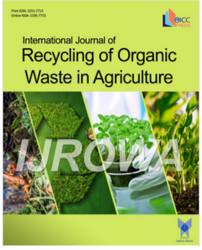

Special Issue (2024), S07 (1-10)

International Journal of Recycling Organic Waste
in Agriculture (IJROWA), Special Issue

https://dx.doi.org/10.57647/ijrowa-tgma-wb03

Assessing the environmental performance of vermicompost from spent coffee grounds based on a life cycle approach

Bhanupong Phrommarat[1,*], Pongsri Paopuree[2]

[1] *Program in Biology, Faculty of Education, Chiang Rai Rajabhat University, Chiang Rai, Thailand.*
[2] *Department of Environmental Science, Faculty of Science, Silpakorn University, Nakhon Pathom, Thailand.*

[*] **Corresponding author:** bhanupong.phr@crru.ac.th

Original Research

Received:
25 October 2023
Revised:
18 April 2024
Accepted:
9 July 2024

Abstract:

Purpose: This study investigated the physicochemical properties of vermicompost from spent coffee grounds (SCG) and assessed its environmental performance using Life Cycle Assessment (LCA). Additionally, the environmental performance of vermicompost was compared to other waste treatment and utilization scenarios.
Method: Two treatments of compost and vermicompost were produced from SCG and solid cow manure (SCM) with three replicates per treatment. *Eudrillus eugeniae* earthworms were used for vermicomposting. The physicochemical characteristics measured included pH, EC, TOM, TOC, TKN, TP, and TK. Statistical analysis was conducted using mean, SD, ANOVA, and Tukey's test. The comparison of the environmental performance of vermicompost and alternative scenarios (compost from SCG and SCM, SCG as soil amendment, and SCG as waste) was assessed through LCA.
Results: Compost and vermicompost contained higher macronutrient contents than SCG. The LCA results revealed that vermicompost produced from SCG and SCM had significant environmental benefits by reducing the reliance on mineral N fertilizers and fishmeal in animal feed production, a 116% reduction in GWP100 compared with disposing in a landfill. A scenario analysis highlighted that disposing of SCG in a landfill had the highest impact on GWP100, while the baseline scenario demonstrated the most notable environmental benefit. In contrast, the baseline scenario exhibited the highest impact on EP, primarily due to NH_3 emissions resulting from organic fertilizers. This underscores the need for effective management practices to mitigate the contribution of NH_3 to eutrophication.
Conclusion: Vermicomposting showed significant potential in reducing organic waste, specifically SCG. According to LCA, it displayed a relatively low environmental impact across various impact categories, primarily due to the substitution of N fertilizers and fish meal.

Keywords: Vermicompost; *Eudrillus eugeniae*; Spent coffee grounds (SCG); Life cycle assessment (LCA); Waste utilization

1. Introduction

Coffee is one of the most popular beverages worldwide and is consumed by people of all ages and backgrounds. While approximately 10 million tons of coffee were globally consumed in 2020/2021, only 30% coffee bean's mass can be extracted into the beverage (Johnson et al., 2022). Consequently, a large quantity of the leftover remnants of coffee beans or spent coffee grounds (SCG) is simultaneously generated. Most SCG is typically treated as general waste and disposed of in landfills or sewage systems, posing environmental concerns related to the potential release of toxic substances such as caffeine, tannins, and polyphenols as well as the decomposition of biodegradable organic matter and the generation of methane (Low et al., 2015; Franca and Oliveira, 2022).

Recently, there has been increasing interest in discovering alternative uses for spent coffee grounds to mitigate their environmental impacts. For example, they can be harnessed as an alternative energy source, including the production of pelletized biofuels, biodiesel, and biogas (Battista et al., 2020; Chen and Chen, 2021). In terms of resource recovery and recycling, SCG can be recycled and used in various ways. They have potential applications as soil amendments for improving soil quality and enhancing plant growth (Hirooka et al., 2021). Biochar produced from SCG has a wide range of possible applications, such as soil improvement, soil carbon sequestration, and pollutant removal (Vardon et al., 2013; Hagemann et al., 2018). In addition, SCG contains fundamental nutrients for plants, including nitrogen, phosphorus, and potassium, thereby conferring notable benefits to plants when applied as organic fertilizer (Emmanuel et al., 2017; Cervera-Mata et al., 2023). However, constraints arise in the utilization of SCG, primarily associated with their toxicity, which is contingent upon the quantity employed. This challenge can be addressed by blending SCG with other waste materials and implementing treatments to remove toxic components such as tannins and caffeine or by using a suitable amount of SCG (Bomfim et al., 2023).

Among the various composting techniques available, vermicomposting is considered to be an environmentally sustainable method that employs earthworms as natural agents for the conversion of solid waste into vermicompost; this approach has been recognized as an effective bioprocess for pollution control (Lirikum et al., 2022). Vermicomposting represents a symbiotic relationship between microorganisms and earthworms. Microorganisms are responsible for the biochemical breakdown of organic waste materials, while earthworms process the decomposed material and influence biological activity, thereby accelerating the composting process (Singh et al., 2022). Several previous studies attempted to investigate different aspects of vermicompost produced from SCG, such as biological processes, physicochemical characteristics, combinations of composting components, and optimal conditions of related parameters (González-Moreno et al., 2020; Hanc et al., 2021). Although vermicomposting offers a sustainable way to manage waste coffee grounds, large-scale operations can experience unique challenges. SCG from different sources (homes, cafés, roasters) can vary significantly in composition, affecting worm health and compost quality. Thus, large-scale operations need a system to pre-treat and standardize the SCG (González-Moreno et al., 2020). Large-scale systems need strategies for breeding enough worms to handle the incoming volume of SCG. This might involve dedicated breeding beds and monitoring worm health indicators (Manaf et al., 2009). In addition, gathering large volumes of SCG from various sources can be challenging. Coordination with coffee shops, offices, and other establishments to collect and transport the grounds to the vermicomposting facility requires organization and planning. Establishing efficient collection routes and schedules is essential to ensure timely delivery of SCG to the composting site.

Although vermicomposting of SCG can provide a wide range of benefits to the environment, it is crucial to address potential negative impacts related to resource use, transportation, direct emissions, and contaminants to maximize the environmental benefits of this practice. Life cycle assessment (LCA), an environmental management tool, is extensively adopted to assess the environmental impacts of a product based on life cycle thinking, namely, raw material extraction, production processes, transportation, use, and disposal. One of the obvious benefits of LCA is that it is able to quantitatively evaluate the potential environmental impacts of a product system by compiling an inventory of relevant inputs and outputs. LCA was used in multiple studies to assess the environmental impacts of different biowaste treatment technologies. Some of them applied LCA to analyze biowaste or green waste composting (Bong et al., 2017; Oliveira et al., 2017; Keng et al., 2020). Moreover, LCA studies associated with biofuel produced from organic waste were conducted (Florio et al., 2019; Shinde et al., 2021). In the context of LCA for vermicompost, Komakech et al. (2016) performed an assessment of the environmental impacts associated with vermicomposting animal manure compared with other alternative manure management systems using LCA. The results suggested that vermicomposting showed satisfactory performance in global warming and eutrophication potential impact when compared with the baseline system of dumping animal waste. Yet, there remains a scarcity of LCA studies examining vermicompost in comparison to alternative treatment technologies. The objectives of this study were to investigate the physicochemical properties of vermicompost from SCG and to assess the environmental performance of vermicompost using LCA. Furthermore, the environmental performance of vermicompost was assessed in comparison to alternative waste treatment or utilization scenarios, including landfill disposal, soil amendment, and compost.

2. Materials and methods

Raw material and earthworms

A mixture of SCG was collected from coffee shops located at Silpakorn University, Sanamchandra Palace campus, Nakhon Pathom Province, Thailand (13°49′07″N, 100°02′24″E). Two distinct coffee varieties, Arabica and Robusta beans, grown in Thailand in an approximate 1:1 ratio, were used in the mixture. Solid cow manure (SCM) used in the compost and vermicompost experiments was obtained from a dairy farm in the same province. The manure was sun-dried and chopped into small pieces. *Eudrilus eugeniae* earthworms, also known as African nightcrawlers, were used in this study. The earthworms belong to the epigeic group, residing in the surface layer of the soil, and are among the most commonly used for vermicomposting in tropical regions.

Experimental design (composting and vermicomposting)

The experimental setup for this study employed a randomized complete block design with three replicates conducted under controlled laboratory conditions. Plastic containers of size 50 × 30 × 30 cm with small drainage holes at the bottom were used. Two treatments were established: one for the composting of SCG and SCM as a control, and the other for the vermicomposting of SCG and SCM, with a 1:1 weight ratio. In each container, a total of two kilograms of the dry material combination was added. The duration of the experiment was 45 days, spanning from March to April 2023. For the vermicomposting treatment, the mixture was pre-composted for 14 days to prevent overheating during the thermophilic phase, which could harm the worms and expedite fertilizer production (Brontowiyono et al., 2022). Following this period, 30 g of adult earthworms (identified by the presence of a clitellum) were introduced into each of the three replicates of pre-compost containers. During the experiment, no additional material was supplied. Moisture content was maintained within the range of 60 – 80%, while the ambient room temperature ranged between 25 – 30 °C. At the end of the experimental period, a 100 g sample was taken from each container. These samples were subsequently dried and stored in a refrigerator at 4 °C. The earthworms were manually separated and weighed.

Physicochemical analyses of fertilizers

The samples (SCG, compost, and vermicompost) were analyzed for physicochemical properties including moisture content, electrical conductivity (EC), pH, total organic matter (TOM), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP) and total potassium (TK). The percentage of moisture content was determined by weight loss on drying in a hot air oven (Binder FD115) compared with the fresh weight of the sample. EC and pH were measured by a pH meter (Accumet AB150) and conductivity meter (Hanna HI9835), respectively. TOC was analyzed based on the Walkley and Black method (Walkley and Black, 1934). A conversion factor of 1.7241 is used to convert TOC to TOM (Nelson and Sommers, 1996). TN was determined based on the Kjeldhal method. The samples were digested by a mixture of K_2SO_4 and $CuSO_4$ in a ratio of 9:1 by volume. As for TP, the samples were digested by a mixture of concentrated HNO_3 and $HClO_4$ (1:1 by volume). Subsequently, TP was quantified by the molypdovanadate method (Horwitz and Latimer, 2005) with a measurement wavelength of 420 nm by a UV/VIS spectrophotometer (Jasco V-530). The flame photometric method (Horwitz, 2000) was used to identify TP. The samples were digested by concentrated HNO_3 and $HClO_4$ (1:1 by volume) and then analyzed by a flame photometer (Sherwood 410).

Statistical analysis

Statistical analysis was performed using the IBM Statistical Package for the Social Sciences (SPSS) software package. A one-way analysis of variance (ANOVA) was conducted to compare the means of parameter values across the treatments at a significance level of $\alpha = 0.05$. Tukey's HSD test was then used to identify which specific treatment groups differed significantly from each other.

LCA methodology

Environmental impact assessment of SCG utilization was conducted using life cycle assessment (LCA). An LCA framework based on ISO14040:2006 and ISO14044:2006 consists of four main phases: goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation of the results.

Goal and scope definitions

The main goal of this study was to investigate the environmental performance of vermicompost produced from SCG. In addition, three alternative scenarios of SCG utilization were compared. The functional unit in the analysis was one kilogram of SCG to produce a quantity of final treated outputs, including vermicompost, compost, soil amendment, and waste, in different scenarios. The system boundaries are illustrated in Figs. 1 and 2.

For the baseline scenario (BS), SCG and SCM were used for the vermicomposting process. SCG was assumed to be disposed of as general waste and treated in a landfill in SC1. SCG was directly applied to soil as a soil amendment in SC2. SCG and SCM were composted and used as organic fertilizers in SC3. The organic fertilizers and soil amendments (BC, SC2, and SC3) contain essential nutrients (N, P, and K) for plants that can potentially substitute synthetic fertilizers. After the vermicomposting process, the worms were assumed to be utilized in animal feed production as a protein source as a replacement for fishmeal. Waste generation and collection processes of SCG were excluded. Inventory analysis and impact assessment were modeled by OpenLCA software version 1.10 along with the LCI database, Ecoinvent 3.4, and Agribalyse 3.1 (only for fishmeal). The environmental impact assessment method adopted in the analysis was CML (baseline) v4.4, which focuses on 11 midpoint impact categories consisting of acidification (AP), climate change (GWP100), depletion

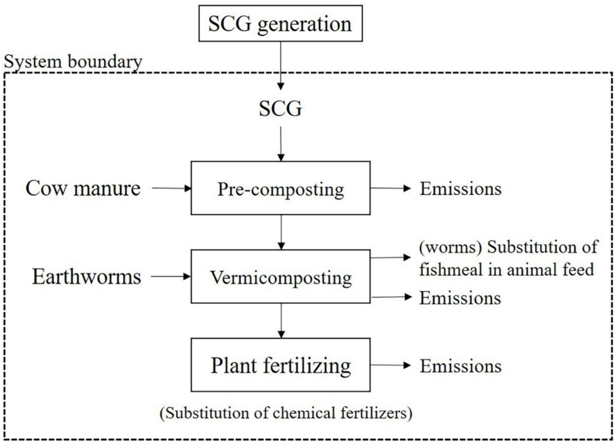

Figure 1. System boundary of SCG vermicomposting.

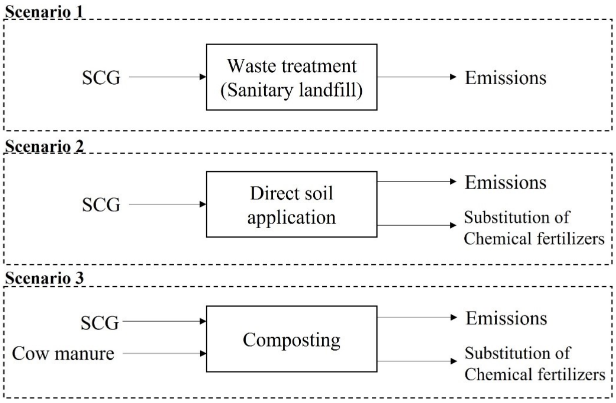

Figure 2. System boundaries of three alternative scenarios.

of abiotic resources – elements, ultimate reserves (ADP-e), depletion of abiotic resources – fossil fuels (ADP-f), eutrophication (EP), freshwater aquatic ecotoxicity (FAETP), marine aquatic ecotoxicity (MAETP), terrestrial ecotoxicity (TETP), human toxicity (HTP), ozone layer depletion (ODP) and photochemical oxidation (POCP). In the scenario analysis, the key environmental impacts relevant to fertilizer, GWP100, and EP, were considered among the scenarios. Allocation was conducted using the mass allocation approach.

Inventory

SCG was derived from a blend of coffee varieties commonly used in local coffee shops. SCM was obtained from an adjacent dairy farm that is located 5 km away from the study area. It was assumed that a vehicle used in transportation was a diesel-powered pickup truck. Environmental impacts associated with SCM (as a byproduct) were allocated based on mass, considering the management of the dairy herd and the production of cow milk as defined in the Ecoinvent database.

Organic fertilizers generated through various waste treatment processes contain nutrients capable of replacing industrial mineral fertilizers. The quantity of fertilizer replaced ($\text{Mass}_{\text{subs}}$) relies on the nutrient content in the organic fertilizer ($\text{Input}_{\text{nutr}}$) and the efficiency of substitution (Sub_{eff}), as suggested by Boldrin et al. (2009) and represented by equation (1). The substitution efficiency values for N, P, and K were 40%, 95%, and 100%, respectively (Boldrin et al., 2009). The environmental benefits or substitution credits, which resulted from avoiding the production of mineral fertilizers, were obtained from the Ecoinvent database.

$$\text{Mass}_{\text{subs}} = \text{Input}_{\text{nutr}} \times \text{Sub}_{\text{eff}} \tag{1}$$

After vermicomposting, the earthworms were assumed to be used in animal feed production as a substitute for fishmeal, resulting in avoided emissions. Therefore, avoided emissions from fishmeal were considered. Data on fishmeal production were derived from the Agribalyse 3.1 database embedded in the OpenLCA software. According to this database, fishmeal typically contains a protein content ranging from 63.0% to 65.0%, while the protein content in earthworms (*E. eugeniae*) ranges from 55.4% to 64.6% (Thongkheaw, 2010). In this study, an equal protein content in fishmeal and earthworms was assumed, resulting in a 1:1 substitution ratio.

Direct emissions, primarily carbon and nitrogen, occurred during composting and fertilizer utilization. In this study, it was assumed that the fertilizers were composted under aerobic conditions; thus, eliminating CH_4 emission during this process. Stable C is partially formed during the production of organic fertilizer and can be credited for avoiding CO_2 emissions in the product system (Favoino and Hogg, 2008). Nonetheless, the credit of stable C as a CO_2 sink was not considered in the current study due to its limited presence in warmer climates (Komakech et al., 2016). Regarding N emissions from fertilizer utilization, nitrous oxide (N_2O), nitrate (NO_3^-), and ammonia (NH_3) were taken into account. The emission factors related to N emissions were derived from the product environmental footprint (PEF) method (Zampori and Pant, 2019), as summarized in Table 1.

For scenario analysis, SCG was treated as household waste and transported to a sanitary landfill by a waste collecting truck in scenario 1. The assumed distance to the landfill was 30 km. In scenario 2, SGC was applied directly to the soil as a soil amendment. Scenario 3 involved the composting of SCG and SCM to produce organic fertilizer. The transportation of SCM followed the same pattern as in the baseline scenario, and associated direct emissions were considered in all scenarios as well as the nutrient substitution credit from mineral fertilizer. The acquisition of data analyzed in the inventory is presented in Table 2. An overview of inputs and outputs for each scenario is summarized in Table 3.

Table 1. Direct emission factors of organic fertilizer used in the life cycle inventory.

Emission	Compartment	Emission factor
N_2O	Air	22 gN_2O/kgN applied
NO_3^-	Water	440 gNO_3-/kgN applied
NH_3	Air	240 gNH_3/kgN applied

Table 2. Acquisition of data and sources.

Data	Source
Physicochemical characteristics of compost and vermicompost (SCG+SCM)	Experimental data
Increase of earthworm biomass after vermicomposting	Experimental data
Physicochemical characteristics of SGC (soil amendment)	Experimental data
Substitution efficiency of nutrients in organic fertilizers	Boldrin et al. (2009)
Direct emission of nitrogen	Zampori and Pant (2019)
Production of mineral fertilizers (N, P, K)	Ecoinvent 3.4 database
Production of fishmeal for animal feed	Agribalyse 3.1 database
Protein content in *E. eugeniae*	Thongkheaw (2010)
Transportation	Ecoinvent 3.4 database
Waste treatment by sanitary landfill	Ecoinvent 3.4 database

Table 3. Inputs and outputs in different SCG treatment scenarios.

Flow	Element	Unit	Baseline	SC1	SC2	SC3
Input	SCG	kg	1	1	1	1
	Solid cow manure (SCM)	kg	1	-	-	1
	Transport of SCM	kg*km	5	-	-	5
	Waste collecting and transport (21t lorry)	kg*km	-	30	-	-
	Earthworms (*E. eugeniae*)	g	30	-	-	-
Output	Organic fertilizer	kg	2	-	-	2
	Biowaste at landfill	kg	-	1	-	-
	Soil amendment	kg	-	-	1	-
	Earthworms (for animal feed)	g	57.7	-	-	-
	Nutrient content					
	- Nitrogen	g	46.6	-	10.5	42.7
	- Phosphorus	g	6.1	-	0.5	5.1
	- Potassium	g	7.7	-	0.8	6.8
	Direct emission from organic fertilizer					
	- N_2O (to air)	g	1.03	-	0.23	0.94
	- NO_3^- (to water)	g	20.50	-	4.64	18.77
	- NH_3 (to air)	g	11.18	-	2.53	10.24

3. Results and discussion

Physicochemical characteristics and earthworm biomass

Fig. 3 displays the initial substrates before and after treatment. The physicochemical characteristics of organic fertilizers produced from SCG are tabulated in Table 4. The results revealed that both compost and vermicompost, produced by combining SCG with SCM, showed distinct properties compared to SCG alone. Compost and vermicompost displayed pH-neutral or slightly alkaline conditions, contrasting with the acidic nature of SCG. The higher EC values in the compost and vermicompost indicated a higher concentration of nutrients and dissolved salts. Similar to %TOM, %TOC was lower in compost and vermicompost compared to SCG. The N, P, and K contents in vermicompost showed the highest values followed by compost and SCG. Specifically, for %TP, vermicompost displayed significantly higher levels than compost. Vermicomposting led to the highest proliferation of phosphate-solubilizing microorganisms and their solubilizing capacity, thereby enhancing phosphorus

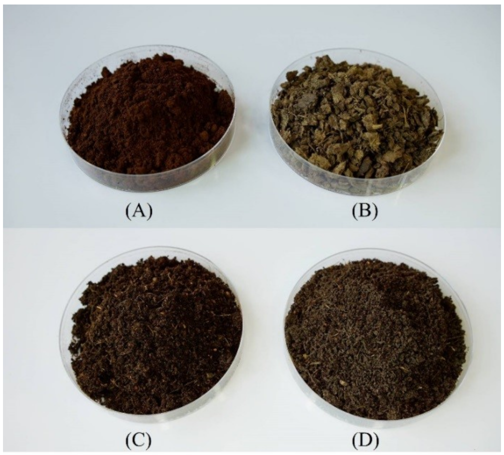

Figure 3. Initial substrates before and after treatment (A) spent coffee ground, (B) Dried solid cow manure, (C) compost, and (D) vermicompost.

Table 4. Physicochemical characteristics of organic fertilizers (mean ± SD).

Parameter	SCG	Compost (SCG+SCM)	Vermicompost (SCG+SCM)
Moisture content (%)	57.3 ± 1.2^a	59.4 ± 2.0^a	54.9 ± 2.8^a
pH	6.2 ± 0.3^a	7.3 ± 0.1^b	7.4 ± 0.1^b
EC (dS/m)	0.67 ± 0.12^a	1.37 ± 0.01^b	1.42 ± 0.03^b
%TOC	25.70 ± 3.55^a	14.61 ± 0.60^b	13.15 ± 1.71^b
%TOM	44.31 ± 6.12^a	25.20 ± 1.03^b	22.68 ± 2.95^b
%TKN	1.05 ± 0.17^a	2.13 ± 0.08^b	2.33 ± 0.05^b
%TP	0.05 ± 0.00^a	0.26 ± 0.02^b	0.31 ± 0.01^c
%TK	0.08 ± 0.01^a	0.34 ± 0.01^b	0.38 ± 0.03^b
C:N ratio	24.92 ± 4.84^a	6.86 ± 0.36^b	5.64 ± 0.70^b

EC = electrical conductivity; TOM = total organic matter; TOC = total organic carbon; TKN = total Kjeldahl nitrogen; TP = total phosphorus; TK = total potassium.
Different superscripted letters in each row indicate significant differences (one-way ANOVA; Tukey's test, $p \leq 0.05$).

availability in vermicompost. (Saha et al., 2010; Champarngam et al., 2013). The biomass of *E. eugeniae* increased by 92.3%, going from 30.0 ± 0.1 g to 57.7 ± 1.7 g by the end of the experiment.

Life cycle impact assessment of vermicompost

LCIA results of vermicompost from SCG and SCM as the baseline scenario were assessed based on the CML (baseline) impact assessment method, as shown in Table 5. Fig. 4 illustrates the contribution of the various processes to the impact categories. A negative sign in the environmental impact indicates a comparative benefit resulting from reduced emissions due to product substitution, in this case, mineral fertilizer and fishmeal. The use of SCG incorporated with SCM vermicompost created environmental benefits that outweighed the negative effects on most impact categories, i.e., ADP, FAETP, TETP, MAETP, HTP, POCP, and ODP. In the mentioned impact categories, a relatively small proportion of the impact was attributed to the acquisition of cow manure and its transportation. Mineral N fertilizers are identified as significant contributors to the environmental impacts in most agricultural processes (Udvardi et al., 2015). The life cycle of mineral N fertilizers involves the consumption of a substantial quantity of energy and resources, along with environmental emissions arising from the extraction of raw materials, transportation, production processes, and the application of fertilizers (IFA, 2009; Basosi et al., 2014). Thus, the substitution of mineral N fertilizer with organic fertilizer yielded substantial environmental benefits.

While organic fertilizers offer numerous benefits, it is important to note that the emissions of nitrogen (N) from organic fertilizers, particularly in the form of NH_3 volatilization, can potentially lead to higher impacts on acidification potential (AP) and eutrophication potential (EP). Previous studies suggested that the addition of manure can increase NH_3 emissions, primarily due to elevated NH_4^+ concentrations in agricultural soils, with the level of N application and the type of fertilizer playing significant roles (Ti et al., 2019). Nevertheless, it is worth mentioning that organic fertilizers tend to release nitrogen more slowly over time as they decompose. This slow release can result in extended periods of nitrogen availability in the soil, which may increase the potential for nitrogen loss through various pathways; in contrast, synthetic fertilizers provide nitrogen in more readily available forms, which can be taken up by plants more efficiently, leading to lower immediate nitrogen losses (Musyoka et al., 2019). Direct emissions of greenhouse gases from vermicompost and mineral fertilizers, mainly N_2O, were found to be similar. However, the substitution can lead to a reduction in GWP100 associated with mineral fertilizer production as well as animal feed production.

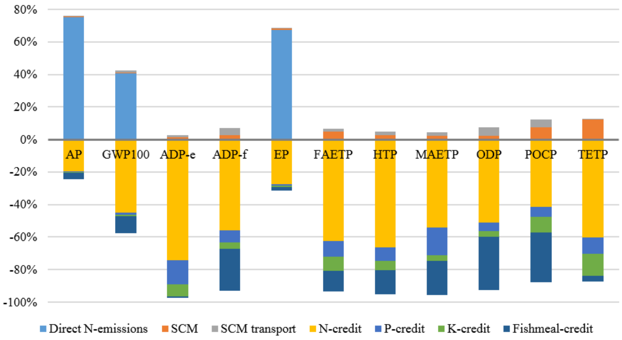

Figure 4. Impact assessment results of the baseline scenario (vermicompost).

Scenario analysis

Apart from the baseline scenario of vermicompost from SCG, three alternative waste management scenarios were analyzed. Two impact categories, GWP100 and EP, were selected for comparison (Figs. 5, 6). In terms of GWP100, the scenario where SCG was disposed of in landfills (SC1) had the highest impact, while the baseline scenario exhibited

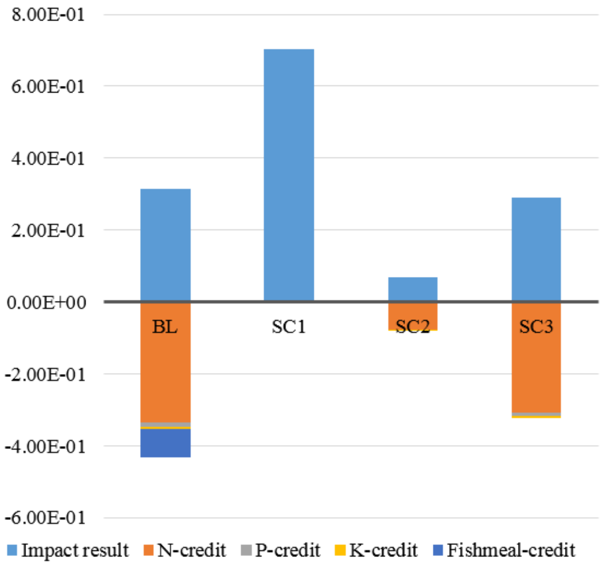

Figure 5. Comparative results of GWP100 across four different scenarios.

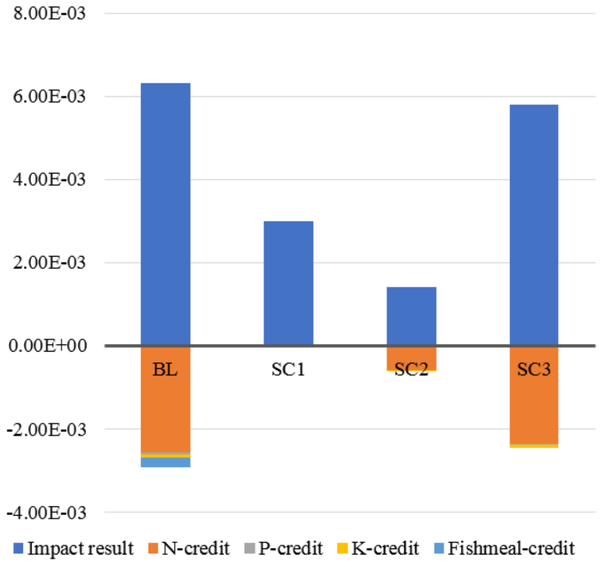

Figure 6. Comparative results of EP across four different scenarios.

Table 5. LCIA results of vermicompost in different process contributions.

Impact category	**Reference unit**	**Direct N-emissions**	**SCM**	**SCM transport**	**N-credit**	**P-credit**	**K-credit**	**Fishmeal-credit**	**Net impact**
AP	kgSO_2-eq.	1.79E-02	1.04E-04	2.90E-05	-4.67E-03	-1.34E-04	-1.25E-04	-8.91E-04	**1.22E-02**
GWP100	kgCO_2-eq.	3.05E-01	2.53E-03	7.59E-03	-3.35E-01	-1.16E-02	-6.55E-03	-7.88E-02	**-1.16E-01**
ADP-e	kgSb-eq.	0.00E+00	3.57E-08	2.51E-08	-1.77E-06	-3.60E-07	-1.70E-07	-2.63E-08	**-2.27E-06**
ADP-f	MJ	0.00E+00	5.79E-02	1.04E-01	-1.31E+00	-1.75E-01	-9.43E-02	-6.05E-01	**-2.02E+00**
EP	kgPO_4^{3-}-eq.	6.24E-03	8.10E-05	8.57E-06	-2.56E-03	-5.87E-05	-7.77E-05	-2.31E-04	**3.41E-03**
FAETP	kg1,4-DCB-eq.	0.00E+00	4.67E-03	1.60E-03	-6.00E-02	-9.16E-03	-8.54E-03	-1.22E-02	**-8.37E-02**
HTP	kg1,4-DCB-eq.	1.12E-03	4.31E-03	4.43E-03	-1.32E-01	-1.65E-02	-1.05E-02	-2.94E-02	**-1.78E-01**
MAETP	kg1,4-DCB-eq.	0.00E+00	6.39E+00	5.00E+00	-1.44E+02	-4.47E+01	-9.12E+00	-5.60E+01	**-2.42E+02**
ODP	kgCFC-11-eq.	0.00E+00	4.66E-10	1.25E-09	-1.15E-08	-1.12E-09	-7.90E-10	-7.37E-09	**-1.91E-08**
POCP	kgC_2H_4-eq.	0.00E+00	7.20E-06	4.56E-067	-3.99E-05	-5.88E-06	-9.20E-06	-2.94E-05	**-7.26E-05**
TETP	kg1,4-DCB-eq.	0.00E+00	1.13E-03	4.09E-057	-5.50E-03	-9.12E-04	-1.27E-03	-2.88E-04	**-6.79E-03**

AP = acidification, GWP100 = climate change, ADP-e = depletion of abiotic resources – elements, ultimate reserves, ADP-f = depletion of abiotic resources – fossil fuels, EP = eutrophication, FAETP = freshwater aquatic ecotoxicity, MAETP = marine aquatic ecotoxicity, TETP = terrestrial ecotoxicity, HTP = human toxicity, ODP = ozone layer depletion, and POCP = photochemical oxidation.

the most significant benefits. The GWP100 results were 7.05E-01, -8.08E-03, and -3.19E-02 kgCO_2-eq for SC1, SC2, and SC3, respectively. The key benefit arose from substituting N fertilizer with SCG, as discussed in the previous section. The findings reaffirmed that utilizing SCG as organic fertilizer, whether as soil amendment, compost, or vermicompost, can reduce greenhouse gas emissions compared to disposing of SCG in a landfill.

In contrast, in the baseline scenario, vermicompost had the highest impact on eutrophication followed by compost in SC3. This can be attributed to the release of NH_3 resulting from the volatilization of organic fertilizers containing livestock manure. All the results indicated a net positive impact, with values of 3.00E-03, 8.19E-04, and 3.34E-03 kgPO_4^{3-}-eq for SC1, SC2, and SC3, respectively. The proportion of NH_3 emissions from livestock manure is substantial but highly variable, ranging from a few percent to 100% of TAN (Hafner et al., 2019). Hence, if not managed properly, it can contribute to eutrophication. To mitigate this concern, several best management practices and strategies can be applied, such as using additives that can bind NH_3 (Stelt et al., 2007), adjusting the dietary composition of livestock (Stelt et al., 2008), and deep placement fertilization (Ti et al., 2019; Li et al., 2022). To minimize the risk of eutrophication from vermicompost made with spent coffee grounds (SCG), maintaining an optimal C:N ratio between 15 and 30 is crucial (Filipović et al., 2023). This ratio balances the decomposition rate while reducing the concentration of readily available nitrogen in the vermicompost. In addition to the C:N ratio, investigating the optimal ratio between SCG and bulking agents such as manure can be another avenue for future research. This could potentially optimize nutrient content and minimize the risk of eutrophication.

4. Conclusion

The study presented results related to the physicochemical characteristics of organic fertilizers produced from spent coffee grounds (SCG) and their impact on earthworm biomass. Compost and vermicompost, produced by combining SCG with SCM, exhibited different properties compared to SCG, particularly higher macronutrient content. The LCA results highlighted that the utilization of SCG incorporated with SCM for the production of organic fertilizers, particularly vermicompost, can have significant environmental benefits by reducing the reliance on mineral N fertilizers and fishmeal in animal feed production. Furthermore, the scenario analysis was performed to compare the baseline scenario of vermicompost from SCG to three alternative waste management scenarios. In terms of global warming potential (GWP100), disposal of SCG in a landfill had the highest impact, while the baseline scenario (vermicompost) showed the most significant environmental benefit, a 116% reduction in GWP100 compared with disposing in a landfill. In contrast, in the context of eutrophication potential (EP), the baseline scenario had the highest impact, primarily due to NH_3 emissions resulting from organic fertilizers. This underscores the need for effective management practices to mitigate the contribution of NH_3 to eutrophication such as using additives that can bind NH_3, adjusting the dietary composition of livestock, deep placement fertilization, and maintaining an optimal C:N ratio between 15 and 30. Future research should pay special attention to investigating the optimal ratio between SCG and manure. This could potentially optimize nutrient content and minimize the risk of eutrophication. Overall, this study contributed valuable insights into sustainable waste management practices and their environmental implications.

Acknowledgment
This study was kindly supported by Chiang Rai Rajabhat University. The authors gratefully acknowledged the Department of Environmental Science, Faculty of Science, Silpakorn University, for facilitating laboratory equipment and chemical agents used in fertilizer analysis.

Authors contributions
The authors confirm the study conception and design: B. Phrommarat, P. Paopuree; data collection: B. Phrommarat; analysis and interpretation of results: B. Phrommarat, P. Paopuree; draft manuscript preparation: B. Phrommarat. The results were evaluated by all authors, and the final version of the manuscript was approved.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Basosi R, Spinelli D, Fierro A, Jez S (2014) Mineral nitrogen fertilizers: environmental impact of production and use. In: Fertilizers: components, uses in agriculture and environmental impacts. *NOVA Publishers, New York,* 3–43.

Battista F, Barampouti EM, Mai S, Bolzonella D, Malamis D, Moustakas K, Loizidou M (2020) Added-value molecules recovery and biofuels production from spent coffee grounds. *Renew Sustain Energy Rev* 131:110007. https://doi.org/10.1016/j.rser.2020.110007

Boldrin A, Andersen JK, Møller J, Christensen TH (2009) Composting and compost utilization: accounting of greenhouse gases and global warming contributions. *Waste Manag Res* 27:800–812. https://doi.org/10.1177/0734242X09345275

Bomfim ASCd, Oliveira DM de, Walling E, Babin A, Hersant G, Vaneeckhaute C, Dumont MJ, Rodrigue D (2023) Spent coffee grounds characterization and reuse in composting and soil amendment. *Waste* 1:2–20. https://doi.org/10.3390/waste1010002

Bong CPC, Lim LY, Ho WS, Lim JS, Klemeš JJ, Towprayoon S, Ho CS, Lee CT (2017) A review on the global warming potential of cleaner composting and mitigation strategies. *J Clean Prod* 146:149–157. https://doi.org/10.1016/j.jclepro.2016.07.066

Brontowiyono W, Rudiansyah M, Mahmudiono T, Shichiyakh RA, Iswanto AH, Abdulkadhim AH, Hussein SA, Yasin G, Sharma S, Aravindhan S (2022) Optimal preparation time in the vermicompost production process. *Food Sci Technol* 42:e03622. https://doi.org/10.1590/fst.03622

Cervera-Mata A, Molinero-García A, Martín-García J (2023) Sequential effects of spent coffee grounds on soil physical properties. *Soil Use Manag* 39 (1): 286–297. https://doi.org/10.1111/sum.12853

Champar-ngam N, Iwai CB, Ta-oun M, Seripong S (2013) The change of phosphorus form in vermicompost using cassava pulp. *Int J Environ Rural Dev* 4 (4): 81–87. https://doi.org/10.32115/ijerd.4.1-81

Chen YC, Chen LY (2021) Pelleting spent coffee grounds by waste utensils as binders of biofuels. *J Environ Chem Eng* 9 (3): 105006. https://doi.org/10.1016/j.jece.2020.105006

Emmanuel SA, Yoo J, Kim EJ, Chang JS, Park YI, Koh SC (2017) Development of functional composts using spent coffee grounds, poultry manure and biochar through microbial bioaugmentation. *J Environ Sci Health* 52 (11): 802–811. https://doi.org/10.1080/03601234.2017.1356165

Favoino E, Hogg D (2008) The potential role of compost in reducing greenhouse gases. *Waste Manag Res* 26 (1): 61–69. https://doi.org/10.1177/0734242X08088584

Filipović A, Mandić A, Hadžiabulić A, Johanis H, Stipanović A, Brekalo H (2023) Characterization and evaluation of vermicomposting materials. *Ekológia (Bratislava)* 42 (2): 101–107. https://doi.org/10.2478/eko-2023-0012

Florio C, Fiorentino G, Corcelli F, Ulgiati S, Dumontet S, Güsewell J, Eltrop L (2019) A life cycle assessment of biomethane production from waste feedstock through different upgrading technologies. *Energies* 12 (4): 718. https://doi.org/10.3390/en12040718

Franca AS, Oliveira S (2022) Potential uses of spent coffee grounds in the food industry. *Foods* 11:2064. https://doi.org/10.3390/foods11142064

González-Moreno MA, García GB, Marcelino SS, Zaratiegui UJ, Robles DE, Pérez EMA, Seco MA (2020) Feasibility of vermicomposting of spent coffee grounds and silverskin from coffee industries: A laboratory study. *Agronomy* 10 (8): 1125. https://doi.org/10.3390/agronomy10081125

Hafner SD, Pacholski A, Bittman S, Carozzi M, Chantigny M, Génermont S, et al. (2019) A flexible semi-empirical model for estimating ammonia volatilization from field-applied slurry. *Atmos Environ* 199:474–484. https://doi.org/10.1016/j.atmosenv.2018.11.034

Hagemann N, Spokas K, Schmidt HP, Kägi R, Böhler MA, Bucheli TD (2018) Activated carbon, biochar and charcoal: linkages and synergies across pyrogenic carbon's ABCs. *Water* 10 (2): 182. https://doi.org/10.3390/W10020182

Hanc A, Hrebeckova T, Grasserova A, Cajthaml T (2021) Conversion of spent coffee grounds into vermicompost. *Bioresour Technol* 341:125925. https://doi.org/10.1016/j.biortech.2021.125925

Hirooka Y, Kurashige S, Yamane K, Watanabe Y, Kakiuchi M, Ishikawa D, Miyagawa T, Iwai K, Iijima M (2021) Effectiveness of direct application of top dressing with spent coffee grounds for soil improvement and weed control in wheat-soybean double cropping system. *Plant Prod Sci* 25:148–156. https://doi.org/10.1080/1343943X.2021.2007142

Horwitz W (2000) Official methods of analysis of AOAC international, 17th edn. *Association of Official Analytical Chemistry International, Maryland*

Horwitz W, Latimer GW (2005) Official methods of analysis of AOAC international, 18th edn. *Association of Official Analytical Chemistry International, Maryland*

IFA (2009) Energy efficiency and CO_2 emissions in ammonia production 2008 – 2009 summary report. *International Fertilizer Association, Paris*

Johnson K, Liu Y, Lu M (2022) A review of recent advances in spent coffee ground up cycle technologies and practices. *Front Chem Eng* 4:838605. https://doi.org/10.3389/fceng.2022.838605

Keng ZX, Chong S, Ng CG, Ridzuan NI, Hanson S, Pan G-T, Lau PL, Supramaniam CV, Singh A, Chin CF (2020) Community-scale composting for food waste: A life-cycle assessment-supported case study. *J Clean Prod* 261:121220. https://doi.org/10.1016/j.jclepro.2020.121220

Komakech AJ, Zurbrügg C, Miito GJ, Wanyama J, Vinneras B (2016) Environmental impact from vermicomposting of organic waste in Kampala, Uganda. *J Environ Manage* 181:395–402. https://doi.org/10.1016/j.jenvman.2016.06.028

Li L, Wu T, Li Y, Hu X, Wang Z, Liu J, Qin W, Ashraf U (2022) Deep fertilization improves rice productivity and reduces ammonia emissions from rice fields in China; a meta-analysis. *Field Crops Res* 289:108704. https://doi.org/10.1016/j.fcr.2022.108704

Lirikum, Kakati LN, Thyug L, Mozhui L (2022) Vermicomposting: an eco-friendly approach for waste management and nutrient enhancement. *Trop Ecol* 63:325–337. https://doi.org/10.1007/s42965-021-00212-y

Low JH, Rahman WAWA, Jamaluddin J (2015) The influence of extraction parameters on spent coffee grounds as a renewable tannin source. *J Clean Prod* 101:222–228. https://doi.org/10.1016/j.jclepro.2015.03.094

Manaf L, Jusho M, Yusoff M, Ismail TT, Harun R, Juahir H, Jusoff K (2009) Influences of bedding material in vermicomposting process. *Int J Biol* 1 (1): 81–91. https://doi.org/10.5539/ijb.v1n1p81

Musyoka MW, Adamtey N, Bünemann EK, Muriuki AW, Karanja EN, Mucheru-Muna M, Fiaboe KKM, Cadisch G (2019) Nitrogen release and synchrony in organic and conventional farming systems of the central highland of Kenya. *Nutr Cycl Agroecosyst* 113:283–305. https://doi.org/10.1007/s10705-019-09978-z

Nelson DW, Sommers LE (1996) Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis, Part 2, 2nd edn. *Am Soc of Agron Inc, Madison, Wisconsin,* 961–1010.

Oliveira LSBL, Oliveira DSBL, Bezerra BS, Pereira BS, Battistelle RAG (2017) Environmental analysis of organic waste treatment focusing on composting scenarios. *J Clean Prod* 155:229–237. https://doi.org/10.1016/j.jclepro.2016.08.093

Saha N, Chattrejee P, Sharma A, Metiya G, Halder M, Mukherjee D (2010) Vermicomposting influences phosphorus microbiology leading to phosphorus enrichment in end product. *Int J Glob Environ* 10 (3-4): 310–326. https://doi.org/10.1504/IJGENVI.2010.037273

Shinde AM, Dikshit AK, Odlare M, Thorin E, Schwede S (2021) Life cycle assessment of bio-methane and biogas-based electricity production from organic waste for utilization as a vehicle fuel. *Clean Technol Environ Policy* 23:1715–1725. https://doi.org/10.1007/s10098-021-02054-7

Singh V, Wyatt J, Zoungrana A, Yuan Q (2022) Evaluation of vermicompost produced by using post-consumer cotton textile as carbon source. *Recycling* 7:10. https://doi.org/10.3390/recycling7010010

Stelt B Van der, Temminghoff EJM, Vliet PCJ Van, Riemdijk WH Van (2007) Volatilization of ammonia from manure as affected by manure additives, temperature and mixing. *Bioresour Technol* 98:3449–3455. https://doi.org/10.1016/j.biortech.2006.11.004

Stelt B Van der, Vliet PCJ Van, Reijs JW, Temminghoff EJM, Riemsdijk WH Van (2008) Effect of dietary protein and energy levels on cow manure excretion and ammonia volatilization. *J Dairy Sci* 91 (12): 4811–4821. https://doi.org/10.3168/jds.2006-449

Thongkheaw M (2010) The determination of protein and certain essential elements in earthworm *Eudrilus eugeniae* fed with different kinds of organic litters. Thesis, Suranaree University of Technology, Thailand.

Ti C, Xia L, Chang SX, Yan XY (2019) Potential for mitigating global agricultural ammonia emission: A meta-analysis. *Environ Pollut* 245:141–148. https://doi.org/10.1016/j.envpol.2018.10.124

Udvardi M, Brodie EL, Riley W, Kaeppler S, Lynch J (2015) Impacts of agricultural nitrogen on the environment and strategies to reduce these impacts. *Procedia Environ Sci* 29:303. https://doi.org/10.1016/j.proenv.2015.07.275

Vardon DR, Moser BR, Zheng W, Witkin K, Evangelista RL, Strathmann TJ, Rajagopalan K, Sharma BK (2013) Complete utilization of spent coffee grounds to produce biodiesel, bio-oil, and biochar. *ACS Sustainable Chem Eng* 1 (10): 1286–1294. https://doi.org/10.1021/SC400145W

Walkley AJ, Black IA (1934) Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci* 37:29–38.

Zampori L, Pant R (2019) Suggestions for updating the Product Environmental Footprint (PEF) method. *Publications Office of the European Union, Luxembourg*