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Enhancing ecosystem services and energy use efficiency under organic and conventional nutrient management system to a sustainable arecanut based cropping system

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ABSTRACT

The present study was undertaken to explore the impact of no nutrient, organic nutrition, and integrated nutrient management on ecosystem services, and the energy balance of the arecanut based intercropping system. Most indicators of ecosystem services were influenced significantly by nutrient management practices. The energy efficiency (1.72) and net energy (19625 MJ ha^{-1}) improved significantly in the organic nutrient practice due to lower energy input (30722 MJ ha^{-1}) and higher energy output (50347 MJ ha^{-1}). The mean values of the indicator of dependence on non-renewable energy sources and an indicator of farm autonomy for organic farms were 0.3 and 0.46, respectively. The study suggests 46% of the inputs produced in the farm were recycled in the organic farms. The significantly higher sustainability yield index (0.25), sustainability value index (0.44) and system economic efficiency (21 USD day^{-1}) were observed in the organic nutrient system. The study concludes that organic nutrition along with adequate management is required to harness the potential of arecanut based cropping system to improve energy efficiency, ecosystem services, and soil quality to achieve sustainability.

1. Introduction

Ecosystem services (ES) are the benefits derived by human beings from an ecosystem such as provisioning, regulating, cultural and supporting services [1]. For example, agroecosystems provide provisioning services such as food, fiber, fodder, fuel, and income generation, etc., regulatory services such as soil conservation, nutrient recycling, water regulation, etc., and cultural services including recreation and aesthetic and others [2]. These services can be enhanced or reduced based on the intensity of management practices and the structure and composition of plant species composition [3]. In intercropping systems, two or more crops are planted simultaneously in the same land that provides the possibility of yield benefit following sole cropping. Intercropping systems as a multifunctional ecosystem provides numerous ES while also component crops in the intercropping systems provide fruits, vegetables, spices, and timber, etc. [4], and act as a major source of livelihood to the farmers. Besides, intercropping systems provide ES like enrichment of soil fertility, soil conservation and creates a suitable microclimate for subsidiary crops in the system [5]. The tree-based intercropping systems help in the mitigation of climate change-induced impacts by lowering canopy temperature [6] in the understory, leading to biodiversity conservation and carbon sequestration [7]. The temperature and relative humidity under areca canopy are lowered by 2 °C and 24% respectively [6] due to intercropping. However, intensive management systems may perturb the natural capability of such systems by air, water and soil pollution leading to disservices to the ecosystems [8]. Hence, the role of management intensity and biomass turnover on different indicators of ES need to be evaluated to enrich the ES from the intercropping systems.

A systematic assessment of energy balance and the economic feasibility of an agro-ecosystem can provide insights on the environmental impacts associated with the crop production technologies and management practices [9–11]. The energy input-output relationship, energy productivity, and specific energy are useful parameters for designing a sustainable production system and in

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Nomenclature

ABCS	Arecanut based cropping system
AEY	Arecanut equivalent yield
BD	Bulk density
CS	Carbon stock
DHA	Dehydrogenase
ES	Ecosystem services
FYM	Farmyard manure
ha	Hectare
IFA	Indicator of farm autonomy
IDNR	Indicator of dependency on non-renewable inputs
INM	Integrated nutrient management
MII	Management intensity index
MBC	Microbial biomass carbon
NM	No Manuring
OF	Organic farming
SRI	Species richness index
SOC	Soil organic carbon
SVI	Sustainable value index
SYI	Sustainable yield index
SEE	System economic efficiency

mitigation of greenhouse gases (GHGs) emissions [12]. Hence, energy balance studies are useful to identify the strategies that save energy and enhance its use efficiency in agricultural production systems and provide a basis for adopting best management practices (BMPs) while also supporting the sound management and policy decisions towards its adoption [12,13]. Several studies have been conducted to quantify the energy use of diverse agricultural production systems globally [14–17]. There is a scarcity of available information about energy use under a tree-based intercropping system, and especially for the arecanut based intercropping system, there is no reported work available in the literature.

Arecanut (*Areca catechu* L.) is a commercial crop in South and South-east Asia. India grows arecanut in 0.44 million ha land area and contributes to 50% of the world production [18]. The arecanut based cropping systems (ABCS) is the most practiced intercropping system on the west coast of India [19]. The main goal of the farmers in the region is to enhance the overall system productivity of the farm that is run for subsistence, and therefore each farm is managed for the production of vegetables, fruit crops, spice crops, timber crops, and firewoods. However, the component crops in the intercropping system compete for space, nutrients, and light, and leading to low productivity of the system [20]. The ABCS was practiced mostly through organic farming practices on the west coast of India, but, in recent years due to the availability of low cost/subsidized inputs (chemical fertilizers and pesticides) farmers have also adopted the modern cultural practices. Understanding the ES provided by ABCS and factors influencing different indicators of ES, and energy balance are important to ensure sustainability particularly on the west coast of India. Hence, we hypothesized that understanding the factors responsible for improving the ES, and energy balance of ABCS will be useful to ensure the long-term sustainability of such systems. In this context, the present study was conducted with the objectives to (i) assess the ES provided by ABCS under different nutrient management practices, and (ii) assess the energy balance of ABCS under different nutrient management practices.

2. Materials and methods

2.1. Experimental design

The field survey of seventy farmers was conducted primarily in five major arecanut growing subdivisions of Goa like Ponda, Bicholim, Satari, Pernem and Canacona (Fig. 1) from September 2017 to April 2018, farms ≥1 ha were surveyed. The farmers were interviewed and the information regarding inputs, outputs, management practices, economics and plant species present in the farm were collected through a detailed questionnaire. It was followed by a visit to farm holding by random transect walks. The *in situ* and *ex situ* addition of biomass in the form of farmyard manure (FYM), green leaf manuring and mulching using crop residue were recorded both through questionnaire and field observations. The ABCS is mainly concentrated under sloppy undulating terrain in the region. Most of the ABCS farmers have medium to high landholding with an average landholding of 1.5 ha. The ABCS was categorized into 3 different classes based on the nutrient management practices followed during the past 15 years as no manuring (NM), organic nutrient farming (OF) and integrated nutrient management (INM). The NM plots were neglected farms with no external addition of organic manure as well as inorganic fertilizer, only occasional irrigation and weed management are followed. Under organic farming plots, the farmers are using farmyard manure, greenleaf manuring, recycling organic residues available in the farm and practicing all the organic farming practices. While the INM farmers practice nutrient management using organic manures and inorganic fertilizers and pest control through the use of pesticides. The climatic condition of Goa is hot and humid, with temperatures ranging from 17 to 35 °C and precipitation ranging from 2500 to 3200 mm annum^{-1}. Most of the rainfall is received through southwest monsoon from June to October. Soils of the region are lateritic, coastal saline, clay and sandy type with a high content of ferric aluminium oxides [21]. The soil is alluvial and loamy in further inland and along the river banks. The soils of the region are rich in minerals and humus, hence favorable for the cultivation of plantation crops.

2.2. Management intensity index (MII)

The information on different management practices followed by areca farmers was collected during the survey. The areca farmers of this region mainly practice ten management practices in a year (Table 1). The common management practices found are basin

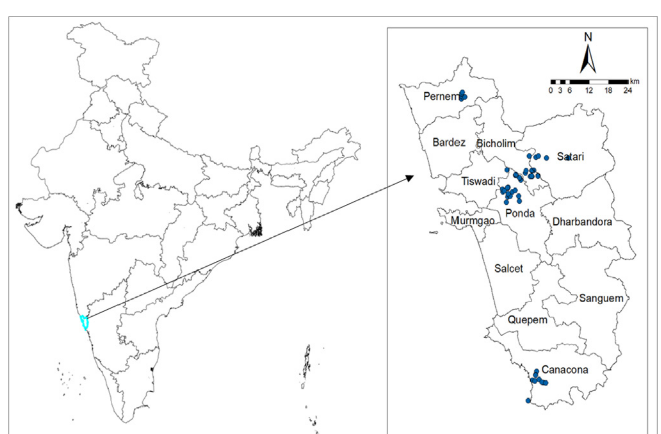

Fig. 1. Location of the study area.

preparation, fertilization, pesticide spraying, weeding, crop geometry, and harvesting. The distance between rows and plants were randomly measured at five locations on each farm and averaged. The MII was computed for each farm separately based on several times each management practices followed in a year. First, for each cropping practice, the number of times per year each practice was followed was transformed to a value between 0 and 1; where 1 indicates the highest level of management practices and zero being the least.

$$Management\ intensity = \frac{value\ -\ minimum}{maximum - minimum} \quad (1)$$

Then, all the transformed values of different cropping practices were summed to obtain the MII of the farm surveyed.

2.3. Cultivated plant species richness

The information on different intercrops present in the ABCS was collected through interview schedules during field visits. The details of the cultivated crop species present in the ABCS were collected excluding the wild plant species. The number of plants of each intercropped plant species was counted and recorded. The use of each species as fruit/vegetable/spice/wood was also recorded. Except for areca and coconut (*Cocos nucifera*), the different crops present in a farm were classified as fruits, spices, vegetables, ornamental plants, medicinal and aromatic plants, forest trees and green manure plants (Table 2). Likewise, MII, the species richness index (SRI) was calculated using sum of the species present in the individual farm. These values were normalized on a scale of 0–1; where 1 indicates the highest species richness and zero being the least. All the transformed values were summed to obtain the SRI on the individual farm.

2.4. Ecosystem service indicators

Yield, economics, and soil nutrient status were studied as the indicators of ES in ABCS. The annual yield of arecanut, coconut, other fruits, spices, and green manure were collected and used as a physical indicator of ABCS (Fig. 2). Economic indicators used in the study were farmer's gross income, net income, cost of cultivation, and family benefits. The several intercrop products produced from the ABCS were also included along with arecanut yield to reflect the overall contribution of the arecanut system to the provisioning services of the farm families and the yield of intercrops were converted into arecanut equivalent yield (AEY) for better comparison using the following formula.

$$AEY\left(t\ ha^{-1}\right) = \frac{\text{Yield of component crop}\ \left(t\ ha^{-1}\right) \times \text{Price of component crop}\ \left(USD\ t^{-1}\right)}{\text{Price of arecanut}\ \left(USD\ t^{-1}\right)} \quad (2)$$

The soil samples were collected at a depth of 0–30 cm from all the three different nutrient management systems surveyed. Soil samples were collected from 9 farms under each nutrient management system and composite samples were prepared. The soil sample was brought to the laboratory and sieved using a 2 mm mesh. The soil fertility was quantified by the analysis of soil samples for soil pH, bulk density (BD), soil organic carbon (SOC %), nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and micronutrient contents such as iron (Fe), copper (Cu), manganese (Mn), zinc (Zn) and boron (B) following standard methods. The soil microbial properties such as microbial biomass carbon (MBC), dehydrogenase (DHA), and urease were estimated as per the standard methodology (Table 3). The soil organic carbon stock was also determined.

2.5. Energy analysis

Various inputs and output(s) were converted to energy form by following the standard procedure [35]. Table 4 shows the energy equivalents of agricultural inputs-output for ABCS. The inputs were

Table 1
Management descriptors of arecanut based cropping system at Goa, India.

Cropping practices	Mean	Max	Min	SD	Median
Distance between rows (m)	2.20	5.20	1.10	0.76	2.10
Distance between plants (m)	1.76	4.03	0.85	0.62	1.60
Basin preparation (no./yr.)	0.96	1.00	0.00	0.20	1.00
Application of organic manures (no./yr.)	1.01	2.00	0.00	0.27	1.00
Application of green leaf manures (no./yr.)	0.73	1.00	0.00	0.45	1.00
Application of fertilizers (no./yr.)	0.49	2.00	0.00	0.53	0.00
Moving of grass cutter machine (no./yr.)	0.73	4.00	0.00	0.92	1.00
Hand wedding's (no./yr.)	1.03	3.00	0.00	0.85	1.00
Application of pesticides (no./yr.)	1.10	3.00	0.00	0.97	1.00
Number of harvests (no./yr.)	2.06	4.00	1.00	0.68	2.00
Diversity of practices	8.70	11.00	4.00	1.55	9.00
Overall (number of practices/yr.)	9.01	14.00	2.00	2.26	9.00
MII	6.16	9.16	1.01	1.60	6.19

*no. – Number; yr-year; max-maximum; Min-minimum; SD - standard deviation; MII: management intensity index.

Table 2
Different plants present in the arecanut agroforestry system.

Plantation crops	Arecanut (*Areca catechu*), coconut (*Cocos nucifera*)
Fruit crops	Jackfruit (*Artocarpus heterophyllus*), mango (*Mangifera indica*), pineapple (*Ananas comosus*), guava (*Psidium guajava*), custard apple (*Annona reticulata*), sapota, (*Manilkara zapota*), kokum (*Garcinia indica*) and papaya (*Carica papaya*), carambola (*Averrhoa carambola*), pomelo (*Citrus maxima*), lemon (*Citrus limon*), jamun (*Syzygium cumini*), wax apple (*Syzygium samarangense*), amla (*Phyllanthu semblica*), bilimbi (*Averrhoa bilimbi*)
Spice crops	Nutmeg (*Myristica fragrans*), pepper (*Piper nigrum*), betel vine (*Piper betle*), curry leaf (*Murraya koenigii*), cinnamon (*Cinnamomum verum*), allspice (*Pimenta dioica*), clove (*Syzygium aromaticum*)
Vegetable crops	Breadfruit (*Artocarpus altilis*), chilli (*Capsicum annuum*), tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), okra (*Abelmoschus esculentus*), yardlong bean (*Vigna unguiculata ssp. sesquipedalis*), red amaranthus (*Amaranthu scruentus*), drumstick (*Moringa oleifera*), elephant foot yam (*Amorphophallus paeoniifolius*)
Forest trees	Dalbergia (*Dalbergia sissoo*), teak (*Tectona grandis*), cotton tree (*Bombax ceiba*), bamboo (*Bambusa sp.*), tamarind (*Tamarindus indica*)
Greenleaf manure plant	Gliricidia (*Gliricidia sepium)*
Ornamental plants	Crape jasmine (*Tabernaemontana divaricata*), hibiscus (*Hibiscus rosa-sinensis*), jasmine (*Jasminum sps.*), rose (*Rosa sps.*), ixora (*Ixora coccinea*), champa (*Magnolia champaca*), Heliconia (*Heliconia sps.*), anthurium (*Anthurium andraeanum*), aster (*Aster sps.*), gomphrena (*Gomphrena globose*), marigold (*Calendula officinalis*)
Other minor crops	Vanilla (*Vanilla planifolia*), coffee (*Coffea* sps.), cashew (*Anacardium occidentale*)

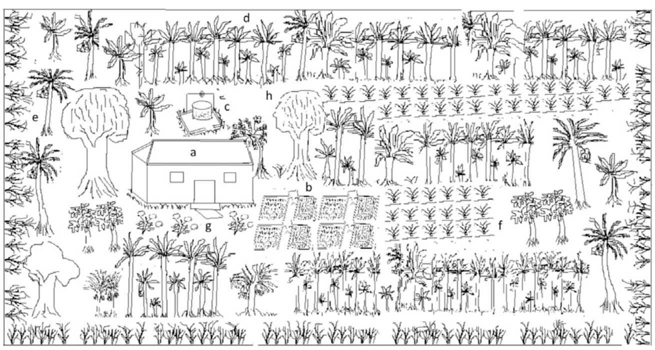

Fig. 2. Schematic view of an arecanut agroforestry system. a) home, b) kitchen garden, c) well d) agroforestry system, e) border planting of gliricidia f) pineapple, vegetables, g) ornamental plants h) timber trees.

labor, agricultural machinery, diesel fuel, farmyard manure (FYM), fertilizers, and pesticides; arecanut equivalent yield was the output. The following formulae were used for computation of the energy indices:

Table 4
Energy equivalents and energy inputs in different land use system.

Inputs (unit)	Energy equivalent (MJ U^{-1})
Input	
Labor (h)	1.96
Machinery (h)	62.7
Diesel fuel (L)	56.31
Farmyard Manure (kg)	0.3
Nitrogen (kg)	66.1
Phosphorus (kg)	12.4
Potassium (kg)	11.1
Herbicides (kg)	102
Fungicides (kg)	97
Irrigation water (m^3)	1.02
Outputs	
Arecanut yield (kg)	15.1 [36]

$$\text{Energy use efficiency} = \frac{\text{Energy Output}\left(\text{MJ ha}^{-1}\right)}{\text{Energy Input}\left(\text{MJ ha}^{-1}\right)} \tag{5}$$

Table 3
List of indicators of ecosystem services and the methods used for measuring them.

Ecosystem services	Indicators of ecosystem services	Methods/Formulas
Provision of ABCS products	Coconut yield (nuts/ha/yr), Arecanut yield (kg/ha/yr), Fruit yield, Spice production and Green leaf manure production (kg/ha/yr) Gross return (USD/ha/yr): GR = AS x MP Cost of cultivation (USD/ha/yr) Net return (USD/ha/yr): NR = GR − COC Family benefit (USD/ha/yr): FB =NR + VDC VDC = ADC × MP	The yield data of different crops were collected from farmers during the survey period Where: GR: gross return from the sale of agroforestry products; AS: the amount of agroforestry products for sales MP: market price; CF: cash flow; COC: the cost of cultivation; VDC: the value of domestic consumption; ADC: the amount of agroforestry products for domestic consumption; FB: family benefit Sources [4,22]:
Maintenance of soil fertility	Bulk density (BD) (g/cm^3)	
	Soil pH	1:2.5 soil to water suspension [23]
	Soil organic carbon (%)	SOC concentration was determined by wet oxidation method [24]
	Available N (kg/ha)	Alkaline potassium permanganate method [25]
	Available P (kg/ha)	Spectrophotometrically [26]
	Available K (kg/ha)	Flame photometrically [27]
	Available S (mg/kg)	[28]
	Available B (kg/ha)	[29]
	Available Fe (ppm)	Determined by DTPA method of [30]
	Available Cu (ppm)	The estimation of elements in the extract is done with the help of Atomic
	Available Mn (ppm)	Absorption Spectrophotometer (AAS)
	Available Zn (ppm)	
	Soil microbial biomass carbon (μg g^{-1})	Chloroform fumigation incubation technique [31]
	Dehydrogenase (μg TPF g^{-1} day^{-1})	Triphenyl tetrazolium chloride method [32]
	Urease (μg urea g^{-1} h^{-1})	[33]
	Soil Organic Carbon Stock (Mg C ha^{-1})	[34]

$$Net\ Energy = Energy\ output\ \left(MJ\ \text{ha}^{-1}\right) - Energy\ input\ \left(MJ\ \text{ha}^{-1}\right) \quad (6)$$

$$\text{External non} - \text{renewable energy} = \text{Fule} + \text{Electricity} + \text{Seed} + \text{Fertilizers} + \text{Chemicals} + \text{machinery}$$

$$\text{Internal renewable energy} = \text{Labour} + \text{Organic fertilizers} + \text{irrigation water}$$

$$\text{External renewable energy} = \text{Labor} + \text{Organic fertilizers}$$

$$\text{Indicator of Dependence on Non} - \text{Renewable Energy Sources} = \frac{\text{Non} - \text{renewable energy input}}{\text{Total energy input}}$$

$$\text{Indicator of farm autonomy} = \frac{\text{Internal renewable energy input}}{\text{Total energy input}}$$

2.6. Sustainability indicators

In this study, the sustainability indicators such as sustainable yield index (SYI), sustainable value index (SVI), sustainable economic efficiency (SEE) were used for evaluation of sustainability under different nutrient management practices. These indicators were estimated by using the following formulae.

$$SYI = \frac{(GY - SD\ )}{Y_m} \quad (7)$$

where GY- AEY, SD-standard deviation of each system, Y_m is the maximum yieldattained under any system

$$SVI = NR - SD/MNR \quad (8)$$

where NR- Net returns, MNR - maximum net return attained under any system

$$SEE = \frac{NR}{T} \quad (9)$$

where T- 365 days.

2.7. Statistical analyses

The different diversity indicators such as Dominance, Simpson index, and Shannon index were determined for each farm using the PAST software version 3.19 [37]. The one-way analysis of variance was carried out to find out the difference between different indicators of ecosystem services, soil quality, and energy balance using SAS [38] software. The separation of means was subjected to Tukey's honestly significant difference test [39]. All the statistical significance tests were performed at the $p = 0.05$ level. Linear regression was performed between indicators of ecosystem services, soil quality, carbon stock, MII and, biomass turnover.

3. Results

3.1. Management intensity index (MII) in arecanut based intercropping system (ABCS)

The MII of the ABCS ranged from 1.01 to 9.16. The distance between rows and between arecanut plants ranged from 1.01 to 5.2 m and 0.85–4.03 m, respectively. The management practices like basin preparation, application of organic manure and green leaf manuring were practiced every year in almost all the farms except in few farms. The usage of chemical fertilizer was found to be very less and restricted only to major nutrients (rock phosphate, muriate of potash and urea application) in some farms. The use of Bordeaux mixture (fungicide) to control fruit rot disease is followed because fruit rot is a predominant disease of arecanut in the area. The herbicide application (Gromoxone) and the mowing of grass cutter machines are the major weed management practices. Hand weeding is practiced wherever labor was available. The number of arecanut harvests varied from 1 to 4 in a year depending on the labor availability. Fallen fruits of areca palms were collected whenever harvest was not practiced. The MII differed significantly due to nutrient management practices (Table 5) and the highest value was recorded in INM farms (7.81) followed by OF fields (6.04) and least in NM fields (3.86).

3.2. Structure and diversity in arecanut based intercropping system (ABCS)

In the study area, the crop species are planted randomly without the following recommended density/geometric pattern. Some of the areca plants in the intercropping system are self-sown by fallen nuts. The farmers grow many fruit trees, spice crops, vegetable crops in the alley space of the arecanut plants (Fig. 2 & Table 2). The ornamental, medicinal and aromatic plants are planted near the home. Timber trees and gliricidia (*Gliricidia sepium*) are planted near the border of the farm. The house, wells, livestock shed, and compost unit is usually located in the center of the farm. In the present study, species richness index (SRI) was found significantly high in the INM farms (1.64) followed by OF farms (1.02) (Table 5). The shannon diversity index did not differ significantly, while the simpson's Index was found significantly high (0.54) in INM farms. However, the dominance index was found high in the NM farms (0.6) showing lesser intercrop diversification and the least values were observed in INM fields (0.46) depicting a high level of intercrop diversification.

3.3. Ecosystem services provided by arecanut based intercropping system (ABCS)

The ecosystem services provided by the arecanut based intercropping system were divided into provisionary services (provisioning of food products) and regulatory services (maintenance of soil fertility).

3.3.1. Provision of different intercrop products

The different provisioning intercrop products produced from the ABCS are the production of arecanut, coconut, fruits, spices, vegetables, and green leaf manures. The details of contribution to the provisioning services from ABCS are summarised in Table 6. The major economic products obtained from the ABCS is arecanut and influenced significantly between the nutrient management practices. The highest arecanut yield was observed in OF farms (2168 kg^{-1} ha^{-1} year) and least in NM plots (1004 kg^{-1} ha^{-1} year). The coconut yield also differed significantly and the highest yield was found in INM plots (4563 $nuts^{-1}$ year). The major fruit crops

Table 5
Structure, plant density, and management intensity in the arecanut intercropping system.

Particulars	NM	OF	INM
Density of arecanut plants (Ind/ha)	670 ± 158	1092 ± 431	1077 ± 426
Density of coconut plants (Ind/ha)	37 ± 40	154 ± 168	100 ± 110
Density of fruit plants (Ind/ha)	29 ± 24	421 ± 623	262 ± 369
Density of spice crops (Ind/ha)	45 ± 64	267 ± 368	285 ± 342
Density of medicinal and aromatic plants (Ind/ha)	6 ± 6	9 ± 9	7 ± 9
Density of vegetable crops (Ind/ha)	29 ± 3	31 ± 7	29 ± 9
Density of Flowering plants (Ind/ha)	8 ± 9	15 ± 13	8 ± 8
Density of forest trees (Ind/ha)	4 ± 5	19 ± 21	11 ± 17
Density of green manuring plants (Ind/ha)	15 ± 28	343 ± 129	401 ± 181
Density of cashew nut (Ind/ha)	5 ± 2	25 ± 4	1 ± 1
Dominance	0.62a	0.46b	0.52 ab
Simpson_1-D	0.38b	0.54a	0.48 ab
Shannon_H	0.89a	1.22a	1.06a
SRI	0.7b	1.64a	1.02 ab
MII	3.86c	7.81a	6.04b
Biomass turnover	3.28c	12.75b	15.97a

NM-No manuring; OF-Organic farming; INM-Integrated nutrient management.
*Ind: Individual; SRI: species richness index; MII: management intensity index.

Table 6
General statistical measures and effects of management intensity index and species richness index on indicators of ecosystem services provided by arecanut based cropping system.

Ecosystem services	Indicators	NM	OF	INM
Provision of ABCS	Arecanut yield (kg/ha/yr)	1004b	2168a	1805a
	Coconut yield (nuts/yr)	445b	2944 ab	4563a
	Fruit yield (kg/yr)	58b	528 ab	844a
	Spice production (kg/yr)	23b	147a	134 ab
	Vegetables production (kg/yr)	435b	3398a	4507a
	Green leaf manure production (kg/yr)	102b	328a	272a
	Arecanut equivalent yield (kg ha^{-1})	1184.3b	3313.1a	3334.2a
	Gross return (USD/ha/yr)	5379b	9222a	8990a
	Cost of cultivation (USD/ha/yr)	967b	1620 ab	1967a
	Net returns (USD/ha/yr)	4412b	7602a	7023a
	Family benefit (USD/ha/yr)	5073b	8742a	8076a
Maintenance of soil fertility	Bulk density (g m^{-3})	1.36a	1.31b	1.35a
	Soil pH	6.7a	6.8a	6.76a
	Soil organic carbon (%)	1.04b	1.63a	1.67a
	Available nitrogen (kg/ha)	97.24b	150.07a	150.8a
	Available phosphorus (kg/ha)	6.78a	6.87a	6.67a
	Available Potassium (kg/ha)	280.9b	390.8a	444.1a
	Available Sulphur (kg/ha)	2.22a	1.93a	1.75a
	Available Boron (ppm)	1.14b	1.32a	1.24 ab
	Available Fe (ppm)	52.92a	58.73a	77.19a
	Available Cu (ppm)	10.73a	11.88a	15.1a
	Available Mn (ppm)	111.57a	116.06a	129.69a
	Available Zn (ppm)	6.6a	7.66a	6.67a
	MBC	404.4b	615.9a	581.3 ab
	Dehydrogenase	164.8a	176.22a	183.53a
	Urease	47.58b	117.43a	108.4a
	Soil organic carbon stock (Mg C ha^{-1})	42.69b	63.56a	66.89a

NM-No manuring; OF-Organic farming; INM-Integrated nutrient management.

present in the ABCS were banana (*Musa* sp.), jackfruit (*Artocarpus heterophyllus*), mango (*Mangifera indica*), pineapple (*Ananas comosus*), guava (*Psidium guajava*), custard apple (*Annona reticulata*), sapota (*Manilkara zapota*), kokum (*Garcinia indica*) and papaya (*Carica papaya*). The highest fruit yield was noticed in INM plots 844 kg $year^{-1}$ followed by OF fields (528 kg $year^{-1}$) and least in NM plots (58 kg $year^{-1}$).

The major spice crops found in ABCS are nutmeg (*Myristica fragrans*) and pepper (*Piper nigrum*), and the spice yield differed significantly and the highest values were observed in OF plots with a mean spice yield of 147 kg $year^{-1}$. The pepper vines were trailed on the arecanut plants whereas the nutmeg plants were planted in between the arecanut plants. A small number of betel vine (*Piper betle*), curry leaf (*Murraya koenigii*), cinnamon (*Cinnamomum verum*), allspice (*Pimenta dioica*), and clove (*Syzygium aromaticum*) were also planted in the backyard of the house for household consumption. In the majority of the farms, breadfruit (*Artocarpus altilis*), chilli (*Capsicum annuum*), tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), and okra (*Abelmoschus esculentus*) plants were common in and around the house and they act as a major source of vegetables to the farm family. Among leafy vegetables, red amaranths, methi, and spinach were also grown. The mean vegetable yield was found to be significantly higher in OF plots (328 kg $year^{-1}$) followed by INM plots (272 kg $year^{-1}$). Gliricidia was the major greenleaf manure plant found all along the boundaries of most farms. Every year these plants are pruned and leaves are used for green leaf manuring purposes as a source of plant nutrition in the system. The average green leaf manure yield was found significantly higher in the INM farms (4507 kg $year^{-1}$).

The mean monetary returns in terms of gross return, net return and family benefits (Table 6) obtained from the ABCS were found to be significantly high in OF plots (9222, 7602, 8742 USD $year^{-1}$respectively) and was on par with INM farms (8990, 7023, 8076 USD $year^{-1}$ respectively. However, the cost of production was high in INM farms (1967 USD $year^{-1}$) followed by OF farms (1620 USD $year^{-1}$).

3.3.2. Maintenance of soil fertility

The bulk density (BD) of the soil in the ABCS varied significantly ($p < 0.05$) (Table 6), with the highest value in NM plots (1.36 g cm^{-3}) and the least values in OF plots (1.31 g cm^{-3}). The soil pH of ABCS was acidic and did not differ significantly between nutrient management systems. The soil organic carbon (SOC) concentration was found significantly higher in INM farms (1.67%) and it was on par with OF plots (1.63%) (Table 6). Available N, K, S, and B were found significantly ($p < 0.05$) higher in OF plots followed by INM plots (Table 6). The available P and micronutrients did not differ significantly between the nutrient management systems. Following OF practices over the year significantly improved the MBC and urease activity (615.93 μg g^{-1}& 117.43 μg TPF g^{-1} day^{-1}) in the soil over NM plots and it was on par with INM plots (Table 6). The highest values were observed in INM plots (183.53 μg urea g^{-1} h^{-1}).

3.4. Carbon stock and biomass turnover

The nutrient management system significantly influenced the SOC stock with the highest value in INM plots (66.9 Mg C ha^{-1}), and the least value in NM plots (42.7 Mg C ha^{-1}) (Table 6). The continuous recycling of biomass in terms of litter, mulching, green leaf manure incorporation, FYM application was found higher in OF plots (15.97 t ha^{-1}) followed by INM plots (12.75 t ha^{-1}), while in NM plots (3.23 t ha^{-1}).

3.5. Energy analysis

The highest energy input and output were incurred in the INM and OF system, respectively (Table 7). There was a marginal variation in the energy output between OF and INM system, however, the energy input in the INM system is found higher due to the use of chemical fertilizers and pesticides (Fig. 3). Since no fertilizers, pesticides, and manure was applied the least energy input and energy output was noticed in NM systems. Indicator of dependence on non-renewable energy sources (IDRN) indicates the dependency of a system on non-renewable sources In the studied farms the mean IDRN values varied from 0.18 to 0.6 the lower values were observed in NM system followed by OF system and higher values were with INM system. The average value of the indicator of farm autonomy (IFA) varied from 0.29 to 0.46 (Table 7) with the highest values in OF system followed by the INM system. The energy efficiency (Fig. 4) and net energy varied significantly due to nutrient management systems and was found significantly higher in the OF system (1.72 & 19625 MJ ha^{-1}) than the other two systems. OF is energy efficient mainly due to zero energy of the nutrient inputs.

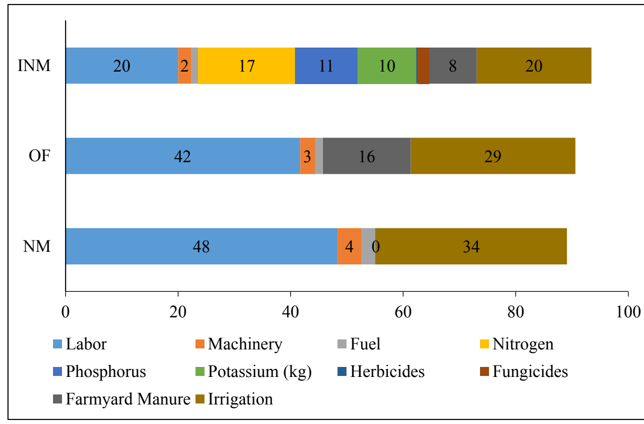

Fig. 3. The share of total mean energy inputs in different land-use system of ABCS.

3.6. Sustainability indicators

The Sustainability indicators such as SYI, SVI and SEE differed significantly due to different nutrient management practices in

Table 7
Mean energy consumption and different energy indices.

Nutrient management systems	NM	OF	INM
A. Input (unit)			
Labor (MJ/ha)	7879	12801	9040
Machinery (MJ/ha)	699	819	1066
Fuel (MJ/ha)	392	430	560
Nitrogen (MJ/ha)	0	0	7768
Phosphorus (MJ/ha)	0	0	5013
Potassium (MJ/ha)	0	0	4720
Herbicides (MJ/ha)	22	0	88
Fungicides (MJ/ha)	0	0	944
Farmyard Manure (MJ/ha)	0	4792	3826
Irrigation (MJ/ha)	5536	8994	9211
Electricity (MJ/ha)	1776	2886	2955
Energy input (MJ/ha)	16304	30722	45189
Energy output (MJ/ha)	17884	50347	50028
Energy Indicators			
External Renewable Input (MJ/ha)	2888	8926	26947
Internal Renewable Input (MJ/ha)	7879	7681	7405
External Non-Renewable Input (MJ/ha)	5536	13786	13875
Indicator of Dependence on Non-Renewable Energy Sources (IDRN)	0.18	0.30	0.6
Indicator of farm autonomy (IFA)	0.34	0.46	0.29
Energy efficiency	1.1	1.72	1.11
Net energy (MJ/ha)	1580	19625	4839

NM-No manuring; OF-Organic farming; INM-Integrated nutrient management.

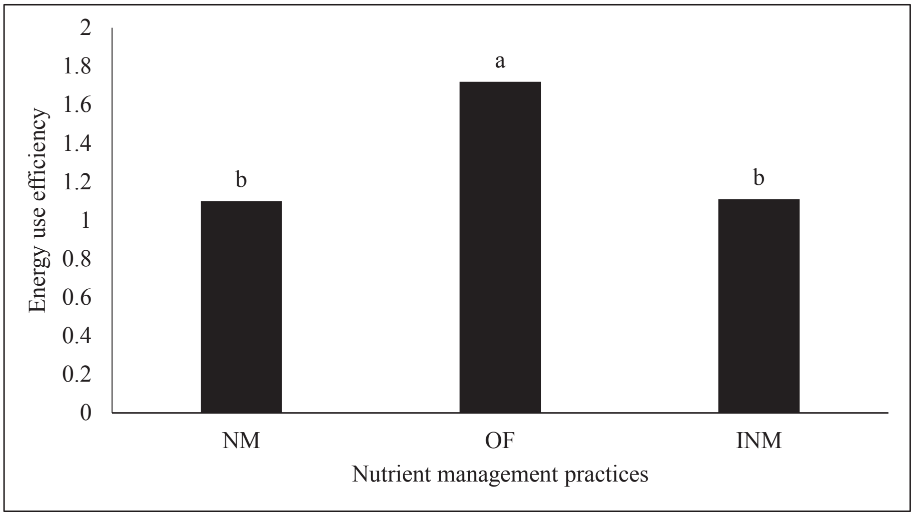

Fig. 4. Effect of different land-use system on energy use efficiency of ABCS.

Table 8
Sustainability indicators influenced by nutrient management practices.

Nutrient management systems	Sustainability Yield Index	Sustainability Values Index	System Economic Efficiency
NM	0.10b	0.31b	12b
OF	0.25a	0.44a	21a
INM	0.17 ab	0.38 ab	19a

NM-No manuring; OF-Organic farming; INM-Integrated nutrient management.

Table 9
Ranking different land-use systems based on different indicators.

	AEY (kg ha^{-1})	Net income (USD)	Carbon stock (Mg C ha^{-1})	Biomass turnover (t ha^{-1})	Energy efficiency	Net energy (MJ ha^{-1})	Total
NM	1184(3)	4412(3)	42.7(3)	3.28(3)	1.1(3)	1580(3)	18
OF	3334(1)	7602(1)	63.6(2)	15.97(1)	1.72(1)	19625(1)	7
INM	3313(2)	7023(2)	66.9(1)	12.75(2)	1.11(2)	4839(2)	11

NM-No manuring; OF-Organic farming; INM-Integrated nutrient management.

ABCS (Table 8). Significantly higher SYI, SVI, and SEE were observed with the OF system followed by INM and the least in the INM system. The higher AEY and net return (Table 6) realized in the OF system led to higher sustainability indicators.

3.7. Ranking of nutrient management practices

Ranking of nutrient management systems based on the seven criteria showed that OF system with the lowest rank-sum score (Table 9), was found to be the best for ABCS in the west coast of India followed by the INM and NM system.

4. Discussion

The impact of management intensity on different ES observed in the current study also corroborates the related studies in the past. Similar results of management intensity influencing the ES were found in cocoa [4] and coffee [40] intercropping systems and in pastures and shifting cultivation systems [41]. The results from the study suggest that ABCS demands specific management practices based on the plant density and requirement of individual component crops. It also implies a need to design good management practices especially optimal planting density, nutrient management, and plant protection measures to improve the productivity and profitability of the ABCS irrespective of the nutrient management systems. Two fungicide sprays per year, balanced fertilization through integrated nutrient management [42], weed management (using grass cutter machine/herbicide application), mulching, and engaging family labor to reduce costs are the set of recommended good management practices for an ideal ABCS. A significant interaction of management intensity is reported by earlier workers on coffee yield in coffee agroforestry system [8].

The present study reveals that different provisioning services obtained from ABCS are influenced by specific nutrient management practices. The variation in the production of different intercrops and their economics is mainly due to varied management practices and biomass turnover. For instance, the higher AEY in OF and INM nutrient management systems over the NM system is attributed to higher availability of SOC, N, K, B, and higher microbial activity with reduced BD. The increased MBC and enzymatic activity improved the soil biological activity in OF and INM system played a crucial role in enhancing the organic matter mineralization and availability of nutrients in the respective systems than the NM system. It further facilitates the root growth, enhancing the nutrient uptake from deeper regions of the soil. The high nutrient uptake facilitates, and the enhanced photosynthetic activity of plants improves growth and yield of intercrops leading to enhanced total system productivity [43]. Sujatha and Bhat [44] while working with the arecanut + vanilla intercropping system, reported that balanced nutrition application of fertilizer with adequate moisture improves the root growth, thereby nutrient uptake, and yield. Similarly, Roy and Hore [45], opined that bio-organic nutrient management in the arecanut + turmeric intercropping system results in higher yield and benefit-cost ratio than inorganic nutrient management only. Combined application of organic and inorganic nutrients and long term use of organics in the cropping system builds up the nutrients and water availability in such systems that support optimal growth and yield [46].

Soil carbon stock in any system is governed by the long-term balance between *ex-situ* addition of organic C, *in situ* decay of organic matter, soil management, and soil biota and its losses through ecological processes like decomposition, erosion, and leaching [47]. Thus the SOC concentration and SOC stock is the direct function of biomass turnover and management practices, as evident from this study. The earlier studies reported that the amount of organic matter addition and level of management play a critical role in the mineralization of organic matter and soil C sequestration [48]. In the present study, higher SOC concentration and SOC stock in INM and OF system is attributed to the reduction in soil temperatures due to mulching, continuous *in situ* root decay, slow organic matter decomposition, and profuse vegetation growth [19]. Manning et al. [49] reported that the INM and OF practices add organic C to the soil and also increase the plant C inputs to the soil through root residue, stubble, rhizodeposition by increasing the production of agro-ecosystem.

Among the three nutrient management practices, the highest energy input under the INM system (45189 MJ ha^{-1}) was three times more than that of the NM system. Such high energy consumption is mainly due to the application of chemical fertilizers and pesticides. While the highest energy output (50346 MJ ha^{-1}) under OF system was mainly due to higher AEY than the NM system. The IDNR indicates the dependency of a production system on non-renewable energy sources like machines, oil, fertilizers, pesticides, herbicides, etc. and is the vital agriculture performance indicator [50]. The results indicated the greatest value of this indicator was found for INM farms (0.6) showing that more dependency on these farms on non-renewable resources. This implies that INM farms had a much higher dependence on non-renewable energy sources majorly for fertilizers, pesticides and machinery usage than OF and NM system. Anna et al. [51] and García-Martínez et al. [52] suggested diversifying the use of inputs and management practices to reduce the use of external inputs.

IFA indicates the ability of a production system to function fully, with less/without the need for external inputs and is also known as energy self-sufficiency of a system [53]. IFA indicates the extent to which the farm can supply its energy and related to renewable energy inputs such as organic manure, irrigation water, and family labor. The low values of IFA correspond to high values of the indicator of dependence on non-renewable energy sources. In the current study, the high mean value of IFA was found for OF farms (0.46) and the low value for INM farms (0.29). It implies that the OF farms showed the highest level of autonomy (46% of input was produced on-farm). Tellarini and Caporali [50], and Anna et al. [51] obtained a higher IFA for the lower input farm (IFA = 0.80, 0.33) respectively. The higher energy efficiency and higher net energy in OF system are mainly due to higher economic yield and lesser energy consumption in the system. The earlier workers [54] also reported the high energy efficiency of organic production systems. The present study suggests the high energy efficiency in OF system can reduce environmental impact and promote renewable resources in crop production. Therefore, improving energy efficiency under OF practices helps to reduce the ecosystem disservices of the arecanut production system [55]. The higher energy gains in the OF system is the most feasible strategy to reduce the cost of production without compromising yield and sustainable production system.

The management practices such as manuring, irrigation, weeding, and periodic harvesting realized higher AEY thereby higher SYI and SVI in OF system followed by the INM system. The identification of nutrient management practices that provide constant and regular income and to generate additional employment in any cropping system is a prerequisite to minimize the risk due to crop failure. The current study indicated that the adoption of the OF systems are very remunerative and also displays the potential to improve the ecosystem services thereby improves the SEE. Furthermore, the result also implies that the OF system has huge potential to generate year-round income to the farm family.

Screening of the nutrient management systems based on rank scoring of six criteria such as AEY, net income, soil carbon stock, biomass turnover, energy efficiency, and energy gain reveals the highest rank was attained by OF system (7) followed by INM (11) and NM system (18). The result indicates that the OF system is the best nutrient management system and can be recommended for the ABCS to ensure sustainable production, soil quality, environmental protection and profitability in the west coast region of India.

5. Conclusion

The influence of different indicators of ecosystem services and energy balance varied significantly due to nutrient management practices. The lower energy input (30722 MJ ha^{-1}) and higher energy output (50347 MJ ha^{-1}) under OF over NM, and INM improved the energy efficiency (1.72) and net energy (19625 MJ ha^{-1}) in the former. Additionally, 35% higher energy efficiency and 75% higher energy gain under OF over INM enhanced the organic farm productivity without depending on external inputs, and thereby reducing the cost of production. The OF systems were found to be highly sustainable over INM based on (i) 32% higher sustainability yield index, (ii) 14% higher sustainability values index and, (iii) 10% higher system economic efficiency. The lower dependence on nonrenewable energy sources and higher farm autonomy under OF system showed the higher recycling capacity of organic farms than that under NM, and INM. The study concludes that organic farming is the best nutrient management practice to improve the system profitability, sustainable farm production, soil quality, energy efficiency, and to enhance the environmental quality of arecanut based cropping system in the west coast of India.

Declarations of interest

None.

Conflict of interests

The authors declare no conflict of interest.

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