Review

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Integrating Organic Fertilizers in Coconut Farming: Best Practices and Application Techniques

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Integrating Organic Fertilizers in Coconut Farming: Best Practices and Application Techniques

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Abstract: Organic fertilizers are a revolutionary concept in coconut farming as they provide a package for sustainable coconut production. This chapter looks at the multiple advantages of organic fertilization methods and types of organic fertilizers which include compost, vermicompost, livestock manure, green manure, crop residues, and biofertilizers. Chapter focuses on the best practices, application methods, time of application, frequency and rate of application of nutrients for coconut palm at various developmental stages. The chapter provides a detailed and systematic review of the environmental, economic and social impacts of organic fertilization. Benefits include enhanced soil health, biodiversity promotion, carbon sequestration, cost effectiveness, quality improvement of the yield, food security and possibilities of creating rural income. Issues including resource accessibility difficulties, nutrient deficiencies, and intensive labor requirement are explored in detail, as well as future trends that focus on advanced technologies, new research areas, and policy approaches. Thus, the chapter on organic fertilization as a coherent concept that can be applied to coconut production and other goals of environmental protection, food security, and sustainable development of agriculture.

Keywords: coconut production; carbon sequestration; environmental protection; food security; sustainable agriculture

1. Introduction

Organic fertilizers are a more comprehensive concept of nutrient supply for plants than the mere provision of nutrients [1]. These natural amendments, unlike synthetic chemical fertilizers, not only supply nutrients but also modify the structure of the soil, stimulate microbial populations, increase water-holding capacity, and support biotic diversity. To coconut growers, knowledge on good organic fertilization practices can go a long way in increasing yield, vigor, and sustainability of the coconut plantations [2]. Organic fertilizers are important in coconut farming because of the special nutritional demands of the crop and the intricate production environments of coconut palms [3]. Coconut palms are established as perennial crops that require well-planned and adequate nutrient supply throughout their growth period, which may extend to several years. The conventional chemical fertilization practices cause decline in soil health, less of microbial population and deterioration of the environment [4]. However, there are natural sources of fertilizers which can be used to supply these nutrients in a more environmentally friendly way. There are a number of organic fertilizers that are especially ideal for coconut production. These are compost, vermicompost, green manure, livestock manure, bio-fertilizer, and crop residues [5]. All of these sources present different nutritional values for the plants and the soil they are applied on.

Several significant factors more need to be understood in the use of organic fertilizers in coconut agriculture. These include nutrient content, rate of decay, type of soil, climatic conditions and the growth stage of the coconut palm in influencing the most appropriate fertilization regime. Farmers need to adopt an integrated strategy that takes into account these variables, if the use of organic amendments is to yield the maximum benefits [6].

Evaluation of the soil health therefore serves as the basis for organic fertilization. Any fertilization program should be preceded by a proper soil analysis in order to determine the current nutrient status, pH, organic matter and microbial populations [7]. These assessments assist in developing strategies for fertilization of coconuts that are specific to each site depending on the nature of the coconut plantation. The most effective method in the use of organic coconut farming is the use of multiple sources of organic fertilizers [8]. This approach is also known as integrated nutrient management where different organic materials are added to the soil in a package to balance nutrient needs.

The timing and method of applying organic fertilizer are as important as the type of fertilizer to be used. Coconut palms have different nutrient needs at different stages of their growth from the young plant development to the mature stage of production [9,10]. Weather conditions such as seasonal changes, rainy period and local climate also affect the efficiency of fertilization measures. Since these are environmental factors, farmers have to come up with strategies that counter them. The use of organic fertilization in coconut farming is one of the progressive methods that are being adopted in the current world trends of sustainable agriculture that enhance productivity, environmental conservation, and sustainable agriculture production [2]. Through the implementation of holistic, systems-oriented organic nutrient management approaches, coconut farmers are better positioned to create more sustainable, productive, and profitable production systems[11]. This chapter aims to provide a detailed insight into the use of organic fertilizers in coconut farming, including types, advantages, best practices of application, limitations and prospects of the technology for sustainable coconut farming.

2. Types of Organic Fertilizers in Coconut Farming

2.1. Compost

Compost is therefore a complex organic fertilizer solution for coconut production that turns a wide range of organic inputs into soil amendments of high nutrient value through the management of biological processes [12]. Composting is the controlled decomposition of organic matter by microorganisms in a systematic way under conditions of temperature, moisture and aeration [13]. The compost that can be made for coconut plantations include, crop residues, livestock manure, kitchen wastes, and perennial weeds [14]. Compost of high quality has several advantages in addition to the supply of nutrients such as increased porosity, water holding capacity, microbial population, and slow-release nutrient [15]. Composting is usually a stepwise process that involves the addition of different organic materials in correct carbon and nitrogen proportions and an occasional turning of the pile [16]. Farmers can make compost from locally available materials to fertilize coconut hence adopting a cheap and sustainable practice (Figure 1). There are other more developed methods of composting such as the vermicomposting which involves using earthworms to speed up the rate of decomposition and come up with better quality organic fertilizers [17]. Compost management is critical in maintaining a constant nutrient supply, soil health and sustainable agriculture.

Figure 1. Heap method compost production in coconut lands. (Source: Figures by authors).

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2.2. Vermicompost

Vermicompost is a complex, biologically alive organic manure that is made through the controlled biological process using earthworms [18]. These remarkable organisms feed on organic waste materials and convert it into nutrient fine textured compost of high agricultural value (Figure 2). In coconut farming, vermicompost plays a role of a better soil conditioner that has several nutritional and ecological values. It also encompasses certain earthworm species as well as *Eisenia fetida* that has the ability to decompose organic matter like agriculture residuals, livestock manure and plant waste with greater efficiency [19]. In the process of decomposition, earthworms have the ability to size reduce organic inputs, introduce microbes and improve the chemical nature of the nutrient through their grinding enzymes. The end product of vermicompost has been noted to contain higher nutrient content than that of compost, such as nitrogen, phosphorus, potassium and micro nutrients [20]. To coconut plantations, therefore, vermicompost has a number of remarkable benefits. It has a fine texture, which makes it allow for quick nutrient uptake, it also has a high microbial population, which shall encourage root growth and strengthen the plant against diseases [21]. In this technique of slow-release nutrients, nutrients do not leach and steadily cover the requirements of the plants for many days.

Figure 2. Vermicompost production in coconut lands. (Source: Figures by authors).

2.3. Livestock Manure

Livestock manure is a rich source of organic manure obtained from different livestock sources and each has its own nutrient value and organic matter for coconut production [11,22]. The provided Table 1 presents the macro and micronutrient contents in major livestock manures. It includes organic sources such as goat manure, cattle manure, boiler litter, layer litter, and pig dung, and lists the percentages or values of various nutrients like nitrogen, phosphorus, potassium, magnesium, calcium, iron, manganese, copper, zinc, and boron present in these organic sources. Before applying livestock manure to coconut plantations, there are some important factors that farmers need to take into consideration [2,22]. The manure should be well decomposed to avoid nitrogen lockout and to avoid spreading of potential pathogens. Appropriate composting processes prevent the emission of bad smells and also fix the nutrients and make it easier to have a standard compost [23]. The application rates are usually recommended to be between 10-25 kg per coconut palm per year depending on the soil type, age of palm and initial soil fertility (Figure 3) [10]. Apart from nutrient supply, the incorporation of livestock manure has many other agronomic benefits. It increases the microbial population in the soil, stimulates the growth of the nutrient-friendly microorganisms, helps in improving the aeration and water retention capacity of the soil and releases the nutrients slowly and continuously in order to feed the plant [24]. Also, livestock manure enhances carbon storage, increases soil organic matter content, and decreases the use of chemical fertilizers [25].

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Table 1. Macro and Micronutrient contents in major livestock manures. Adapted from [10].

	Organic Source	**Nitrogen (N)%**	**Phosphorus (P)%**	**Potassium (K)%**	**Magnesium (Mg)%**	**Calcium (Ca)%**
Macronutrient %	Goat manure	2.2-3.4	0.3-0.7	1.5-2.5	0.4-0.8	1.5-2.4
	Cattle manure	1.2-1.9	0.2-0.5	0.5-1.1	0.5-0.6	1.3-1.8
	Boiler litter	2.0-2.3	0.6-1.0	1.7-2.0	0.5-0.6	1.0-4.9
	Layer litter	1.8-2.4	0.6-1.2	0.6-2.0	0.4-0.7	2.7-5.3
	Pig dung	1.0-2.0	0.6-0.9	0.4-0.9	0.4-0.6	1.0-1.5
	Organic Source	**Iron (Fe)**	**Manganese (Mn)**	**Copper (Cu)**	**Zinc (Zn)**	**Boron (B)**
Micronutrient ppm (mg/kg)	Goat manure	1449-2174	246-505	20-38	112-184	29-66
	Cattle manure	690-1518	167-389	24-40	128-183	13-30
	Boiler litter	723-1565	213-421	27-40	166-271	15-27
	Layer litter	1144-2215	287-450	22-38	182-329	12-2
	Pig dung	1020-1990	180-207	45-48	186-575	34-13

Figure 3. Application of goat manure to coconut palms. (Source: Figures by authors).

2.4. Green Manure

Green manure fertilizers as a practice in coconut production is one of the most sustainable practices that improve the fertility of the soil. Among the tree or creep legumes gliricidia, sunn hemp, pureria, and mucuna are very effective because they are nitrogen fixing [26–29]. Wild sunflower is used as a source of potassium and as green manure enhancing nutrient uptake and growth of coconut palms [30]. According to the data, gliricidia leaves contain 3.5% nitrogen, 0.2% phosphorus, and 1.7% potassium, while wild sunflower has 2.39% nitrogen, 0.42% phosphorus, and 4.18% potassium [30]. These plants can be planted and grown as cover crops or as intercrop with coconut palms before being tilled back into the soil before they come into maturity. It enhances soil organic content as well as the structure of the soils and has capability of providing nitrogen through biological nitrogen fixation [31]. Some of the plants include wild sunflower and gliricidia among others since they have fast growth rates and high biomass production rates [32–35]. Another way is that such aquatic vegetation as water hyacinth or water lettuce can be used as needed as green manure in addition to providing additional organic matter and nutrients [36]. When burying or applying into the top soil, these plants breakdown and release slowly, nutrients which help nourish the coconut palms for a long-term other than fertilization that usually imparts a short-term gain at the expenses of the plant's health (Figure 4). Farmers can choose and change the green manure crops in a way that would benefit the soil fertility and the ecosystems [1].

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Figure 4. Gliricidia green manure as an organic fertilizer. (Source: Figures by authors).

2.5. Crop Residue

Coconut plantations can benefit from crop residues in the form of an easily accessible and effective organic fertilizer. Such materials include plant residues from prior harvests, for example, the fronds, empty bunches, husk residues, and other plant residues [37]. The residues from coconut crops can also be recycled effectively, coconut husk residue, and fronds are good organic matter (Figure 5). Crop residues if well utilized as a resource provide one of the most important sources of soil organic matter, determine the soil structure, increase water holding capacity and release nutrients slowly [38]. The decomposition process is a function of microbial activities that work to break down residual plant matter into useful organic products. Farmers can use different methods such as mulching, composting or direct application into the soil to optimize nutrient value of crop residues [39]. The carbon to nitrogen ratio of various residues determines the rate of decomposition and the rate of nutrient liberation. Through such dynamics, coconut farmers can enhance crop residue management and minimize the use of external fertilizers, which should enhance sustainable coconut farming practices that will support soil health and fertility in the long run [11].

Figure 5. Coconut petiole residue as an organic fertilizer. (Source: Figures by authors).

2.6. Biofertilizers

Biofertilizers are one of the most promising, environmentally friendly technologies for the use of nutrients in coconut production [2]. These living microorganism preparations improve the fertility of the soil through mutualism with the roots of plants, which in turn improves the uptake of nutrients and general growth of the plant [40]. Each type of biofertilizer is composed of different strains that have unique capability to transform nutrients including nitrogen fixing, phosphorus solubilizing, and production of plant growth hormones. The microorganisms used in the preparation of biofertilizers are *Rhizobium spp.*, *Azospirillum spp.*, *Azotobacter spp.* and *Trichoderma spp.* (Figure 6) [41]. These beneficial microbes inhabit the rhizosphere, enhancing nutrient uptake and utilization and enhancing

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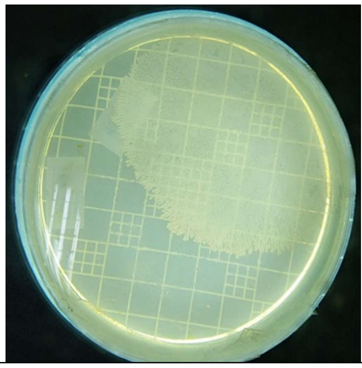
plant tolerance to biotic and abiotic stresses. When it comes to coconut plantations, biofertilizers can be applied in seed treatment technique, soil treatment technique or root treatment technique [22]. It has been ascertained that they have immense benefits over chemical fertilizers such as; environmentally friendly, cheaper to produce and improve soil microbial population. Biofertilizers are rich in various microbial populations that enhance the overall nutrient cycling, structure of the soil and make the agricultural system sustainable [42].



Isolation of *Trichoderma* from biofertilizer

Figure 6. *Trichoderma* enriched biofertilizer. (Source: Figures by authors).

3. Application Techniques and Best Practices

3.1. Correct Application Time and Frequency

While best time for application of organic fertilizers were found to affect the growth and productivity of coconut palm significantly, so also the correct application frequency [19]. It is therefore important to understand the ecological interactions of tropical regions in order to determine the appropriate application strategies of the proposed seasonal application strategies for coconuts taking into consideration rainfall and temperature as well as the growth cycle of coconut palms [43]. Fertilization of coconut in the growth stage needs a special consideration because the nutrient needs of the palm changes greatly from the seedling stage to the fruit bearing tree [22]. Suggested application frequency varies from different times per lifespan with great consideration given to climatic conditions as well as the type of soil. Timing is critical in most applications; as a result, farmers must decide when best to apply fertilizers as well as control factors that enhance effective nutrient uptake and reduce situations where nutrients might be washed away by rains or other natural occurrences [44]. Sophisticated methods such as, soil moisture control and climatic characteristics determination are useful in enhancing even more detailed and appropriate nourishing management to minimize the pollution impacts of fertilizers [45].

3.2. Dosage and Nutrient Management

Formulating elaborate dosage and nutrient management plans requires a systems approach and a dynamic perspective to the nutrition of coconut palms[46]. Fertilization needs vary with the age of the coconut palms hence the need to have dynamic nutrient delivery systems that meet the dynamic nutrient needs of the coconut palms at every stage in their development (Table 2). Soil condition adaptation measures include soil analysis, nutrient mapping, and soil specific fertilization that takes into consideration micronutrient and macronutrient deficiencies[47]. The nutrient concentration calculation methods should be able to include complex analysis such as; soil testing, plant tissue analysis and nutrient uptake and utilization models[48]. Sustainable and comprehensive application systems focus on the nutrient management where the biological activity, soil microorganisms and the health of the soil in the long run are not left out when determining the chemical composition[49]. This

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approach needs constant supervision, evaluation, and frequent changes in fertilization methods to sustain the coconuts palm's nutritional needs and productivity.

Table 2. Recommended organic fertilizers applications rates in different coconut age categories. Adapted from [10].

Source	**Time after transplanting**				
	6 months	**1 years**	**2 years**	**3 years**	**4 years up to bearing (every year)**
Goat manure (Moisture 20 - 30 %)	3kg	7kg	9kg	11kg	13kg
+					
Eppawala Rock Phosphate (in wet and intermediate zones)	200g	450g	600g	750g	100g
or					
Triple Super Phosphate (in dry zone)	85g	200g	270g	340g	420g
+					
Muriate of Potash	50g	120g	150g	190g	225g
+					
Dolamite	250g	250g	250g	250g	250g
Cattle manure (Moisture 20 - 30 %)	5kg	12kg	16kg	20kg	25kg
+					
Eppawala Rock Phosphate (in wet and intermediate zones)	200g	450g	600g	750g	1000g
or					
Triple Super Phosphate (in dry zone)	85g	200g	270g	340g	420g
+					
Muriate of Potash	30g	200g	250g	325g	400g
+					
Dolamite	250g	250g	250g	250g	250g
Poultry manure (20 - 30 %)	5kg	12kg	16kg	20kg	25kg
+					
Dolamite	250g	250g	250g	250g	250g
Gliricidia leaves (Moisture 20 - 30 %)	5kg	12kg	16kg	20kg	25kg
+					
Eppawala Rock Phosphate (in wet and intermediate zones)	275g	650g	825g	1100g	1350g
or					
Triple Super Phosphate (in dry zone)	120g	285g	370g	470g	580g

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+					
Muriate of Potash	60g	150g	200g	250g	250g
+					
Dolamite	250g	250g	250g	250g	250g

3.3. Efficient Application Methods

The use of accurate methods in applying organic fertilizer to coconut plants is a refined method of improving nutrient utilization in coconut production [2]. Trench and surface application methods include establishment of nutrient delivery areas around the palm root system so as to allow direct nutrient access (Figure 7). Broadcasting methods are more extensive in nutrient coverage and are best suited for young palms or during early stages of soil modification [50]. The use of an advanced fertigation system is identified as a state-of-the-art technology that focuses on the integration of irrigation and fertilization to develop efficient fertilization technologies [51]. These methods need proper standardization depending on the soil type, age of palms, nutrient status of the soil and the prevailing climatic conditions. Advanced application methods apply modern technology tools such as GPS equipped application equipment, sensors and nutrient management software to enhance efficiency of fertilizer usage and to reduce losses [52].

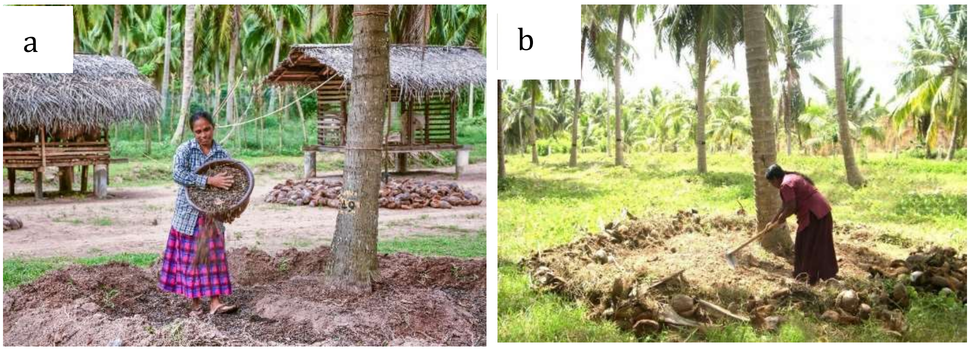

Figure 7. Organic fertilizer application by (a) Trench method, (b) Surface method. (Source: Figures by authors).

3.4. Monitoring and Aftercare Operations

Monitoring and aftercare activities are important in the use of organic fertilizer in coconut farming. When using organic fertilizer, it is important for moisture conservation and nutrient retention that is why mulching is an important process [53]. After applying organic fertilizers, check the mulch layer frequently and keep it at 10-15 cm thickness surrounding the coconut palms. It should also be evenly distributed and replaced because it breaks down over time. watering is important especially when there is dry season or drought. Check the availability of moisture in the soil and ensure to supply moisture content at fixed intervals preferably by drip or other irrigation methods [54]. Weed control is important in order to avoid competition for nutrients. Farmers can use manual weeding or use of organic mulch to prevent weed growth in the garden [55]. Coconut palms should be weeded around the base, but the weeds should not be removed in a manner that affects the root system. Pest and disease management is something that needs keen observation. Follow methods such as biological control measures; implementing beneficial insects, treating pests with neem and rotating crops [56]. Remove those parts of the plant that are affected by pests or diseases, apply organic fungicides for pest and diseases control and ensure good field hygiene.

4. Benefits of Organic Fertilizers in Coconut Farming

4.1. Environmental Benefits

4.1.1. Soil Health Improvement

Organic fertilizers are thus a revolution in improving soil health in coconut plantations and are a good solution to sustainable agriculture [57,58]. These fertilizers added in the soil alters the soil structure in such a way that additional natural organic matter to improve it by making it porous and well aerated required for the growth of coconut palms. The improvement of the internal structure of the soil also increases the porosity and capacities for water retention and thus increases out the uptake of water for periods of drought [59,60]. This improvement is especially important for tropical climates where coconut production takes place because it reduces the susceptibility to moisture changes. However, not only it supports and enhances the beneficial microbial growth in the soil but also makes a population of a living soil ecosystem [61]. These microorganisms decompose the organic matter, make the required nutrients soluble and form mutually beneficial interactions with the coconut palm roots. Sustained use of organic fertilizers gradually accumulates organic matter over time and gradually over time alters the soil structure and productivity of the agricultural land [62].

4.1.2. Biodiversity Promotion

Organic fertilizers act as a stimulus for the development of the biological structure of the coconut plantations' ecosystems, which are complex and diverse [63]. Because these fertilizers do not contain synthetic chemicals, known to suppress the soil microbiome, they promote complex soil communities that include bacteria, fungi and other beneficial microorganisms that result from natural inclusion of natural organic matter [64]. These diverse microorganisms are also involved in biogeochemical cycling, soil aggregation, and plant health. Converted soil environment to a microhabitat which may improve the population of useful insects, pollinators and natural enemies of pests [65]. These microorganisms and insects help to maintain a better and healthier ecosystem in the agricultural field, and have less requirement of external pest control. The diversity also goes beyond the soil which could again help form a more connected ecosystem able to fight out environmental factors [66]. Organic fertilizers also make the coconut growing environment to be more dynamic and self-controlling as it supports the lives of many other forms of life in the soil.

4.1.3. Carbon Sequestration

Organic fertilizers in coconut cultivation are shown to be a significant contributor to carbon sequestration and therefore a valuable input to fighting climate change. These fertilizers include organic matter, which facilitates sequestration of carbon in the soil as it reduces the chances of the gas being released into the atmosphere [67]. Over time as the organic matter and carbon breaks down, it assimilates itself into the land and creates very stable carbon which can stay locked up in the ground for relatively long periods. Coconut plantations using organic fertilizers can thus change agricultural landscapes into carbon sinks and thus decrease greenhouse gases [68]. An increase of these types of carbon performs the 'soil health service' to increase the organic matter which helps in improving the structure of the soil, as well as improves the ability of the soil to store more carbon forming a virtuous cycle [69]. Besides, this approach helps not only in coconut palm nutrition but also in the natural solution of climate change problems worldwide [70]. The proposed modes of organic nutrients are effective not only to promote agriculture and food production, but also to enhance the efforts in capturing carbon all at the same time, meaning farmers can support both environmental conservation and agriculture production in the long run.

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4.2. Economic Benefits

4.2.1. Cost-Effectiveness

The use of organic fertilizers is economically viable for coconut farmers and provides a more economically sustainable way to feed the plants. These fertilizers are made on the farm through composting, crop residues and other organic wastes, hence greatly reducing the cost of purchasing costly chemical fertilizers [71]. The use of locally available materials to produce fertilizers makes waste management a value-added agricultural practice which brings down input costs significantly [72]. Farmers can use locally available organic materials such as plant residue, livestock manure and green waste to formulate quality nutrient blends at a relatively low cost. This approach also helps to minimize the reliance on the external markets for agricultural inputs, which is normally volatile and unpredictable. When farmers reduce the number of inputs they have to purchase, they are able to control their own economic destinies more effectively [73]. The positive impacts of the organic fertilizers on the long-term soil health also adds to the economic sustainability since the farmer may not have to spend a lot of money to rehabilitate the soil, control pests and diseases and recover the crop [74]. This comprehensive economic approach helps farmers to produce more sustainable and less dependent on external support agricultural systems.

4.2.2. Increase the Yield Quality

Organic fertilizers provide a good hope for increasing coconut production and better-quality yield that are of immense economic importance to the farmers. Due to the slow released nutrient that is available in the natural fertilizers, plant growth is steady and vigorous, which may enhance the overall coconut yield [75]. The comprehensive nutrition leads to a healthier palm growth and thus, produces bigger and better coconuts that can be sold in the market at higher prices [76]. The status of organic cultivation itself becomes a desirable characteristic in marketing the produce, given the growing consumer concern for sustainably produced agricultural products [77]. Fresh coconuts grown organically are usually sold at a premium because of perceived health and environmental benefits hence an added economic advantage for farmers. The enhanced soil health from organic fertilization also enhances long-term production potential and thereby decreases the variability of yields and the corresponding variability of farm income [78]. This approach turns organic fertilization from a simple nutritional concept into an elaborate economic one that solves production, quality, and market positioning at once.

4.2.3. Income Diversification

Organic fertilizer production can be viewed as the promising sector for diversification of the coconut farming economy [79]. It is possible for farmers to turn waste management into an opportunity for income generation through producing high quality organic fertilizers for the local and regional markets [80]. Through the production of surplus organic fertilizer products, farmers can develop other market outlets apart from the usual coconut sales. This approach promotes the generation of small-scale circular economy systems in which agricultural and organic waste is turned into valuable farming inputs. The farmers can also have an opportunity to create market opportunities other than the agricultural products through branding of organic fertilizer lines [81]. There is increasing market demand for organic and sustainable agricultural inputs, which is the right environment for such endeavors. Furthermore, this diversification strategy helps in the economic diversification since the agricultural businesses are developed to be more economically robust with many sources of income [82]. Those involved in organic fertilizer production can also benefit from consulting and training services, which are other economic possibilities for innovative farmers.

4.3. Social Benefits

4.3.1. Health and Safety Benifits

Organic fertilizers provide deep health and safety benefits to farmers, farm workers and consumers, providing a new social context to coconut farming [83]. These natural alternatives eliminate use of synthetic chemical fertilizer, which when used in agriculture exposes human being to many harmful agricultural chemicals that pose severe health consequences. Farmers and agricultural workers do not have direct contact with toxic substances that cause acute or chronic diseases, dermatitis, respiratory diseases, and other diseases in the long term [84]. Consumers enjoy the coconuts that are grown from organic fertilizers that reduce the chances of chemical contaminants. The lowered chemical content means that the food products are less toxicologically hazardous [85]. This approach is a human health centered approach that is implemented along the agricultural value chain from the growers to the consumers. The holistic health protection includes not only the safety from the aggressors but also the health protection and, therefore, potentially contributes to overcoming the modern tendencies in agriculture [86]. Which are based on hardly sustainable to the human health priority, and potentially can enhance and rescue the healthcare sphere by avoiding increasing costs and providing better and more human-oriented priorities to agriculture.

4.3.2. Food Security

Organic fertilizers are a vital input in sustaining food production stability and improving food security in coconut growing areas [11]. Therefore, the natural fertilization ways of restoring and equally enhancing the quality of the soil results in more reliable and long-lasting production methods for agriculture. The slow-release of nutrients and enhancements of the structural of the soil known with the organic fertilizer are conducive to stable growth condition that will enhance organisms to endure the challenges of the natural conditions such as climate volatilities, water, and changing agriculture terrains [87]. Appropriate farming practices involving use of organic fertilizers also contribute to conservation of agriculture productive land resource for future generation food production. These approaches are less dependent on external inputs and also on chemical intervention as they encourage increased organic production. Organic fertilization thus helps to enhance the health of ecosystems hence a better and more sustainable environment for agriculture that will deliver food production as needed [1]. The long-term view inherent in organic farming practices is a clear response to the most acute problems of food security of agricultural populations.

4.3.3. Rural Development

Organic fertilizers are a revolution in the development of rural areas, providing full-spectrum solutions for economic and social development of agricultural regions [88]. These natural fertilization methods therefore help to advance more sustainable forms of rural economy that go beyond conventional farming. Organic farming opens up niches for value added agricultural produce that could attract high end markets and contribute to the development of the regional economy [89]. These practices support knowledge intensive agricultural systems, skills, technology and entrepreneurship among the rural people. Such focus can draw external investment, technical workshop and educational programs that are interested in the responsible agriculture models [90]. Organic fertilizer production can thus act as a trigger for wider rural economic diversification and the generation of employment, local industries and the evolution of more robust community economic structures [91]. Organic fertilization embraces the principles of respecting local resources, indigenous knowledge, and sustainable practices, which makes it a part of a more holistic approach to rural development as compared to the conventional, purely economic approach.

5. Challenges of Organic Fertilizers in Coconut Farming

5.1. Difficulties of Accessibility and Resources Availability

Organic fertilizer is a major challenge for coconut farmers especially in the remote and less developed areas to source the commodity. The scarcity of organic inputs as well as the restricted access to the processing facilities poses a major challenge to the adoption of sustainable fertilization [92]. Rural farmers face problems of inadequate supply of organic wastes, poor or no means of transport, and lack of expertise in the production of organic fertilizers. Small and isolated farming areas can limit the availability of a wide variety of organic matters and thus limit the development of effective fertilization plans [93]. These challenges can be effectively tackled by the government and agricultural development organizations by setting up community composting centers, extending requisite infrastructural facilities and developing micro-organic waste collection systems. Cooperative farming techniques, municipal waste recycling, and extension services can go a long way in filling the resource gap so that farmers can come up with sustainable and locally driven solutions to organic fertilization [94].

5.2. Nutrient Deficiencies and Imbalances

Nutrient management is one of the most complicated issues in coconut farming when it comes to the change in organic fertilization. Organic fertilizers are generally characterized by slow nutrient liberation rate and this may lead to temporary nutrient depletion during the initial stages of conversion from synthetic fertilizers [95]. Coconut palms are highly sensitive to macronutrient and micronutrient ratios, and as such, nutrient management is very important [96]. Some of the common deficiencies are nitrogen, phosphorus, potassium and micro nutrients such as magnesium and zinc which affect coconut production and tree health. Like any other crop, farmers need to apply complex nutrient management plans that include detailed soil analysis, application of organic matter, and use of fertilizers [49]. Some of the suggested possibilities include the formulation of the site-specific organic fertilizers, application of multiple sources of organic nutrients and the application of other techniques such as intercropping and green manuring.

5.3. Intensive Labor and Knowledge Requirements

The production and use of organic fertilizers require significantly more time and effort from workers and more expertise than chemical fertilization [97]. Farmers should be able to master all forms of composting methods, organic waste management, nutrient recycling and complex soil fertility management. Organic fertilizer preparation is a labor-intensive process requiring collection of wastes, composting, processing, and application methods [98]. Most of the farmers especially those in the developing countries' traditional agricultural sectors do not possess the technical know how to properly apply organic fertilization. This is where education interventions come in handy thus requiring a lot of farmer training, educational extension services, and practical skills development [99]. Government agencies, agricultural research institutions and NGOs can thus have significant roles in the development of complete training packages, showing examples of practical organic fertilization, and offering technical back up [100]. Extension models such as those based on community learning, farmer-to-farmer knowledge transfer, and online learning might be useful in the more effective transfer of the critical knowledge in organic farming.

6. Future Perspectives Are Organic Fertilizers in Coconut Farming

6.1. Advanced Technological Innovations

Advanced technologies are already changing the ways of using organic fertilizers in coconut production. Precision agriculture will be used to feed nutrients to the crops using GPS drones and satellite imagery [101]. Genetically modified microbiological inoculants will be created to increase nutrient uptake and improve plant tolerance. Soil nutrient sensors will be nano sensors that will help farmers to monitor nutrient content in the soil in real time and make adjustments to fertilization accordingly [102]. The recommended fertilization schedule will be predicted by machine learning algorithms depending on the analysis of the coconut soil microbiome, climate, and coconut variety. Advances in biotechnology will enable the creation of targeted microbial communities that enhance nutrient access and plant growth [103]. By incorporating IoT devices in smart fertilization, the rate at which nutrients are absorbed, the health of the soil, and the performance of crops will be immediately determined [104]. These technological developments will go a long way in increasing the efficiency of organic fertilization, decreasing the effects of the environment and increasing the productivity and sustainability of coconut plantations.

6.2. Research and Development Focus

Subsequent research on the use of organic fertilizers in coconut production will focus on extensive genomic analysis to determine the coconut varieties that benefit most from organic nutrient application[105]. Molecular biology tools will assist in identifying specific microbes that can form a microbial consortium that will benefit given coconut varieties and the ecological conditions of a particular region[106]. Organic fertilizer formulation will be a key area of emphasis in climate change adaptation research because of the fluctuations in weather conditions that may affect the effectiveness of the fertilizer[107]. Multi-disciplinary approaches will be used in the identification of new and sustainable approaches to recycling organic waste for nutrient production. Coconut root systems genetics will be mapped, enhancing the knowledge of nutrient uptake processes, and hence, better fertilization. Coconut plant physiologists will study the relationships between the soil microbial communities, organic fertilizers, and coconut plant to design nutrient management strategies[105].

6.3. Policy and Institutional Support

The governmental policies will further consolidate the sustainable agricultural practices via entire support framework. Farmers are likely to adopt the organic fertilization methods due to the incentives that will be offered such as subsidies and tax holidays [108]. The funding for research institutions will be raised to create protocols for organic fertilization for specific locations. To ensure that the best practices in the production of organic coconut are put in place, more extensive certification programs will be developed [109]. Agricultural extension services will initiate appropriate training for farmers with a view of enhancing their abilities in organic fertilization [110]. Local partnerships will enhance exchange of knowledge and technology in sustainable agriculture practice among nations. There will be policy harmonization between climate change mitigation measures and policies supporting organic farming [111]. Measures will be put in place to regulate the quality of the organic fertilizers so that there is no act of green wash. Institutional support will therefore aim at developing sound impacts assessment mechanisms for monitoring the effects of intervening in organic farming on the environment and the overall economy.

7. Conclusions

The use of organic fertilizers in coconut production is a major turning point towards sustainable production that has both ecological, economic, and social impacts. This approach does not only feed coconut palms while meeting their requirements but also improves the soil condition, encourages other plants and trees growth, and helps store carbon, making coconut production systems more adaptive to climate change. More desirable and effective for this case are organic fertilizers since they release the nutrients slowly into the soil allowing for improved and healthier crop yield, without polluting the environment. Farmers financially are benefited through organically being relieved from expensive and synthetic inputs and creating awareness to use locally available resources. This practice also creates opportunities for the higher value markets that appreciate coconuts produced through sustainable means and give farmers better income prospects and more sources of income.

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Economically and environmentally, the use of organic fertilizers make food more secure for human consumption by promoting soil health that will support productivity in the future and would contribute a lot to the improvement of the livelihoods of farmers in the rural setting. It also protects the health of the farmer, the worker, and the consumer from toxic chemicals and reinforcing the organic farming in a healthier society. From the above-discussed challenges, it is clear that various barriers exist including labor intensity, and a general difficulty in resource accessibility. However, through enhancements in technology, research, together with mainly enforced supportive policies, it is possible to conquer the aforementioned barriers. The use of organic fertilization in coconut farming is one way of making the activity more productive, sustainable and friendly to the environment in order to sustain the coconut farming in the future.

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