STUDIES ON RECYCLING USE OF ORGANIC WASTES FOR SUSTAINABLE AGRICULTURE IN VIETNAM

ベトナム農業の持続的発展のための有機性廃棄物リサイクル利用に関する研究

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ABSTRACT

The use of recycled organic wastes as fertilizer has gained attention because of a variety of reasons. Among others, the need to find a sink for the growing amount of wastes and the necessity to reduce soil exposure to degradation and other negative effects of the use of conventional chemical fertilizers, are the factors that are most crucial. In Vietnam, different kinds of fertilizers that are labeled as “organic fertilizer” are available; however, as the raw material and manufacturing process are poorly regulated, their quality has yet not been fully explored. Organic fertilizer has the potential to improve the physico-chemical properties of the soil and minimize groundwater contamination by nutrient leaching. Under the Asian monsoon climate, loss of applied N due to leaching is excessive due to the high frequency of heavy rainfall. In order to promote the use of recycled organic wastes as fertilizer in Vietnam, the objectives of this dissertation are three-fold: (1) to evaluate organic waste-based fertilizers with an emphasis on the nitrogen dynamics of the plant-soil system, (2) to demonstrate an on-farm rapid composting method, and (3) to make suggestions regarding the recycling of organic waste and the utilization of organic fertilizers under humid tropical climates.

To clarify the efficacy of composted organic wastes as fertilizer, a cultivation experiment using the technique of ^{15}N labeling was conducted in sandy loam-textured soil in a greenhouse. Composted municipal solid waste (MSW), sewage sludge (SS), and cow dung (CD) were applied as the basal fertilizer, while ^{15}N labeled urea was applied 4 weeks after planting, as an additional fertilizer. There were no significant differences in the shoot dry weight among the MSW, SS, and chemical fertilizer treatments. The uptake of N from the compost by the plants was as follows: MSW (39.4%) = SS (39.6%) > CD (17.1%). Meanwhile, approximately 4.0% of the N derived from the urea-N fertilizer was assimilated by the plants. Approximately two-thirds of the urea-N

fertilizer was lost by leaching while half of the N derived from the compost remained in the soil after 14 weeks of cultivation. As the efficacy of the compost might depend on the type of raw material and composting technique, the following investigations were carried out to verify the effects of these factors on the quality of the finished compost.

To investigate the quality of the "organic fertilizers" which are being sold in Vietnam's markets, 16 products (12 domestic and 4 imported) were acquired from 4 provinces of Vietnam. On these fertilizers, the nutrient contents were analyzed and experiments were conducted. A 20-day incubation experiment involving 80 g sandy-textured soil mixed with the fertilizer at a rate of 109.4 mg N kg^{-1} soil was performed in 150 cm^3 glass bottles at 25°C in the dark. In addition, komatsuna (*Brassica rapa* var. *perviridis*) was cultured in sandy-textured soil using some typical "organic fertilizers" applied at a rate of 200 mg N kg^{-1} soil in a greenhouse. The nutrient content greatly varied among the domestic products, whereas there were some similarities observed between the imported products. Two-thirds of the domestic products contained over 30% of the total N in the inorganic form, implying that the concentration of the inorganic N dramatically increased in some products rather than in their supposed raw materials. The remarkably high ratio of the inorganic N to the total N was attributed to the excessive N leaching from the soil by the application of domestic fertilizers.

As the product label contained insufficient information and therefore, the comparison could not be drawn between the commercial products and the raw materials. To clearly explain the characteristics of domestic "organic fertilizers," we further studied the production of one such "organic fertilizer" made from coffee by-products (the discarded shells of the cherries in the coffee processing industry). The stages involved in the production were composting, the addition of extra soil as a bulking agent and the mixing-in of chemical substances to increase the nutrient content. The analysis of the nutrient levels of the collected samples at each stage indicated that the coffee by-products were nutrient-rich organic material. The total C content was high, up to 423.2 g kg^{-1}, and the N and K contents were 32.80 g kg^{-1} and 9.71 g kg^{-1}, respectively. After composting, a slight decrease was observed in the C content but the concentration of the total N and K showed an increase. The compost was found to contain 34.8 g kg^{-1} of N and 12.54 g kg^{-1} of K. After increasing the bulk of the compost with extra soil, the total C, N, and K contents reduced to 83.20, 6.40, and 4.48 g kg^{-1}, respectively. However, at the time of shipment, it was observed that the total N content nearly doubled from 6.40 to 11.20 g kg^{-1}, while the total P content tripled from 0.99 to 2.99 g kg^{-1}. These observations provide evidence to confirm that the addition of chemical material is typically the final step in the production of organic waste-based fertilizers in Vietnam.

Moreover, being the second largest coffee-producing country worldwide, Vietnam is estimated to generate approximately 1 million m^3 of coffee pulp (coffee by-products of wet processing) annually. Instead of being effectively utilized in the form of recycling resources, most of the waste is discarded, causing serious environmental pollution even though it contains essential macronutrients in high concentrations. This large volume of organic waste is mainly generated during the months of the harvesting season. Additionally, it is difficult to store this material because of its high moisture content. On the other hand, for a long time, farmers have mainly used chemical fertilizers instead of organic fertilizers, resulting in soil degradation. Therefore, a simple method of rapid on-farm composting is the need of the hour to establish a system for recycling organic waste for sustainable agriculture. Five on-farm small-scale composting trials of coffee pulp were performed to examine the feasibility of the composting process with bulking agents under different aerobic conditions. After 2 months of composting, samples were collected for analysis and a cultivation experiment was conducted to clarify the effectiveness of the composts. The total C, N, and K contents of the composts were in the range of 340.35-386.02 g kg^{-1}, 23.80-

36.70 g kg^{-1}, and 18.86-25.13 g kg^{-1}, respectively. In the compost where wood chips were used as the bulking agent under air flow, exhibited a concentration of inorganic N that was significantly higher than that of the other composts. This indicates that the most important factor influencing the composting process is the control of aeration with wood chips and air flow. The plant biomass corresponding to the composts showed similarity with chemical fertilizers. Additionally, the fertilizer effect depended on the type of soil. Furthermore, the P content and the plants produced by the compost in which chicken manure was added, were investigated. The results obtained clearly indicate that the addition of P-sources as manure in the manufacturing process enhanced the fertilizing efficiency of the compost. However, replications were not included in separate composting trials; thus, further work is required to understand the optimum conditions of composting.

These results suggest the need for quality criteria and guidelines for organic fertilizers in Vietnam that not only specify the nutrient levels, but also control the raw materials used and the manufacturing process. Production of coffee pulp composting within 2months might be a feasible method to recycle coffee pulp into good-quality organic fertilizer. The majority of N in the self-make compost was in the organic form, requiring an enhancement to make it available to plants. In this regard, urea might have a role to play in enhancing the N mineralization of organic-N in compost when applied together. Under humid tropical climates, a combined application of compost and urea with lower amount of applied urea might extend the benefits. Further field experiment is required to evaluate the effectiveness of this suggestion.

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CHAPTER 1. INTRODUCTION

1.1 Background

The use of recycled organic wastes as fertilizer have been paid attention because of variety of reasons. Among others, the need to find a sink for the growing amounts of the wastes, the necessity to reduce soil exposure to degradation and the use of conventional chemical fertilizers, are the factors that are the most crucial.

The amount of organic materials from agro-industrial and municipal origins have been increased, and thus their storage problem has appeared. In the developed countries, day-to-day generation of enormous quantities of municipal solid waste (MSW) has brought the sanitary landfills and other MSW handling facilities to the limits of their capacity. In developing world, agricultural by-products are often burned in the open air to generate fertilizer in the form of ash, but this not only destroy a great deal of carbon and other nutrients but also is a source of air pollution and global warming. MSW strewn almost everywhere of most developing countries (S. Gajalakshmi and S. A. Abbasi, 2008; C. Edward et al., 2007). For sustainable development, those so-called wastes must be recycled and composting appears to be an attractive alternative.

Organic fertilizer has the potential to improve the physico-chemical properties of the soil and to minimize groundwater contamination by nutrient leaching. Since the end of World World II famers have markedly increased the use of chemical fertilizers in place of organic fertilizers and amendments. Soils in many parts of the world are increasingly stressed from long-term cultivation and the resulting losses of soil carbon, loses of soil productivity (C. Edward et al., 2007). Carbon lost from the soil must be replaced by crop residues or organic amendments. The application of compost increased soil fertility and decreased nutrient leaching (M. Mamo et al., 1998; Mohammad et al., 2007; Paul et al., 2009).

Since the majority of N of organic fertilizers is organic form, requiring an enhancement of plant-available N. Organic N in organic fertilizers must be mineralized before plants can use or it becomes susceptible to loss as N leaching. The N mineralization depends on many factors such as compost quality parameters, soil properties and application rate and time. So, it is necessary to have site-specific study to get accurate prediction of N crop requirement and potential N leaching (Florian et al., 2003). The fate of N applied via fertilizer is relevant not only to plant production but also to groundwater contamination by N leaching. Under the Asian monsoon climate, the loss of applied N is excessive (Nguyen et al., 2014).

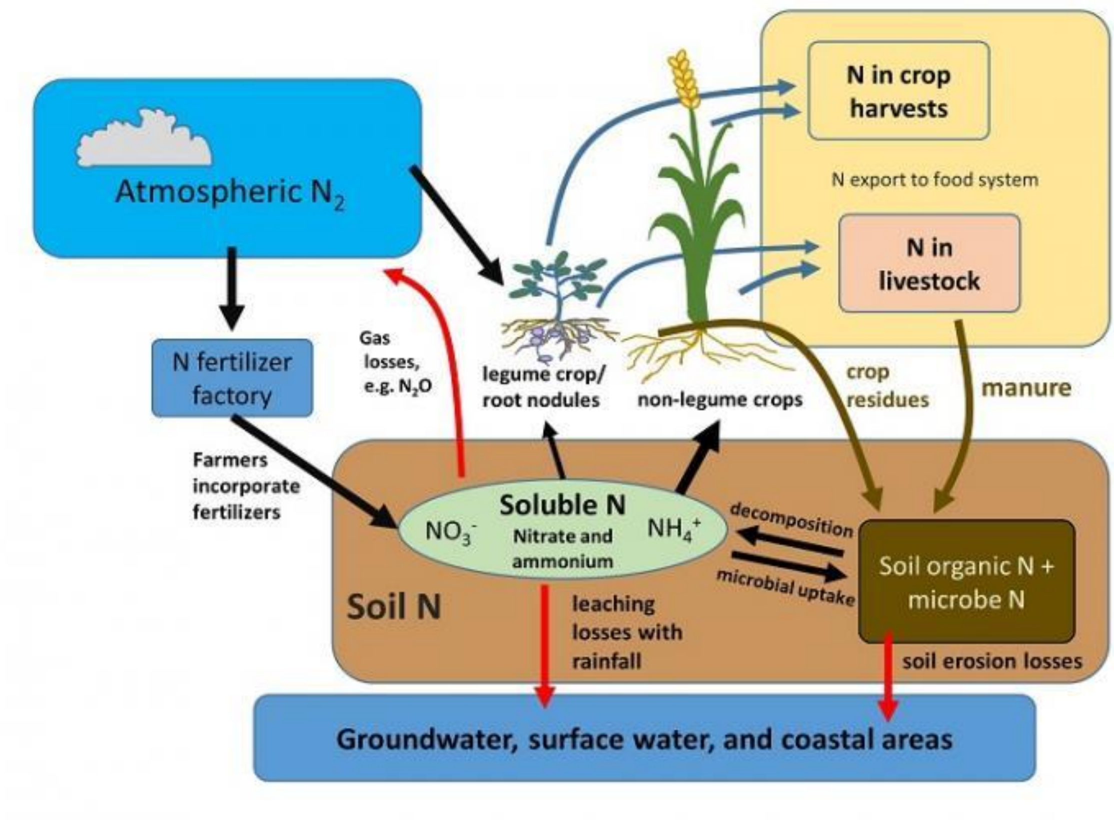

Fig. 1.1 The nitrogen cycle and human management of soils

(https://serc.carleton.edu/integrate/teaching_materials/food_supply/student_materials/1175)

In Vietnam, one of the most striking problems is the widespread soil degradation in agricultural areas, requiring the use of the land in a more sustainable manner (Vu et al., 2014; Shima et al., 2015; Tran et al., 2015). An improved land tenure security is associated with a higher level of manure use by farm households (Nguyen et al., 2016). There are a lot of different kinds of fertilizers labeled as “organic fertilizer” are being sold in the markets; however, with the manufacture being poorly regulated, their quality has not been fully explored. On the other hand, composting is not a common practice and farmers do not make the best use of organic recycling opportunities available to them due to lack of efficient expeditious technology.

1.2 Objectives

The objectives of this dissertation are three-fold: (1) to evaluate organic waste-based fertilizers with an emphasis on the nitrogen dynamics of the plant-soil system, (2) to demonstrate an on-farm rapid composting method, (3) to make suggestions regarding the recycling organic waste and the utilization of organic fertilizers under humid tropical climates.

1.3 Outline

The outline of thesis is presented in figure 1.2. Chapter 1 introduces the necessity of using recycled organic wastes as fertilizer and related issues. The chapter also states the objectives and the outline of thesis. Chapter 2 presents the efficacy of using composted organic wastes as fertilizer when applied in concert with chemical fertilizer. Under humid tropical climates, how organic fertilizers provide advantages over chemical fertilizers? To investigate this question, a cultivation experiment using the technique of 15N labelling was conducted. There were no significant differences in shoot dry weight among the composts and chemical fertilizer treatments.

Approximately two-thirds of the urea-N was lost by leaching while half of N derived from composts remained in the soil after 14 weeks cultivation. The following chapter focusses on so-called organic fertilizers in Vietnam's markets. What is "organic fertilizer" in Vietnam? Is it effective? To investigate these questions, 16 commercial products were acquired from 4 provinces of Vietnam. On these fertilizers, the nutrient composition were analyzed and experiments were conducted: incubation experiment to evaluate N mineralization rate of the fertilizers, and a cultivation experiment to assess the effects of the fertilizers on plant and N leaching. The nutrient content greatly varied among domestic products, whereas they were quite similar among imported products. The remarkably high ratio of inorganic N to total N in domestic products was attributed to excessive N leaching from soil. Why domestic "organic fertilizers" differ from the other? As the product packaging of the collected samples lacked information regarding raw materials, the comparison could not be drawn between the commercial products and their supposed raw materials. And therefore, an investigation the production of one such "organic fertilizer" was carried on. The involved stages were composting, the addition of extra soil as a bulking agent, and the mixing-in of chemical substances to increase the nutrient content. For sustainable agriculture, the use of these fertilizers should be considered. Chapter 4 proposes a simple method of composting to establish recycling of organic waste for sustainable agriculture in Lam Dong province of Vietnam. On-farm small-scale composting trials of coffee by-products were performed. After 2 months composting, samples were taken for analysis and cultivation experiment. Total C, N and K contents of composts were in the range of 340.35-386.02 $g \cdot kg^{-1}$, 23.80-36.70 $g \cdot kg^{-1}$, and 18.86-25.13 $g \cdot kg^{-1}$, respectively. In the compost where wood chips were used as the bulking agent under air flow, exhibited a concentration of inorganic N that was significantly higher than that of the other composts. It indicated that the most important factor influencing composting process was the control of aeration with wood chips and air flow. The plant biomass corresponding to composts showed similarity with chemical fertilizer. Finally, some implications and further work are presented in chapter 5.

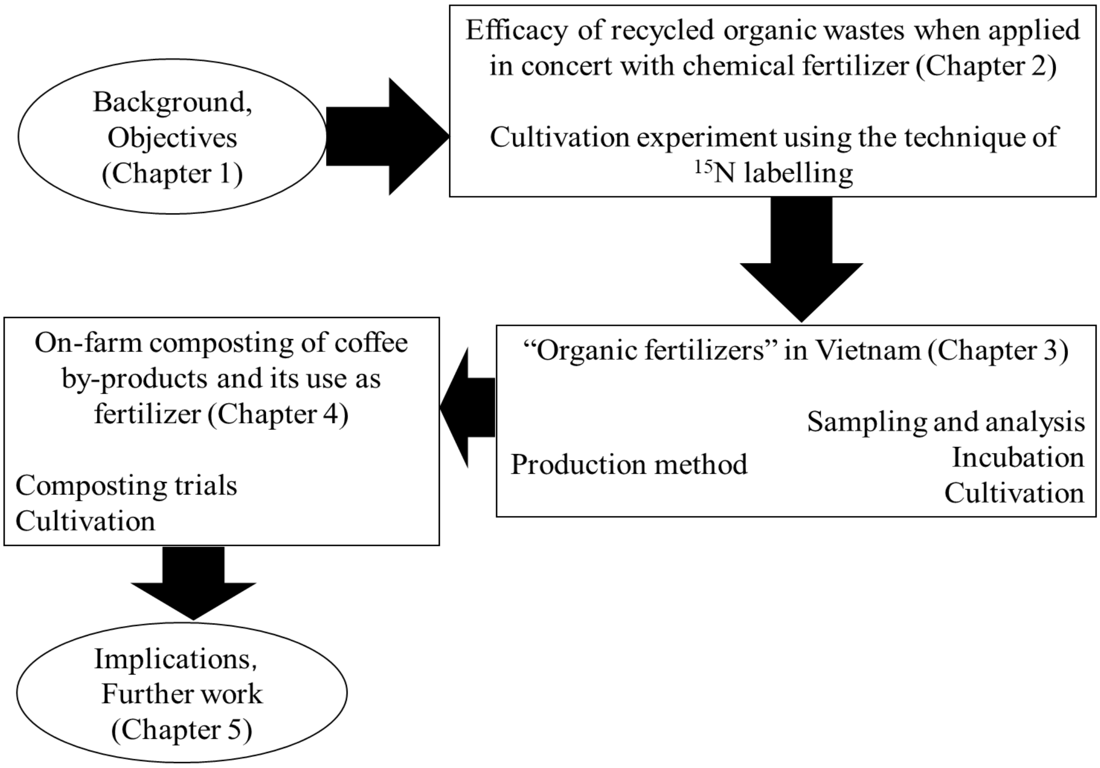

Fig. 1.2 An outline of the thesis

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CHAPTER 2. EFFICACY OF COMPOSTED ORGANIC WASTES WHEN APPLIED IN CONCERT WITH CHEMICAL FERTILIZER

Abstract

Recycling organic waste for agricultural use is gaining interest in Vietnam. This study investigated the effect of using composted municipal solid waste (MSW) as fertilizer to grow Sudan grass (*Panicum maximum*) and compared it with composted sewage sludge (SS), composted cow dung (CD), and traditional urea-based chemical fertilizer. A cultivation experiment (using containers) was conducted by growing the grass in sandy loam-textured soil using an automatic irrigation system in a greenhouse. ^{15}N labeled urea-N was used to distinguish N (nitrogen) that derived from urea-N or from compost. The various types of compost (MSW, SS, CD) and urea-N were applied as a basal fertilizer (incorporating into soil), while additional urea-N fertilizer was applied 4 weeks after planting. There was no significant difference in either grass shoot length or shoot dry weight among the MSW, SS, and urea-N treatments and their values were higher than grass grown under the CD treatment. The order of percent N uptake by grass derived from compost was as follows: MSW (39.4%) = SS (39.6%) > CD (17.1%). In contrast, approximately 4.0% of N derived from urea-N was assimilated by the grass. Approximately two-thirds of the urea-N fertilizer was lost by leaching while half of N derived from organic fertilizers remained in the soil. The amount of leached N from soil decreased in the following order: MSW = CD > SS. These results provide data needed to support the development programs for organic waste recycling and agricultural use of organic waste-based fertilizers in Vietnam.

Index Terms Municipal solid waste, sewage sludge, N uptake, leaching, agricultural use, Vietnam.

2.1 Introduction

A large amount of municipal solid waste containing organic carbon and nutrients are produced daily. In Vietnam, most solid waste is sent to landfills, creating an environmental burden on the government to find suitable disposal sites. The generation of solid waste increased annually by 10% in period of 2011-2015; that amount is expected to grow rapidly in future years. Municipal solid waste accounted for 46% of the waste generation with 63 thousand tons daily produced. Furthermore, the waste has high moisture content and contains a high proportion of organic matter, ranging from 54.0% to 77.1% across cities [1]-[4]. Therefore, biomass recycling has been gaining favor as an approach to reduce solid waste in landfills.

Monoculture agricultural practices in humid, tropical climates accelerate soil degradation. In Vietnam, degraded soil is widespread in agricultural areas. Most soil carbon (in topsoil) is lost via erosion; therefore, intensely-cultivated soils cannot retain nutrients [5]-[7].

Application of organic matter is recommended for improving soil productivity [8]-[10]. Most farmers believe that mineral fertilizers are more quickly assimilated by crops than organic fertilizers; therefore, farmers often apply organic fertilizers to crops at the time of planting (basal fertilizers) and then apply chemical fertilizers later when needed. However, the efficacy of this practice requires further study.

Manure is popularly used as an organic fertilizer worldwide. In addition, sewage sludge is becoming an important recyclable organic material in developing countries that are rapidly urbanizing [11], [12]. Recently, urban areas in Vietnam have begun to compost their solid waste. However, regulations on the recycling of organic fertilizers have not been sufficiently established in Vietnam [13]. Therefore, the development of composting techniques and utilization of compost has become an important focus of research.

This study focuses on the efficacy of and mechanisms for using composted municipal solid waste (MSW) in soil-plant systems when applied in concert with chemical fertilization. We conducted a trial experiment to assess the usefulness of MSW for growing crops relative to using composted sewage sludge (SS) or composted cow dung (CD). Specifically, our study investigates the following aspects: (1) the effects of composted MSW on crop productivity and (2) the proportions of N (nitrogen) derived from composted MSW assimilated by plants, stored in soil, and leached to groundwater.

2.2 Materials and Methods

2.2.1 Compost sampling

MSW from the Thuy Phuong waste treatment plant (Vietnam), and SS and CD from the Chugoku Yuki composting plant (Japan) were collected. The chemical properties of these materials are summarized in Table 2.1.

2.2.2 Cultivation experiment

A cultivation experiment was conducted using culture containers (0.45 × 1.05 m, depth: 0.32 m) filled with the decomposed granite soil (sandy loam). Sudan grass (Panicum maximum) was planted in the containers and grown with an automatic irrigation system in a greenhouse. A diagram of the experimental setup is shown in Fig. 2.1; a picture is provided in Fig. 2.2.

One of the four types of fertilizers (MSW, SS, CD, or urea-N) was applied to the upper 5 cm of the soil of each container at the beginning of the experiment (i.e., basal fertilization). The beginning N concentration of the experimental soils was 15.98 g N/m2. Treatments were arranged in a randomized design with three replications.

Table 2.1 Chemical properties of the materials

Constituents	Municipal solid waste (MSW)	Sewage sludge compost (SS)	Cow dung compost (CD)
T-C (g kg^{-1})	122.60	248.10	260.50
T-N (g kg^{-1})	9.90	37.70	24.70
NH_4^+ (g kg^{-1})	0.97	11.65	-
NO_3^- (g kg^{-1})	0.03	0.79	-
T-P (mg kg^{-1})	3.40	33.16	9.85
K (mg kg^{-1})	7.72	5.54	18.53
Mg (mg kg^{-1})	2.38	5.41	4.38
Ca (mg kg^{-1})	43.18	17.40	12.76
Zn (mg kg^{-1})	205.42	198.61	117.74
Cu (mg kg^{-1})	137.70	318.63	34.62
Cd (mg kg^{-1})	8.19	8.02	4.24
Ni (mg kg^{-1})	18.33	99.27	4.04

Seeds of Sudan grass were sown into the containers at a density of 10 g/m^2, equivalent to approximately 210 seeds per culture container. Water was supplied continually to plants with an automatic watering apparatus at a necessary and sufficient amount.

Four weeks after sowing, the first additional (chemical) was applied at a rate of 18.38 g N/m^2 fertilization along with ^{15}N-labeled urea-N: 8% by atom. Six weeks later (10 weeks after sowing), the aboveground biomass of the mature grass was harvested by cutting it 2 cm above the soil surface. After the grass had regrown, it was fertilized again; then, the second harvest was conducted.

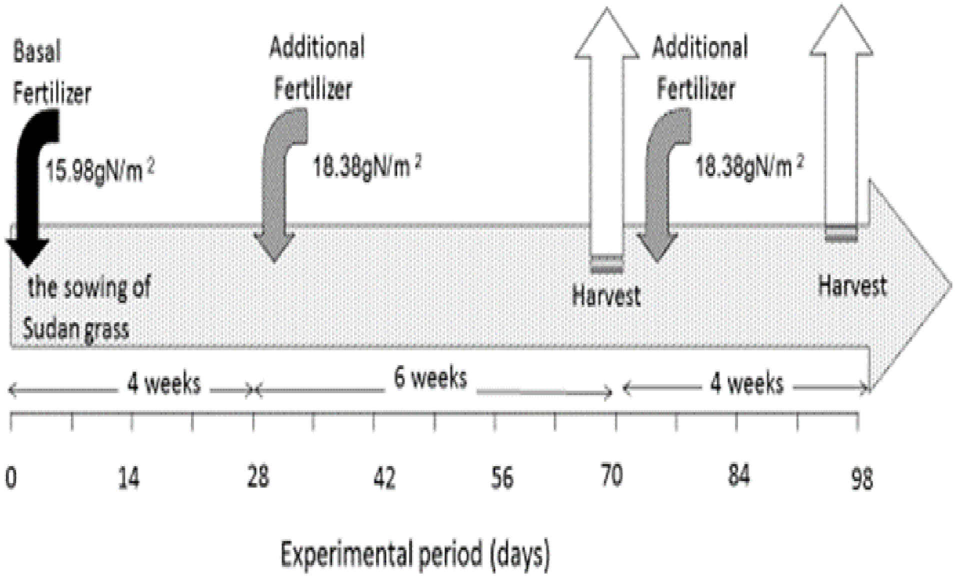

Fig. 2.1 A diagram of the experimental setup

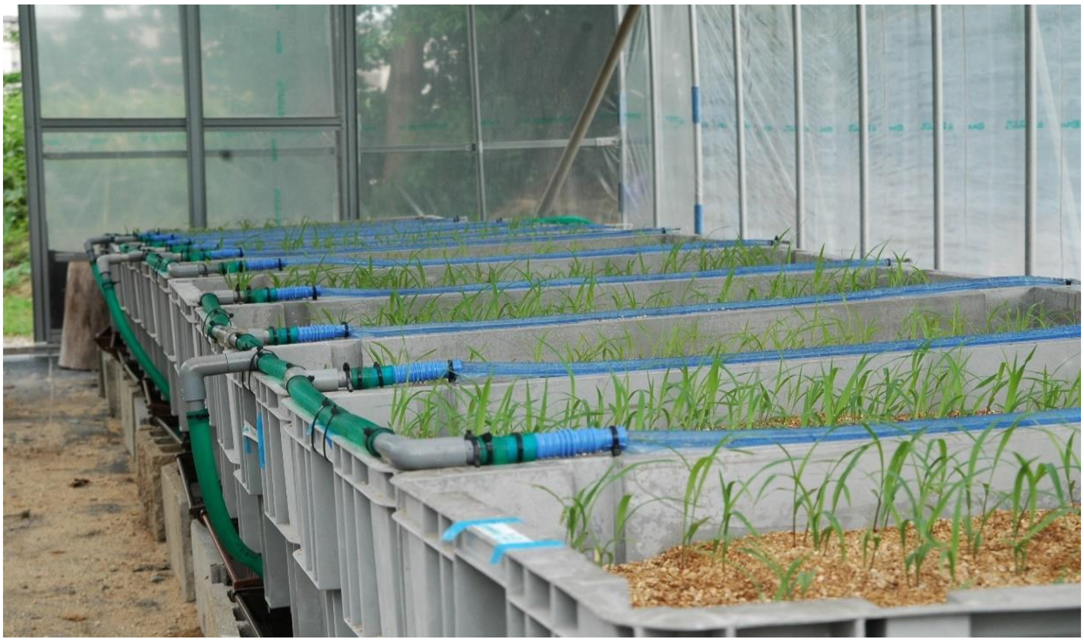

Fig. 2.2 A picture of the cultivation system

2.2.3 Sampling and analysis

Plant growth was monitored weekly by measuring the shoot length of five randomly chosen plants in each culture container. Length was defined as the height of top leaves. At harvest, grass was cut at 2 cm length above the soil surface to collect samples. At the end of the experiment, soil samples were collected from each container from the top 5 cm of the soil, from the 5- to 10-cm depth stratum, and from the bottom soil stratum. Plant and soil samples were dried in an oven at 105°C for 24 h, weighed, ground, and stored for further analyses.

Chemical analysis:

Total N and C content were determined using a CN-Analyzer. 15N isotope ratios were measured in plants and soil samples (from stable isotope culture containers) using the CN-Analyzer coupled with isotope Quadrupole mass spectrometry [14].

Statistical analysis:

Analysis of variance (ANOVA) was used to test whether effects of the experimental treatments on shoot dry weight and total N uptake were significant. When effects were significant at the 0.05 level of probability, the means for each factor pair were separately compared using the Fisher's least significant difference (LSD) test. Finally, ANOVA and LSD tests were applied to the factor scores to identify significant differences among treatments.

2.3 Results and Discussion

2.3.1 Effect of compost on crop productivity

To assess the effects of compost application on plant, we statistically compared shoot length and shoot dry weight of plants grown under each treatment type.

Changes in shoot length were evaluated weekly prior to the first harvest (Fig. 2.3). I found that before our first application of additional fertilizer (at week 4), shoot length after the MSW treatment was statistically shorter than that after the SS and urea-N treatments, but higher than that after the CD treatment. After the second fertilizer (urea-N) application at week 10, there were no significant differences in shoot lengths among the MSW, SS, and urea-N treatments; in addition, shoots grown under these treatments were significantly longer than shoots grown under the CD treatment. The slow-release of available-N following the application of MSW may result in a lower rate of plant growth in early growth stages. Therefore, application (as additional fertilizer) may have helped enhance plant growth in the MSW treatment. In later sections, we discuss N utilization relative to various forms of N.

There were no significant differences among treatments in the dry weight (biomass) of shoots relative to the MSW, SS, and urea-N applications; in addition, biomass of shoots was significantly higher than the biomass of shoots obtained from the CD-treated containers (Fig. 2.4). These results agreed with the results we obtained from our shoot length experiment.

In summary, when compost was applied as a basal fertilizer (and urea-N applied later as an additional fertilizer), the agronomical efficiency of the MSW compost was equivalent to the efficiency of the SS compost and chemical (urea-N) fertilizer treatments.

2.3.2 Dynamics of compost-N amended soil

Efficient use of organic fertilizers on agriculture lands requires controlling both the quality of the raw material and the amount and dynamics of the nutrients applied. The fate of compost-N is relevant to plant productivity; however, excess N exported to water bodies has environmental consequences, such as eutrophication [8], [10], [15], [16].

My measurement of ^{15}N isotope ratio in plants and soils of the stable isotope culture containers provided information about N dynamics of the applied N and enabled us to estimate the amount of N lost via leaching (Fig. 2.5).

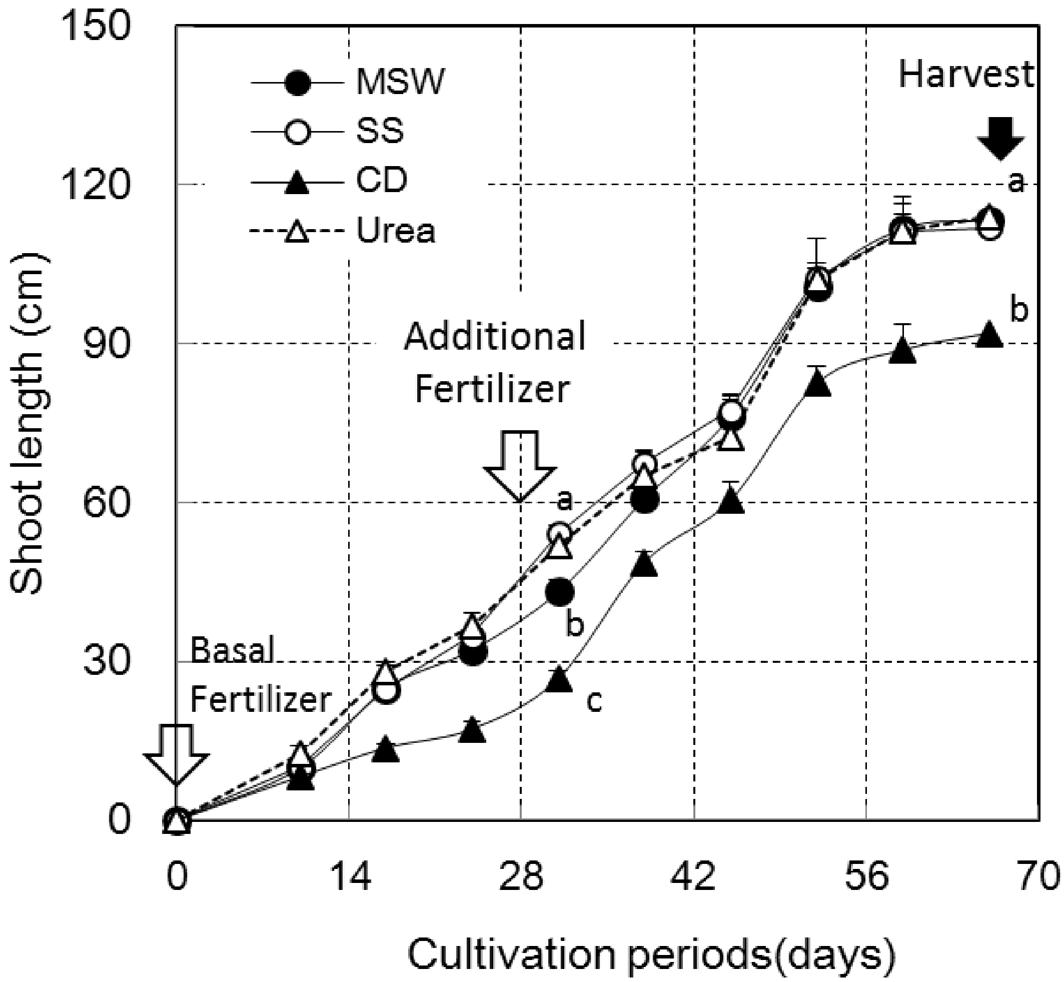

Fig. 2.3 Changes in shoot length at the first harvest as influenced by different treatments.

Note: MSW, composted municipal solid waste; SS: composted sewage sludge; CD: composted cow dung.

Values are means ± SD (n=15). Means with the same letter are not significantly different from each other (p<0.05)

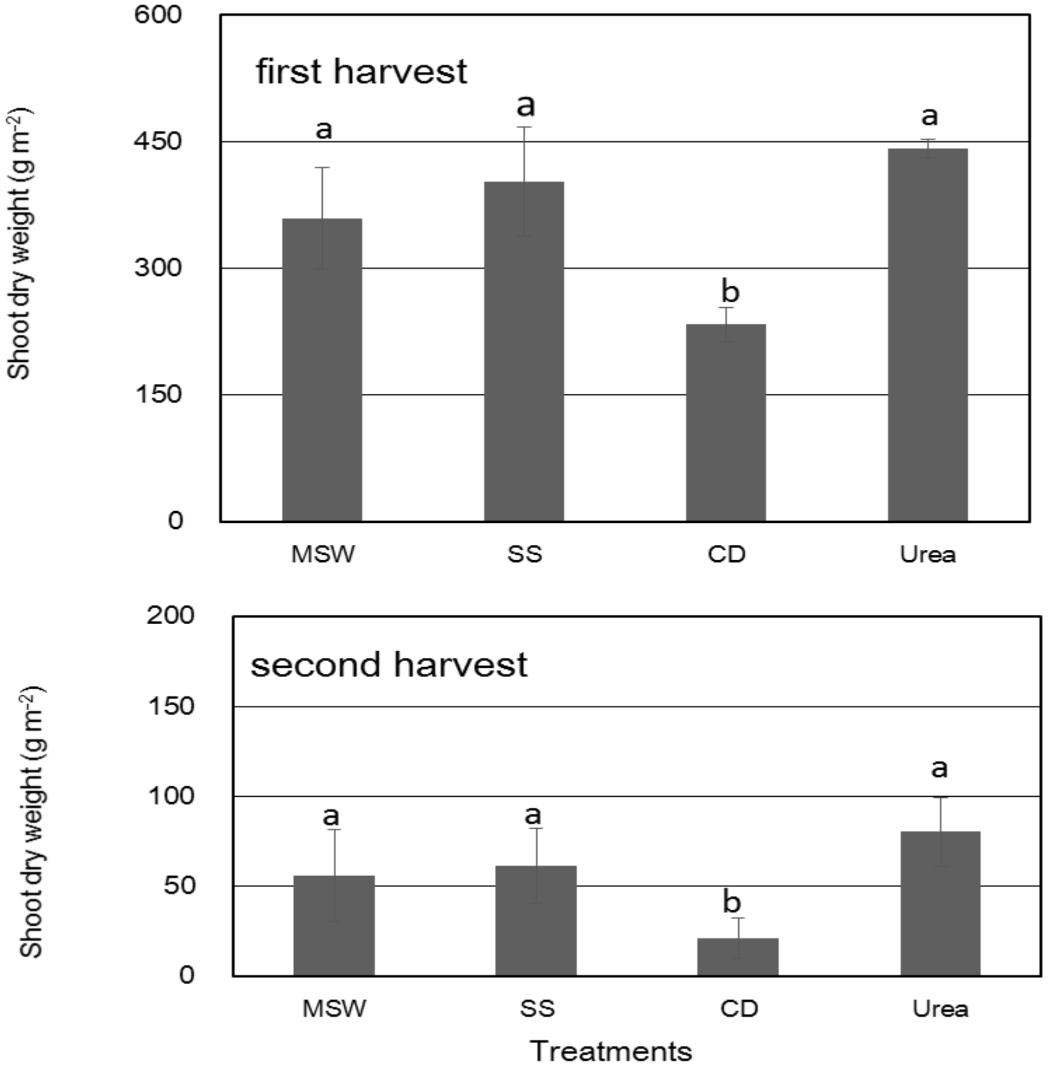

Fig. 2.4 Shoot dry weight as influenced by different treatments.

Note: MSW, composted municipal solid waste; SS: composted sewage sludge; CD: composted cow dung. Values are means ± SD (n=3).

Means with the same letter are not significantly different from each other (p<0.05).

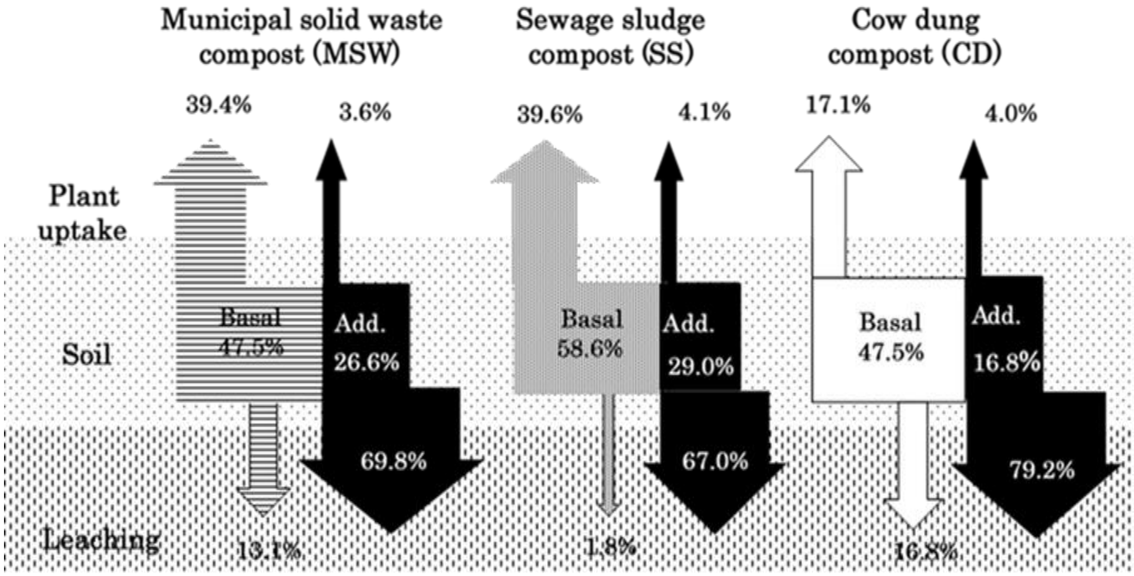

Fig. 2.5 N dynamics of basal fertilizer (Basal) and additional fertilizer (Add.) as influenced by different treatments

N uptake by grass planted in the various types of composts we tested was higher than N uptake in the urea-N fertilized containers. The order of treatments relative to percent N uptake was as follows: MSW (39.4%) = SS (39.6%) > CD (17.1%). In contrast, only 3.6%−4.1% of urea-N was assimilated by the grass. N uptake by grass from compost-N in our study was remarkably higher than N uptake by plants fertilized with compost in other studies. In those studies, uptake generally did not exceed 15%–20% of the total N supply in the first year of growth [15]. In contrast, in this study, leaching loss of N was higher in the urea-N application treatment than in any of our other (compost) treatments. N loss in soil via leaching decreases with an increase in the N-immobilization rate. Although approximately two-thirds of urea-N was lost via leaching in this study, approximately half of N derived from organic fertilizers remained in the soil. N leaching, by treatment type, decreased in the following order: MSW = CD > SS. The less N is leached from the soil, the less likely the groundwater will be contaminated by NO_3^-. Despite higher leaching potential, urea-N applied as an additional fertilizer can provide an important role for an effect rate of MSW treatment.

Combining the application of organic compost and inorganic fertilizer to crops has been shown to be more effective in increasing the yield than an application of either fertilizer type alone [14]. Further, Han et. al. [17] showed that a blend of chemical fertilizers and compost could increase the mineralization rate of compost-N. In this study, after adding urea, crop yield (shoot length) of the MSW treatment improved. However, ^{15}N data in this study indicated that most N uptake was derived from compost-N rather than urea-N. This result is consistent with above-described studies.

2.4 Conclusion

In Vietnam, the amount of organic waste (including municipal solid waste, sewage sludge, and waste of agro-industrial origins) generated has increased rapidly over time. Most of these waste streams are deposited in landfills or are incinerated, creating unnecessary environmental burden. Therefore, there is widespread interest in recycling these organic-waste products into soils that are low in organic matter. In the present study, the effects of MSW were evaluated and compared with SS, CD, and traditional chemical fertilizers (urea-based N). Using compost as a basal fertilizer and urea as additional (amendment) fertilizer, the agronomical efficiency of using MSW as fertilizer was found to be equivalent to efficiencies of SS and chemical fertilizers, and more than the efficacy of CD as fertilizer. The order of N uptake derived from compost was as follows: MSW = SS > CD. Meanwhile, N leaching decreased in the following order: MSW = CD > SS. The difference in N leaching rates between MSW and SS may depend on the type of raw material and/or the composting technique. In the following studies, I intend to clarify this.

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CHAPTER 3. “ORGANIC FERTILIZERS” IN VIETNAM

Abstract

Organic fertilizers have recently been gaining popularity; however, their governance is not completely assessed in developing countries. This study investigated the nutrient composition of so-called organic fertilizers in Vietnam’s markets and issues related to their production and evaluated their potential to contaminate the groundwater. We analyzed physicochemical properties of 12 domestic and 4 imported products of the fertilizers, and conducted a cultivation experiment in sandy soil with the fertilizer applied at a rate of 200 mg N kg^{-1} soil using an automatic watering apparatus in a greenhouse. We further studied the production of an “organic fertilizer” from coffee by-products. The nutrient content greatly varied among domestic products, whereas they were quite similar among imported products. The product packaging of the collected samples lacked information regarding raw materials. Two thirds of domestic products contained over 30% of the total N in the inorganic form, implying that the N content dramatically increased in the fertilizers rather than in their supposed raw materials. The stages involved in the production were composting, the addition of extra soil as a bulking agent, and the mixing-in of chemical substances to increase the nutrient content before packing. The remarkably high ratio of inorganic N to total N was attributed to excessive N leaching from soil by the application of domestic fertilizers. These results suggested the need for quality criteria guidelines for organic fertilizers in Vietnam that underline not only nutrient levels, but also the control of raw materials and production process of compost because they are closely related to nutrient uptake and leaching loss of nutrients.

Keywords Coffee by-products, nutrient composition, N leaching, production, “organic fertilizer”.

3.1 Introduction

Organic agriculture according to the internationally accepted standards is a relatively new method of farming in developing countries. Consumers have difficulty in distinguishing between genuine organic and other “clean” products [1-4]. Vietnam is one of the most dynamic emerging countries in the East Asia region, with GDP growth rate of 6.8% in 2017. The country’s economic performance reflected strong export-oriented manufacturing, strong domestic demand, and the gradual rebound of agriculture [5]. One of the most striking problems for Vietnam is widespread soil degradation in agricultural areas, requiring the use of the land in a more sustainable manner [6-8]. Nguyen et al. [9] reported that improved land tenure security is associated with a higher level of manure use by farm households. Sustainability certification has become increasingly popular in recent years even though the excessive application of fertilizers and irrigation have made it difficult for farmers to conform to most certification standards and programs. Easy labeling showing environmental performance costs much less than certifying with international agencies has probably led Vietnamese farmers to move away from international certification and opt for cheaper labelling scheme [10].

In this context, the organic fertilizer industry has recently expanded. The organic fertilizer market is estimated to have increased at an impressive 11% compound annual growth rate from 2016 to 2021. The country annually produces >1.2 million tons of organic fertilizers [11-13]. Various fertilizers labeled as “organic fertilizer” are being sold in the markets; however, criteria of their raw materials and production have not been established. Quality of these fertilizers requires clarification.

On the other hand, composting is considered a proper approach to the rising amount of organic waste from municipal solid waste, sewage sludge and agricultural by-products in developing countries. In Vietnam, composting the wastes have recently begun. Adding chemical fertilizers to the waste during composting is a common practice [14-15]. There is a lack of empirical evidence for the effectiveness of this practice.

The application of compost is recommended not only for improving soil productivity, but also for reducing eutrophication because of excessive application of chemical fertilizers [16-20]. Under the Asian monsoon climate, nutrient leaching via surface runoff or percolation through the unsaturated zone into groundwater is predicted to be high because of the high frequency of heavy rainfall [21]. Thus, the evaluation efficacy of the fertilizers should involve assessing leaching of nutrients from agricultural soil.

The objectives of this study were to clarify the nutrient composition of the so-called organic fertilizers and to elucidate the effects of their application on cropping plants and the leaching loss of nutrients from agriculture land. Therefore, nutrient composition was analyzed and a cultivation experiment was conducted using some typical “organic fertilizers”. Moreover, to determine the reasons why nutrient content greatly varied among “organic fertilizers” I investigated the flow of raw materials and manufacturing processes for an “organic fertilizer” made from coffee by-products.

3.2 Materials and Methods

3.2.1 Sampling and chemical analysis

I acquired 16 so-called organic fertilizers (12 domestic products, V1–V11 and VC, and four imported products, I1–I4), which were being sold in the markets of Hanoi, Thua Thien Hue province, Lam Dong province, and Ho Chi Minh City in Vietnam. Hanoi and Ho Chi Minh City are two of the largest municipalities located in Northern Vietnam and Southern Vietnam, along with large suburban areas for vegetable production to meet urban vegetable demand. Lam Dong province in the Central Highlands is known as not only the largest vegetable producer, it also has the second largest area of coffee plantations in Vietnam. Vegetable production is characterized by a high level of fertilizer input. Thua Thien Hue province is located in the Central Coastal Region of Vietnam which is dominated by poor-quality sandy soil. Samples were collected in November 2015 and June 2016; replicate samples were deleted. These goals were to ensure that selected samples were representative of "organic fertilizers" in Vietnam. Samples were then brought to the Laboratory of Environmental Soil Science of Okayama University, Japan to analyze their physicochemical properties and to conduct a cultivation experiment.

The pH was measured using a pH electrode (1:5 fresh sample: water, w/v). The total C and N were determined using a CN-analyzer (CN Corder MT-700; Yanaco, Japan). In the organic form (NH_4^+, NO_3^-), N was extracted using 2 mol L^{-1} KCl, and concentrations of NH_4^+ and NO_3^- were measured using the phenate method and vanadium (III) chloride reduction method, respectively, with a spectrophotometer (UV-1200, Shimadzu, Japan) [22-23]. Exchangeable cations (Exch.K, Exch.Mg, and Exch.Ca) were extracted using 1 N NH_4OAc. The remaining total nutrient content was assessed by wet digestion with HNO_3 and perchloric acid. Available phosphorus (Truog P) was extracted using 0.002 N H_2SO_4. Total K, Ca, and Mg contents were measured using atomic absorption spectrophotometry. The total P and Truog P contents were determined using the ascorbic acid sulfomolybdo-phosphate blue color method [24].

3.2.2 Investigation of the flow of raw materials and manufacturing process of an "organic fertilizer"

The research site of this study covered two districts (Duc Trong district and Lam Ha district) of Lam Dong province in the Central Highlands, which is the main coffee producing area in Vietnam. The coffee processing industry employing either wet or dry method to remove the shells from the cherries generates a large volume of coffee by-products. Most of the waste was deposited on land, causing environmental pollution and composting is suggested as an attractive solution for handling the waste. Consultation with local experts in coffee production and sampling coffee by-products for nutrient analysis were conducted as preliminary work in the early 2016. In June 2016, I visited coffee plantations that are mainly operated by households, with small production scale of several hectare. During the harvest time, they collect the cherries and sell them to processing companies in the area.

A survey using face-to-face interview was conducted at three of 11 coffee processing companies and a private fertilizer company that made a so-called organic fertilizer from coffee by-products (VC) in the area. In the coffee processing companies, I gathered data on the working capacity, technology employed (wet method or dry method), input materials and output materials, waste generation and disposal costs, and, we visited disposal sites of coffee by-products. In the fertilizer company, I collected information on source of raw materials, composting technique, stages involved in the manufacturing process, the purpose of each stage, the target customers, and the price of coffee by-products and the commercial product of fertilizer. I also took samples at each stage of the manufacturing process and brought them to Japan for analyses, aiming to evaluate changes in the nutrient levels during the process. Parameters were measured as described above.

3.2.3 Cultivation experiment

Japanese Komatsuna (*Brassica rapa* var. perviridis) was cultivated in 1/5000a Wagner pots in a greenhouse using an automatic watering apparatus for six weeks. The design was completely randomized, with three replicates per sample, using nine selected "organic fertilizers," a chemical inorganic fertilizer, and a control (soil only). Sandy soil was first passed through a 2 mm sieve. Then, 2.2 kg of the graded soil was placed in planting pots, followed by 1 kg of the graded soil into which the fertilizer was mixed. Table 3.1 presents the pH value and nutrient contents of the soil used in this experiment.

Table 3.1 pH and nutrient contents (g kg^{-1}) of soil used in the cultivation experiment.

Constituents	**Values**
pH (H_2O)	8.99 ± 0.17
Total C	≤0.001
Total N	≤0.001
Total P	0.01 ± 0.00
Total K	2.26 ± 0.04
Total Mg	1.72 ± 0.00
Total Ca	3.24 ± 0.10

Values are means ± SD (n = 3).

The following two nutritional supplementation treatments were used: N-fertilizer alone and N-fertilizer + P, K. For the N-fertilizer treatments, "organic fertilizers" and a chemical inorganic fertilizer were applied at a rate of 600 mg N per pot (equivalent to 300 kg N ha^{-1}). To prepare the N-fertilizer + P, K treatments, I calculated the total P and K contents contributed by the "organic fertilizers" and supplemented these with P as super phosphate and K as potassium chloride to bring the P content to 410 mg per pot and the K content to 1150 mg per pot (except for the soil-only control). Twelve seeds of Komatsuna were sown in each pot. One week after germination, the seedlings were thinned to a density of eight seedlings per pot.

Plant and soil samples were taken at harvest (six weeks after sowing). The dry weight of plants in each pot was measured. Soil samples were collected from each pot from the top and bottom soil stratum. Plant and soil samples were dried in an oven at 105°C for 24 h, ground, and stored for further analysis. An analysis of variance (ANOVA) was used to compare the effects of the fertilizer type and nutritional supplementation on the dry weight and nutrient uptake of plants. Differences between individual averages were tested using the *post-hoc* least significant difference (LSD) test at $p < 0.05$.

3.3 Results and Discussion

3.3.1 Characteristics of "organic fertilizers"

Figures 3.1–3.3 show the N, P, and K contents of the collected samples. Table 3.2 presents the summaries of pH (H_2O), the C: N ratio, and the concentrations of other nutrients.

I found that N and other nutrient contents greatly varied among the domestic products, whereas these were quite similar among the imported products. In the domestic products, the total N, P, and K contents were in the ranges of 4.9–48.5 g kg^{-1}, 0.0–12.7 g kg^{-1}, and 5.8–26.0 g kg^{-1}, respectively, whereas in the imported products, these were in the range of 24.6–40.2, 9.7–12.5, and 14.2–29.0 g kg^{-1}, respectively. The ratio of inorganic N to total N in most domestic products was high. Two-thirds of domestic products contained approximately 30% of the total N in the inorganic form, and the imported products contained approximately 10%. In contrast, the ratio of Truog P to total P greatly varied among domestic products.

Raw materials, which are the foundation for the quality of organic fertilizers are varied. They are by-products of vegetable, animal, and human origin that have been popularly used worldwide for over a thousand years. They are organic materials from municipal solid waste, sewage sludge and waste of agro-industrial origin whose use recently markedly increased in modern agriculture as organic waste-based fertilizers [25]. These wastes are becoming important recyclable organic materials in developing countries. Composting the wastes has recently begun in Vietnam; however, governance instruments and policies on this recycling activity have not been established. There is no standard for raw materials of organic fertilizers in regulations regarding fertilizer production, distribution, and use [26]. Varied raw materials and poorly controlled manufacturing could cause a wider range of nutrient content of domestic “organic fertilizers” compared with that of the imported ones.

Since there was no information regarding raw materials on the product packaging of our collected “organic fertilizers” I guessed their feedstock based on their N content and appearance. The N content of organic fertilizers depends on the raw materials. The percentage of N recorded in poultry manure, dairy manure, municipal solid waste, crop residue, and sewage sludge are in the ranges of 2.0-4.0, 1.0-2.0, 1.0-1.5, 1.5-2.5, and 3.7-5.0, respectively [27-28, 16]. Two-thirds of domestic “organic fertilizers” contained less than 2% N (Figure 3.1) and various pieces of litter, branches, nylon, and stones were observed in the fertilizers (Table 3.3). To date, the waste has not yet been separated at the source in Vietnam. It appeared that most of the domestic products might have been produced from municipal solid waste.

It must be emphasized that the percentage of inorganic N within total N in most collected domestic “organic fertilizers” was noticeably high. Many studies show that inorganic N comprised less than 10% of compost N [27, 29-30]. The ratio of inorganic N to total N in our collected samples of imported products was approximately 10%. Meanwhile, the ratio for two-thirds of the collected domestic products was over 30%. For example, V6 sold at Hanoi as named Que Lam 01 contained 7.3 kg kg^{-1} N, but approximately 50% of it was the inorganic form. V1 sold at Thua Thien Hue province and named Song Huong contained 38.6 kg kg^{-1} N, but inorganic N also accounted for approximately 40% of the total N.

Figure 3.4 shows the relationship between total N and P of the collected samples. We categorize them into two groups: the first included four imported and five domestic products (V3, V4, V7, V8, and V9) containing both N and P and the second included the remaining seven domestic products containing N but less P. Interestingly, the price of the former group was higher than that of the latter group (Table 3.3). It implies that the adjustment of N and P plays an important role in the price of the fertilizers. Thanh and Matsui [14] reported that the addition of N, P, and K to matured compost is typically the final step in the production process for organic solid waste compost in Vietnam. This supportably explains the common increase in the ratio of inorganic N to total N of domestic "organic fertilizers" in this study. Since the product packaging of the collected samples lacked information regarding raw materials, I could not precisely compare the nutrient content of commercial products with those of their supposed raw materials. To determine the reason for the remarkable proportion of inorganic N in domestic products, it was necessary to investigate the manufacturing processes and changes in nutrient composition during each process of a so-called organic fertilizer made from coffee by-products.

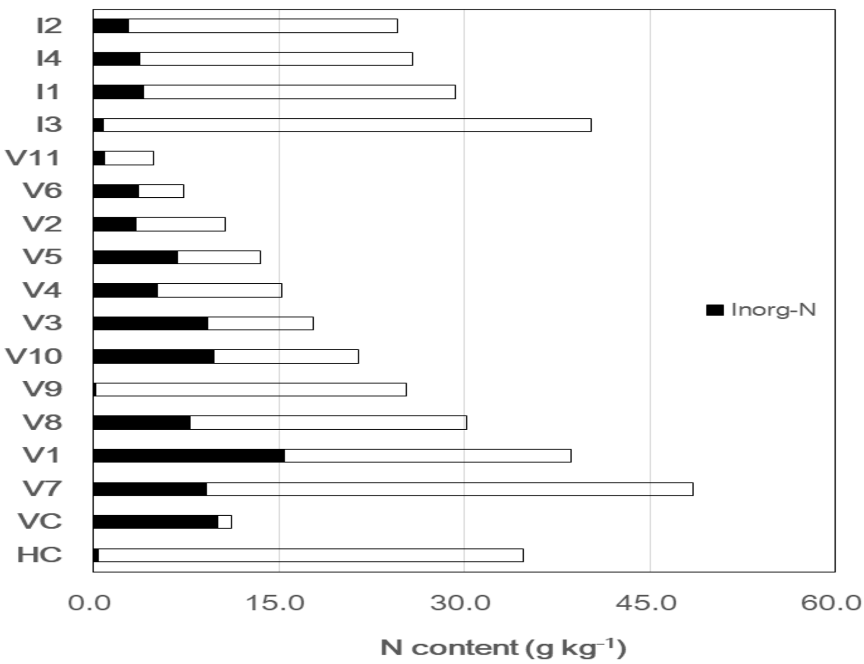

Fig. 3.1 N content of so-called organic fertilizers in Vietnam's markets.

Notes: V1-V11, VC: domestic products; I1-I4: imported products; VC: the so-called organic fertilizer made from coffee by-product; HC: coffee by-products compost.

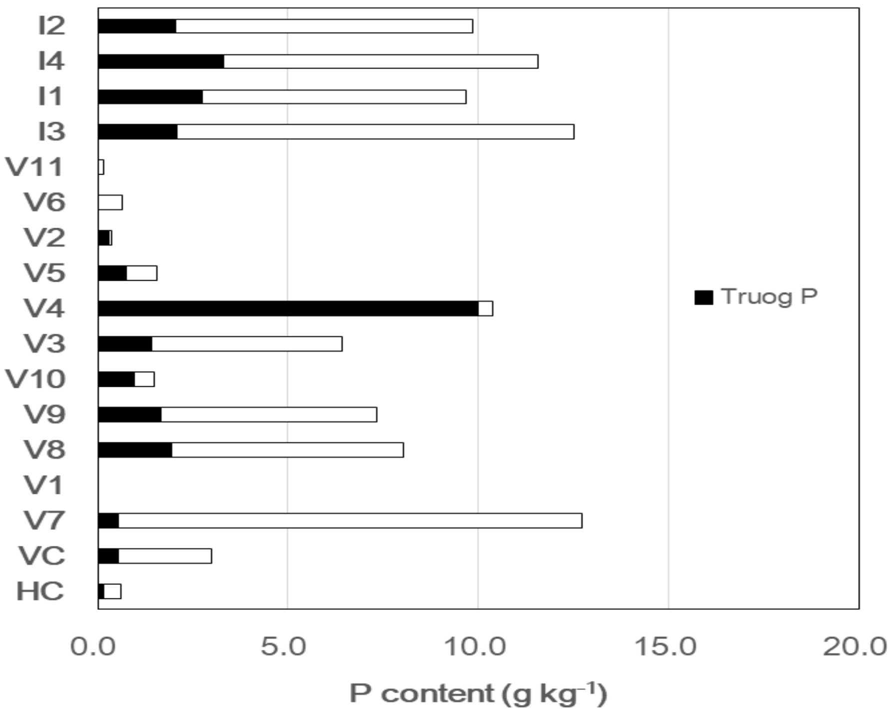

Fig. 3.2 P content of the so-called organic fertilizers in Vietnam's markets.

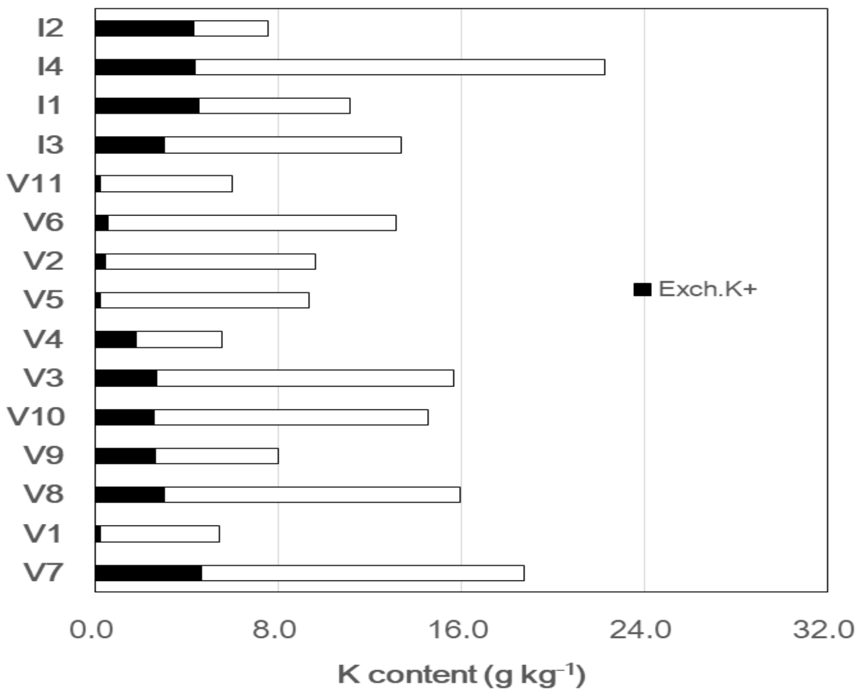

Fig. 3.3 K content of the so-called organic fertilizers in Vietnam's markets.

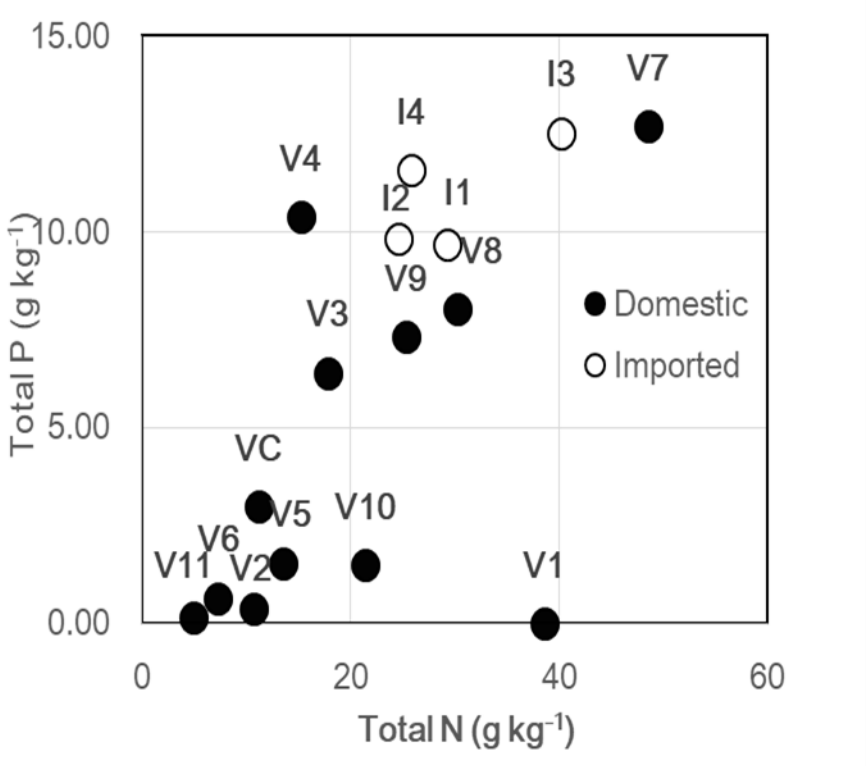

Fig. 3.4 Relationship between total N and P of the "organic fertilizers"

Table 3.2 pH, C: N ratio and concentration of other nutrients in the "organic fertilizers"

	Domestic products		**Imported products**	
pH (H_2O)	7.22	(5.14~9.07)	8.35	(7.40~8.97)
C:N ratio	8.88	(3.22~19.43)	9.16	(7.71~10.62)
Total Ca	28.45	(10.44~61.78)	60.14	(40.29~69.59)
Exch.Ca	0.02	(0.00~0.05)	0.04	(0.03~0.05)
Total Mg	3.88	(0.88~7.19)	5.20	(4.34~6.40)
Exch.Mg	2.40	(0.13~5.77)	3.92	(2.91~4.40)

Values are average and the rages are given in parentheses. Total Ca and Total Mg are expressed in g kg^{-1}. Exch. Ca and Exch. Mg are expressed in cmol kg^{-1}.

Table 3.3 General available information on collected samples.

Products name	Sample label	Ingredient descriptions	Foreign objects mixed in products	Product shape, instructions for use	Market price (USD/kg)
TRIMIX - N1	V7	Without indication		Small granules, For horticulture	1.46
SONG HUONG	V1	Without indication	Small pieces of branches and litter	Small granules, For all crops	0.09
HADICO -THANG LONG 03	V8	Without indication	Small pieces of branches and litter	Small granules, For horticulture	0.33
CFARM Pb02	V9	Without indication	Small pieces of wood and nylon	Small granules, For vegetables, horticulture	0.56
TRIBAT T-O	V10	Without indication		Small granules,	0.40

				For all crops	
DAU TRAU HCMK7 -HUU CO TRICHODERMA + TE	V3	Without indication		Small granules, For all crops	1.56
ORMIC 02-TRICHODERMAR sp -Azotobacter sp	V4	Without indication		Fine powder For all crops	2.22
HUU CO VI SINH MOI TRUONG HA NOI	V5	Without indication	Small pieces of wood	Small granules, For vegetables, horticulture	0.22
SONG GIANH 1	V2	Without indication	Small pieces of stone	Small granules, For all crops	0.18
QUE LAM 01	V6	Residue of crops, fish, and seaweed	Small pieces of wood	Small granules, For all crops	0.44

SONG GIANH 2	V11	Without indication	Small pieces of wood, branches, stone	Small granules, For horticulture	0.22
PHAN CA PHE	VC	Coffee by-products		For vegetables	0.11
MIEN TAY-WOPROFERT (Holland)	I3	Without indication		For all crops	2.22
NEUTROG-Rapid Raiser (Australia)	I1	Without indication	Pieces of rice husks	For all crops	2.22
VIMAX 3-3-3 (Malaysia)	I4	Without indication		For vegetables, fruits, tobacco, coffee tree, flowers and rice	2.22
NEUTROG-Bounco Back (Australia)	I2	Without indication	Pieces of rice husks	For all crops	2.22

3.3.2 Production method of an “organic fertilizer” from coffee by-products

Figure 3.5 illustrates the flow of raw materials and manufacturing processes for an “organic fertilizer” made from coffee by-products. After harvesting, coffee cherries were processed by one of two methods: dry or wet. In the wet method, the outer covering of the coffee bean was removed when the cherries were still fresh. This is a popular technique in this area, which generates a large volume of by-products (coffee pulp). For example, a medium-scale processing factory with a working capacity of 150 tons per day generates approximately 100 m^3 of coffee pulp. Companies arrange brokers to collect the waste, and the fee is based on the disposal volume (currently 1.3 USD per m^3). The brokers then deposit it on private land or sell it to fertilizer companies (currently at a price of 3.3 USD per m^3).

The composting companies use aerobic composting over several months, after which extra soil is added to increase the volume and density. Finally, they add chemical substances such as urea and phosphate to enhance the fertilizer effect before packing the product for sale in the markets as “organic fertilizer” at a price of 11 USD per 100 kg (current price). My investigation results are in accordance with the findings of Thanh and Matsui as reported above. However, the authors did not provide evidence of changes in the nutrient levels during the manufacturing processes. My study clarifies this limitation.

Table 3.4 shows changes in the nutrient levels during the manufacturing processes of an “organic fertilizer” made from coffee by-products. It indicates that coffee by-products are rich organic material, with nitrogen and potassium. The total C content was high, being up to 423.2 g kg^{-1}, and the N and K contents were 32.80 g kg^{-1} and 9.71 g kg^{-1}, respectively. However, the P content was very low. After composting, the carbon content slightly decreased but the concentration of total N and K increased. The compost contained were 34.8 gN kg^{-1} and 12.54 gK kg^{-1}, respectively. After bulking out the compost with extra soil, the total C, N and K contents were reduced to 83.20 g kg^{-1}, 6.40 g kg^{-1} and 4.48 g kg^{-1}, respectively. The concentration of exchangeable K^+ was reduced from 25.68 cmol kg^{-1} to 4.13 cmol kg^{-1}. After packing, the total N content nearly doubled from 6.40 g kg^{-1} to 11.20 g kg^{-1}. NH_4^+ concentration increased 34-fold, whereas NO_3^- concentration remained unchanged. The total P content tripled from 0.99 g kg^{-1} to 2.99 g kg^{-1}, and the Truog P content increased 13-fold from 0.04 g kg^{-1} to 0.54 g kg^{-1}.

3.3.3 Effects of "organic fertilizers" on plant growth and N leaching

The dry weight and N uptake of plants were significantly influenced by the fertilizer type and nutritional supplementation. The combined interaction of these factors had no significant effect on the dry weight and N uptake (Tables 3.5 and 3.6, respectively). P uptake was significantly influenced only by the fertilizer type (Table 3.7).

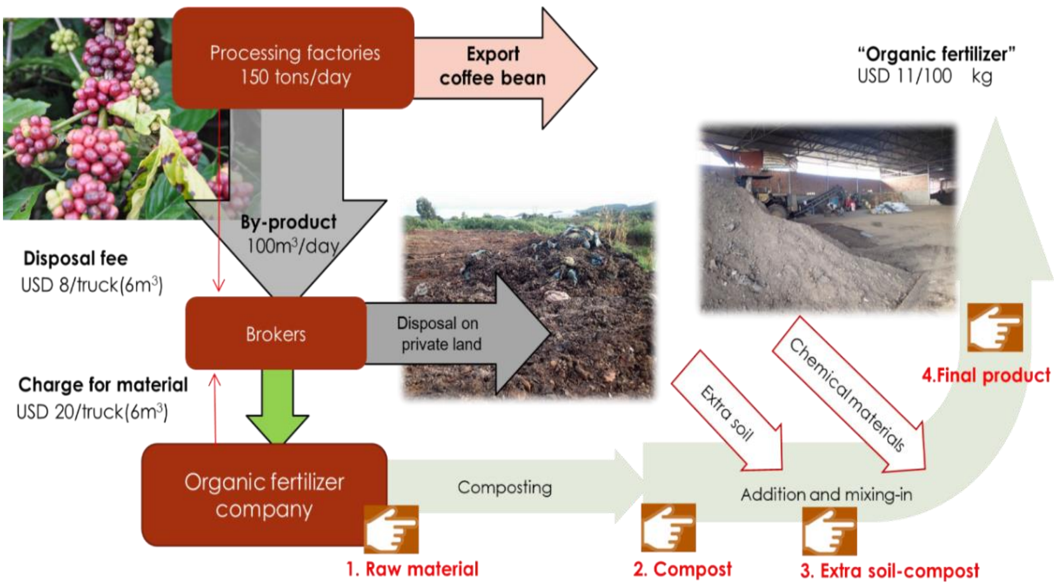

Fig. 3.5 Flow of raw materials and production method of an "organic fertilizer" from coffee by-products.

Table 3.4 Changes in the nutrient levels during the production of the "organic fertilizer".

	Raw material	**After composting**	**After bulking out**	**Final product**
pH	NA#	8.51	8.03	9.01
Total C	423.20	417.20	83.20	64.20
Total N	32.80	34.80	6.40	11.20
NH_4^+-N	NA#	0.37	0.25	8.47
NO_3^--N	NA#	0.01	0.19	0.16
C:N ratio	12.92	12.01	13.02	5.76
Total P	0.70	0.61	0.99	2.99
Truog P	0.28	0.17	0.04	0.54
Total K	9.71	12.54	4.48	4.20
Exch.K	37.87	25.68	4.13	5.06
Total Mg	0.41	0.71	0.37	0.65
Exch.Mg	2.39	2.30	0.66	0.82
Total Ca	1.55	2.49	0.83	3.05
Exch.Ca	3.26	4.69	2.02	7.98

Nutrient contents are expressed in g kg^{-1}. Exchangeable cations are expressed in cmol kg^{-1}.

NA#: not analyzed.

The dry weight and nutrient uptake effects of the fertilizer type and/or nutritional supplementation are presented in Table 3.8. Generally, the order of treatments for dry weight and nutrient uptake was as follows: domestic fertilizers ≥ chemical fertilizer ≥ imported fertilizers > control. Conversely, the effect of the domestic V4 treatment was not significantly greater than that of the corresponding control. With a single application (N-fertilizer), there was no significant difference in the dry weight among the domestic V6 and VC treatments and chemical fertilizer. In treatments with additional P and K (N-fertilizer + P, K), the dry weight was significantly greater for half of the domestic treatments (V2, V5, V6, and VC) than that of the corresponding chemical fertilizer. There were no significant differences in dry weight among treatments using the remaining domestic products, imported products and chemical fertilizers.

The measurement of N uptake by plants and N stored in soil enabled us to estimate N leaching. A single application of chemical fertilizers and most domestic "organic fertilizers" resulted in significantly higher N leaching from soil than that by the application of imported products. The positive correlation between N leaching and the ratio of inorganic N to total N in the applied fertilizers is illustrated in Figure 3.6 ($r = 0.77$, $p < 0.01$).

It has been reported that the majority of N in manure or compost is in the organic form that must first become mineralized before plants can uptake it, or it becomes susceptible to loss by leaching. Only a small fraction (3.5%) of their total N was mineralized within the growing season, resulting in the lowly met N requirement of crops. Compost is often reported to be less effective in supplying available N to plant during the first year of application compared to inorganic mineral fertilizer [28, 31-32]. Organic fertilizers have been commonly applied to the soil to increase soil fertility and minimize N leaching. The application did not increase the loss of N through leaching compared with controls and the compost provided advantages over mineral fertilizers from a water quality perspective [16, 17-20].

However, the so-called organic fertilizers collected in this study showed the opposite effect. My study ranked dry weight and nutrient uptake as follows: domestic "organic fertilizers" ≥ chemical fertilizers ≥ imported organic fertilizers > control. In addition, a single application of either chemical fertilizers or most domestic "organic fertilizers" resulted in significantly greater N leaching from the soil than that by the application of imported products. This indicates clearly that in poor-quality sandy soils, the application of chemical fertilizers or "fake" organic fertilizers should be considered a significant threat to groundwater (from excessive N leaching). The high leaching rate can be attributed to the high proportion of inorganic N to total N in the applied fertilizers. Figure 3.7 illustrates the relationship between dry weight and N leaching under a single application of the fertilizers. The application of chemical fertilizer and domestic "organic fertilizers" V2, V6, and VC resulted in an increase in both dry weight and N leaching, which was probably because of the high ratio of inorganic N to total N in these fertilizers. Application of imported fertilizers (I1 and I2) resulted in a lower dry weight of plants but reduced N leaching. The poor crop response to the fertilizer, V4, and low level of N leaching from the soil in this treatment indicate N immobilization.

Finally, the effect of domestic "organic fertilizers" on crop yield was not in accordance with their price, which might be decided by the adjustment of the N and P content of the fertilizers. V6, V2, and VC were categorized as lower priced and had a lower concentrations of total N and total P but their application was effective on plant growth. Meanwhile, V4 was the most expensive domestic "organic fertilizer" with higher concentrations of total N and total P, but was not effective on plant growth.

Table 3.5 Two-way analysis of variance (ANOVA) testing the effects of fertilizer type and nutritional supplementation on dry weight of plants.

Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Fertilizer type	153238.00	10	15323.80	9.32	4.7E-08	2.05
Nutritional supplementation	13825.79	1	13825.79	8.41	0.0058	4.06
Interaction	12841.96	10	1284.19	0.78	0.6463	2.05

Table 3.6 Two-way analysis of variance (ANOVA) testing the effects of fertilizer type and nutritional supplementation on N uptake.

Source of variation	SS	df	MS	F	P-value	F crit
Fertilizer type	155.23	9	17.25	6.14	$2 \cdot 10^{-5}$	2.12
Nutritional supplementation	17.67	1	17.67	6.29	0.016	4.08
Interaction	15.08	9	1.68	0.60	0.792	2.12

Table 3.7 Two-way analysis of variance (ANOVA) testing the effects of fertilizer type and nutritional supplementation on P uptake.

Source of variation	SS	df	MS	F	P-value	F crit
Fertilizer type	0.08	9	0.01	6.24	$18 \cdot 10^{-6}$	2.12
Nutritional supplementation	0.00	1	0.00	0.86	0.3601	4.08
Interaction	0.05	9	0.01	3.82	0.0015	2.12

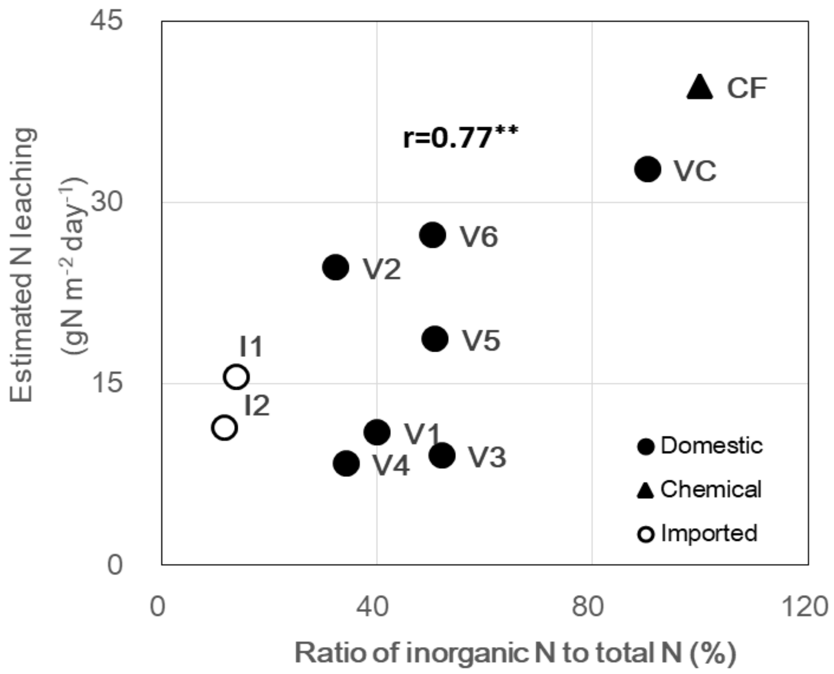

Fig. 3.6 Correlation between N leaching and ratio of inorganic N to total N in the fertilizers.

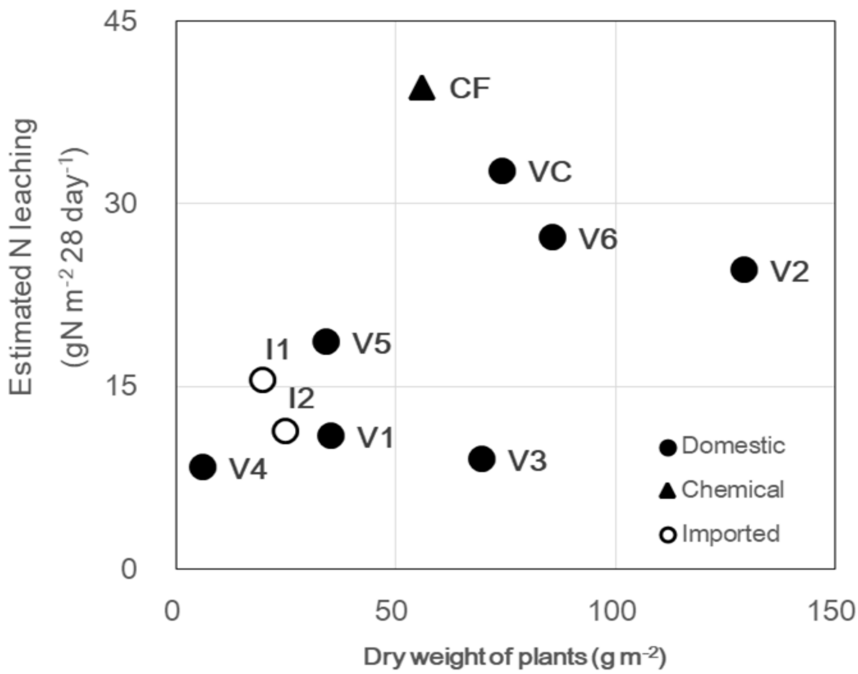

Fig. 3.7 Relationship between dry weight of plants and N leaching

Table 3.8 Dry weight and nutrient uptake of treatments.

Treatment	N-fertilizer						N-fertilizer + P, K					
	Dry weight ($g\ m^{-2}$)		Uptake ($mg\ kg^{-1}$)				Dry weight ($g\ m^{-2}$)		Uptake ($mg\ kg^{-1}$)			
			N		P				N		P	
V1	41.83	ab	2.60	b	0.03	ab	52.33	ab	2.64	ab	0.04	ab
V2	161.67	c	3.70	bc	0.13	c	174.83	b	5.33	b	0.11	b
V3	77.33	ab	4.61	c	0.21	d	86.17	ab	4.81	b	0.04	ab
V4	7.67	a	0.17	a	0.01	a	12.50	a	0.52	a	0.02	a
V5	37.50	ab	2.29	b	0.06	b	109.67	b	4.37	b	0.08	ab
V6	106.75	b	0.96	ab	0.07	b	191.50	b	4.44	b	0.11	b
VC	81.00	b	3.99	bc	0.09	b	119.17	b	5.15	b	0.06	ab
I1	24.83	ab	0.26	a	0.02	ab	69.50	ab	0.80	a	0.04	ab
I2	30.33	ab	0.37	ab	0.03	ab	69.67	ab	1.07	ab	0.05	ab
Chemical	69.83	ab	1.63	ab	0.05	ab	71.83	ab	2.29	ab	0.05	ab
Control	9.50	a	0.07	a	0.01	a						

Different letters within a column indicate difference among treatments at the 0.05 level.

3.4 Conclusions and Implications

Various fertilizers labeled as “organic fertilizer” are sold in Vietnam’s markets; however, with their manufacture being poorly regulated, their quality has not yet been fully explored. My study clarified the nutrient composition of these fertilizers and elucidated their effects on plant growth and leaching loss of N from soil. Domestic products greatly varied in nutrient contents and most of them contained a noticeably high proportion of inorganic N. In poor-quality sandy soil, the application of these fertilizers constituted a threat to groundwater quality because of N leaching. To clearly explain the marked difference in “organic fertilizers” we investigated the production of a typical “organic fertilizer”. This helped to confirm that the addition of chemical materials is typically the final step in the production process for organic waste-based compost. No regulations on the raw material and the manufacturing process of organic fertilizer and an insufficient understanding of organic waste-based fertilizers are considered to be the main reasons for this situation.

These findings pose two important recommendations. First, it is necessary to build quality criteria guidelines for organic fertilizers in Vietnam. In developed countries, the criteria usually not only include nutrient levels and properties of compost, but also thresholds for pathogens and heavy metals. The operators of composting sites are cautious about accepting feed materials for composting process that will ensure that the finished compost product will meet requirements. They also give indicators to assess compost maturity level [33]. Second, the following issues regarding compost need to be evaluated and farmers, organic fertilizer companies, and related managers should be cautioned. N and P are the most controlled factors of plant growth, but the quality of compost does not depend on only their content. The addition of chemical substances to enhance the nutrient content in commercial products of so-called organic fertilizers need to be considered because of both agronomic effectiveness and environmental aspects. Application of immature compost fixes N in the soil and restricts plant growth and thus compost must be mature before applying.

This research provides useful information on the status of so-called organic fertilizers in Vietnam’s markets. However, the work has a number of limitations that need to be addressed by further study. Firstly, the collected sample quantity should be greater. Secondly, investigation of the flow of raw materials and production method of compost must be taken into account in various products that were made from different materials. Finally, in order to fully evaluate the effects of "organic fertilizers" on plant growth and nutrient leaching, more cultivation experiments need to be conducted.

Supplementary materials

Incubation experiment

I performed incubation experiments to analyze the N mineralization rate of the fertilizers. We added 80 g sandy-textured soil containing the fertilizers at a rate of 109.4 mg N kg^{-1} soil into 150-cm^3 glass bottles. The soil water content was adjusted to 50% MWHC. The bottles were placed in a completely dark room at 25°C for 20 d. Triplicate samples were removed to determine changes in the inorganic N after 0, 10, and 20 d. Mineralization rates were calculated from changes in the mineral forms of N during the incubation. Table 3.1 presents pH and nutrients content of soil used in incubation experiment.

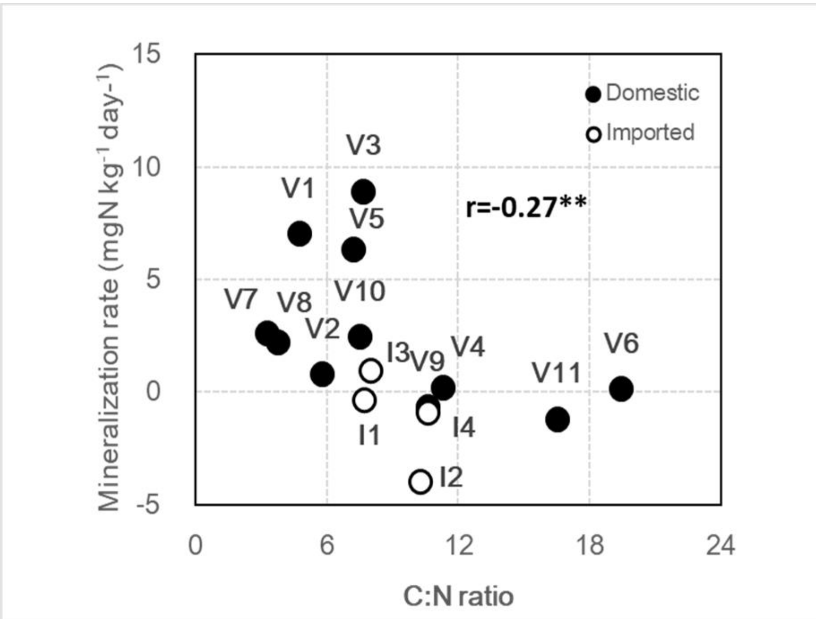

Fig. 3.8 Correlation between N mineralization rate and C:N ratio of the "organic fertilizers".

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CHAPTER 4. RAPID ON-FARM COMPOSTING OF COFFEE BY-PRODUCTS AND ITS USE AS A FERTILIZER

Abstract

Being the second largest coffee-producing country worldwide, Vietnam is estimated to annually generate approximately 1 million m^3 of coffee pulp (coffee by-products of wet processing). A simple method of rapid on-farm composting is the need of the hour to establish a system for recycling organic waste for sustainable agriculture in Vietnam. Five on-farm small-scale composting trials of coffee pulp were performed to examine the feasibility of the composting process with bulking agent under different aerobic conditions. After 2 months of composting, samples were collected for analysis and a cultivation experiment was conducted to clarify the effectiveness of the composts. Komatsuna (*Brassica rapa* var. *perviridis*) cultured in sandy soil and andosol soil. The total C, N, and K contents of the composts were in the range of 340.35-386.02 g kg^{-1}, 23.80-36.70 g kg^{-1}, and 18.86-25.13 g kg^{-1}, respectively. In the compost where wood chips were used as the bulking agent under air flow, exhibited a concentration of inorganic N that was significantly higher than that of the other composts. This indicates that the most important factor influencing the composting process is the control of aeration with wood chips and air flow. The plant biomass corresponding to the composts showed similarity with chemical fertilizers. Furthermore, the P content and the plants produced by the compost in which chicken manure was added, were investigated. The results obtained clearly indicate that the addition of P-sources as manure in the manufacturing process enhanced the fertilizing efficiency of the compost. The study demonstrated a practical composting method to recycle coffee pulp, contributing to inhibit pollution and support sustainable agriculture in the country.

Key words Biomass, coffee pulp, inorganic N, on-farm composting, P-source, simple aeration.

4.1 Introduction

Coffee is said to be the second most traded commodity in the world after petroleum, signifying its importance to the global economy. More than 2.3 billion cups of coffee are daily consumed in the world. Most consumption takes place in industrialized countries, while over 90% of coffee production occurs in developing countries. Vietnam is the second largest coffee producing nation worldwide, accounting for approximately 20% of the world coffee production. The coffee production averaged 1.5 million metric tons from 2013 to 2017, of which Central Highland contributed 90% (Stephen et al. 2014; GAIN report 2015; GAIN report 2017; Statistics Portal 2018). The coffee production of beans generates an enormous amount of organic waste, ranging from 30% to 50% of the weight of the total coffee produced, depending on the type of processing (Leandro S. Oliveira and Adriana S. Franca 2015; Genet Getachew and Deriba Muleta 2016). Thus, an amount of coffee by-products in range of 0.40-0.67 million tons is estimated to annually generate in the area. Instead of being effectively utilized in the form of recycling resources, most of the waste is discarded, causing serious environmental pollution even though it contains essential macronutrients in high concentrations.

Composting was defined a feasible solution for the adequate handling coffee by-product problem (Fekadu et al. 2014; Genet Getachew and Deriba Muleta 2017; Leandro S. Oliveira and Adriana S. Franca 2015; Nguyen et al 2013). In Central Highlands of Vietnam, Nguyen et al (2013) demonstrated an anaerobic composting of coffee husk generated from dry method. They mixed the husk with 10% cow manure (w/w), 2% lime (w/w), 0.5% urea (w/w) water to reached 60% humidity of the mixture, then supplemented 0.1% effective microorganisms. However, the proposed method took 3 months and it might be not an easy-to-manage method to farmers. Additionally, there was a shift from the dry to wet coffee processing, leading to the change of the type and volume of wastes which were generated during the production of beans. It has been reported that wet mills, on average, released 20.69% bean, 18.58% water and 60.74% solid waste (Mihret D Ulsido and Meng Li 2016). My recently survey revealed that wet coffee processing is mainly employing in the area at present, and a medium-scale factory with working capacity of 150 tons per day generated approximately 100 m^3 of coffee pulp. In other word, a rough estimate of the annual generation is 1 million m^3 of the pulp. This large volume of organic waste is mainly generated during the months of the harvesting season (October, November and December). In addition, it is difficult to store this material because of its high moisture content.

On the other hand, for a long time, farmer have mainly used chemical fertilizers instead of organic fertilizers, resulting in soil degradation. My previous study reported that the production of organic waste-based fertilizers has not sufficiently regulated in Vietnam. Most domestic products labeled as "organic fertilizer" contained remarkably high ratio of inorganic N to total N arising from the addition of chemical substances before packaging. The application of these organic fertilizers resulted in significantly higher N leaching than that by application of genuine organic fertilizers (Hoang Thi Quynh and Shima Kazuto 2018).

Therefore, a simple method of rapid on-farm composting which then can transfer to farmers is the need of the hour to establish a system for recycling organic waste for sustainable agriculture in the area. Specifically, this study investigated the following aspects: first, to examine practicability of a simple method of an aeration composting of coffee pulp using air flow and wood chips with adding chicken manure; and second, to evaluate the effect of finished composts on plant cultured in different soil types.

4.2 Materials and Methods

4.2.1 Coffee by-products and bulking agent

I collected coffee pulp (by-products of wet processing) from a processing company, coffee husk (by-products of dry processing) from the Hope Land Farm in Lam Dong province of Central Highlands, Vietnam. Table 4.1 presents moisture content and nutrient content of the materials. Wood chips, a by-products of wood processing company in the area, were used as the bulking agent.

4.2.2 Composting facilities

I performed an aerated composting experiment with five treatments in field under the local environment condition in Lam Dong province. Air were forced up through holes perforated on two open-ended parallel PVC piles (Ø 50 mm) laid at the base. The piles were covered by wood chips to prevent blockage of the holes, and connected to a blower with 40 cm^3 min^{-1}. Ventilation was provided by intermittent aeration of 15 minutes on/45 minutes off. The temperature within the compost piles were recorded by thermocouples which were horizontally placed at the top, middle and bottom of the compost piles. Another thermocouple was set up outside to measure the ambient temperature. However, temperature data were not available in this work due to sudden power failure.

Figure 4.1 shows a schematic diagram of the composting system. Table 4.2 presents materials and conditions of composting trials. Coffee pulp used in this work had high moisture content, suggesting the requirement for drying of material to gain to initial optimum moisture content. I sun-dried the material for 1 day before beginning experiment. And, mixing the pulp with wood chips is expected to allow a more suitable moisture content and air-filled porosity across the composting piles. For T5, coffee husk of dry method that had low moisture content was used instead of wood chips.

Table 4.1 Moisture content (%) and nutrient content (g kg^{-1}) of the materials.

	Coffee pulp （wet processing）	Coffee husk （dry processing）
Moisture content	303.3	13.1
Total C	423.20	470.84
Total N	32.80	16.85
C: N ratio	12.90	27.94
Total P	0.70	0.84
Total K	9.71	23.76
Total Mg	0.41	5.83
Total Ca	1.55	1.25

4.2.3 Sampling and analysis

After 2 months composting, triplicate samples were taken. I separated wood chips in the field and then brought collected samples to Okayama University (Japan) to analyze properties of finished composts and to conduct a cultivation experiment. In laboratory, the composts passed through a testing sieve 4.0 mm. pH were measured using a pH electrode (1:5 fresh sample: water, w/v). In the organic form (NH_4^+, NO_3^-), N was extracted using 2 mol L^{-1} KCl, and concentrations of NH_4^+ and NO_3^- were measured using the phenate method and vanadium (III) chloride reduction method, respectively, using a spectrophotometer (UV-1200, Shimadzu, Japan) (M. R. Carter and E. G. Gregorich 2007; Timothy A. Doane and William R. Horwath 2003).

The samples were also dried in an oven at 105°C for 24 h to measure moisture content, and stored for further analysis. The total C and N were determined using a CN-analyzer (CN Corder MT-700; Yanaco, Japan). The remaining total nutrient content were assessed by wet digestion with HNO_3 and perchloric acid. Available P (Truog P) was extracted using 0.002 N H_2SO_4. Exchangeable cations were extracted using 1 N NH_4OAc. The total P and Truog P contents were determined using the ascorbic acid sulfomolybdo-phosphate blue color method (Kim 1996). The total and exchangeable cations of K, Ca and Mg were measured using the atomic absorption spectrophotometry.

4.2.4 Cultivation experiment

I cultivated Japanese Komatsuna (*Brassica rapa var. perviridis*) in 1/5000a Wagner pots (surface area: 200 cm2, height: 20 cm) in a greenhouse using an automatic watering apparatus for 42 days. The design was completely randomized, with three replicates per sample, using five finished composts, chemical inorganic fertilizer, and control (only soil). The following two soil type treatments were used: sandy soil (Arenosols) and andosol soil. These are major soil groups in Vietnam. The former is poor fertility and commonly found in coastal areas of Central Vietnam. The latter is more fertile and found in volcanic area which is historically related to Central Highlands, Vietnam (Vu Tan Phuong 2007; Pham Quang Ha 2010; Tran Minh Tien 2015). The soil was first passed through a 2-mm sieve. Further, 2.2 kg of the graded soil was placed in planting containers, followed by 1 kg of the graded soil into which the fertilizer was mixed. Table 4.3 presents pH value and nutrient content of the soil used in this experiment.

The fertilizer were applied at a rate of 600 mg N per pot (equivalent to 300 kg N ha^{-1}). I calculated the total P content contributed by the composts and supplemented these with P as super phosphate to bring the P content to 410 mg per container. Twelve seeds of Komatsuna were sown in each pot. One week after germination, the seedlings were thinned to a density of eight seedlings per pot. Plant samples were taken at harvest (42 days after sowing). The plant biomass (dry weight) in each pot was measured. Collected samples were dried in an oven at 105°C for 24 h, ground, and stored for further analysis in laboratory.

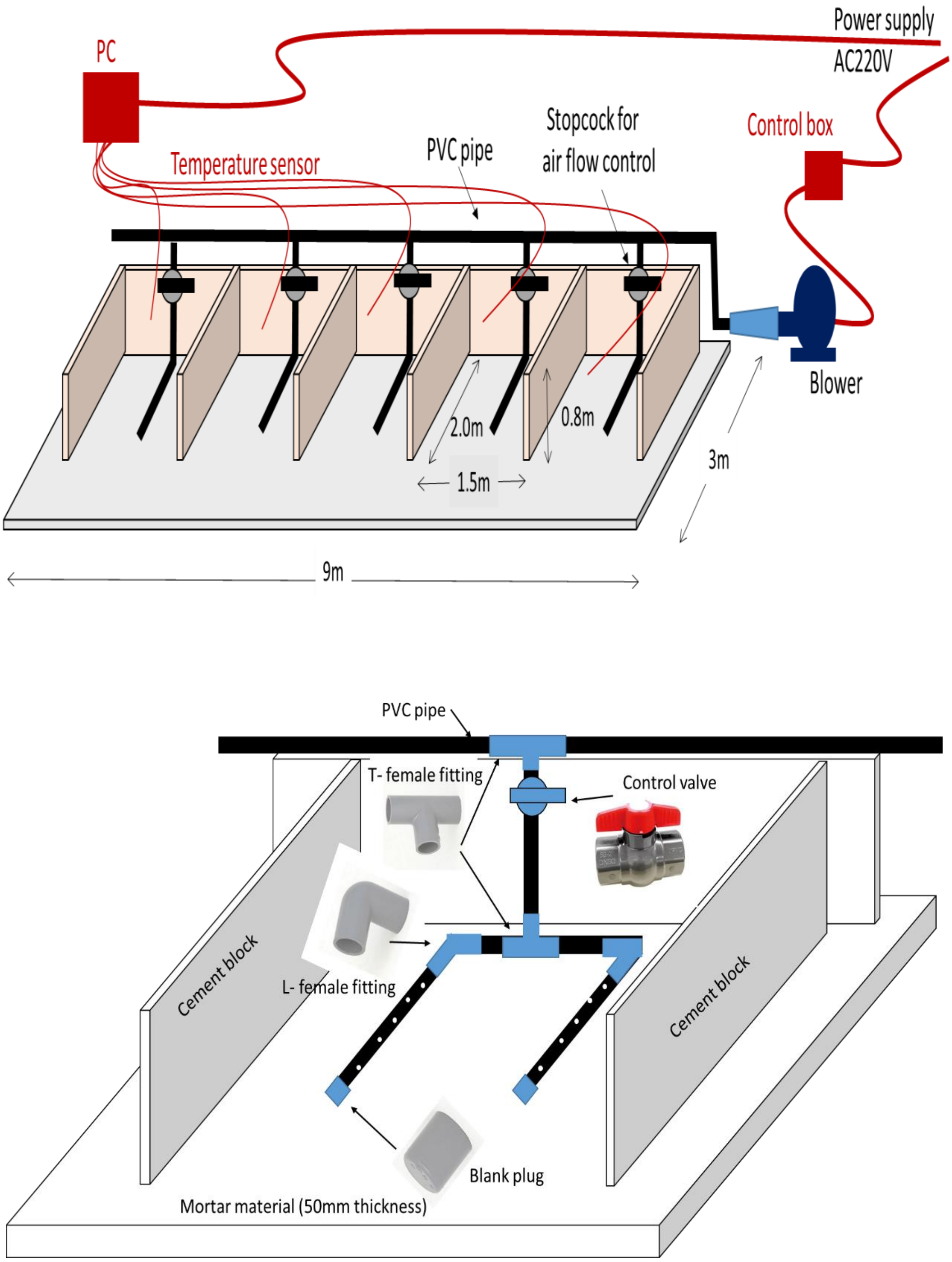

Fig. 4.1 Schematic diagram of the composting system.

Table 4.2 Materials and conditions of composting trials.

	T1	T2	T3	T4	T5
Coffee by-products	pulp	pulp	pulp	pulp	pulp+husk
Air flow	○	○	×	○	○
Wood chips	×	○	○	×	×
(volume ratio: husk/wood=1/5)					
Added P-source	×	×	×	○	×
(chicken manure)					

Note: ○: include, ×: not include.

Table 4.3 pH and nutrient content of soils used in the cultivation experiment.

	Sandy soil	Andosol soil
pH (H_2O)	8.99±0.17	8.223±0.16
Total N (g kg^{-1})	<0.001	2.667±0.16
Total C (g kg^{-1})	<0.001	40.313±1.88
Total P (g kg^{-1})	0.01±0.00	0.088±0.02
Total K (g kg^{-1})	2.26±0.04	1.294±0.14
Total Mg (g kg^{-1})	1.72±0.00	1.369±0.19
Total Ca (g kg^{-1})	3.24±0.10	7.788±0.93

Note: Means are means ± SD (n=3).

4.3 Results

4.3.1 Physicochemical properties of finished composts

The moisture data in this study is expressed on a dry weight basis which emphasizes on the changes of mass of water compared to initial dry mass of solid. Figures 4.2 shows moisture content of finished composts after 2 months composting. Moisture content of compost of T1 was significantly higher than that of T2, indicating the effectiveness of wood chips to improve ventilation condition. There was no significant difference in moisture content of composts between T2 and T3, implying that air flow did not affected on change of moisture content.

Nutrient content of composts under the composting treatments were shown in Table 4.4. The composts were rich organic material, nitrogen and potassium. The total C, N and K contents were in the range of 340.35-386.02, 23.80-36.70, and 18.86-25.13 g kg^{-1}, respectively.

The inorganic N concentration and P content of the composts were significantly affected by composting trials (Fig. 4.3, Fig. 4.4). The order of the inorganic N concentration was as follows: T2 > T4> T1 = T3 = T5. It indicates the effectiveness of air flow and wood chips in composting process. Furthermore, the total P and Truog P of T4 compost were significantly higher than those of remaining treatments, indicating that higher fertilizing efficiency was obtained with added P-source as manure.

4.3.2 Effects of the composts application on plant growth

The dry weight of plants were significantly influenced by the soil types and applied fertilizers (Table 4.5, Fig. 4.5). In general, the plant biomass of using the composts was found to be equivalent to that of chemical fertilizer, and their values were significantly greater with the corresponding control. In sandy soil, the order of plant biomass under treatments as follows: T1 = T2 = T3 = T4 = Chemical > T5 > Control. In andosol soil, the biomass decreased in the following order: T1 = T4 > T2 = T3 > T5 = Chemical > Control. In short, finished composts of T1 and T4 was found to be most effective to plant.

Table 4.4 pH and nutrient content of finished composts influenced by composting trials.

Composting trials	T1	T2	T3	T4	T5
pH (H_2O)	8.56	8.41	8.34	8.07	7.49
Total C (g kg^{-1})	386.02	340.35	364.16	344.61	369.79
Total N (g kg^{-1})	36.70	33.30	34.40	33.40	23.80
C: N ratio	10.52	10.21	10.58	10.31	15.56
NH_4^+-N (g kg^{-1})	0.11	0.22	0.12	0.15	0.09
NO_3^--N (g kg^{-1})	0.12	0.10	0.13	0.13	0.18
Total P (g kg^{-1})	0.65	0.57	0.67	1.53	0.63
Truog P (g kg^{-1})	0.21	0.21	0.24	0.81	0.32
K (g kg^{-1})	19.86	19.40	18.86	20.40	25.13
Mg (g kg^{-1})	3.07	2.90	3.06	3.67	2.14
Ca (g kg^{-1})	15.83	15.56	14.12	15.15	16.48
Exch K^+ (cmol kg^{-1})	17.58	24.51	17.05	24.67	34.88
Exch Mg^{2+} (cmol kg^{-1})	7.78	6.89	6.84	8.18	5.90
Exch Ca^{2+} (cmol kg^{-1})	21.27	18.41	19.87	20.04	15.53

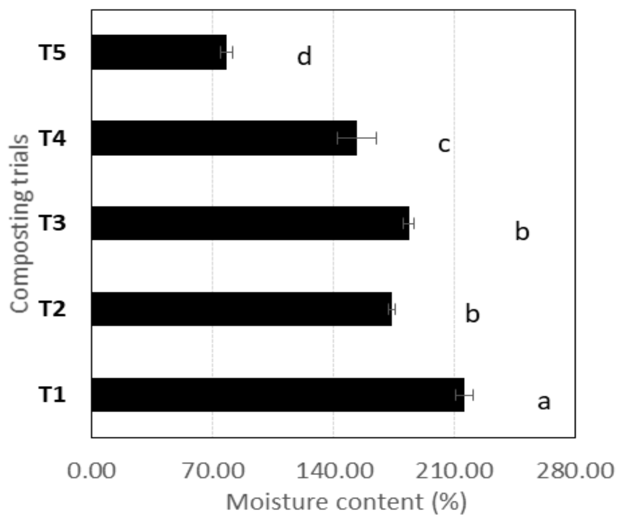

Fig. 4.2 Moisture content of finished composts influenced by composting trials.

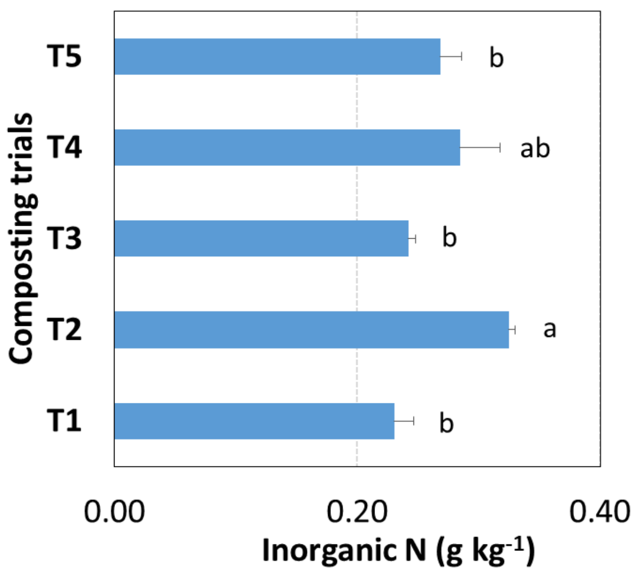

Fig. 4.3 Inorganic N of finished composts influenced by composting trials.

Note: Bars presents standard deviation of the mean (n=3). Different letters indicate significant differences (P<0.05).

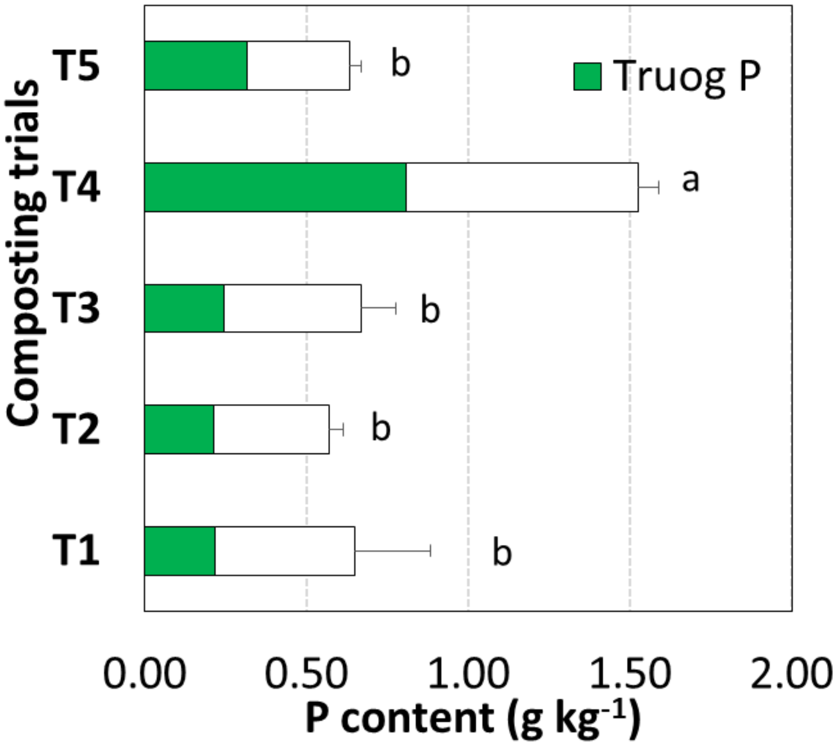

Fig. 4.4 P content of finished compost influenced by composting trials.

Note: Bars presents standard deviation of the mean (n=3). Different letters indicate significant differences (P<0.05).

Table 4.5 Two-way analysis of variance testing the effects of soil types and applied fertilizers on dry weight of plants.

Source of variation	SS	df	MS	F	P-value	F crit
Applied fertilizers	20292.976	6	3382.163	6.059	0.00036961	2.445
Soil types	10880.381	1	10880.381	19.491	0.00013696	4.196
Interaction	7221.619	6	1203.603	2.156	0.07803265	2.445
Within	15630.000	28	558.214			
Total	54024.976	41				

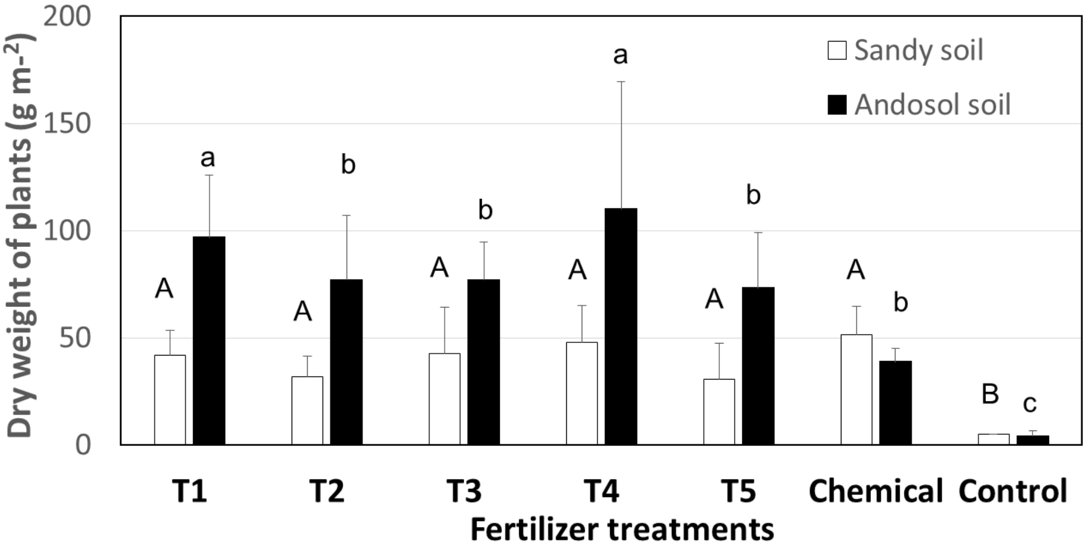

Fig. 4.5 Plant biomass influenced by the fertilizer treatments and soil types.

Note: Bars presents standard deviation of the mean (n=3). Different letters indicate significant differences ($P<0.05$).

4.4 Discussion

4.4.1 Quality of finished composts

The application of immature compost fixes N in the soil and restricts plant growth by competing for oxygen in the rhizosphere and releasing toxic substances. Thus, a number of methods to test compost stability have been proposed, including physical analyses, chemical analyses, microbiological assays, plant assays and spectroscopy analyses. Most compost quality standards require a C: N ratio test; the preferred range in C: N ratio < 15:1 is recommended for finished composts (S. Kuo et al. 2004; M. P. Bernal et al. 2009; Olufunke Cofie et al. 2016). In this study, chemical analyses with focusing on the measurement of C: N ratio, NO_3-N and NH_4-N were employed to assess compost maturity and then, a cultivation was conducted to evaluate efficacy of using finished composts.

The wood chips properly help to achieve better performance for composting. Mixing the pulp with wood chips allows a more suitable moisture content, increase C: N ratio and air-filled porosity across the composting piles. In general, initial C: N ratio of 25-30 are considered ideal for composting (S. Kuo et al. 2004; Rui Guo 2012). The ratio of coffee pulp used in this study was approximately 12.90 (Table 4.1), lower than optimum value. After composting, moisture content of compost under T1 was significantly higher than that of T2 (Fig 4.2), explaining the effectiveness of wood chips to improve ventilation condition. C: N ratio of composts of T1-T4 was in range of 10.21-10.58, indicating proper mature composts. The ratio of T5 was higher due to higher the initial ratio of coffee husk from dry process, but it is consider as "acceptable" value (Table 4.4).

During composting, the mineralization of organic nitrogen resulting in an increase of inorganic N (NH_4^+, NO_3^-). The concentration of inorganic N of finished compost of T2 was significantly higher than that of other remaining treatments (Fig. 4.3), indicating the effectiveness of aeration condition in this treatment. Compost with NH_4-N to NO_3-N ratio in the range of 0.16 and 2 is reported to be acceptable for land application (Olufunke Cofie et al. 2016). The composts in this study met this requirement with the ratio in the range of 0.5 to 2 (Table 4.4).

The results from cultivation experiment indicated the agronomical efficiency of using the finished composts to plant. Total plant biomass produced by the composts was higher than that of the control and comparable to chemical fertilizer. The plant biomass corresponding to composts of T1 and T4 is highest even inorganic N concentration of finished compost was highest in T2. It might be attributed to mineralization rate of compost in soil and the high value of available P in finished compost of T4. More experiments are required to clarify this point.

4.4.2 Applicability in Vietnam

Composting offers several benefits in developing countries because it is a relatively simple, inexpensive alternative to reduce biodegradable waste and to meet demand for fertilizer using in agriculture. However, famers here is not making the best use of organic recycling opportunities available to them due to absence of efficient expeditious technology, intense labor. In Central Highlands, Vietnam, farmers need an on-farm rapid composting method to recycle coffee by-products of wet method. To meet that demand, this work studied feasibility of aerated static pile technique. It was reported that the method is commonly used for treatment of municipal sewage sludge, and there is little experience using "aerated static piles" with agricultural wastes (Thanh Binh Nguyen and Kazuto Shima 2018; FAO 218). This study showed its practicability for treatment of coffee pulp. No turning of the materials happened once the pile was formed and aeration was provided by using blower and wood chips, helping to withdraw manual labor during making compost. Evaluation quality of finished composts indicated effectiveness of using the compost as a soil fertilizer.

The replications were not included in separated composting piles within the same condition; therefore, I could not precisely evaluate the effectiveness of different composting piles. However, this work provides a valuable information on efficacy of different composting treatments for coffee pulp and its finished compost quality, supporting for the further work on recycling coffee by-products to a genuine organic fertilizer in Central Highlands, Vietnam.

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CHAPTER 5. IMPLICATIONS AND FURTHER WORK

In order to establish a recycling system of organic wastes for sustainable agriculture in Vietnam, it is necessary to assess the current status of so-called organic fertilizers in the markets and to propose an applicable composting technique and an effective use of compost.

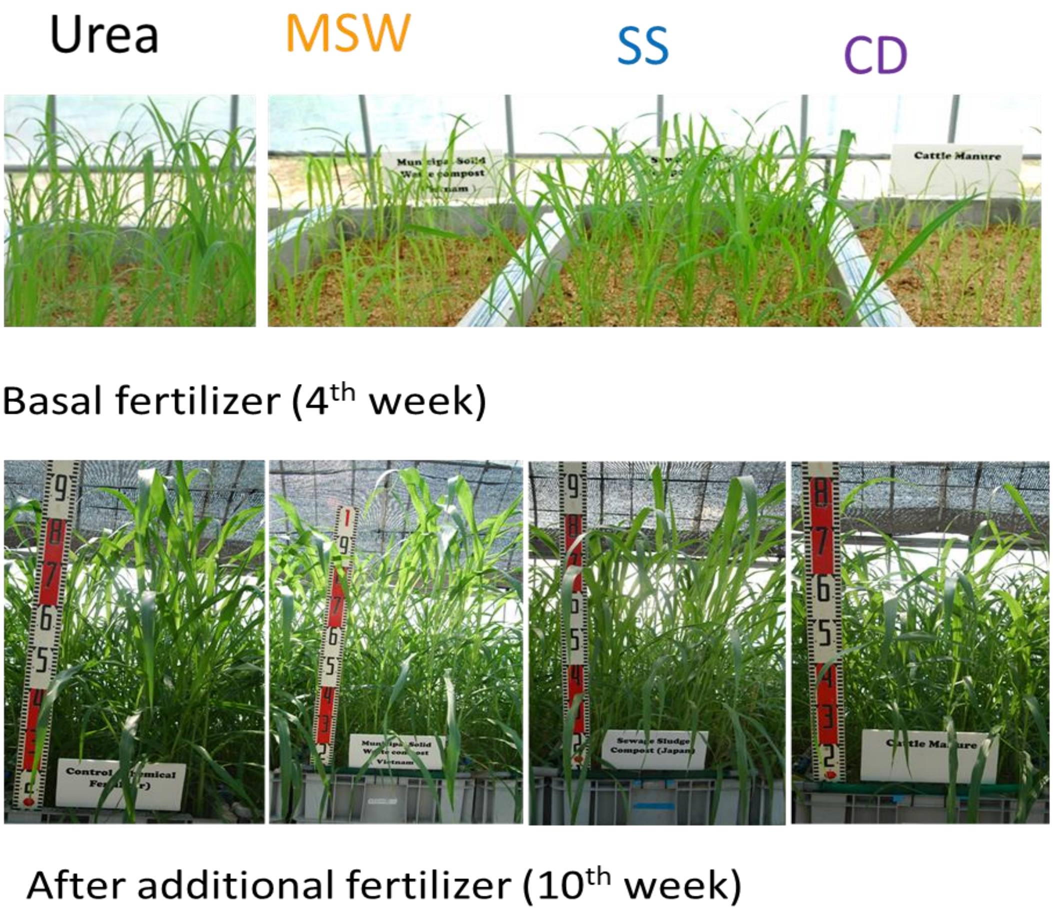
Firstly, the study clarified nutrient composition of these fertilizers and elucidated their effects on plant growth and N leaching from soil. Domestic products of the fertilizers greatly varied in nutrient content and most of them contained a noticeably high proportion of inorganic N to total N. In poor-quality sandy soil, the application of these fertilizers constituted a threat to water quality because of N leaching. Being poorly regulated on the raw material and the manufacturing process of organic fertilizers are considered the main reasons for this situation. It suggested the need for quality criteria guideline of organic fertilizers that underline not only nutrient levels, but also the control of their raw materials and the manufacturing process.

Secondly, the study performed a simple method of on-farm rapid composting to recycle coffee by-products from wet processing. Aerated composting using air flow, wood chips, and added P as manure might be a feasible technique to obtain a high-quality organic fertilizer. Self-make compost indicated the majority of compost N is organic form, requiring to enhance availability of compost N to plant.

Thirdly, the study showed that when applying compost in concert with urea, most of urea-N was lost via leaching but it helped to improve N mineralization of compost. The finding suggested that a combined application of compost and urea with lower amount of applied urea helps to extend the benefits. Further field experiments are require to evaluate the effectiveness of this method.

APPENDIX

Sudan grass was planted in the containers



Visible response of the grass to fertilizer treatments

Collected samples of so-called organic fertilizers in Vietnam’s markets

A view of pot cultivation experiments

1 week ater sowing 4 weeks after sowing

Visible response of Komatsuna to fertilizer treatments

Sampling of pot cultivation experiments


Coffee plantation in Lam Dong province, Vietnam



A factory made "organic fertilizer" from coffee by-products in Lam Dong province, Vietnam.

Making compost from coffee by-products at Hope Land Vietnam farm in Lam Dong province, Vietnam.