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The long-term impact of the integrated crop-livestock system on carbon emission, sustainability and livelihood security of small and medium farmers

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ABSTRACT

In India, 80 per cent of the farmers are small and marginal farmers. They primarily depend on agriculture and allied activities for their livelihood security. The rice-rice cropping system reduces farm income, declined soil fertility and other soil degradation problems. The farming system approach is a holistic tool to address the problems of mono-cropping through diversification that enhances farm income, production and employment. A field study was conducted during 2011–2018 to study the impact of the rice-based integrated crop-livestock system (ICLS) for profitability, carbon emission and sustainability. Recycling of resources and residues led to higher productivity (58.9 %) and net profit (48.5 %) over the initial year by adopting rice-based ICLS. This system had a net profit of $ 3097/year and generated 776 man T days/ha/year employments. In ICLS, the recyclable farm waste material of 28.98 tons is converted into organic manures of 16.03 tons and saves the fertilizer's cost of $ 504 per year. It can be a sustainable model with a sustainable yield index (0.11) of for wet situations with less carbon-emitting and profitable.

Introduction

To meet the demand for food and nutrition over the same period of time, the farmers use a variety of agricultural enterprises, including crops, dairy, poultry, pigeons, fish, sericulture, apiculture, and others that are appropriate for the size, agro-climate, and socioeconomic conditions of their farms. The integrated crop-livestock system (ICLS) is a common term for the development of a more comprehensive, resource-based, client-oriented, and collaborative strategy to address various and risk-prone environmental issues (Kumar *et al.,* 2011). IFS idea reduces reliance on outside resources by effectively using and recycling all agricultural resources. (Hilimire, 2011). Similarly, crop residues of preceding crops are recycled for succeeding crops to maintain soil's physicochemical properties, increase the crops nutrient uptake, and ensure a better soil environment for crop growth (Behera and Mahapatra, 1999). Enhancing productivity, profitability, and agriculture sustainable production methods all need efficient energy usage (Paramesh *et al.,* 2014). Integrated farming system is using farm produced energy like organic manure and reduced external use of energy thereby it is more efficient system for energy usage (Devasenapathy, 2009). Crop residue, conservation tillage, crop rotations, integrated nutrient management, and efficient irrigation all contribute to soil fertility and environmental quality by effectively managing soil carbon in agricultural fields (Gebeyehu and

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Soromessa, 2018). All of these beneficial farming techniques are part of ICLS, which also decreases soil erosion and boosts soil organic matter to slow down climate change (Paramesh *et al.,* 2014). Thus, ICLS provides scope for minimum tillage operations, reduced soil disturbances, recycling of crop residue and consequently improves soil fertility, crop productivity and environmental quality. In this regard, the study was conducted to identify a technically feasible, economically viable, and eco-friendly integrated crop-livestock system by integrating cropping with allied enterprises.

Material and Methods

Experimental site and soil characteristics

The study was carried out as a part of All India Coordinated Research Project on the Integrated Farming System at Agricultural and Horticultural Research Station, Kathalagere, Davanagere district of Karnataka, India, under canal irrigation of Bhadra command area. The experiment was established in 2011-2018 under the semi-arid tropic of wetland ecology, involving crops (rice, arecanut and vegetables), dairy and sheep as the livestock component. The present study was carried out in one hectare area to assess the effect of different components of ICLS on productivity and profitability. The experiment site had a semi-arid tropic climate with rainfall ranging from 600 mm to 1100 mm, with the received from June to October which is from the southwest monsoon rains. The soils of the experimental site are classified under Alfisols (sandy clay loam) and those re acidic to neutral in reaction (6.80), medium in soil organic carbon (0.52 %), high in available nitrogen (355 kg/ha), medium in available phosphorus (22.56 kg/ha) and potassium (234 kg/ha).

Farming and cropping system

The one hectare integrated crop-livestock system comprises of 0.50 ha of rice-rice cropping system, 0.34 ha for Arecanut, Coconut, Banana, Vegetables and Drumstick which horticulture crops, as additional enterprises Diary and Sheep components were also introduced HF cow (3+1) and sheep (12+1). Green fodder block was fixed in an area of 0.03 ha (Figure 1).

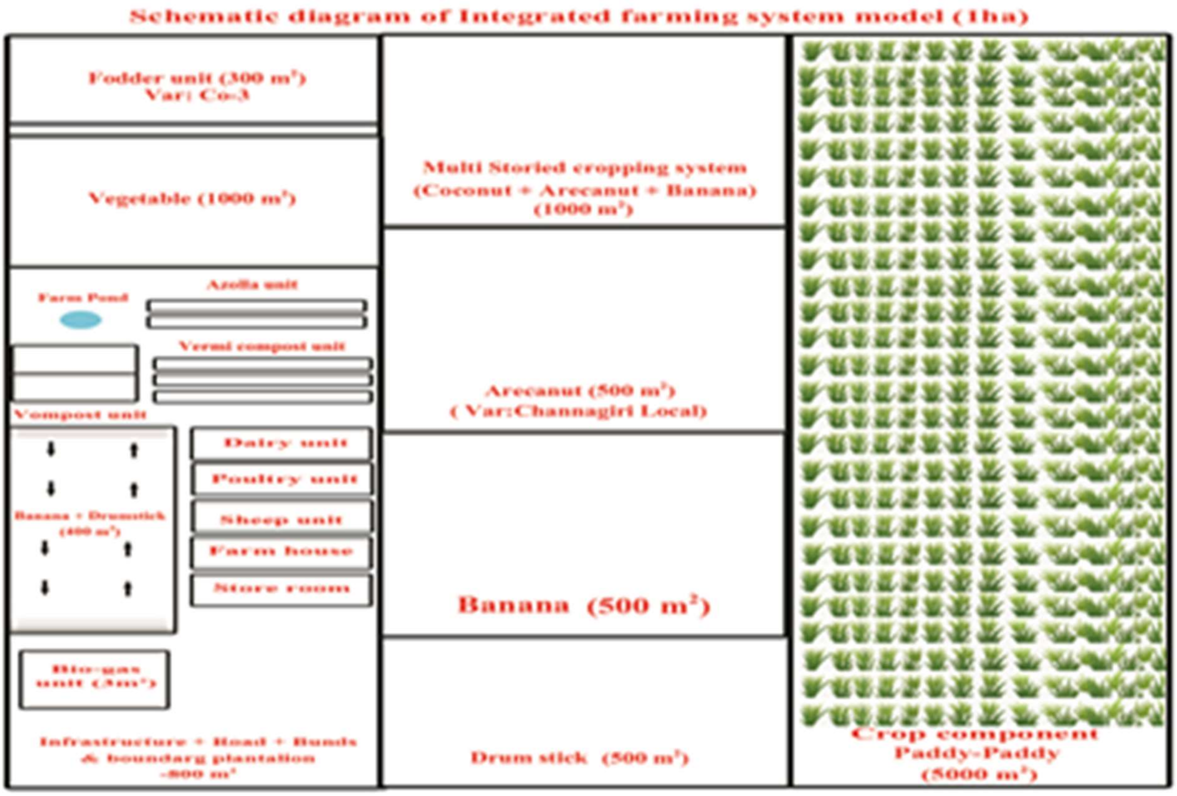

Figure 1: Schematic daigram of integrated farming system model (1 ha)

Additional components *viz*., compost (2 units), vermicompost (3 units), Azolla (2 units) and border planting of forest trees (teak, drumstick, *Glyricidia sepium*) were included in the system. The model details were depicted in Table 1 and Figure 1.

Table 1: Component-wise farming system model (1.0 ha)

Components of the integrated farming system model	Area (m^2)	% share
Crop Components:		
Rice-Rice	5000	50
Horticulture Components:		
Vegetable	1000	10
Arecanut garden	500	05
Arecanut+banana intercropping	1000	10
Banana (Sole Crop)	500	05
Drumstick	500	05
Banana + drum stick	400	04
Fodder (CO-3)	300	03
Farmhouse	800	08
Sheep		
Dairy		
Vermicompost unit (3-Nos.)		
Azolla (2-Nos.)		
Compost (1-No.)		
Road and bunds		
Border planting (Teak-74 no's and *Glyricidia*-12 no's)		
Total	10000	100

Animal and fodder component

In an area of 66 m^2, a low-cost cowshed and sheep shed were built with enough light and a hard floor, and three milch crossbreed cows and one calf, as well as sheep (12 +1), were kept under stall feeding. In order to meet the livestock unit's needs for feed, 300 m^2 of multi-cut Napier hybrid (CO-3) was planted.

Productivity (Rice equivalent yield)

The economic yield of vegetables, arecanut, coconut, banana, milk yield and meat were converted in to rice equivalent yield (REY) based on their prevailing marketable price including rice and expressed in kg per unit area.

$$REY\ (kg) = \frac{Yield\ of\ component\ crops\ (kg) \times Price\ of\ component\ crops\ (\$/kg)}{Price\ of\ rice\ \ (\$/kg)}$$

Sustainability indicators

IFS models were assessed as by Vittal *et al*. (2002) on sustainability indices (S.I.). The sustainable yield index (SYI), sustainable value index (SVI) and sustainable economic efficiency (SEE) may all be used to calculate the S.I. for any IFS model . These indicators were estimated by using the following formulae.

Sustainable yield index (SYI)

$$SYI = \frac{Grain\ yield - Standard\ deviation}{Maximum\ yield\ attained\ under\ any\ component}$$

Sustainable value index (SVI)

$$SVI = \frac{Net\ returns - Standard\ deviation}{Maximum\ yield\ attained\ under\ any\ component}$$

Sustainable economic efficiency (SEE)

$$SEE = \frac{Net\ returns}{365\ days}$$

On farm bioresource flow

Using Perionyx excavates species of earthworms in the ICLS modules, compost and vermicompost production operations were started during the lean time to recycle the farm's animal waste, agricultural leftovers, grass, fodder, weeds, and tree wastes, among other things. These byproducts provide useful manure to agricultural activities and lessen reliance on market-purchased inputs and external chemical fertilizers.

Employment generation

Employment generation was calculated for various components of the integrated crop-livestock system. Farm Family member engaged in various activities throughout year with eight working hour is considered as a 1 man day by using formula (Anup *et al.,* 2021).

$$Man\ days\ (man\ days) = \frac{Working\ hours}{8}$$

Economic analysis

The Agriculture Produce Market Committee used market rates for inputs and outputs to calculate the cost of cultivation and gross returns for each firm. Chemical fertilizers, micronutrients, FYM, pesticides, seeds, feed, concentrate, mineral mixture, labour, and equipment costs are all included in the input cost. The crop's economic value was used to assess the gross returns. Cost of cultivation and gross returns were worked out for all the enterprises by taking into considering the market rates of inputs and outputs at the Agriculture Produce Market Committee. The input cost includes the cost of FYM, fertilizers, micronutrients, seeds, pesticides, feed, concentrate, mineral mixture, labor, and machines. The total gross returns was computed from the economic value of the crop. The net returns was computed for all the components.

$$Net\ returns\ (\$/ha) = (Gross\ returns\ (\$/ha)) - (\text{Cost of cultivation (\$/ha)})$$

$$Benefit\ cost\ ratio = \frac{Gross\ returns\ (\$/ha)}{\text{Cost of cultivation (\$/ha)}}$$

Analysis of soil

Soil samples were collected at 0-30 cm depth from the field after the completion of each cropping sequence. Soil pH determined through glass electrode by pH meter and EC through Conductivity Bridge as per the method by using a soil water suspension at ratio of 1:2.5 (Sparks, 1996). The soil organic carbon was determined by wet digestion method (Sparks, 1996) and expressed in percentage. Soil available nitrogen (Sharawat and Buford, 1982), phosphorus and potassium was estimated as per standard method explained by Sparks (1996) and expressed in kg/ha.

Soil Carbon Stock Determination

The soil samples were collected at interval of 15 cm from 0-105 cm depth of the soil, from all the components of IFS model, for soil organic carbon estimation a specific volume of soil samples were collected, air-dried, processed and sieved through 2 mm diameter sieve. 5 grams of the sieved soil was used for SOC determination, whereas core sampling method was used for B.D estimation (Black, 1973). Based on the soil analysed data, considering soil organic carbon concentration, bulk density (BD) and soil depth (Manjunath *et al.,* 2014) soil organic carbon was estimated using the following formula.

$$Carbon\ (Mg\ C/ha) = \frac{\text{Soil Organic carbon (g/kg)} \times \text{Soli bulk density (Mg/m}^3) \times \text{Depth of soil (cm)} \times 10}{100}$$

Greenhouse gas emission

Work has been started to identify the sources and sinks of greenhouse gases such as methane, nitrous oxide, and carbon dioxide in the current IFS model of Southern Transitional Zone of Karnataka. The model consists of different cropping systems such as rice-rice (5000 m^2), vegetable (1000 m^2), arecanut sole (500 m^2), arecanut + coconut + banana (1000 m^2), drumstick + banana (400 m^2), banana (500 m^2), drumstick (500 m^2), sheep (12+1), dairy (3+1), fodder unit (300 m^2), vermicompost (3 no.) etc. also maintained in the boarder teak, drumstick and glyricidia were established. The Indian Institute of Farming System Research, Modipuram, Meerut, Uttar Pradesh released an excel application that predicts the greenhouse gas emissions from several IFS model components using the IPCC guidelines

$$Emission = A \times EF$$

Where,

emission = annual emission in units of kg of CO_2 eq. per farm
A = Activity data (kg of N used, liters of fuel used etc.)
EF - Emission factor = IPCC default emission factors of country specific emission factors.

Data analysis

The gathered information was tallied, and relevant graphs and tables with the mean and standard deviation were created (S.D.) (Gomez and Gomez, 1984). The data of average of eight years from 2011 to 2018 on production, productivity and income presented in this manuscript.

Results and Discussion

Productivity and economics of ICLS model

In ICLS model, the different components were compared based on the REY (Table 2). The REY of the different components ranged from 833 to 6188 kg/ha/year. The results revealed that maximum REY was achieved in rice–rice cropping system (6188 kg/ha/year) followed by dairy (4501 kg/ha/year) and vegetables (4107 kg/ha/year). Among the animal components, dairy produced 46 % higher REY compared to sheep and in horticulture component arecanut showed higher REY (2711 kg/ha/year) fallowed by arecanut + coconut + banana (2323 kg/ha/year) than drumstick and banana. The cost of cultivation, net returns and benfit cost ratio had been assesed for each component of ICLS model (Table 2 and Figure 2). The cost of cultivation ranged from (13 to 410 $/ha/year) from different farm enterprises, results revealed that the rice-rice system yielded the maximum cost of cultivation followed by the vegetable unit. Among the animal components, the dairy component recorded higher cost of cultivation followed by sheep (Table 2). The total net returns realized from the ICLS model were $ 3097 and it also highest in rice-rice cropping system (1125 $/ha/year) fallowed by vegetable (552 $/ha/year) and the lowest net returns was obtained from arecanut + coconut + banana cropping system (26 $/ha/year). Benfit cost ration was maximum in rice-rice cropping system (3.66) fallowed by vegetable (3.35) and lowest was observed in arecanut + coconut + banana (1.74) and in animal component sheep component resulted in higher B:C ratio (3.82) than dairy unit (3.79).

Table 2: Productivity and Economics of integrated crop-livestock system (2011-2018)

Treatments	Productivity (kg/ha/year)	Cost of Cultivation ($/ha)	Net returns ($/ha)	B:C ratio
Rice-Rice	6188	410	1125	3.66
Vegetables	4107	217	552	3.35
Banana sole crop	2014	63	87	2.36
Banana + Drumstick intercropping	1910	68	65	2.68
Drumstick	833	84	151	2.80
Fodder	1007	15	-	-
Areca nut (64No's)	2711	37	117	2.98
Areca nut + Coconut (18No's) + Banana	2323	27	26	1.74
Boundary plantation	0	13	0	0.00
Dairy (Milk)	4501	218	641	3.79
Sheep	2397	93	269	3.82
Vermicompost	1293	35	-	-
Mean	2662.2	106.7	309.7	3.07
SD	472.7	32.7	107.1	0.20

The integration of rice with dairy and sheep resulted in higher REY due to the significant contribution of cow and sheep with higher milk and meat production over monocropping. Higher monetary efficiency and net returns was observed in rice-rice system due to use of high yielding cultivars and improved cultivation practices. The ICLS approach aims at increasing farm income

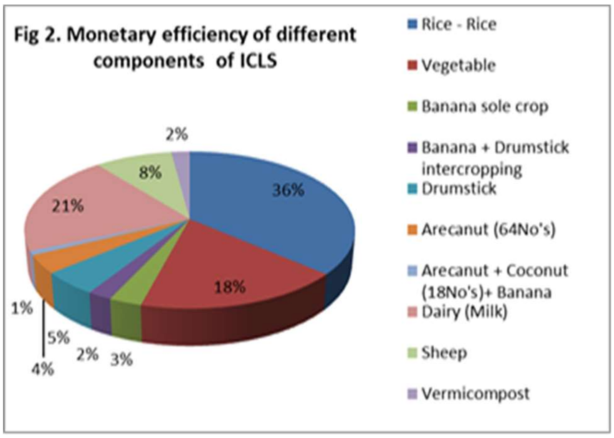

Figure 2: Monetary efficiency of different components of ICLS

from small and marginal farmers by integrating the various farm enterprises within the farm itself. Rearing of sheep recorded the highest benefit-cost ratio, followed by dairy due to lesser management cost mainly use of on farm resources via paddy straw and green fodder. The overall system more intensive cultivation of vegetables and crop production activities around the year under irrigated conditions may add profit to the system. The risk is reduced in a rice-based farming system due to diversification of the system with low-risk enterprises and vegetable cultivation (Paramesh *et al.,* 2014) ICLS would positively influence the economic viability of the system.

Sustainability indices

Existing ICLS is a fusion of animal with crop component help to achieve higher sustainable yield index (0.11), sustainable value index (0.78) and system economic efficiency (464) (Table 3). Existing ICLS is fusions of animal with crop component help to achieve higher sustainability indices like sustainable yield index, sustainable value index and system economic efficiency. Higher the, yield, benefit cost ratio and net returns and also maintained sustainability index, economic efficiency and sustainability value index (Vittal *et al.,* 2002).

Bio-resource flow

Integrated crop-livestock system provides chance for efficient utilization of farm waste or by products from one component as input for another (Figure 3).

Table 3: Sustainable yield index (SYI), sustainable value index (SVI) and sustainable economic efficiency (SEE) of ICLS system. (2014-2018)

Year	REY	Net returns ($./ha)	Sys. Economic Efficiency
2014-15	56.64	2220	452
2015-16	9.73	1928	392
2016-17	12.73	2507	510
2017-18	73.13	2136	435
2018-19	16.85	2603	530
Indices	SYI	SVI	SE
	0.11	0.78	464

The compost and vermicompost was prepared from the left-over straw, weed waste along with the livestock waste (dung, urine) after the decomposition it was applied to crops as a source of nutrients. In rice-rice cropping system after the harvest of the rice, the straw is feed to the dairy animals and the azolla grown on the surface of the pond is also fed to the animals which in-turn increases the milk yield (Hilimire, 2011). In this way there is an efficient way for resources recycling in ICLS model to reduce the overall cost of cultivation or to increase the net returns of the system along with it maintains the soil health status (Yadav *et al*., 2019).

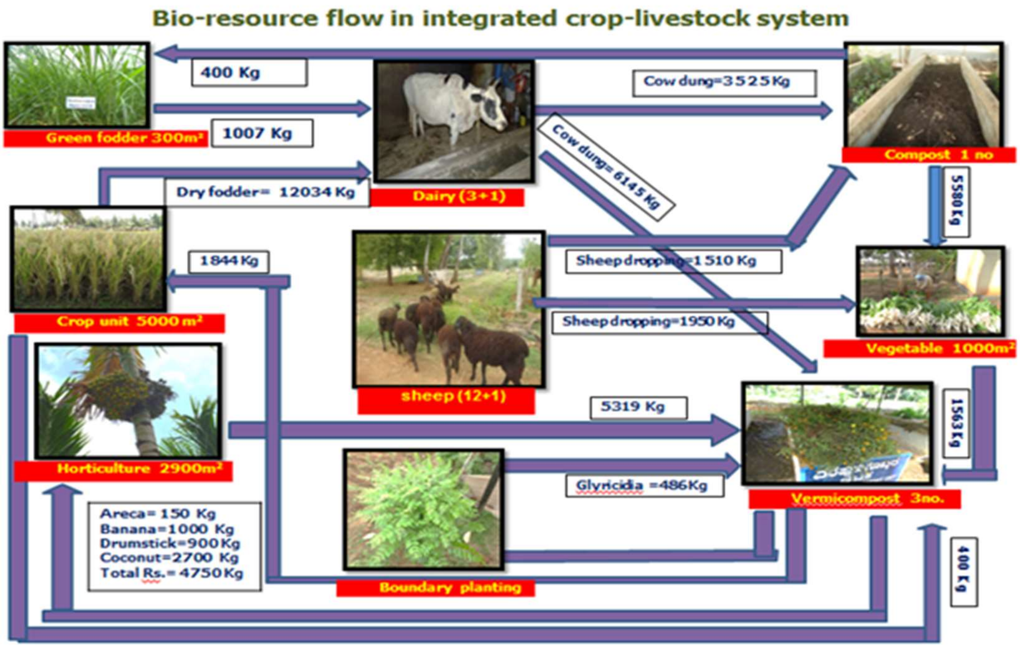

Figure 3: Bio-resource flow in integrated crop livestock system

Employment generation

An integrated crop livestock system is a labor-intensive model; in ICLS model multiple components are maintained throughout the year as against monocropping of rice. Hence, it provides higher employment opportunities for family labor than rice-rice cropping systems (Table 4).

The average employment generation in the 1.0 ha integrated crop livestock system was 776 man-day per year. The labor involvement was higher in dairy (205 man days/year) fallowed by sheep rearing (200 man days/ year) and lesser employment generation was seen in fodder (5 man days/year).

An integrated crop - livestock system is a labor-intensive model provides higher employment opportunities for family labor than rice-rice cropping systems (Ansari *et al.,* 2014). A multi-enterprise agricultural system evenly distributes employment creation throughout the year (Paramesh *et al.,* 2014). Due to the intensification of crops and other businesses, it also boosts productivity and income per unit area and time. Adoption of pond base IFS with vegetable and livestock components generated more employment (434 man days/ha) than the traditional system of rice–rice cropping system. The average employment generation in the 1.0 ha integrated crop livestock system was more than that of the rice-rice Cropping System (Anup *et al.,* 2021).

Table 4: Employment generation of the integrated crop-livestock system (mean of 2011- 2018)

Treatments	Employment generation (man days)
Rice-Rice	132
Vegetables	103
Banana sole crop	12
Banana + Drumstick intercropping	13
Drumstick	10
Fodder	5
Areca nut (64No's)	12
Areca nut + Coconut (18No's)+ Banana	17
Boundary plantation	
Dairy (Milk)	205
Sheep	200
Vermicompost	67
Mean	**70.6**
SD	**22.4**

On farm bio resources flow in integrated crop livestock system

In integrated farming system by–product of one component was input for other components. Similarly, the excreta of livestock (Dairy and sheep) were used for compost and vermicompost and applied to the crops after decomposition. The manure production in different livestock components were presented (Table 5). On an average dung production from dairy (13-15 kg dung/day/cow) and sheep dropping (600-700 g/day/sheep) and total farm waste produced in the various activities of ICLS model was 28.98 tons which was converted in to 16.03 tons of organic manure and it saves chemical fertilizers cost $ 504 per year.

Greenhouse gas emission

Results of greenhouse gas emissions during 2018 from different bio-energy cropping systems are presented (Table 6). The present ICLS has shown sequestration of CO_2 into the system mainly through above-ground biomass of the agroforestry system and residue recycling greenhouse gas

Table 5: Bio-resource production from crop-livestock system (mean of 2011 – 2018)

Components	Pooled data of total produce recycled (kg/lit./Nos.)	Pooled data of total value of the recycled product ($)
Crops (Paddy straw, Weeds and crop residue)	12434	200
Horticulture (Crop residue & Banana waste)	5319	39
Dairy (Dung, urine & shed waste)	9670	4
Other units (Dried leaves & coconut plant debris)	1563	4
Total	**28986**	**247**
Vermicompost	6594	293
Compost	5980	81
Sheep dropping	3460	130
Total	**16,034**	**504**

Table 6: Net greenhouse gas emission (GHG) in integrated crop- livestock system (CO_2-e in kg) during 2018-19

Components	CO_2-e (kg)
Carbon sources- Rice-Rice cropping system	4253.8
Vegetable Unit	865.2
Banana Sole	511.6
Banana + Drumstick intercrop	495.8
Drumstick	358.2
Arecanut Sole (64 No.s)	661.4
Arecanut (69 No.)+ Coconut (8 No.)+ Banana (60 No.) intercrop	364.9
Dairy (3+1)	1655.8
Sheep (12+1)	473.1
Fodder crop	210.1
Pond	18.4
Carbon sinks- Border plantation and agroforestry	0.0
Agroforestry- SINK	1121.9
Total Biomass/compost added – SINK	13876.0
Total SOURCE	9868.3
Total SINK	14998.0
GHG-Integrated farming system	-5,129.7

emission (-5129.7 CO_2^{-e} in kg). The total source for GHG emission noticed from the integrated model was 9868.3 CO_2-e in kg and the total sink from the model was 14998 CO_2^{-e} in kg. Higher greenhouse gas emission was from rice-rice cropping system (4253.8 CO_2^{-e} in kg) fallowed by dairy (1655.8 CO_2^{-e} in kg) and lowest was from pond (18.4 CO_2^{-e} in kg).Crop rotations with green manure improve soil structure, reduce N_2O emissions and improve soil aeration, according to a study by the International Council on Crop Solutre (ICCS) and the Netherlands Institute for Climate, Land and Soil Sciences (NCLS) (Kumar *et al.,* 2006). The amount of CO_2 emission caused by agricultural practices equal 20-25 per cent of the whole CO_2 flux of the atmosphere (Devasenapathy *et al.,* 2009). Rice-Rice cropping system contributed more CO_2 due to use of more fertilizer, which release higher CO_2 and cultivation (puddling) of soils resulting in the loss of soil organic matter (Nadelhoffer, 1995).

Carbon sequestration

Any system's soil carbon stock is determined by the long-term equilibrium between ex-situ carbon addition, in situ organic matter degradation, soil management, soil biota and soil carbon losses due to biological processes such decomposition, erosion, and leaching (Table 7).

Table 7: Carbon sequestration in various components of the integrated crop- livestock system (2011- 2018)

Cropping systems	Bulk Density (Mg/m3)	Soil organic carbon (g/kg)	Carbon Stock (Mg C/ha)
Rice-Rice	1.20	4.16	8.20
Vegetables	1.23	4.53	8.24
Banana sole crop	1.17	4.56	8.08
Banana+ Drumstick intercropping	1.14	4.68	8.06
Drumstick	1.15	4.25	8.23
Fodder	1.18	4.74	8.38
Arecanut (64 No.s)	1.22	4.85	8.91
Arecanut + Coconut (18 No.s) + Banana	1.21	4.69	8.56
Mean	1.19	4.56	8.33
SD	0.01	0.08	0.09

Summarizes the SOC, bulk density (BD) and soil carbon stock in the IFS model. The results revealed that higher soil organic carbon levels were showed in Arecanut (4.85 g/kg) followed by fodder component (4.74 g/kg) and reduced BD were observed with banana + drumstick cropping system (1.14 Mg/m^3) fallowed by drumstick (1.15 Mg/m^3). Green manure crops, leguminous crops and low tillage operations have been shown to increase soil carbon uptake. Legumes reduce atmospheric carbon by absorbing and translocation of these carbons to soil through leaf fall and higher root biomass (Devasenapathy *et al*., 2008). The carbon inputs from crop residues might have contributed to the improvement of carbon stocks. The lower carbon sequestration was observed in the banana + drumstick cropping system, which were nutrient exhaustive. Similarly, proper integration of cereal, legumes and livestock enriches soil quality and sustainability (Wilkins *et al.,* 2008 and Hilimire *et al.,* 2012).

Conclusion

An ICLS is a location and demand specific integration of diary, sheep, arecanut, coconut, vegetable, rice, banana and drumstick and it was found suitable and performance was encouraging. The most notable advantage is that utilizing low-cost or no-cost material at the farm level for recycling certainly reduces the production cost and ultimately improves the farm income. Therefore, it is imperative that integrated farming system concepts and expertise be spread throughout the nation's many agroclimatic regions in order to advance the national mission of improving the economic standing of low-income rural households and providing for their nutritional needs. ICLS model helps to achieve higher sustainable yield index, sustainable value index and system economic efficiency and reduced atmospheric carbon by absorbing and translocation of these carbons to soil through leaf fall and higher root biomass by legumes.

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Conflict of interest

The authors declare that they have no conflict of interest.

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