]**			
	T1 (n = 3)	**T2** (n = 3)	**T3** (n = 3)	**Standards***
Moisture content (%)	30.7 ± 1.9 [29.6]	18.4 ± 0.5 [18.3]	27.6 ± 1.9 [27.8]	≤ 35
pH	7.9 ± 0.05 [7.9]	7.8 ± 0.06 [7.8]	7.7 ± 0.09 [7.8]	5.5 - 8.5
EC (mS/cm)	1.5 ± 0.19 [1.4]	2.3 ± 0.06 [2.4]	2.2 ± 0.08 [2.2]	≤ 3
Organic carbon (%)	30.1 ± 0.7 [29.8]	32.0 ± 1.0 [31.5]	36.2 ± 1.2 [36.0]	-
Organic matter (%)	51.8 ± 1.2 [51.0]	55.0 ± 1.8 [54.8]	62.3 ± 2.1 [60.9]	≥ 35
C/N ratio	15.1 ± 0.3 [14.9]	11.0 ± 0.2 [10.9]	12.1 ± 0.3 [12.0]	≤ 20:1
TN (%)	2.0 ± 0.05 [2.0]	2.9 ± 0.08 [2.9]	3.0 ± 0.09 [3.0]	≥ 1.0
TP (%)	0.3 ± 0.08 [0.3]	1.5 ± 0.05 [1.4]	2.6 ± 0.06 [2.6]	≥ 0.5
TK (%)	2.1 ± 0.8 [2.3]	1.6 ± 0.8 [1.9]	1.8 ± 0.9 [1.8]	≥ 0.5
Germination Index (%)	118.7 ± 0.9 [119.2]	127.7 ± 1.7 [128.6]	130.8 ± 1.1 [130.4]	≥ 80

* Thai Agricultural Commodity and Food Standards, Ministry of Agriculture and Cooperatives (2005).

Final moisture contents of the derived compost were 30.7%, 18.4% and 27.6% for T1, T2 and T3, respectively. These values are acceptable to according to the standard (less than 35% for moisture content) of the Thai Agricultural Commodity and Food Standards (2005). Moisture content is a key factor to fermentation since moisture is essential for microorganism survival (Singh and Kalamdhad, 2012). After the composting process, the weight of the compost may be reduced by about half of the original weight due to oxidation reaction of carbon to carbon dioxide and subsequent loss of moisture (FAO, 1987). During the composting process, the initial moisture was controlled between 40-60% for each treatment condition (54.1%, 52.4% and 56.8% of T1, T2, and T3, respectively). Composting requires optimum moisture content for microorganism growth. If the moisture is too high, the organic matter decomposition rate will slow and generate odorous conditions. It has been recommended that optimum moisture content for composting should be in the range of 50% to 70% (Haug, 1993; Imbeah, 1997; Richard *et al.,* 2002).

The pH values of compost product were 7.9, 7.8 and 7.7 for T1, T2 and T3, respectively. When compared with the standard of 5.5-8.5, the pH values are acceptable from all treatments of this study. The results of this study are similiar to those reported by Petric *et al.* (2012) which found a final slightly alkaline pH value (pH = 7.6, 8.0, and 8.1 for the 3 treatments). Throughout the period of the composting process the pH values during this study were slightly alkaline under all treatment conditions. The pH value for all treatments did not change significantly during the composting process (initial pH of T1, T2, and T3 were 7.9, 7.8 and 7.8, respectively). If the compost is too acidic or too alkaline, the growth of plants will be inhibited. The increase in pH is attributed to the degradation of organic acids and release of ammonia. The low-molecular weight fatty acids and CO_2 generated by biodegradation greatly contributed to the decrease in the pH of the compost (Liu *et al.,* 2017; Wu *et al.,* 2017).

The electrical conductivity (EC) of derived composts were observed as 1.5, 2.3 and 2.2 mS/cm for T1, T2 and T3, respectively. It is noted that the electrical conductivity increased throughout the composting process for all treatments. The initial T1, T2, and T3 values were 1.3, 1.6 and 1.9 mS/cm, respectively. Compost products are suitable for use in agriculture when the value of electrical conductivity is less than 3.0 mS/cm according to the Thai standard. Electrical conductivity is of great importance for compost. High electrical conductivity can be a limiting factor of plant growth and seed germination (Banegas *et al.,* 2007). Additionally, Hou *et al.* (2017) reported that compost with high electrical conductivity may be injurious to plants.

Organic matter values of derived compost were determined as 51.8%, 55.0%, and 62.3% for T1, T2, and T3, respectively. When compared with the Thai standard, the organic matter percentages were found acceptable under all treatment conditions. Organic matter throughout the composting process period yielded a similar pattern of decrease for all treatments (initial organic matter for T1, T2, and T3 were 82.6%, 85.8%, and 90.0%, respectively). The decrease of organic matter in the composting process indicates organic degradation as also shown in the study of Benjawan *et al.* (2012). Both organic carbon and organic matter contents decreased throughout the composting process period due to continuous biodegradation. When stable, the rate of decrease of organic matter content slows. This is due to a lower temperature and the decrease of easily degradable organic matter leading to reduced microbial activity (Liu *et al.* 2017). Organic carbon has a direct relationship with organic matter in that a higher amount of organic carbon helps decrease the period of fermentation (Benjawan *et al.,* 2012). At the end of the composting process, the percentages of organic carbon for T1, T2 and T3 were 30.1%, 32.0%, and 36.2%, respectively. The maximum organic carbon content was observed for scenario T3; while the minimum was found for T1. For all treatments, the pattern of decreasing organic carbon was similar during the composting period (initial organic carbon for T1, T2, and T3 were 48.0%, 49.9%, and 52.3%, respectively). Microorganisms use carbon as an energy source, therefore the organic carbon decreased throughout the period of the composting process as expected.

The C/N ratio is an important proportion in composting. If the C/N ratio is insufficient, it will slow the composting process. At the end of the composting process, the C/N ratio of derived compost for T1, T2 and T3 were 15.1, 11.0 and 12.1, respectively. When compared with the Thai standard, the C/N ratios are acceptable for all three treatments, with the T1 value higher than T2 and T3. The composting period for T1 therefore should be longer than 21 days in order to adjust its C/N ratio to be lower. In addition, Pace *et al.* (1995) reported that initial C/N ratios of 20-40 consistently gave good composting results. The C/N ratio for all treatments was characterized by a decreasing trend during the composting period (initial C/N for T1, T2 and T3 were 32.4, 27.3 and 26.2, respectively). The decreased C/N ratios are attributed to the decompositions of organic matter and the corresponding increase in nitrogen content (Zhang *et al.,* 2017; Gaind, 2014).

Total nitrogen of derived composts for T1, T2, and T3 were 2.0%, 2.9%, and 3.0%, respectively. These values are higher than those reported by Jantapon (2013) for organic waste composting because of the high nitrogen in the water lettuce and pig manure. The total nitrogen content displayed an increasing trend throughout the composting period (initial total nitrogen for T1, T2, and T3 were 1.4%, 1.8%, and 2.0%, respectively) indicating that the degradation of organic matter was continuous (Liu *et al.,* 2017). The maximum total nitrogen content of the compost was observed in treatment scenario T3; with the minimum found in T1. When compared with the Thai standard, the total nitrogen for all treatments was acceptable.

Total phosphorus and total potassium are macronutrients needed for plant growth. Phosphorus is an important nutrient for root development, while potassium is essential for the formation of proteins and carbohydrates (Fan *et al.,* 2018). At the end of the composting process, the values of total phosphorus for T1, T2 and T3 were 0.3%, 1.5%, and 2.6%, respectively. The highest total phosphorus content was found for treatment T3; whereas, the minimum was observed in T1. The total phosphorus value for T3 is maximum due to a higher content of pig manure than in T1 and T2. The total phosphorus value for final compost of T2 and T3 met the Thai standard; whereas, that of T1 was less than 0.5 and does not meet the standard. The addition of pig manure at the appropriate ratio in T1 could be beneficial to the composting process by helping to decrease the decomposition period and increase the nitrogen and phosphorus contents of the compost.

At the end of the composting process, the values of total potassium for T1, T2 and T3 were 2.1%, 1.6% and 1.8%, respectively. The maximum total potassium was observed in treatment scenario T1; whereas, the minimum was detected in T2. Total potassium values when compared with the Thai standard are acceptable for all treatment conditions.

The germination index (GI) is the most commonly used parameter to evaluate the phytotoxicity of final compost and effects on seed germination (Chan *et al.,* 2016). Investigation of germination index using mung beans for all final compost products found that the germination index values for T1, T2 and T3 were 118.7%, 127.7% and 130.8%, respectively. When compared with the Thai standard germination index of 80%, all compost treatments exceeded this value. Thus, compost maturity should present no toxicity to plant growth. Moreover, this finding also corresponds to findings from Ponsa et al. (2009) which reported that the germination index in all treatments ranged from 130.1% to 149.3%. Research of Tiquia *et al.* (1996) as well as Tiquia and Tam (1998) reported that germination index values of more than 80% is phytotoxic-free and the compost is considered to have reached complete maturity. Thus, the derived compost in this study appears non-phytotoxic to plant growth according to the acceptable germination index.

Compost parameters were monitored regularly during the compost process. These measurements were used to ensure that the compost process followed the standard protocol. Temperature was measured daily; moisture content, pH, electrical conductivity, C/N ratio, organic matter, organic carbon, total nitrogen were measured every 7 days; and total phosphorus, total potassium, germination index were added to all others at the final measurement of compost parameters.

Limitations of this study include small sample size, lack of a control treatment, and no full plant growth study with treatment composts. A more rigorous experiment with a control, larger sample size and full plant growth studies is suggested with analytic statistical analysis for comparison of compost parameters and treatment types in the future.

Water lettuce produces a nutrient material which has the potential to replace chemical fertilizers and become a sustainable contribution to organic methods to improve soil fertility, plant tolerance and crop productivity. (Chew *et al.,* 2019). In July 2019, the EU Fertilizers Regulation was published. "It aims to enable recycled organic fertilizers and soil improvers (composts and digestate products) access to the EU internal market so that they can compete on an equal level with mineral fertilizers." (European Compost Network, 2021) The availability of this new opportunity for plant-waste compost to compete with chemical fertilizers is an important advance in using water plant nutrients for environmental sustainability in countries worldwide.

Further, plant-based composting can also contribute to the reduction of greenhouse gas emissions as mention in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) Working Group in 2008. (Bogner *et al.*, 2008)

4. Conclusion

The quality of derived composts from the three treatment scenarios evaluated using water lettuce as a base material meet the Thai agricultural standards of the National Bureau of Agricultural Commodity and Food Standards (2005) except in Treatment T1 with regards to C/N ratio and total phosphorus. Our nutrient analysis shows that water lettuce compost can be produced with high nitrogen and potassium content, and with better phosphorous levels by adding some manure to the compost mixture. Monitoring the process of compost production has shown the interplay of mixture and conditions necessary for quality compost. Given that quality compost can be produced from what has been considered a water weed, often requiring costly removal, one turns to the practicalities of producing such soil enriching material. The fact that plant-based fertilizers are now being sought to replace chemical fertilizer as recently allowed in the European Union, makes the possibility of water plant compost more economically viable. This realization, with the ecological benefits of crop production through organic means to reduce green-house gas emissions makes for a more positive outlook for water lettuce and other water plants in their use in producing organic fertilizers. Our results and food policy changes imply that conditions worldwide could allow increasing use of biomass waste in compost and fertilizers, a more sustainable agricultural approach in line with environmental priorities like the development of a nutrient cycle for food production.

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