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REVIEW ARTICLE

Sustainable diversification in Indian agriculture: Effectiveness of integrating horticultural crops as intercrops in mono-cropping coconut system

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Abstract

Coconut, also known as Kalpaviruksha, is a gift from nature that is grown all over the world for its many uses. The distinctive characteristics of the coconut tree indicate that mono-cropping coconut results in extremely low land use efficiency. Another drawback of mono-cropping from an economic standpoint is the substantial initial investment required to develop the crop until it reaches bearing age, which may be beyond the means of smallholders. In most coconut-growing countries, planting coconut alongside a range of other crops is a popular practice to maximise land use efficiency. It has been determined that over 100 distinct crop and system combinations can be cultivated as intercrops alongside coconut plantations. Intercropping is more efficient than mono-cropping and increases yield, if the components of the intercrop utilize natural resources in ways that complement each other's utilization of those resources, which generates a higher benefit-cost ratio than the sole crop. The relevance and possibilities of multiple-cropping and intercropping systems suitable for different coconut stands are covered in this article. The results provide an overview of coconut farming's lucrative and sustainable intercrop species that support the income of farmers, as well as the advantages, drawbacks and prospects of several multiple-cropping systems. The paper concludes by outlining potential research avenues for the effective adaptation of different cropping systems based on coconut.

Keywords

coconut; horticulture; intercrops; coconut based multiple-cropping system; sustainability

Introduction

The coconut (*Cocos nucifera* L.) is a multipurpose crop that can be used for fuel, shelter, food, medicine, fibre and other purposes. After Indonesia and the Philippines, India is one of the world's top producers of coconut. More than 91% of the acreage and output of coconut in India is grown in the southern states of Tamil Nadu, Kerala, Karnataka and Andhra Pradesh (1). These states are the main coconut-growing regions. Even at ideal plant density, this smallholder crop's monoculture status prevents it from giving its dependent households sufficient income and productive work. Research showed that an adult coconut palm planted as a single crop and spaced 7.5 m × 7.5 m apart uses only 22.3% of the land area (2, 3). In addition, the canopy uses about 30% of the air space on average and hinders only 45-50% of solar radiation (4). Thus, the farmer has access to an immense quantity of land that is not covered by coconut plantations.

In a 2 m radius surrounding the palm, more than 80% of the active roots are found in the 25-60 cm soil layer, leaving 70-75% of the soil available for use by other crops (Fig. 1). Less than 10% of the potential dry matter output in the tropics is produced by coconut, which only occupies 25% of the land during the yielding phase and makes extremely low use of natural resources (5). Hence, they provide more opportunities for intercropping with a diversity of crop species.

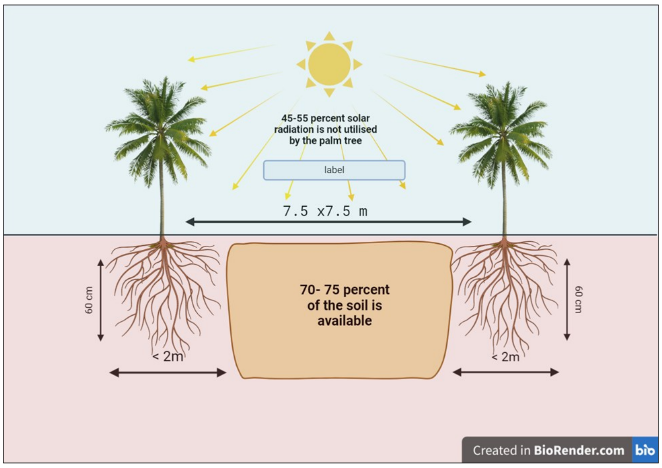

Fig. 1. Suitable characteristics of coconut for multi-species cropping system.

When compatible crops are grown in the spaces between coconut trees, production and productivity per unit area increase significantly as cropping intensity increases due to more efficient use of sunlight, soil, water and labour (6). Among these, fruit, vegetable, tuber, spice and beverage and legume crops hold a special role (7). A well-organized, multi-story crop model with high density that is customized to a particular agro-climatic condition produces more biomass output, more economically viable produce, a consistent and increased overall income, more job opportunities for local people and satisfies a variety of farmer needs, including food, fruit, vegetables, medication, oleoresins, essential oils and so forth (8-10). Export of its flowers can also be a large source of foreign exchange. According to Mohandas (11), medicinal plants are traded in the world's largest medicine markets and have a constantly expanding market. To satisfy their needs and achieve extremely efficient resource utilization, the high-density multi-species cropping system (HDMSCS), which consists of many species of seasonal, annual and perennial crops, arose (4). By using resources like sunlight, soil, water and labour more effectively, coconut-based cropping systems (CBCS), which cultivate compatible crops in the spaces between coconuts, provide significant potential for increasing productivity per unit area, time and input. Hence, the multi-cropping system based on coconut cropping is an agronomic method for effective resource usage in addition to boosting farm profitability.

Survey methodology

This investigation aims to conduct a comprehensive review of the literature on the viability of incorporating other horticultural crops as intercrops in a mono-cropping system centered on coconut. Research on the intercropping system based on coconut may be found in several places. A coconut-based agricultural system has been cultivated and managed using a range of combinations to provide a year-round source of sustainable income. Our main goal is to encourage farmers to become more knowledgeable about the advantages of multi -cropping systems and how they may be adapted to current farming practices. The survey technique that we employed to compile our comprehensive evaluation of the efficacy of integrating horticulture crops as intercrops in a mono-cropping coconut system is covered in this section.

Keyword selection and data sources

The first set of search terms was carefully selected based on our study goal. Several keywords were created by combining new phrases discovered in numerous relevant papers after a preliminary search had been performed using terms like "coconut," "intercropping system," "coconut intercropping system," "effect of intercropping in coconut," "intercropping benefits," etc. Later, these keywords were condensed to meet the goals of the study better. Based on the objective of our work, we picked certain search terms, from which a number of keywords were extracted from a few chosen articles following a preliminary search. A range of keyword terms was utilized, such as "coconut-based multi cropping system," "benefits of coconut intercropping," "coconut-based farming system," and "coconut with intercrops."

Database selection

For the purpose of conducting the literature review, we retrieved research articles from a few academic digital sources. We consulted experts while choosing our sources and we gathered academic papers for our study from databases such as Google Scholar and Tamil Nadu Agricultural University (TNAU) online digital library. Table 1 below lists the data sources (along with links) that we used for our research.

Table 1. Description of academic data sources collected and their links

Data sources	Search string	Links
Google Scholar	Coconut based multi cropping system, Benefits of coconut intercropping, Coconut based farming system and coconut with intercrops	https://scholar.google.com/
TNAU online digital library	Coconut intercropping	https://agritech.tnau.ac.in/tnau_publish_eresource.html

To determine potential relevance to this review, the titles of all the papers were analyzed. Any publication that did not include a cropping system based on coconut was disqualified from additional research. To conduct a more thorough study and gain a deeper knowledge of the studies, the publications' abstracts and keywords were examined. We may conclude that the majority of the data included in this study came from research publications, with just a small amount coming from agricultural statistics, textbooks and other sources for the systematic literature review.

Compositions of multi-cropping systems in coconut mono-cropping

In coconut gardens, a variety of fruits, spice crops, tuber crops, aromatic and medicinal plants, flowers and vegetable crops can be effectively produced as mixed or intercrops (12) (Table 2). Crop compatibility, planting material availability, crop demand in the area, nutrient status and market pricing should all be taken into consideration when selecting an intercrop.

Table 2. Annuals and perennial horticultural crops suitable for intercropping in coconut plantation (13, 14)

Category	Intercrops suitable	Scientific name
Fruits	Banana	*Musa*
	Pineapple	*Ananas comosus*
	Papaya	*Carica papaya*
	Guava	*Psidium guajava*
	Mango	*Mangifera indica*
	Passion fruit	*Passiflora edulis*
	Pomegranate	*Punica granatum*
	Lemon	*Citrus limon*
Vegetables	Brinjal	*Solanum melongena*
	Tomato	*Solanum lycopersicum*
	Okra	*Abelmoschus esculentus*
	Chillies	*Capsicum spp.*
	Cabbage	*Brassica oleracea*
	Ridge gourd	*Luffa acutangula*
	Sponge gourd	*Luffa cylindrical*
	Snake gourd	*Trichosanthes cucumerina*
	Bottle gourd	*Lagenaria siceraria*
	Drumstick	*Moringa oleifera*
Spices	Pepper	*Piper nigrum*
	Vanilla	*Vanilla planifolia*
	Turmeric	*Curcuma longa*
	Ginger	*Zingiber officinale*
	Cardamom	*Elettaria cardamomum*
	Cinnamom	*Cinnamomum verum*
	Clove	*Syzygium aromaticum*
	Nutmeg	*Myristica fragrans*
Plantation crops	Coffee	*Coffea spp.*
	Cocoa	*Theobroma cacao*
Flowers	Gerbera	*Gerbera spp.*
	Gladiolus	*Gladiolus spp.*
	Tuberose	*Polianthes tuberosa*
	Marigold	*Tagetes erecta*
Leguminous crops	Pigeon pea	*Cajanus cajan*
	Cowpea	*Vigna unguiculata*
	Mung bean	*Vigna radiate*
	Groundnut	*Arachis hypogaea*
Medicinal and aromatic crops	Aloe vera	*Aloe barbadensis miller*
	Neem	*Azadirachta indica*
	Tulsi (Holy Basil)	*Ocimum tenuiflorum*
	Brahmin	*Bacopa monnieri*
	Kalmegh	*Andrographis paniculata*
	Coleus	*Plectranthus scutellarioides*
	Kacholam	*Kaempferia galangal*
	Roselle	*Hibiscus sabdariffa*
	Citronella	*Cymbopogon nardus*
	Lemon grass	*Cymbopogon citratus*
	Cowhage	*Mucuna pruriens*
	Cassava	*Manihot esculenta*
Tuber crops	Sweet potato	*Ipomoea batatas*
	Elephant Foot Yam	*Amorphophallus paeoniifolius*
	Greater yam	*Dioscorea alata*
	Lesser yam	*Dioscorea esculenta*
	Tannia	*Xanthosoma spp.*
	Taro	*Colocasia esculenta*
	Chinese potato	*Plectranthus rotundifolius*
	White yam	*Dioscorea rotundata*

Multiple advantages of a coconut-based multi-cropping system

A multi-cropping system based on coconut provides farmers with a number of advantages in addition to sustainability and profitability. Fig. 2 lists the advantages of a farming system centered on the coconut with intercrops. Increased productivity per unit area, improved resource utilization (land, labour, time, light, water and nutrients), decreased damage from pests, diseases and weeds and socioeconomic factors (better stability, economics, human nutrition and biological aspects) are just a few of the many benefits that make intercropping so effective (15). A common cropping strategy used in coconut production around the globe is intercropping (7, 16, 17). Intercropping is a perfect instance of a more productive use of labour and natural resources (18). It increases farmer revenue and food security while also aiding in weed management (19).

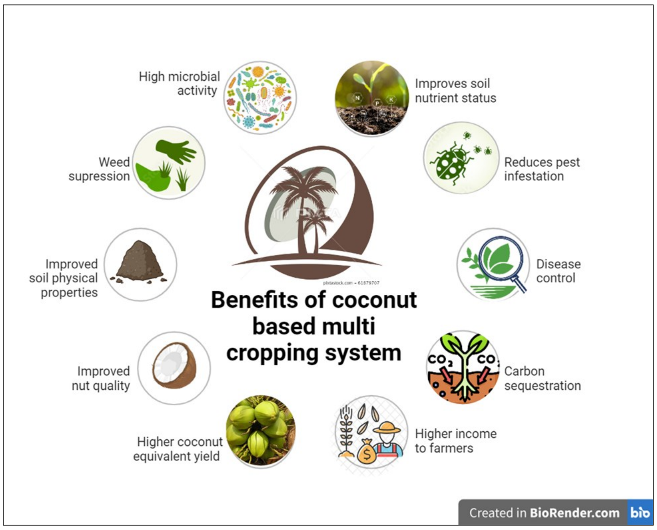

Fig. 2. Various benefits of the coconut based multi-cropping system.

Selection of varieties to be grown as intercrops in a coconut -based cropping system

Panniyur-1 recorded the highest net returns with a 37% increase in average net profit from the coconut + pepper model compared to mono-crop cultivation, according to an assessment of the economics of black pepper varieties as an intercrop in coconut gardens in the lower Brahmaputra valley of Assam (20).

Black pepper, when intercropped with coconut under Kasaragod conditions, provided additional income under a high-density multi-species cropping system based on coconut (21). Karimunda and Panniyur-1 cultivars perform better in multi-storied cropping systems and mixed cropping systems. Thevam, Panniyur-1 and Panniyur-5, Sreekara, Panchami, Kottanadan and Malabar Excel (HP 813) were found to perform well in a mixed crop coconut garden under Kasaragod conditions. Therefore, it is recommended that black pepper be grown as an intercrop in that area (22-24).

Sweet potatoes are another good intercrop that could potentially be grown in young orchards of coconut (25) and the variety "Samrat" would be especially suitable and deserving of recommendation for growing under Odissa weather conditions (26).

Effect on the vegetative growth of coconut and its intercrops

The growth of *Ailanthus triphysa* in monospecific and coconut-based cropping systems was compared and the mixed stand exhibited larger mean annual height and basal stem diameter increments. The increased rates of growth reported in mixed species production systems were attributed to the micro-environmental modifications inherent in intercropping scenarios, which facilitated the growth of *Ailanthus* (27). Under the conditions of South Gujarat, the experimental garden showed enhanced growth and productivity in the coconut variety West Coast Tall (WCT) intercropped with cocoa. The fact that cocoa is a cauliflorous plant, an increase in the number of leaves on the crown, tree height and stem girth all suggest strong plant vigor, which is directly correlated with bearing (28).

When the coconut is intercropped with vegetables in coastal regions, the outcome of the study showed that the average number of main roots was roughly the same in both, mono-crops and palms intercropped with vegetables. However, the intercropped zone, with 85 new roots, exhibited a significantly higher root count compared to the mono-crop's interspace, which had only 49 new roots.In the intercropped area, vegetables in coastal regions were maintained with irrigation and manuring, resulting in constant availability of water and nutrients that influenced root growth. This was mostly caused by the long-term effects of vegetable cultivation in the interspaces. In contrast to the mono-crop (in the interspace area), where the roots stayed dry and black in color, this has allowed the roots to stay alive and actively absorbing (29). Additionally, there were fewer fine roots because there was less water and nutrients available. In addition, the average number of fine roots was higher in the intercropped area, with 43 roots, compared to the mono-cropped area, which had an average of 21.5 roots. Despite having an adequate number of fine roots, the roots in the mono-crop's interspace were dry, darkly colored and inactive. However, new and white-colored roots of intercropping palms were discovered. This was mostly caused by the water and nutrients that were present in the trench that was covered with coconut husk to make vegetable planting easier. In the sandy coastal soil, the husk prevented leaching and allowed water and nutrients to be retained. For improved root growth, this husk allowed for a sufficient supply of nutrients and water. Vegetables grown through intercropping in a coconut garden with husk as an amendment yielded higher nut yield over the mono-cropping.(30)

The application of husk and coir pith in the pits had a positive effect on the growth of ash gourd and pumpkin. Intercropped palms exhibited higher physiological indicators, including photosynthetic rate, stomatal conductance and transpiration rate. The intercropped palms' enhanced production was caused by their higher photosynthetic rate, which was affected by the constant availability of water and nutrients (31).

Effect of coconut intercropping on improving soil properties and nutrients

When the palms are young and as they get older and their stems get longer, coconut mono-crop stands only partially cover the ground. As a result, during these times the soil is more vulnerable to erosion and degradation. Moreover, these are the most ideal times to intercrop because it is both most desirable and practicable. Many of these soil conservation measures that might otherwise be required could be avoided by engaging in intercropping and using responsible land management techniques for the intercrops. Therefore, boosting soil fertility is one important benefit of intercropping, which can make coconut fields more sustainable. The palms benefit from the manures and fertilizers given to the intercrops, elimination of weeds, soil working and other management practices, etc. (Fig. 3). The organic matter content of the soil is increased by intercropping systems compared to single coconut systems. Hence, a productive soil has a high quantity of organic matter because it promotes enhanced soil structure, aeration, lower bulk density and a high water-holding capacity (32).

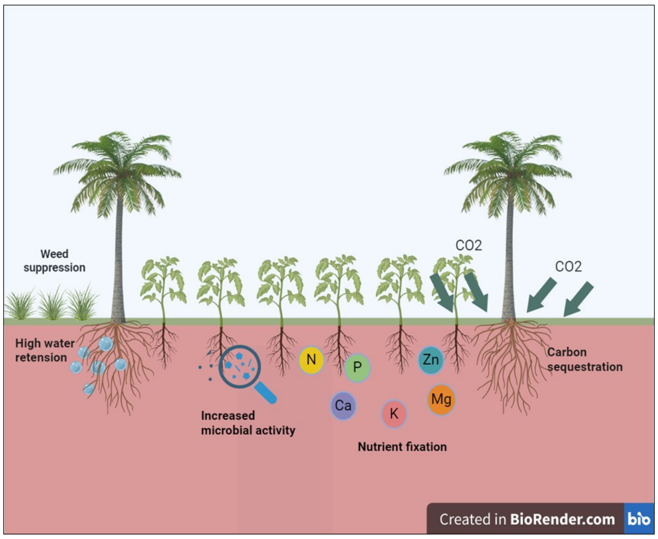

Fig. 3. Effect of coconut intercropping on improving soil properties and nutrients.

Microbial activity

The microbiological activity of mixed coconut and cocoa crops has been found to be greater than that of a coconut mono-cropping system. Beneficial microorganisms are among the most crucial elements of the soil system because they maintain the soil's health and quality, making it dynamic to the cropping system sustainability and nutrient turnover (33). In coconut plantation, marigold intercropping treatment had the highest beneficial microbial population throughout the flowering season. Additionally, it manages harmful soil microorganisms through its natural production of alpha-terthienyl and thiophene compounds. These biochemicals suppress soil-borne pathogens, especially *Fusarium* species and plant parasitic nematodes, while the root exudates create unfavorable conditions for harmful microbes. This creates long -lasting changes in the soil microbiome, breaking disease cycles and promoting a healthier balance between beneficial and harmful microorganisms, ultimately improving soil productivity and plant health, which has an impact on the productivity of soils as well as the microbial ecological balance in the soil. Higher microbial populations in intercropping treatments are due to a healthy and conducive environment for the microorganisms as compared to the control plots (34). When comparing the cashew coconut intercropping system to the pure coconut system, higher soil microbial activity was noted. This is mostly because the intercropping method adds more organic matter to the system, improving the quality and fertility of the soil (35, 36).

Nutrient cycling and fixation

The process of cycling and fixing nutrients involves legumes such as *Gliricidia sepium* fixing atmospheric nitrogen through their roots, which enriches the soil for the intercrop and coconut. Legumes and cover crops, for instance, enrich the soil with organic matter that promotes microbial activity and nutrient release (37). The release of fixed phosphorus was favorably influenced by the greater phosphatase enzyme activity in the coconut mixed farming plots (38). Compared to coconut mono-cropping, mixed farming systems had higher concentrations of phosphate-solubilizing bacteria and nitrogen -fixing bacteria. There was a greater increase in soil microbial biomass and soil enzyme activity (urease and dehydrogenase).

In comparison with previous studies on nitrogen (264.07 kg ha^{-1}) and potassium (288.11 kg ha^{-1}) accumulation in the soil, it was reported that maximum nitrogen (271.63 kg ha^{-1}) and potassium (292.39 kg ha^{-1}) accumulation were recorded in the coconut + black pepper + ginger + colocasia model cropping system. Relative to coconut mono-cropping, the combination of coconut, black pepper, onion and potato demonstrated the highest P accumulations (85.84 kg ha^{-1}) (39). This could be due to the fact that in the coconut-based cropping system model, a companion crop of partially shade-loving, high-value, long-duration broad-leaved crops was introduced. In addition to increasing the growth of companion crops, this promoted long-duration management that had a favorable impact on soil moisture conservation in the coconut root zone through natural mulching (40-42).

Soil physical properties and water retention

The soil's physical, chemical and biological properties improve with intercropping. The organic carbon content, total nitrogen, available phosphorus, exchangeable potassium and earthworm activity increased, while bulk density decreased when coconut was intercropped with cocoa, coffee and pepper (43). Intercropping is most beneficial due to the addition of organic matter to the soil (44).

Intercropping improves water retention and nutrient preservation by reducing soil erosion caused by wind and rain (37). In a high-density multispecies cropping system study conducted at CPCRI, Kasaragod, it was clearly revealed that a higher number of species diversity enhanced the nutrient recycling capacity. The contribution of each component crop, viz. coconut and intercrops to the nutrient pool is explicitly influenced by the nature of the species. Intercrop roots improve drainage and aeration by loosening the soil, which is good for the growth of intercrop and coconut roots (45). Enhancements in the soil's organic matter status and water-holding ability, together with the consequent yield increases, are essential components of ecosystems oriented around coconut. In Ghana, the cacao + coconut mixture retained more soil moisture than the cacao + *Gliricidia sepium* system. (46) A study from Sri Lanka found that the soil profiles of interplanted acacia (*Acacia auriculiformis*) and gliricidia plots had higher bulk density, aeration, water content and soil organic matter status than those of solo coconut (6).

The organic matter content of coconut inter-planted with cocoa increased significantly from 0.86% in a mono-crop to 1.42%. The coconut intercropped with pepper and cocoa had the highest organic matter content and the greatest capacity to store water. Seasons that receive extensive rainfall reduce surface runoff due to enhanced water retention capacity, which boosts plant water economy (44).

Carbon sequestration

Storing carbon in the biosphere as a means of removing it from the atmosphere is known as carbon sequestration (47). The coconut-based cropping systems, which entail the cultivation of compatible crops, particularly fruit crops, in the interspaces, may offer significant potential for increasing production and productivity per unit area, time and input by more efficiently utilizing resources like sunlight, soil, water and labor. It may also have a lot of area for fixing and storing carbon dioxide from the atmosphere, which is essential for preserving the environment. It will resemble a forest system (48). It is evident that mixed stands of coconut palms store more carbon than solitary stands do, particularly when there are trees in the species mix. For example, in a system with different intercropped fruit trees planted along with coconut, such as guava (*Psidium guajava*), litchi (*Litchi chinensis*), sapota (*Manilkara zapota*) and custard apple (*Annona reticulata*), better soil carbon sequestration occurs for mixed-species systems than for monocultures of coconut (49).

Weed suppression

Perennial and annual weeds can grow in the empty space beneath the coconut palms, competing with the coconut for plant nutrients and moisture in the soil. By competing with weeds for nutrients, light and space, intercrops naturally prevent weed growth. Weeds in coconut orchards can be effectively and inexpensively controlled by using mixed farming systems and intercropping based on coconut, which makes use of the understory's unused area. Different cropping techniques have a significant impact on soil organism diversity and abundance because of the variability of soil quality (37). Intercropping coconut with other suitable crops generally lowers weed populations and raises coconut yields (50).

Effect of intercrops on entomofauna in coconut plantation

Attracting beneficial insects and preserving biodiversity

A more balanced environment is produced by a greater variety of insects, birds and other beneficial species that are supported by diverse vegetation. Through food web research and observational investigations, 23 parasitoid species that are present in the surrounding agro-ecosystems attack *O. arenosella*, often known as the Black Head Caterpillar (BHC), which is a major issue in coconut plantations. In cropping systems based on coconut, intercrops (such as cucumber, mulberry, key lime and papaya) that provide alternative hosts for the shared parasitoids have the potential to boost parasitoid abundance year-round and lower the burden of *O. arenosella* infection. Consequently, a range of intercrop species enhances the effectiveness of parasitoid-mediated BHC control (51).

A multi-cropping system based on coconut attracts beneficial insects that help suppress pest populations in a variety of ways. For example, they can prey on harmful pests like mealybugs, scales and beetle larvae and can parasitize pest insects by laying their eggs inside their bodies, killing the host and allowing the beneficial insect offspring to grow. The significance of choosing suitable intercrops, such as legumes and flowering plants, was highlighted (52).

Beneficial insects are drawn to the coconut plantation by the pollen and nectar that these trees frequently produce. It gives beneficial insects a different habitat for appropriate reproduction and refuge, which increases their population and increases their ability to control pests. It's vital to remember that a variety of factors, including the particular intercrop selected, the local environmental circumstances and the presence of pest pressures, might affect how efficient intercropping is at attracting beneficial insects. On coconut farms, intercropping can be a useful tactic for fostering a robust and harmonious environment.

Disease management

It has been demonstrated that high-density multi-species gardens enhance the root wilt-damaged gardens' production system. In a garden suffering from root wilt, growing tuber crops including *Amorphophallus*, *Dioscoria* and *Colocasia* recovered their capacity to yield nuts within a high-density multi-species cropping system based on coconut, increasing net revenue. The interplanted trees may also act as natural enemies' refuge, a barrier to insect migration and a mask for odors emitted by other components of the system (53).

The implementation of a high-density multi-species cropping system resulted in an approximate 17% increase in the overall production of coconut palms afflicted by root (wilt) disease, compared to the baseline output of 53 nuts/palm in the fourth year, according to studies carried out in Kerala. It was shown that the high-density multispecies cropping system based on coconut, with a BC ratio of 1.59, provided a 61% economic advantage over mono-cropping in areas affected by root (wilt) disease. This suggests that the system is economically sustainable, provided integrated strategies are used to control disease incidence and other production and price-related risks are kept at a suitable level (54).

Reduction in pest incidence

Growing cocoa under coconut palms has a significant benefit in terms of land and sunlight efficiency. Furthermore, *Helopeltis* is killed by black ants (*Dolichoderus thoracicus*), which is why coconut can biologically aid in the indirect reduction of *Helopeltis* infestation in cocoa plants (55). The diversity or abundance of natural enemies, which are frequently found in mixed plantations, can lead to biological control of pest insects as well as disruption of pest insects caused by the presence of another, more palatable host tree species in the same stand, when comparing the incidence of insect pests in single-species versus mixed forest plantations (56).

Using coconut as a model, researchers studied *Ailanthus triphysa* growth in monospecific and mixed species settings in an agroforestry system. They noted changes in the miro-environment caused by intercropping as well as a decrease in the frequency of two of the plant's main insect pests, *Atteva fabriciella* (Lepidoptera: Yponameutidae) and *Eligma narcissus* (Lepidoptera: Noctuidae). Higher pest frequency in mono-specific situations is caused by the likelihood of adult insects in a solid stand striking against a prospective target tree more frequently than in a mixed species stand (27).

Effect on the yield and socio-economics of coconut and various intercrops

Due to the recent fluctuations in coconut prices and the high cost of production, pure coconut harvesting is no longer cost-effective. Therefore, in order to increase the financial well-being of the coconut farmers as well as the coconut production and nut quality, intercropping in coconut gardens with appropriate crops is essential.

Intercropping several combinations of component crops-such as vegetable cowpea, banana, ginger, turmeric and elephant foot yam-in a coconut garden can boost net income (57). Banana and elephant foot yam were determined to be the perfect companion crops for coconut (58). The nut production in coconut on a poor site should increase after inter-planting (27). Growing cassava, elephant foot yam, greater yam, lesser yam and taro in the rotation increased coconut palm productivity by five to fifteen percent (59).

Regarding nut production, in cocoa intercropped with coconut, the palms yielded 60 nuts per palm year from 2008 to 2010 and the rate improved to 82 nuts per palm year in 2016–17. Better growth, as seen by an increase in the number of functioning leaves, may be the cause of the phenomenon. The growth and yield of coconut may have been aided by the intercropping-induced favorable microclimate, increased microbiological activity and improved soil fertility (60, 61). In India, a coconut + ginger combination planted in rainfed circumstances produced good returns since ginger did well in shaded conditions, outperforming some other crops by 11-27% when compared to open fields.

Aromatic crops like citronella intercropping in coconut fields enhanced land use efficiency from 21-46% while also increasing the primary crop's productivity (11, 62). When herbal plants were interplanted with coconut, the mean annual nut yield increased to 18000 nuts per palm year, or 18% more than when coconut was grown solely. While various crops can be cultivated successfully in coconut gardens (63), quite a handful of researchers have reported on the profitability of cultivating flower crops as intercrops in mature coconut gardens (64, 65). Intercropping a variety of flowers, including jasmine, chrysanthemum, crossandra, china aster, marigold, gomphera, celosia and zinnia, boosted the productivity of the flower crop and raised the coconut equivalent yield (64). Gerbera, tuberose, gladiolus and marigold may be planted as profitable intercrops in mature coconut gardens without lowering nut production, based on the productivity and economics of commercial flower crops (65).

Mixing coconut with gerbera produced the highest overall coconut equivalent production (48920 nuts/ha/year). After that, coconut was combined with gladiolus (42334 nuts/ha/year) and tuberose (42717 nuts/ha/year). Compared to other coconut crops of a similar size, the coconut mono-crop produced substantially less, with an annual yield of 10430 nuts/ha. Increased input in the form of fertilizers, irrigation, weed control and other variables led to improvements in nut output and coconut equivalent yield in the coconut-based system. This proved that flower crops may be cultivated alongside coconut as an intercrop without compromising the primary plants' development or yield (66).

Effect on the economics of different coconut-based multi-cropping systems

The majority of the research focused on how the intercrop combination improved grower income while examining its financial implications. It is widely acknowledged that intercropping under coconut trees is more profitable than mono-cropping and it offers farmers several benefits in addition to creating new job opportunities (67). Intercropping coconut with field crops (68), vegetables (69), aromatic and medicinal plants (70) and flower crops (64, 65, 71) has also been shown to increase economic return. The practice of growing flower crops alongside coconut trees in Assamese coconut gardens has been studied which indicates that the coconut + gerbera cropping system yielded a much greater net income of Rs. 380075/ha and a B:C ratio of 3.5 in comparison to the coconut + tuberose cropping system, which produced a net revenue of around Rs. 323420/ha and a B:C ratio of 3.1 (72).

In terms of financial considerations, coconut-based intercropping systems are the best choice. Specifically, compared to coconut mono-crops, these systems yield Net Present Values that are 11, 9, 8.7 and 5.7 times higher for coconut + betel, coconut + pineapple and coconut + betel + banana, respectively (73). In the model of a coconut-based cropping system, ginger, turmeric, colocasia and elephant foot yam can be suggested as companion crops in addition to black pepper for a better economic return. The combination of coconut, black pepper, ginger and colocasia produced an excellent B:C ratio (1.91) and net income (Rs. 410018 ha^{-1}) (39).

The coconut groves in Kerala are an excellent choice for intercropping medicinal plants such as ginger, turmeric, satharathai, patchouli and kasturimanjal. Studies conducted in a coconut garden with numerous medicinal crops as intercrops revealed that Sintharathai obtained a net return of Rs. 89898 ha^{-1} and a B:C ratio of 1:3.2, while Aloe vera and Tulsi achieved a net return of Rs. 91058 and 43280 ha^{-1} and the B:C ratio of 1:3.8 and 1:3.0, respectively (74). When it comes to aromatic plants, lemon grass yielded a net return of Rs. 16085 ha^{-1}, while patchouli earned a net return of Rs. 19010 ha^{-1} and a B:C ratio of 1:2.1. It was noted that using ravolfia as an intercrop can increase coconut plantations' profitability (75). Patchouli may be grown economically in Kerala's irrigated coconut groves with 25-50% shadow intensity (76). Based on their performance and economics, it was concluded that the chosen plants-Sitharathai, Chothukathalai, Tulsi, Lemon grass and Patchouli-were all effective intercrops in mature coconut gardens (Table. 3).

The most profitable crop combination among the possibilities provided is Coconut + Aloe, with a benefit-cost ratio (BCR) of 3.8 based on the BCR values. A very good profitability is shown by the favorable BCRs for coconut + black Pepper (Panniyur), coconut + black Pepper (Sreekara), coconut + gerbera and coconut + sitharathai. Therefore, it can be said that combining coconut and black pepper with any medicinal crop will increase farmer profits (Fig. 4). It is important to remember that other elements such as market demand, regional climate and farming resources may also have an impact on the selection of the optimal crop combination. Farmers should adopt a comprehensive strategy, considering other pertinent aspects of effective and sustainable farming in addition to the BCR.

Table 3. Benefit-Cost ratio (BCR) of different intercrop combinations in coconut-based cropping system

Crop combinations	B:C ratio	References
Coconut + Tuberose	3.1	(72)
Coconut + Gerbera	3.5	
Coconut + Bird of Paradise	2.7	
Coconut + Gladiolous	2.9	
Coconut + Marigold	2.8	
Coconut + Sitharathai	3.2	(11)
Coconut + Aloe	3.8	
Coconut + Tulsi	3.0	
Coconut + Lemon grass	2.1	
Coconut + Patchouli	2.1	
Coconut + Black Pepper + Ginger + Colacasia	1.91	(39)
Coconut + Black Peer + Coriander + Sweet Potato	1.59	
Coconut + Black Pepper +Chilli	1.52	
Coconut + Black pepper + Onion + Potato	1.27	
Coconut + Black Pepper +Sweet Potato +Onion	1.65	
Coconut + Black Pepper + Turmeric + Elephant Foot Yam	1.83	
Coconut + Black Pepper (Panniyur)	3.48	(78)
Coconut + Black Pepper (Sreekara)	3.12	
Coconut + Kalmegh	2.56	(13)
Coconut + Coleus	1.66	
Coconut + Arrow Root	2.28	
Coconut + Cowhage	2.41	
Coconut + Lemongrass	2.89	
Coconut + Vettiver	2.25	

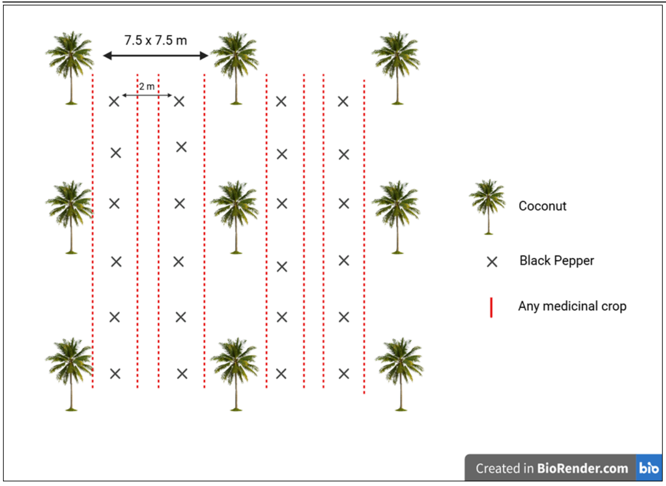

Fig. 4. Layout of coconut-based multi-cropping system using Coconut + black pepper + medicinal crop under square system.

Constraints in coconut based multi-storey cropping systems

Although the high-density multi-species cropping system has many advantages, it also has several drawbacks. Priority-wise, the biggest obstacles to CBI were the high cost of inputs, especially agrochemicals and inorganic fertilizer and the unpredictable and low price of intercrops (77). Other significant barriers were the drought, disease and pest problems, lack of understanding and lack of extension help. Disease issues provide a serious barrier, with bunchy top and Panama in bananas, wilt in pineapples and soft rot in gingers being the most common ailments. One other significant issue that the farmers have noted is the lack of hired labour. The labour needs on an annual average for bananas, pineapples, ginger and betel are approximately 2, 4, 11 and 17 times higher, respectively, than those of coconut monoculture. This demonstrates unequivocally that cultivating intercrops associated with coconut offers more employment opportunities. Despite the fact that these items' market prices are currently set by free market forces, middlemen may alter farm-gate pricing in certain areas (73).

Conclusion

Giving coconut farmers access to subsidized fertilizer, ensuring a fair price for intercrops, providing technical assistance, offering financial support in the form of low-interest loans and subsidies and providing them with subsidized agricultural equipment are the main suggestions to promote intercropping based on coconut. The most crucial recommendation is to guarantee that the inter-croppers' produce is sold at a fair price. While research on drought-resistant intercrops under coconut shade may be kept as a long-term plan, research on effective moisture conservation strategies may be highlighted as an immediate problem related to the coconut inter-cropping system. Increased export opportunities and enhanced marketing channel efficiency (i.e., preventing intermediaries from taking an excessive share of high prices) may result in higher prices for the producers. Enhancing the technical guidance provided to current inter-croppers is the other significant recommendation. The prevalence of the recent, widespread Panama disease in banana and the ongoing wilt disease in pineapple have highlighted the significance of expert guidance.

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Authors' contributions

SF carried out the collection of literature and drafted the manuscript. SSB and ARMS carried out the data collection. SR participated in the design of the study and performed the statistical analysis. SK conceived of the study and participated in its design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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