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Review

Potentiality of Vermicomposting in the South Pacific Island Countries: A Review

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Abstract: Incorporation of vermin culture in the composting system produces "vermicompost", an enriched biofertilizer known to improve the physical, chemical, and biological properties of soil. It is applied in granular form and/or in liquid solution (vermiwash), and in both open fields and greenhouses. Vermicompost has been shown to contain plant growth hormones, which stimulate seed germination and improve crop yield, the 'marketability' of products, plant physiology, and their ability to fight against disease. In recent years, South Pacific island countries (SPICs) have placed an increasing emphasis on the importance of organic agricultural practices as a means of achieving more sustainable and environmentally friendly farming practices. However, vermiculture is not practiced in South Pacific island countries (SPICs) largely due to the lack of awareness of this type of application. We consider the inclusion of vermiculture in this region as a potential means of achieving sustainable organic agricultural practices. This study represents a systematic review in which we collect relevant information on vermicomposting and analyze the applicability of this practice in the SPICs based on these nations' physical, socioeconomic, and climatic conditions. The tropical climate of the SPICs means that they meet the combined requirements of a large available biomass for composting and the availability of earthworms. *Perionyx excavatus* and *Pontoscolex corethrurus* have been identified as potential native earthworm species for vermicomposting under the conditions of the SPICs. *Eisenia fetida*, a well-known earthworm species, is also effectively adapted to this region and reported to be an efficient species for commercial vermicomposting. However, as a new input into the local production system, there may be unforeseen barriers in the initial stages, as with other advanced technologies, and the introduction of vermiculture as a practice requires a steady effort and adaptive research to achieve success. Further experimental research is required to analyze the productivity and profitability of using the identified native earthworm species for vermiculture using locally available biomass in the SPICs.

Keywords: vermicompost; vermiwash; plants nutrients; organic fertilizer; South Pacific island countries (SPICs)

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1. Introduction

Chemical fertilizers and pesticides are commonly used in agriculture to improve soil fertility and combat pests due to the perceived ease of their application and the fact they give more rapid results. However, such rapid methods are associated with a decline in the potentiality of surrounding ecosystems [1–4]. These methods may also have adverse effects on the health of humans and animals due to the accumulation of residues from these agrochemicals in food chains. There has therefore been increasing focus on using alternative interventions, namely organic practices.

Any intervention used to combat the noxious effects of synthetic chemical traces in the food chain needs to focus on soil health, as this represents the primary element in agricultural production and underpins the optimization of the productivity or profitability of agricultural production system. The integration of organic amendments in agriculture has been shown to result in the long-term improvement of the soil's physical, chemical, and biological properties [5]. Indeed, organic amendments help to provide a stable niche for soil microorganisms, thus improving soil fertility [6,7]. Organic amendments improve the productivity of the soil by facilitating water infiltration, increasing the availability of plant nutrients, and enhancing the capacity for plants to tolerate biotic stress [8–11]. They also lead to improved soil aggregation and a reduction in soil bulk density [12].

Vermicompost is an organic fertilizer obtained by the decomposition of degradable residues through the digestive tracts of earthworms. It is regarded both as a sustainable approach to agricultural production and a safe means of waste management [7]. Indeed, it can be produced from waste that is rapid-growing and has a deleterious impact on groundwater resources [13–15]. Waste is converted into vermicompost, which has a high-nutrient value that has been shown to contribute to an improvement in soil fertility and plant productivity [1,3,4]. Figure 1 summarizes the waste conversion to beneficial vermicompost and its influences on soil fertility and crop productivity. Studies have highlighted numerous benefits following its application to many crops, such as cereals and field crops [16–19], legumes [20], and vegetables [21–23], with different amounts of vermicompost applied in each study. It has been shown that vermicompost contains plant hormones that stimulate growth and anticipate the spread or the severity of disease [1,3,7]. Vermicompost provides essential nutrients to the plants in a form they can readily utilize [16,23]. Vermiculture is therefore regarded as a slow and steady application that can be both beneficial for soil health and crop productivity.

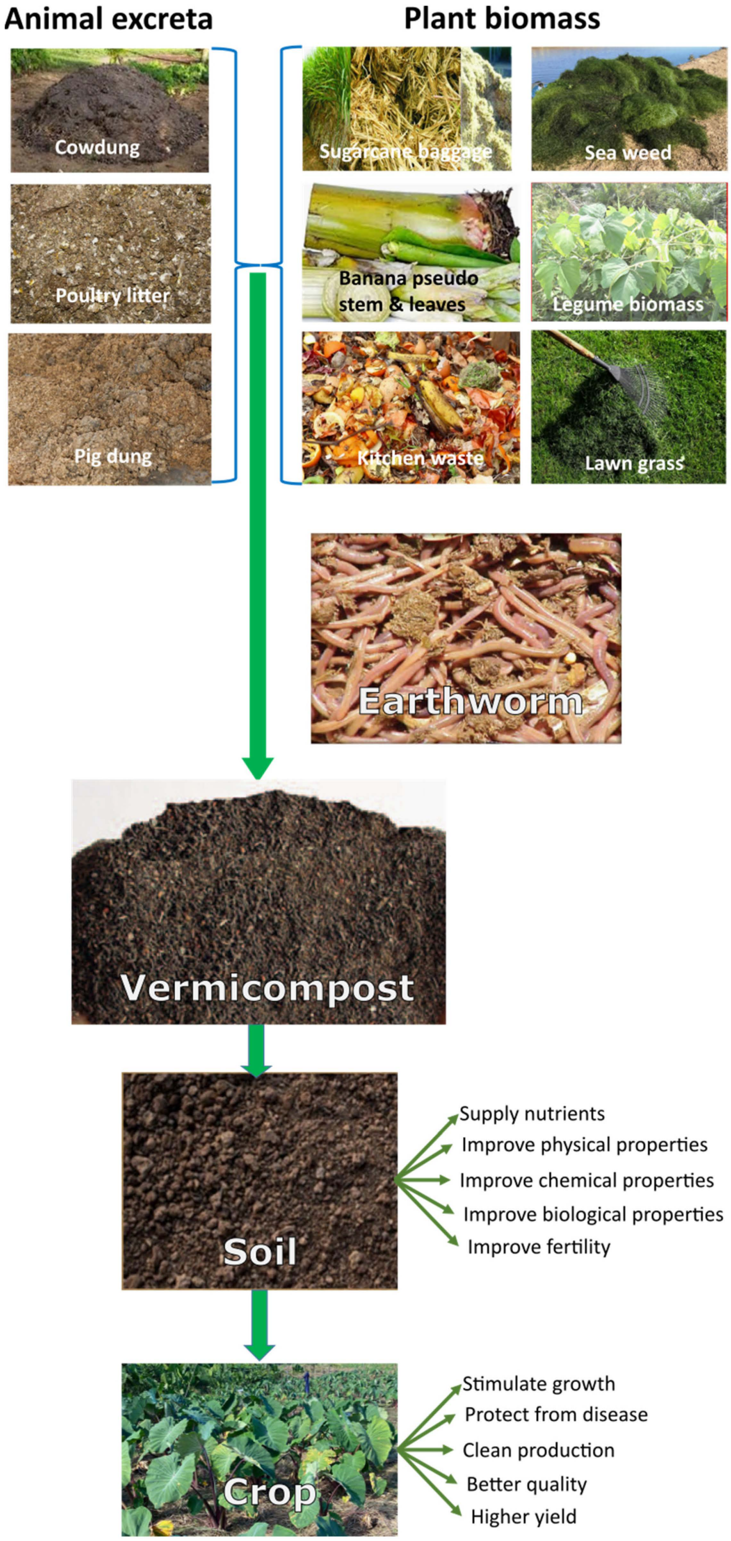

Figure 1. Schematic summary of the vermicomposting process and its beneficial effects on soil health and crop productivity (Adapted from Chatterjee et al. (2021) [24]).

In the tropical South Pacific islands nations, including Samoa, agriculture is one of the main sources of income and a major source of employment. For example, in Samoa, 40% of its population is employed in agriculture [25]. The Samoan government has increasingly recognized the importance of organic amendments, particularly after several natural disasters back in the 1990s [26]. Since then, the government has initiated several programs promoting the application of organic fertilizer in the region. Through such initiatives, awareness amongst farmers has improved and they have shown greater interest in following organic practices in their crop production. However, there is a lack of knowledge regarding the quality of organic amendments and the appropriate amounts needed for maintaining soil fertility and productivity in Samoa, along with other South Pacific Island countries (SPICs) [27]. Vermicomposting is arguably an affordable and sustainable organic practice that could be introduced in the region to help farmers in improving soil fertility and crop production. However, there is currently only a very limited amount of information regarding the potential application of vermicompost in the SPICs. This warrants a systematic review to fill the knowledge gap about vermicomposting in the region that includes an assessment of its potential based on the physical, socioeconomic, and climatic conditions in the SPICs.

2. The Vermicomposting Process

Vermicomposting is a non-thermophilic (mesophilic) process that uses the digestive system of earthworms to transform organic waste into a humus-like product that represents a high-value nutrient fertilizer and soil amendment [28–30]. In this complex decomposition process, earthworms feed on fungi and other available microorganisms and produce vermicompost that is enriched relative to the initial status of the ingested wastes. The vermicomposting process has both physical and biochemical components. Physical processes include fragmentation, turnover, and aeration, while biochemical processes include enzymatic digestion, nitrogen enrichment, and transformation of inorganic and organic materials [31]. Through these supplementary microbial processes, important plant nutrients such as nitrogen, potassium, phosphorus, and calcium present in the organic waste are converted into inorganic forms that are much more soluble and available to the plants than those in the parent substrate [32,33]. Consequently, the application of vermicompost could both reduce the demand for chemical fertilizers and their adverse effects on soil and other natural resources and reduce the amount of organic waste going to landfill [34].

3. Earthworm Species Used for Vermicomposting

Presently, there are more than 3000 species of earthworms in the ecosystem. However, not all of them are appropriate for vermicomposting [35]. Earthworms that are typically used in the vermicomposting process are categorized as 'epigeic' species, that is 'surface dwellers' [35,36]. Because of their high reproductive rates, endurance, and tolerance to living in close proximity to each other, epigeic species have the capacity to colonize in high numbers in organic waste and therefore produce large volumes of vermicompost. Their presence has no harmful effects on the soil structure as the worms create small burrows [37]. One study identified six earthworm species as the most suitable for vermicomposting: *Eisenia andrei*, *Eisenia fetida* (old spelling: foetida), *Dendrobaena veneta*, *Polypheretima elongate*, *Perionyx excavates*, and *Eudrilus eugeniae* [38]. Other studies have suggested that *Perionyx sansibaricus*, *Pontoscolex corethrurus*, *Megascolex chilensis* [39], *Lumbricus terrestris* and *Dendrobaena veneta* [40], *Lumbricus rubellus* and *Amyanthes diffrigens* [41] have strong potential for vermicomposting.

4. Characteristics of Vermicompost

The vermicompost product is a fine, enriched manure, made of digested cocoons or 'worm castings' excreted by the earthworms. The earthworm castings are garnished with various microorganisms and are clear of disease pathogens [42]. Due to the presence of humic acid, vermicompost is seen as a biofertilizer and both sustainable and 'eco-friendly' [43]. Such enriched manure contains humus, which could be used in horticultural crop production systems. The moisture content of vermicompost ranges between 32 and 66% [40]. Vermicompost is generally found in a granular form, which can be mixed with the soil like a nutrient supplement. Alternatively, 'vermiwash' can be applied in liquid form produced by allowing water to pass through a column of vermicompost where worms have been active [44]. Vermiwash is composed of organic matter, microorganisms, and nutrients from the vermicompost and can be sprayed directly to the physical parts of the plants and to the soil to enhance biological activity [45].

Overall, vermicompost is rich in polysaccharides, which improve soil aeration, drainage, and aerobic conditions [46]. Vermicomposts produced from different sources of organic waste have a diverse range of nutritional compositions and pH, as outlined in Table 1 [24,31,47]. For example, a sheep-manure vermicompost has a typical pH of 8.6, whereas a cattle-manure vermicompost has a pH of around 6.0, and a pig manure vermicompost has a pH of ~5.3 [48]. Depending on the type of organic waste used in the vermicomposting process, the nutritional composition of the end product varies widely, for example in terms of organic carbon (9.15–34%); Ca and Mg (22–70 Cmol (+)/kg); available S (128–548 ppm); Cu (100 ppm); Fe (1800 ppm); and Zn (50 ppm) [24,40].

Table 1. Nutrient content of vermicompost produced from different starting materials (Source: Lim et al. (2015) [30]) and Chatterjee et al. (2021) [24]).

Organic Waste	pH (-)	TOC (%)	TN (%)	TP (%)	TK (%)	TS (%)	Zn (mg/kg)	Cu (mg/kg)	Fe (%)	Mn (mg/kg)
KW	-	10.30	0.85	0.15	-	-	-	-	-	-
ST	6.55	24.62	1.14	0.46	1.61	-	-	-	-	-
CD	7.04	32.16	3.60	0.23	0.89	-	-	-	-	-
FW	7.30	34.0	1.30	2.70	9.20	-	-	-	-	-
PL + SP	8.89	16.70	2.06	0.67	5.09	0.48	440	51	0.50	300
PL + AZ	8.23	16.50	1.82	0.87	3.68	0.41	520	49	0.40	390
PL + BA	9.01	15.40	1.54	0.74	3.99	0.46	415	45	0.45	280
PL + PS	8.91	16.20	1.54	1.06	7.23	0.58	520	61	0.50	590
CD + SP	6.92	20.90	1.75	0.25	1.84	0.47	290	10	0.60	100
CD + AZ	6.35	19.30	2.17	0.30	1.70	0.49	285	20	0.59	210
CD + BA	7.00	16.50	1.89	0.24	1.65	0.46	215	9	0.78	110
CD + PS	6.75	29.30	2.24	0.34	1.51	0.41	225	12	0.60	310
PD + SP	7.34	19.00	2.20	0.35	2.05	0.33	210	19	0.70	120
PD + AZ	6.69	28.70	2.20	0.32	1.76	0.40	220	22	0.81	115
PD + BA	7.15	20.10	2.17	0.22	2.10	0.28	150	12	1.10	110
PD + PS	6.80	13.90	2.48	0.56	2.15	0.36	230	19	1.00	300

Note: KW = kitchen waste, ST = sugarcane trash, FW = food waste, PL = poultry litter, CD = cow dung, PD = pig dung, SP = *Spermacoce*, AZ = *Azolla pinnata*, BA = banana pseudo stem and leaf, PS = paddy straw, TOC = total organic carbon, TN = total nitrogen, TP = total phosphorus, TK = total potassium, TS = total sulphur.

Often, vermicompost nutrient concentrations are optimized by using different sources of raw material in the vermicomposting process, as the combination of raw materials decreases the chances of the vermicompost being deficient in a certain element. Notable combinations include sewage sludge [49], vegetable and kitchen waste [30], and agro-industrial waste [50,51]. Some experiments favor a combination of cattle manure and sawdust [52], or vegetable waste combined with cow dung [53]. Regardless of the source, the vermicomposting end-product tends to have higher nutrient content than traditional compost (Table 2) [24,30,49].

Table 2. Nitrogen (N), phosphorus (P), and potassium (K) content of different organic fertilizers (Source: Chanda et al., 2010 [34]; Murmu et al., 2013 [54]; Hernandez, 2010 [52]).

Element	Vermicompost	Farmyard Manure	Bacterial Compost
N (%)	1.3–1.84	1.10	1.40
P (%)	0.92–1.3	0.42	0.016
K (%)	0.21–1.2	2.00	0.55

5. Use of Vermicompost

Vermicompost has been applied as an organic fertilizer to multiple crops in greenhouses and in open fields. As well as supplying plant nutrients, it has been used as a plant growth regulator, a bio pesticide, and as a soil amendment agent. The vermicomposting process is also a useful method for recycling solid organic wastes. Applications of vermicompost are described below in more detail.

5.1. Plant and Soil Nutrients Supply

Vermicompost has high concentrations of humus, nitrogen (2–3%), phosphorous (1.55–2.25%), potassium (1.85–2.25%), micronutrients, and beneficial soil microbes such as nitrogen-fixing bacteria, mycorrhizal fungi, phosphate solubilizing bacteria, and actinomycetes [15,40]. Bio-oxidation and stabilization of organic matter and biomass occur during the vermicomposting process and increase enzymatic activities such as amylase, lipase, cellulose, chitinase, urease, dehydrogenase and phosphatase, and microbial populations [15,55,56]. For example, vermicomposting stimulates nitrogenase enzyme activity, and therefore nitrogen mineralization and nitrogen availability. Mineralization of nitrogen induces phosphorus availability and uptake. Additionally, vermicomposting also increases the availability of other nutrients such as soluble potassium, nitrates, calcium, and magnesium [44]. Vermicompost application increases the availability of nitrogen in soil mostly in the form of nitrate relative to ammonium due to better soil aeration [24]. Plots treated with vermicompost showed higher levels of total N [57]. In parallel, phosphorus was shown to be more available, and it was released in large amounts due to microorganism activity [15]. Interestingly, reports have shown that when vermicompost is applied in combination with commercial NPK fertilizer, nitrogen availability improved to a greater extent than when only NPK fertilizer was applied [58]. It has also been proposed that, due to the slow mineralization of N with the use of vermicompost, its application leads to improved crop yields and an increase in plant leaf area and number of leaves per plant [58]. Furthermore, with the application of vermicompost, the organic matter releases the nutrients slowly and steadily into the soil and allows the plants to absorb the available nutrients. Hence, the application of vermicompost leads to an increase in cation exchange capacity [59]. High activity of basic cations, e.g., Ca, Mg, K etc., was also reported in the vermicast (earthworms castings) compared to soil [38].

Vermicompost has been included in plant nutrient management programs in large-scale greenhouse production systems. For both fruit and vegetable crops cultivated in greenhouses, when vermicompost is used as a growing medium alone or in combination with soil, it has been shown to improve the release and availability of plant nutrients. Hence, a fertigation practice in greenhouse production systems that includes vermicompost would substitute other plant nutrients within the range of 20–40%. Under large open field conditions, vermicompost is typically applied to soil at a rate of 1–5 tons ha^{-1} yr^{-1} [60]), unless the soil is unfertile where it is applied in larger doses. The application of vermicompost significantly improves the organic carbon content in soil as it is enriched with stable organic matter [44,61]. The application of fully decomposed vermicompost has been shown to reduce the loss of nutrients through leaching [24], due to an increase in total soil organic carbon [62]. In addition, vermicompost helps to remediate the stability of the soil from toxicity [63]. This shows that the application of vermicompost in soil enhances soil physicochemical properties and biological activity, and, thereby, crop production [64]. It has been reported that the population of microbes is more than three times greater where vermicompost is applied compared with a control (only soil) [65].

Nonetheless, there are reasons to approach the use of vermicompost with caution [29]. A few studies have shown negative impacts on plants and soil, typically related to the quantity of vermicompost applied. The application of higher percentages of vermicompost could create an uncomfortable zone for root growth, which directly induces phytotoxicity [66,67]. Furthermore, high concentrations of vermicompost could result in the rapid destruction of the plant due to the accumulation of salt in the soil.

5.2. Growth Regulator

Many studies have reported that improvement in plant growth parameters is achieved rapidly with the addition of vermicompost [68]. Vermicompost application enhances the release of plant hormones, which lead to desirable changes in plant growth parameters [40]. The presence of gibberellic acid (GA) in vermicompost influences Ca and K uptake and leads to better development of shoot elongation [69]. Experiments on the use of vermicompost along with other organic matter substrates show that it leads to relatively more branching than where inorganic fertilizer is used alone, due to phytohormones in the vermicompost [34]. Additionally, the quality of humic and fulvic acids originally obtained from animal manure is improved through the vermicomposting process: vermicompost retains humic and fulvic acids in more active forms, which act as growth promoters similar to hormones and lead to plant nutrients being converted into bioavailable mineral nutrients [30,70]. Consequently, the application of vermicompost improves fruit quality parameters such as firmness, color, and the multiplication of marketable fruits [71]. Improved lettuce weights and plant heights were reported where vermicompost was used due to the presence of the plant growth regulators viz. auxins, IAA, gibberellins, and cytokinins in plots treated with food and paper vermicomposts [52,57,66]. Vermicompost application is reported to have led to improved seed germination in cabbages, radishes, and Swedish turnips [72,73]. Similarly, vermicompost was shown to accelerate the germination of beetroot, bean, and pea seeds [74], as well as tomato and marigold crops [34,57,72]. Results also suggest that leaf chlorophyll, carotenoid content, and the efficiency of plant photosynthesis also improved [75]. Some reports show that the concentration of essential oils in the leaves of mint plants (*Thymus vulgaris*) also increased with the use of vermicompost, as did total concentrations of carbohydrates, fiber, and vitamin C in cabbage heads [76]. Similarly, tomato crops treated with vermicompost were shown to have higher Ca and vitamin C contents compared with control plots. Due to better interactions between microbes and vermicompost, tuber quality (based on N and protein content) in potato crops improved when treated with vermicompost [73].

In some studies, plants grown with pot mix and vermicompost as growing media produced better quality and heavier products than those treated with plant growth regulator Metro-Mix 360 (Sun Gro Horticulture, Agawam, MA 01001, USA) [57]. Similar trends were also observed in the production of different seasonal crops such as okra, cucumber, pepper, eggplant, strawberry, and Amaranthus species [44,53,77–84].

5.3. Bio-Pesticide

The digested organic waste in the form of earthworm casts contains antifungal compounds such as phenolic substances, which contribute to plants' defense mechanisms and help combat the spread of disease and attacks from pests [75]. The synthesized hormones strengthen the plants and create a barrier for pathogen multiplication [75,85,86]. Protection of plant system against diseases is also possible because of the availability of oxidative enzymes in the earthworm casts. These oxidative enzymes facilitate the formation of a lignin (via the phenylalanine ammonia lyase (PAL) enzyme) which, in turn, reinforces the cells of the plant [75]. It has been shown that actinomycetes present in vermicompost help develop resistance within the plants cells and improve their ability to combat pests and diseases [40]. This combating mechanism is mainly due to microbially-mediated synthesis of the enzyme chitinase, which breaks down the chitin in the insect exoskeleton [87]. It can be deduced that the promotion of enzymatic activities through vermicompost application both ameliorates and promotes soil rehabilitation/regeneration and leads to the protection of plant cells and their ability to tolerate biotic and abiotic stress [46,88]. *E. eugeniae* creates a barrier to soil against contamination with glyphosate-based herbicides (GBH) [89].

Field experiments also suggest that the application of vermicompost leads to the suppression of diseases and a reduction in pest attacks. Application of vermicompost to a field site was shown to reduce attacks by jassid (*Empoasca verri*) and aphids (*Aphis cracivora*) [90]. It was also associated with reduced incidences of parasitic fungi such as *Pythium*, *Rhizoctonia*, and *Verticulum* as well as populations of parasitic nematodes and other types of parasite. The application of vermicompost was also associated with a reduction in the growth of *Fusarium oxysporum f. sp. Lycopersici* in an in vitro trial [91]. Experiments consistently show that plants are more resistant to insect attacks where vermicompost is used and the final plant products are less damaged by sucking or chewing by insects. This was attributed to the presence of organic matter in the vermicompost which, in turn, provides a suitable environment for a balanced nutrient regime required for plant growth and better physiological development [92–94]. With a dose of 75% (by volume), vermicompost was applied in the cultivation of balsam (*Impatiens wallerana*), and this was linked to a reduction in the occurrence of *Rhizoctonia* disease [95]. A significant reduction in numbers of mealy bugs was observed in the pots of pepper plants that were treated with varying percentages of vermicompost [92]. It has also been observed that the spray application of aqueous vermicompost is effective in controlling foliar diseases. It was demonstrated that 20% of the aqueous solution could suppress the numbers of aphids on tomato plants for up to 14 days [60].

5.4. Recycling of Solid Waste

Vermicomposting creates a win-win situation by offering a means of recycling organic waste as well as an organic fertilizer [14]. The waste utilized in the process of vermicomposting remains a key parameter for determining the nutrient value of the "end product". A wide range of parent materials can be used in vermicomposting, such as food waste [70], sugarcane trash, sugar industry bi-products, municipal organic waste, bio solids, animal manures [48,96], and paper [97]. It was found that pig manure vermicompost produces a humus-rich odor free vermicast with Zn and Cu as the limiting nutrients [20,98]. Vermicompost produced from sugarcane trash showed the following composition: 24.62% organic carbon, 1.14% nitrogen, 0.46% phosphorus, and 1.61% potassium [30]. However, vermicompost prepared from sugar industry waste bagasse is enriched with nutrients, with 55.53% organic carbon, 0.26% total Kjeldahl nitrogen, a C:N ratio of 213.57, a Zn concentration of 21.54 mg kg^{-1}, and an Mn concentration of 16.79 mg kg^{-1} [99]. Some studies favor a 50:50 mix of bagasse and cattle dung, which gave optimal results in terms of earthworm biomass, cocoon production, and hatchling formation [99,100]. Conversely, vermicompost produced from of a 100:0 mix of bagasse and cattle dung resulted in a maximum increase of total nitrogen, which was attributed to the deterioration of dead earthworm tissue and a subsequent improvement in nitrogen content in the vermicompost [99]. Furthermore, analysis shows that the use of bagasse mixed with cattle dung induces a reduction in total organic carbon, which was more pronounced in the 50:50 mix compared to the 100:0 mix. The total productivity of vermicompost was amplified when sugar cane bagasse was combined with rice straw [100].

6. Potentiality of Vermicompost in South Pacific Island Countries

South Pacific Island Countries (PICs) are scattered across the world's largest ocean, which covers almost one third of the Earth's surface. They comprise only a very small landmass and have a tropical climate with little seasonal variation. Agriculture remains the backbone of the SPIC economies: it is the main source of livelihood for the population as well as a major export earner. Agriculture in most of the SPICs still mostly follows traditional subsistence farming systems, very much in line with organic agriculture practices with no or minimal use of chemical inputs. This leads us to believe that there are good prospects for incorporating vermicomposting into organic traditional subsistence farming systems in the SPICs. The potentiality of vermicomposting in the SPICs is analyzed below with considerations of climate, soils, economy, and existing agriculture systems.

6.1. Availability and Adaptability of Earthworm Species Suitable for Vermicomposting

To exploit the possibility of vermicomposting in the SPICs, such as Samoa and Fiji, the suitability of endemic earthworms for vermicomposting needs to be investigated. If the native earthworm species do not perform well in vermicomposting, non-endemic species need to be imported. The success of the vermicomposting process is greatly dependent on the adaptability of the earthworm species, with different factors influencing their performance. The selection of appropriate earthworms for vermicomposting should follow a set of criteria, which include (a) ease of culturing, (b) high reproduction rate, (c) high affinity for the substrate, and (d) high rate of vermicomposting. Furthermore, one must consider the following parameters that determine the activity and the distribution of earthworms: (a) food, (b) moisture, (c) temperature, (d) light, (e) pH, and (f) protection from predators [101]. A handful of sources within the literature have commented on the availability and suitability of earthworms in the SPICs (Table 3). *Perionyx excavatus* and *Pontoscolex corethrurus* were identified in Upolu of Samoa and Fiji [102]. Additionally, *Eudrilus eugeniae* was found in St Helena [103] and *Polypheretima elongate* species activity was recorded in American Samoa [104]. Initial screening showed that *Eisenia fetida* is well adapted under SPIC conditions [105]. The use of *Eisenia fetida* will increase the efficiency of the vermicomposting process in SPICs as observed elsewhere [48,70,75]. It is important to mention, however, that *E. fetida* is not endemic to Samoa, and neither to Fiji [105]. The preference for this species is based on its identified antifungal trait, which has the capacity to suppress certain diseases, such as *Fusarium moniliforme*, as well as its rapid development and endurance [43]. Studies have suggested that, along with *E. fetida*, other earthworm species such as *Eudrilus eugenia* and *Perionyx excavatus* also exhibited a greater ability to decompose a wide range of organic wastes. All these species have a high reproduction rate and inhabit the humus-laden upper layers of garden soil. *P. excavatus* has a life cycle of 40–71 days and tolerates a temperature range of 20–30 °C, dying at temperatures below 5 °C and above 30 °C [55]. *Eisenia fetida* tolerates a similar temperature range to that of *P. excavatus*, but can also live at higher temperatures up to 40 °C [82]. Other beneficial traits associated with *E. fetida* include its ability to adjust to a greater variety of organic waste types with a wide range of moisture contents (75–90%). Interestingly, *E. eugeniae* is the preferred vermicomposting species used in some tropical countries due to its rapid multiplication and thus high volume. It can tolerate higher temperatures (25–30 °C) but its reproduction and growth rates decrease considerably at below 15 °C. It can tolerate a range of moisture content of 80–82% and its life cycle is 50–70 days [55].

Table 3. Potential earthworm species for vermicomposting in South Pacific island countries.

Earthworm Species	Reference
I. Indigenous	
Perionyx exavatus	[102]
Pontoscolex corethrurus	[102]
Polypheretima elongate	[104]
Eudrilus eugeniae	[103]
II. Introduced	
Eisenia fetida	[105]

Studies investigating the potential of vermicomposting under SPICs are limited and so it has not been commonly integrated into farming practices. However, a vermicomposting startup program has been initiated by the Grace Road Food Company based in Suva, Fiji. At the start, the company obtained the earthworm, *Eisenia fetida* (the "Red Wiggler") from Australia. Since then, the earthworms have multiplied and the company continues to use the same culture in vermicomposting.

6.2. Traditional Organic Farming Systems

Organic farming with minimal or no use of chemical fertilizers is commonplace in traditional farming practices in the SPICs. Due to the high cost of chemical fertilizers, in some SPICs it is obligatory for farmers to use organic fertilizers. However, many still opt to use chemical fertilizers for ease and rapidity.

Most of the SPIC governments emphasize the importance of using natural or organic inputs into the production of crops and some of them restrict chemical use in agriculture. For example, the Republic of Kiribati announced a policy regarding the restriction of chemical applications in agriculture, unless permission is granted. The Food and Agriculture Organization of the United Nations is in partnership with some small islands in the South Pacific to reinforce food self-reliance and reduce the dependence of food imports [106]. Many islands have organizations and institutions that educate scholars and farmers about chemical fertilizers and there is an emphasis on sharing knowledge about compost preparation and usage. In Niue, the Cook Islands, and the Republic of Marshall, organic farming is highly recommended. Niue is in the process of being named an 'Eco-Nation' that practices exclusively organic farming. In the Solomon Islands, a guide has been published to educate farmers about different methods of organic food production [106]. This shows that organic farming is considered an integral part of the economic evolution and food security of each nation. We propose that vermicomposting could be a good option for promoting organic farming in the region. Some SPICs (particularly atoll nations) are dealing with soil infertility and subsequent reductions in crop yield. The input of vermicompost could be applied in these soils to determine the extent to which it can replenish their nutrient content. The benefits of the product should also be examined in the high-salt soils that exist in many of the SPICs.

6.3. Tropical and Sub-Tropical Climates

The activity and productivity of earthworms in vermicomposting are highly influenced by temperature and humidity. Some species have a tolerance to higher temperatures while others produce more cocoons in cold environments. Indeed, the most commonly used vermicomposting species, *E. fetida*, performs profitably in a temperature range of 0 to 35 °C and the same range is applicable for *P. excavatus* and a few other species [82,107]. The vermicomposting process requires a temperature around 10 °C to 32 °C [40]. The question remains whether their optimal temperature ranges are aligned with the temperatures in the SPICs.

The annual temperatures of the SPICs are very similar. Among them, the lowest average annual temperature registered at 20 °C and the highest at 31 °C. Samoa has an annual average temperature of 28.5 °C [108]. The Australian Bureau of Meteorology and CSIRO (2011) [109] reported an annual average temperature in the Cook Islands of 24.5 °C in the South and 28 °C in the North, an annual temperature range of 23.5–27.5 °C in Vanuatu, and 20–27 °C in Fiji. Additionally, Kiribati has an average annual temperature of 27 °C [109,110]. Therefore, the SPICs have a climate that is suitable for maintaining the fertility and growth of earthworms.

6.4. Availability of Biomass for Vermicomposting

The South Pacific region has a year-round growing season. Due to the high temperatures, high humidity, heavy precipitation, and fertile volcanic soil, there is continuous growth of large amounts of plant biomass that could be used as the raw material for vermicomposting alone or in combination with locally available pig, poultry, or cattle manure. In addition, Fiji has a large sugarcane industry that produces lot of sugarcane baggage and trash. Utilization of these industrial by-products (waste) for vermicomposting would be beneficial for these industries as it allows them to be recycled. Vermicomposting would transform these wastes into a product that can be used for promoting organic agriculture in this region. Moreover, the rapidly expanding urbanization in this region produces huge amounts of organic waste that are presently only partially collected and mostly landfilled. This waste causes environmental pollution and greenhouse gas (GHG) emissions, as they are not managed sustainably. Thus, recycling of organic waste through vermicomposting may reduce the deterioration of the environment as well as produce organic inputs for agriculture.

6.5. Demand for Biopesticides

As with chemical fertilizers, pesticides are not easily accessible by the farmers of SPICs, and therefore, are not widely used in agriculture in the SPICs. Vermiwash can be used as a growth fertilizer [111], but also as bio pesticide. It produces a layer of protection for the plants against diseases and pests. The fungus, *Phytophtora colocasiae*, is one of the major sources of crop destruction in taro production within the SPICs. There has been no effective method found to date to control the destructive impact of the fungus especially in Samoa, except with synthetic chemicals, but their high cost makes their use prohibitive and they have harmful effects on the environment [112]. Vermiwash could provide a sustainable environmentally friendly alternative and should be investigated as a means of effectively protecting these crops from disease. In addition, it could be used to control wilt disease in banana crops in the Solomon Islands [113], Panama disease in banana crops (*Musa* sp.) in Vava'u, or to fight against Yam anthracnose (*Glomerella cingulata*), which affected several countries in the South Pacific [113].

6.6. The Low-Tech Nature of Vermicomposting Systems

The materials used in the vermicomposting process are mostly handmade. The structures are built using cement blocks, wood, or plastic materials. The three main types of vermiculture systems are as follows: beds or bins, flow-through reactors, and windrows [87,114]. All of them are affordable but the choice of the system and its methodology should be made and mastered to suit South Pacific crop production systems, weather conditions, and the availability of materials.

6.7. Suitability for SPICs Crops

South Pacific agriculture incorporates a lot of organic inputs and organic farming continues to be promoted in the region, as there is an increased demand for high quality products in export markets. In addition, there is a national desire of SPICs to protect the environment, biodiversity, and family farming structures. To address this, vermicompost could be very much suitable as an organic fertilizer. Most of the crops cultivated in the region, viz. sweet potato, taro, cassava, tomato, capsicum, spinach, watermelon, squash, okra, eggplants, ginger, papaya, banana, and lemon, respond well to vermicompost based on the literature from other parts of the world (Table 4).

Table 4. Potential South Pacific Islands crops that might benefit from vermicompost application.

Crops	Vermicompost Application Rate	Reference
I. Field crops		
Taro (*Colocasia esculenta*)	5–10 t/ha	[115]
Sweet potato (*Ipomoea batatas*)	10–15 t/ha	[116,117]
Cassava (*Manihot esculenta*)	5–10 t/ha	[118,119]
Sugarcane (*Saccharum officinarum*)	5 t/ha	[120]
II. Horticulture crops		
Eggplant (*Solanum melongena* L.)	3–6 t/ha	[121]
Tomato (*Solanum lycopersicum*)	5 t/ha	[122,123]
Okra (*Abelmoschus esculentus*)	5 t/ha	[124]
Capsicum (*Capsicum annuum*)	10 t/ha	[24]
Water melon (*Citrullus lanatus*)	10 t/ha	[125]
Ginger (*Zingiber officinale*)	2–5 t/ha	[126]
Turmeric (*Curcuma longa*)	2–5 t/ha	[126]
Papaya (*Carica papaya*)	20 kg/plant	[127]
Coconut (*Cocos nucifera* L.)	2–20 kg/plant	[115]

6.8. Required Adaptive Research

Although the literature suggests that production and use of vermicompost is very much feasible in the region, some tailor-made adaptive research interventions are required for adjusting the technology under Pacific agro-eco systems. The following are some suggestions for future adaptive research:

Assessments of the suitability of native earthworm species for vermicomposting;
Analysis of the suitability of available raw materials (substrate) for vermicomposting;
Standardization of protocols for vermicompost production in a Pacific context;
Situation-based crop response studies;
Awareness development for adoption of vermicompost use.

7. Conclusions

The South Pacific region has a suitable climate and sufficient amounts of organic biomass for promoting vermicomposting technology. Furthermore, the declining soil fertility of the South Pacific region must be addressed if they are to sustain food security. Moreover, the organic based agriculture system of the South Pacific region requires organic inputs. Thus, it can be concluded that vermicomposting has a high potential in this region for sustaining organic based agricultural production systems and improving the environment. However, some adaptive research is required to identify suitable and efficient earthworm species and utilization of locally available biomass before promoting this technology to farmers.

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