



Research article

Development of organic medium from agricultural by-product for cultivation of romaine lettuce

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Article Info

Article history:

Received 30 September 2024

Revised 7 January 2025

Accepted 12 February 2025

Available online 28 February 2025

Keywords:

Compost,
Dried growing media,
Fish bio-extract,
Horticulture,
Romaine lettuce

Abstract

Importance of the work: The development of an organic growth medium can promote sustainability in lettuce (*Lactuca sativa* L.) cultivation; however, costs remain an issue in developing countries.

Objectives: To develop an optimal growth medium using compost from local organic sources for lettuce cultivation and to investigate the effects of heat treatment.

Materials and Methods: Coir, charcoal, manure, soybean meal, molasses and rice bran were composted with fish bio-extract. The dry medium was produced via heating and regenerated using fish bio-extract. A completely randomized design was used for the lettuce growth experiment. The performance was evaluated of compost, dry and regenerated media and topsoil.

Results: The compost medium had better nutrient profiles and microbial counts than common topsoil and commercial soil products, which led to improved lettuce growth. Heating the compost at 105°C significantly reduced the bulk density and the nitrogen content in the dry medium. The regeneration of the medium with the fish bio-extract increased the nitrogen content to the level of the compost medium and significantly restored the microorganism count. When used in romaine lettuce cultivation, the regenerated medium improved lettuce growth parameters, (plant height and width, fresh and dry weights) equal to those of the lettuce grown in the compost medium.

Main finding: An accessible method was identified for producing inexpensive and an effective organic growth medium for lettuce cultivation. The heat treatment reduced the bulk density, microorganism count and nitrogen content; however, these could be restored via treatment with fish bio-extract.

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<https://doi.org/10.34044/j.anres.2025.59.1.12>

Introduction

Lettuce (*Lactuca sativa* L.) has been widely cultivated in many countries due to increasing consumer demand for leafy vegetables across the world (Ahmed et al., 2021). In 2017, the gross yield of lettuce was estimated to be approximately 27 million t and was projected to increase (Shatilov et al., 2019). In addition, lettuce has great nutritional value, with its consumption being linked to positive health impacts such as anti-inflammatory functions (Kim et al., 2016). Thus, the cultivation of lettuce has become a topic of global health and economic value (Alneyadi et al., 2024). Commonly, lettuce is grown in a protected environment, such as a greenhouse to maximize productivity and promote the conservation of water and land use (Sabir and Singh, 2013). However, lettuce production in a greenhouse system in Thailand is not as developed as in some other countries despite an increase in consumer demand and support from the government (Wattanapreechanon and Sukprasert, 2012). The main challenge reported by Thai lettuce farmers was the costs incurred in the cultivation processes, including the cost of growth media and transportation (Thiewkrathoke, 2015).

In areas where growth media were not locally available, the transportation cost could be the highest logistical expenditure (Uttankanchana, 2022). This situation could be alleviated at least in part by the development of an organic medium made from local agricultural by-products and whose bulk density could be reduced for transportation, which may include using a dry growing medium. While the optimal bulk density depends on several factors, a bulk density below 400 kg/m³ was considered beneficial to plant growth (Goh and Haynes, 1977). In addition to the ease of transportation, dry media can also provide other advantages such as reduced severity of root diseases (Gossen et al., 2016) and improved aeration (Fernandes and Corá, 2004). Various dry growth media have been used for the cultivation of potted vegetables to reduce the dependence on traditional soils (Waiba et al., 2020). However, despite the disadvantages of the soils, they remain the most popular choice for lettuce cultivation in Thai greenhouses due to having a lower costs and greater availability (Mondal et al., 2014). Therefore, these issues must be addressed for dry growth media to become a more attractive alternative to Thai farmers. A few alternative media have been used on some Thai lettuce farms. For example, perlite has been used as an inorganic substrate in hydroponic systems, where it can be combined with other materials to enhance plant growth since perlite itself contains few nutrients (Stoian et al., 2022). However, due to perlite requiring nutrient supplements,

its cost remains prohibitive in Thailand. Peat moss quality has been considered one of the highest because it contains high levels of plant nutrients, high water retention and a suitable structure (Hernández-Rodríguez et al., 2017). Nevertheless, due to a lack of sources in Thailand, peat moss must be imported, leading to greatly increased cost. Coconut coir is abundant and inexpensive in Thailand and is inert and highly porous, as well as being able to absorb moisture efficiently; however, it contains few plant nutrients (Olle et al., 2012). Often, in lettuce cultivation, coir is mixed with other expensive materials, such as peat moss, to improve its nutrient profile (Colla et al., 2007), which consequently increases its actual cost. For this reason, Thai farmers rarely use coir in lettuce cultivation. Overall, the use of common and expensive dry growth media for lettuce cultivation in Thailand remains limited.

The issues of cost and availability could be addressed via the development of organic media for lettuce cultivation that include materials easily and inexpensively accessible to most Thai farmers. Compost is a versatile and diverse material that has been incorporated into horticultural use as a source of organic material and plant nutrients (Wurff et al., 2016). The use of compost in organic farming has been promoted by the Thai government and has thus gained increasing traction among Thai farmers (Supaporn et al., 2013). Various organic materials accessible to local farmers have been explored as base materials for compost. For example, compost-based fertilizers made from pig manure, rice husk charcoal and wood charcoal were reported to have high total nitrogen concentrations and thus improve the germination of potherb mustard (Li et al., 2014). Compost as a growth medium or component is a concept that has been explored and implemented for many years and has been proven to be beneficial to plant growth, providing the proper materials were selected as base components (Nappi and Barberis, 1993). For example, compost comprised of plant waste and sewage sludge had a high nitrogen and potassium contents, as well as a high carbon-to-nitrogen ratio and was reportedly as effective as peat moss when used for growing wax begonia (Grigatti et al., 2007). As a medium for the cultivation of lettuce seedlings, compost made of exhausted grape and tomato waste could serve as a partial substitute for peat (Bustamante et al., 2011).

Nevertheless, there are drawbacks to using compost as a component in growing media, including its high bulk density (Raviv, 2013), which was the focus of the current study. Attempts have been made to reduce the density of composts; however, some limitations remain, especially in the context of usage in Thailand. For example, hardwood bark was used as a main component of a compost medium for the growth of poinsettias and was shown to provide fungicidal

effects (Hoitink, 1980). However, peat was also another necessary component of this compost, resulting in a higher cost. Composted rice hulls were incorporated in growth media for landscape plants to reduce costs and weight (Laiche and Nash, 1990). While the results revealed that the addition of the compost enhanced plant growth, the media still required the inclusion of sand, leading to a substantial increase in density. Composts can be used to produce dry aggregates, which can serve as growing media (Ronga et al., 2020); however aggregates with controllable sizes and low densities require sintering at high temperatures (above 900°C) and grinding and sieving processes (Farias et al., 2017). These processes can greatly increase the costs of procuring dry aggregates, especially in developing countries.

The current study addressed these issues by exploring the production of an organic medium based on compost that is low-cost and accessible to growers in Thailand and considered studies on the use of this medium for the potted cultivation of romaine lettuce in a greenhouse. In addition, the preparation was investigated of a high-quality organic growth medium for lettuce cultivation in combination with methods to reduce the bulk density and restore the pre-drying nutritional profile when regenerated.

Materials and Methods

Preparation of compost medium

The developed compost medium was prepared and evaluated for their properties to ensure sufficient nutrients for lettuce growth. The process for preparing 550 L of compost medium (which was considered typical for this product) involved using a soil mixer for 10 min for mixing: 1,140 L (80 kg) of coconut coir powder, 296 L (25 kg) of rice husk charcoal, 237 L (20 kg) of cow manure, 179 L (15 kg) of poultry manure, 0.56 L (0.5 kg) of soybean meal, 0.35 L (0.5 kg) of molasses, 146 L (100 g) of microbial activator (Super LDD-1, developed by the Thailand Land Development Department), 0.82 L (0.5 kg) of rice bran powder, 20 mL (20.1 g) of fish bio-extract and 20 L (20 g) of water. Then, the product was transferred to 25 L opaque plastic bags. The bags were tied and placed in the shade for 20 d before the medium was ready to be used. In addition, the fish bio-extract used in compost preparation was produced by mixing 41.0 L (50 kg) of ground tilapia fish, 9.7 L (10 kg) of ground pineapple, 7.0 L (10 kg) of molasses, 16.4 L (10 kg) of rice bran powder, 10 L (10.1 kg) of coconut juice and 39.7 L (25 g) of microbial activator (Super LDD-2, developed by the Thailand Land Development Department) in a 200 L

opaque plastic tank that was then filled with water. The tank was loosely covered to allow airflow and left in the shade. The compost process continued for 12 mth.

Growth medium properties and lettuce cultivation

A topsoil sample (collected in Pathum Thani Province, Thailand) and two commercial soil samples (labeled as #1 and #2 and sourced from Talaad Thai, Pathum Thani Province, Thailand) were acquired for comparison. These three soil samples, along with the compost medium, were sent to the Science Center at Valaya Alongkorn Rajabhat University, Pathum Thani Province, Thailand for chemical analysis, for determination of the pH (using a pH meter), electrical conductivity (using a soil conductivity meter), nitrogen content (based on titration), phosphate content (based on colorimetry), potash content (based on flame photometry), carbon-to-nitrogen ratio (Walkley and Black method and Kjeldahl method) and organic matter (based on titration). The number of bacteria colony-forming units per dry weight of each sample was quantified, according to Suanmali and Junthakhao (2017). The retail price of the commercial soil was USD 0.074/kg (USD 0.026/L).

The experimental evaluation of the media for romaine lettuce cultivation in a greenhouse was arranged in a completely randomized design (Fig. 1). Each treatment was carried out using four replications, each containing 25 potted plants. Prior to the treatments, romaine lettuce seeds were sown in plug trays placed in a greenhouse with translucent roof panels. The lettuce seedlings were watered twice daily; after 14 d, they were transferred into pots for the experiment. Each pot (15 cm diameter) was filled with a medium sample (approximately 1.5 L) up to 3 cm from the top of the pot. Next, the pots were moved to the part of the greenhouse with transparent polycarbonate roof panels.



Fig. 1 Romaine lettuce cultivated in pots in a greenhouse.

The structure of the greenhouse and the random arrangement of the samples ensured that the effects of sunlight direction were minimized. The lettuce plants were watered three times daily. After 28 d of growth, measurements were recorded of leaf greenness (based on the SPAD index; Fanizza et al., 1991), the number of leaves, leaf length, plant height and width, as well as the fresh and dry weights. Leaf greenness was determined using a SPAD 502 Plus chlorophyll meter (Spectrum Technologies Inc.). The data were analyzed using a one-way analysis of variance and Fisher's least significant difference *post hoc* test.

Preparation, regeneration and evaluation of dry medium

Each dry growth medium was produced by heating the compost in a furnace at 105°C for 72 hr. The net cost of the compost and the dry medium was USD 0.046/kg (USD 0.023/L) and USD 0.088/kg (USD 0.022/L), respectively. The regeneration of the dry medium was investigated by regenerating it with water or fish bio-extract, mixing 4.05 L (1 kg) of dry medium with 1 L of water or 1 L of the fish bio-extract diluted in water at a ratio of 1:20, respectively. The regeneration proceeded for 24 hr in the shade. The chemical and biological properties of the dry medium, the compost medium, the medium regenerated with water and the medium regenerated with the fish bio-extract were characterized using the methods described in the previous section. In addition, soil moisture was determined using a moisture balance (Shimadzu MOC63U) and bulk density was measured using a liquid pycnometer. The use of these medium samples for romaine lettuce cultivation was evaluated based on experiments, as described in the previous section, using

dry and regenerated medium samples instead of the topsoil and the commercial soil.

Statistical analysis

The data were analyzed using one-way analysis of variance (ANOVA), followed by Fisher's least significant difference (LSD) *post hoc* test. Differences were considered statistically significant at $p < 0.05$.

Results

The properties were determined of the medium samples prepared for the production of dry medium, topsoil and two commercial soils (Table 1). Based on the results of the one-way analysis of variance, there was a significant difference among the four groups in the bulk density, pH, electrical conductivity, nitrogen content, phosphate content, potash content, carbon-to-nitrogen ratio, organic matter and the number of bacteria colony-forming units per dry weight. The topsoil had the highest bulk density, followed by the compost medium and the two commercial soils. The compost medium had the lowest pH and the highest electrical conductivity, nitrogen content, phosphate content, carbon-to-nitrogen ratio and bacteria colony-forming units per dry weight, followed by the topsoil. The two commercial soil samples had the highest pH and the lowest quantities of these variables, but there was no significant difference between the two. The compost medium contained the highest potash content, followed by the topsoil. The potash content in the topsoil was similar to that in commercial soil #1.

Table 1 Properties of prepared compost medium, topsoil and two commercial soils

Medium sample	Medium property				
	Bulk density (kg/m ³)	pH	Electrical conductivity (mS/cm)	Nitrogen content (%)	Phosphate content (%)
Compost medium	508±13 ^c	6.47±0.32 ^a	4.70±0.14 ^a	1.13±0.04 ^a	0.91±0.06 ^a
Topsoil	712±28 ^b	7.55±0.30 ^b	1.45±0.05 ^b	0.56±0.02 ^b	0.77±0.03 ^b
Commercial soil #1	351±17 ^a	8.22±0.33 ^c	0.98±0.03 ^c	0.12±0.01 ^c	0.45±0.01 ^c
Commercial soil #2	375±24 ^a	7.98±0.24 ^c	0.81±0.07 ^c	0.23±0.01 ^c	0.36±0.02 ^c
<i>p</i> value	0.001	0.003	0.005	0.01	0.012
	Potash content (%)	Carbon-to-Nitrogen ratio	Organic matter content (%)	Microorganism count (log(CFU/g))	
Compost medium	1.67±0.06 ^a	25.2±0.8 ^a	1.43±0.06 ^a	82.13±1.70 ^a	
Topsoil	0.92±0.05 ^b	23.1±0.5 ^b	0.70±0.03 ^b	22.06±1.65 ^b	
Commercial soil #1	0.80±0.03 ^{bc}	20.3±0.7 ^c	1.17±0.05 ^b	8.11±1.32 ^c	
Commercial soil #2	0.71±0.02 ^c	20.7±0.6 ^c	1.02±0.01 ^b	12.24±1.35 ^c	
<i>p</i> value	0.004	0.006	0.013	<0.001	

Within each trait, values (mean ± SD) in the same column with different lowercase superscripts are significantly ($p < 0.05$) different.

Commercial soil #2 had the least potash content, but there was no significant difference between the two commercial soils. In addition, the compost medium had the highest organic matter, while the topsoil and commercial soils had a similar amount of organic matter. Overall, the compost medium had the best growth quality.

The effects are shown of the compost medium, topsoil and two commercial soils on the growth of romaine lettuce in Table 2. Leaf greenness, number of leaves, leaf length, plant height, plant width, fresh weight and dry weight were highest when the romaine lettuce samples were cultivated in the compost medium. Except for dry weight, the use of topsoil produced better growth characteristics than those of the two commercial soils, with no significant difference between the use of the two commercial soils. There was no significant difference in lettuce dry weight when the topsoil and the two commercial soils were used.

Dry growth medium products were produced when the compost medium was burned. Subsequently, prior to use, the samples were regenerated using either water or fish bio-extract. The effects of these treatments on medium quality are displayed in Table 3. Compared to the compost medium, the dry medium had significantly less moisture, bulk density, nitrogen content, carbon-to-nitrogen ratio and microorganism counts but had a similar level of pH, electrical conductivity, phosphate content, potash content and organic matter. When the dry medium was regenerated with water, their moisture and bulk density increased but were still lower than those of the compost medium. Compared to the dry medium, the regeneration with water had different levels of the other parameters. Furthermore, compared to the compost medium, the regenerated medium had lower levels of nitrogen, phosphate and potash contents, lower carbon-to-nitrogen ratios and fewer microorganisms. When the dry medium was regenerated with the fish bio-extract,

Table 2 Growth of romaine lettuce cultivated in prepared compost medium, topsoil and two commercial soils.

Medium sample	Lettuce growth			
	Leaf greenness (SPAD index)	Number of leaves	Leaf length (cm)	Plant height (cm)
Compost medium	35.0±4.37 ^a	16.1±0.7 ^a	13.1±1.0 ^a	17.1±1.3 ^a
Topsoil	21.3±1.24 ^b	13.3±1.6 ^b	11.8±1.3 ^b	14.9±1.4 ^b
Commercial soil #1	12.3±1.03 ^c	9.5±0.8 ^c	9.7±0.8 ^c	13.1±0.7 ^c
Commercial soil #2	13.2±0.77 ^c	9.3±1.1 ^c	8.8±1.0 ^c	12.6±0.6 ^c
<i>p</i> value	<0.001	<0.001	0.003	0.016
	Plant width (cm)	Fresh weight (g)	Dry weight (g)	
Compost medium	19.6±2.4 ^a	120.3±9.0 ^a	5.3±0.5 ^a	
Topsoil	15.8±1.3 ^b	100.0±4.9 ^b	3.2±0.4 ^b	
Commercial soil #1	9.1±0.8 ^c	65.1±8.1 ^c	1.7±0.2 ^b	
Commercial soil #2	8.5±1.1 ^c	60.0±5.0 ^c	1.6±0.1 ^b	
<i>p</i> value	0.008	<0.001	0.004	

Within each trait, values (mean ± SD) in the same column with different lowercase superscripts are significantly ($p < 0.05$) different.

Table 3 Properties of dry medium (DM), dry medium regenerated with water (DM + water) or fish bio-extract (DM + fish) and prepared compost medium

Medium sample	Medium property				
	Humidity (%)	Bulk density (kg/m ³)	pH	Electrical conductivity (mS/cm)	Nitrogen content (%)
DM	6.2±0.1 ^c	247±5 ^c	6.83±0.19	4.60±0.06	0.82±0.07 ^b
DM + water	26.1±0.8 ^b	478±8 ^b	7.07±0.15	3.77±0.23	0.73±0.21 ^b
DM + fish	26.0±0.9 ^b	472±7 ^b	6.30±0.20	4.40±0.26	1.17±0.15 ^a
Compost medium	37.6±1.4 ^a	508±13 ^a	6.47±0.25	4.70±0.10	1.13±0.32 ^a
<i>p</i> value	<0.001	0.003	0.117	0.435	0.032
	Phosphate content (%)	Potash content (%)	Carbon-to-Nitrogen ratio	Organic matter content (%)	Microorganism count (log(CFU/g))
DM	0.96±0.05	1.58±0.26	22.4±0.1 ^b	1.45±0.05	18.51±0.49 ^c
DM + water	0.88±0.08	1.63±0.42	21.7±0.1 ^b	1.43±0.06	19.02±1.01 ^c
DM + fish	0.92±0.25	1.61±0.14	26.0±0.2 ^a	1.48±0.08	72.04±6.20 ^b
Compost medium	0.91±0.10	1.67±0.26	25.2±0.1 ^a	1.43±0.15	82.13±2.65 ^a
<i>p</i> value	0.518	0.662	0.022	0.641	<0.001

Within each trait, values (mean ± SD) in the same column with different lowercase superscripts are significantly ($p < 0.05$) different.

their moisture and bulk density were similar to those of the medium regenerated with water. Nevertheless, the regeneration with the fish bio-extract significantly increased the nitrogen, phosphate and potash contents, the carbon-to-nitrogen ratio and microorganism count compared to the dry medium and the medium regenerated with water. Additionally, these improved medium properties were similar to those of the compost medium.

The growth of romaine lettuce cultivated in the regenerated medium, the dry medium and the compost medium is shown in Table 4. Lettuce samples grown in the compost medium and the medium regenerated with fish bio-extract had significantly greater values for leaf greenness, number of leaves, leaf length, plant height, plant width, fresh weight and dry weight than those grown in the dry medium and the medium regenerated with water. There was no significant difference in the growth quantities of the lettuce grown in the compost medium and the medium regenerated with fish bio-extract. Overall, the regeneration of the dry medium with the fish bio-extract improved the quality of the dry medium for lettuce cultivation.

Discussion

The dry medium was made from compost that had been treated with heat. Thus, the compost materials should have high levels of plant nutrients and appropriate physical and chemical properties to improve the chance that medium regeneration would successfully restore nutritional contents. As shown in Table 1, the compost medium had the highest pH, the highest electrical conductivity, the greatest quantity of nitrogen, phosphate and potash, the highest carbon-to-nitrogen ratio, the highest organic content and the highest count of microorganisms. These values indicated that this compost medium was of the

highest quality, as a result of the careful selection of the base materials. High alkalinity is a common problem in compost (Benito et al., 2006), which can negatively impact the growth and yield of plants, including lettuce (Roosta, 2011). The compost medium in the current work did not have this high pH problem because the fish bio-extract was included, that included a Super LDD-2 microbial activator that contained lactic acid bacteria (Land Development Department, n.d.) and thus reduced the pH of the compost. The relatively high electrical conductivity of the compost medium corresponded to the higher nitrogen, phosphate and potash contents resulting from the inclusion of the manures, the soybean meal and the bacterial sources. The salinity level of the compost could be considered slightly high (Richards, 1954), which could have negatively affected the microorganism population. Nevertheless, as shown in Table 1, the microorganism count was the highest in the compost medium despite the salinity. The C-to-N ratio of the compost was considered to be a good balance between nitrogen mineralization and microbe immobilization (Brust, 2019). Furthermore, the higher organic matter in the compost reflected an overall healthier growth medium. Based on these results, the compost process effectively produced a high-quality growth medium. Consequently, when the compost medium was used to cultivate romaine lettuce, the plants had better growth parameters compared to the other treatments, as shown in Table 2. This trend was well aligned with results reported in several works involving lettuce cultivation (Bustamante et al., 2011; Hernández-Rodríguez et al., 2017; Radziemska et al., 2019; Alromian, 2020). While the commercial soils had a lower bulk density, this advantage could not overcome their lower nutritional quality. Thus, the results of the lettuce growth confirmed the effectiveness of the compost process implemented in this work.

Table 4 Growth of romaine lettuce cultivated in dry medium (DM), dry medium regenerated with water (DM + water) or fish bio-extract (DM + fish) and prepared compost medium

Medium sample	Lettuce growth			
	Leaf greenness (SPAD index)	Number of leaves	Leaf length (cm)	Plant height (cm)
DM	32.3±4.37 ^b	9.8±0.7 ^b	12.6±1.0 ^b	10.0±1.3 ^b
DM + water	31.5±1.24 ^b	11.3±1.6 ^b	12.3±1.3 ^b	9.2±1.4 ^b
DM + fish	35.8±1.03 ^a	17.9±0.8 ^a	15.4±0.8 ^a	15.5±0.7 ^a
Compost medium	36.6±0.77 ^a	18.4±1.1 ^a	15.3±1.0 ^a	16.4±0.6 ^a
<i>p</i> value	0.007	<0.001	0.002	0.001
	Plant width (cm)	Fresh weight (g)	Dry weight (g)	
DM	12.8±2.4 ^b	70.4±9.0 ^b	1.9±0.5 ^b	
DM + water	11.8±1.3 ^b	67.2±4.9 ^b	2.0±0.4 ^b	
DM + fish	16.9±0.8 ^a	114.4±8.1 ^a	5.2±0.2 ^a	
Compost medium	17.5±1.1 ^a	110.1±5.0 ^a	5.0±0.1 ^a	
<i>p</i> value	<0.001	<0.001	<0.001	

Within each trait, values (mean ± SD) in the same column with different lowercase superscripts are significantly ($p < 0.05$) different.

The effects of the heat treatment to generate the dry medium from the compost are shown in Table 3. The heat treatment successfully reduced the bulk density of the medium. Because there was no significant change in organic matter, the loss of density was mainly due to moisture loss. While there were some changes in the pH, electrical conductivity and the phosphate and potash contents under the heat treatment, there was a reduction in nitrogen, along with a decrease in the microorganism count. The nitrogen loss was likely caused by ammonia volatilization (Chang et al., 2019), while the microorganism loss was simply due to the sterilizing effects of heating. While the nitrogen content in the dry growth medium was still greater than that in the topsoil, the decrease in the nitrogen content and in microorganisms resulted in reduced growth compared to cultivation in the unheated compost medium. Compared to the lettuce grown in the topsoil, lettuce cultivated in the dry medium had reduced levels for many measured parameters, except for leaf greenness. Nevertheless, the quality of the dry medium was still better than in the commercial soils concerning lettuce plant width and the fresh and dry weights. In terms of cost per volume, the dry medium was approximately 17% less expensive (data not shown) than the commercial soil due to the decrease in the bulk density. Furthermore, if transportation costs were included, the net cost of the dry medium would be even lower. However, the listed price of the commercial soil was the retail price, so the actual material cost of the commercial soil could be closer to or even lower than that of the dry medium. Therefore, other less expensive methods for drying, such as sun drying, should be explored to further reduce the costs.

The regeneration process applied to the dry medium should be investigated to achieve a product that would be competitive with the topsoil and the compost medium. The effects of the regeneration with water and the fish bio-extract are displayed in Table 3. The treatment with water did not improve the nitrogen content or the microorganism population, though it did result in a higher bulk density. On the other hand, the regeneration with the fish bio-extract restored the nitrogen content to that of the compost medium and significantly increased the microorganism count. Thus, with this regeneration, the quality of the medium was better than that of the topsoil. This improvement was reflected in the growth of romaine lettuce, as shown in Table 4. The regenerated medium enhanced the growth of romaine lettuce in every category to the equivalent of using the compost medium for cultivation. These results indicated that the regeneration of the dry medium with the fish bio-extract was an inexpensive method for enhancing the growth medium quality.

In conclusion, a compost medium was produced using an inexpensive method. The careful selection of the base materials for the compost medium ensured that it had better properties than the topsoil or the commercial products. Furthermore, using the heat treatment on the compost produced a dry medium that was less expensive than the commercial soil when both were used at similar volumes. The regeneration of the dry medium with the fish bio-extract significantly improved the medium nitrogen content and microorganism count, with the growth of the romaine lettuce in this medium being equal to that in the compost medium. These methods for producing the compost medium and the dry medium should be useful for lettuce growers, especially those in areas where other media are expensive or are not locally available. Nonetheless, further work should explore the use of the developed medium for other plants, as well investigating adjustments to the components of the compost according to locally available materials and their properties, because components of the compost may vary in different locations. Furthermore, the development of an inexpensive dry medium should continue until its quality matches that of composted media to enhance the productivity of lettuce growers to meet increasing demand and alleviate the impact of climate change on lettuce cultivation.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

Valaya Alongkorn Rajabhat University under the Royal Patronage provided funding for this research and a greenhouse for the experiment. This study was partially supported by the National Science and Technology Development Agency, under grant P2351618.

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