Agricultural Systems 141 (2015) 126–137

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Resource use and benefits of mixed farming approach in arecanut ecosystem in India

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ARTICLE INFO

Article history:
Received 24 January 2015
Received in revised form 5 October 2015
Accepted 19 October 2015
Available online 29 October 2015

Keywords:
Arecanut
Mixed farming
Livestock
Ecosystem services

ABSTRACT

An eight-year experiment studied the sustainability, profitability, interdependencies and ecosystem services of crop–livestock integration in an arecanut plantation (ABMS) in humid tropics of India during 2007–2014. Arecanut registered similar kernel yields in both sole and intercropped systems in all years. The sole Napier Bajra Hybrid (NBH) recorded significantly higher green fodder yield than intercropped NBH. There was 5–47% yield reduction in intercropped NBH in different plantations over sole NBH on unit area basis. The total standing carbon stocks were significantly higher in arecanut + fodder system (210–228 t ha^{-1}) than arecanut sole and fodder sole. Total water use was 47 to 50% higher in arecanut sole (2340–3280 m^3) compared to ABMS (1178–1546 m^3) per unit area. The contribution of livestock to total outflows was high (82 to 87%) from 2008 to 2014 except in establishment year of dairy unit (54%). On an average, organic waste recycling potential of arecanut + dairy unit was 13.7 t ha^{-1} and dairy unit alone contributed to 87% of the manure production. Total nutrient supply from ABMS after recycling to the system was estimated at 218 kg N, 51.8 kg P and 33 kg K that can meet N and P demand of 1.7 and 2.2 ha of arecanut, respectively. The farm gate nutrient surplus was five times higher than utilization in ABMS that enables farmers to earn higher profits. The use of hard laterite soil for livestock enterprises like dairy, fishery and fodder cultivation resulted in improved resource use efficiency and profits per unit area per unit time. Dairy was economical under all scenarios due to on-farm fodder availability throughout the year. Our main recommendations are to include livestock components in arecanut ecosystem to adapt to climate change scenario, to provide ecosystem services and to reduce ecological imbalances arising due to continuous cultivation of perennial crop.

1. Introduction

Agriculture is affected by several problems due to climate change, degradation of natural resources, proliferation of pests and diseases, market fluctuations and policy changes (MA, 2005; Pretty, 2008; Place and Mitloehner, 2010). It is necessary to devise suitable management strategies to adapt to these challenges especially in the tropics. Shaner et al. (1982) stated that farming systems approach addresses the problems of complex, marginal, diverse and risk prone agriculture. Integration of crop and livestock systems is one of the several farming strategies to restore agricultural diversity and to improve ecosystem services (Altieri, 2001; Magdoff, 2007). Integrated farming systems allow intensification of production and income, reduce adverse environment impact and benefit poor farmers (Edwards, 1998; Costa-Pierce, 2002; Devendra and Thomas, 2002; Karim, 2006). Mixed crop–livestock systems are favoured due to availability of resources, recycling of nutrients among farm components and reduced fluctuations in cash flows (Prein, 2002; Bell and Moore, 2012). The complementary role of different components of mixed crop–livestock farming on small land holdings of East Africa is reported (Tittonell et al., 2005). Thus, integrated crop–livestock systems are regaining interest worldwide for their economic and environmental advantages (Russelle et al., 2007; Wilkins, 2008; Ryschawy et al., 2012; Lemaire et al., 2014). Australian farmers are motivated by the risk mitigation benefits of mixed farming to dampen fluctuations in income as a result of both price and climate variability (Bell and Moore, 2012). Integrated farming systems that include semi-intensive aquaculture can be less risky because of synergism among enterprises, diversity in produce and environmental soundness (Devendra, 2002).

The systematic research work on mixed farming systems is limited in India (Maheswarappa et al., 2001; Jayanthi et al., 2002). About 85% of the land holdings are small and marginal and the average size of land holding is 1.16 ha in India (NABARD, 2014). Demand for livestock products is increasing rapidly in the tropics and the contribution of animals to the total income in smallholder mixed farming systems is as high as 64–70% for cattle and small ruminants (Delgado et al., 1999; Devendra, 2002). Global aquaculture is now the fastest growing

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http://dx.doi.org/10.1016/j.agsy.2015.10.005
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food production sub-sector in many countries. Food security, rural development, and poverty alleviation are closely linked. Most of the farmers in India have small fragmented land holdings where modern large scale production technologies with large input requirements do not offer any solution to their problems. It is also increasingly realized that rural people do not depend for their livelihood on the agricultural sector alone, but rather on a range of livelihood options, which together offer their families food security and reduce vulnerability to conditions over which they have no control. These marginal farmers have livestock in the form of few numbers of cattle or a few pigs, a small flock of ducks or chicken and no doubt a surplus family labour where females and children of the house can work all day long.

This emphasizes the need for supplementing livestock based activities with crop based agricultural activities in small and marginal holdings. The production system at present is virtually traditional monocropping of plantation crops like arecanut, coconut and cashew in humid tropics of India, which are ecologically sensitive regions due to inherent climatic and soil constraints. Plantation crops are highly economical, but adoption of farming systems is necessary due to recurring problems like weather aberrations, soil fertility imbalance, yield variability, price fluctuations, and pest and diseases.

Arecanut (*Areca catechu* L.) is a commercially and socially important non-food crop in South-east Asia. In the world scenario, India accounts for the largest acreage of arecanut (0.446 m ha, GOI, 2014). Though the dry kernel is the main economic part, all parts of the palm can be utilized efficiently by value addition (Chowdappa et al., 1999; NIANP, 2011; Sujatha et al., 2015). Farmers' production goals in plantation belt are generally geared at high output/input ratios. But profits are reducing due to stagnant productivity (1200–1292 kg ha^{-1}) and increasing cost of production. Cropping system approach is followed in arecanut with highly competitive crops such as cocoa, banana, and coffee and yield losses are reported in all component crops due to improper management. Higher resource use efficiency and net income are reported due to nutrition, irrigation and intercropping in arecanut (Bhat and Sujatha, 2006; Bhat et al., 2007; Sujatha and Bhat, 2010; Sujatha et al., 2011a; Sujatha and Bhat, 2013). But it is very difficult to enhance the farm family income unless crop based agriculture is supplemented with integrated animal based enterprises. Adoption rate of arecanut based farming system is less in small and marginal farms compared to medium and large farmers (Jayasekhar, 2011).

Research, policies and interventions on the farm based on sound understanding of small-scale mixed farming systems will be more effective in South Asia (Thomas et al., 2002). The greatest challenge confronting the livestock systems of Asia is insufficient availability of animal feeds, both in terms of quantity and quality (Thomas et al., 2002). Arecanut is an irrigated crop and has lot of potential for inclusion of fodder crops and livestock components in it's ecosystem. Green fodder availability is plenty in plantation belt due to heavy rainfall but dairy is not treated as a business enterprise but practiced only for meeting the needs of household on a small scale. While talking of importance of fish farming in rural development in India, presently the greatest attention is being paid on the integrated approach of fish farming with agriculture and livestock. Promotion of integrated aquaculture with crops and livestock requires consideration of both bio-physical and socio-economic contexts (Nhan et al., 2007). Freshwater aquaculture contributes to over 95% of the total aquaculture production in India. This enterprise has tremendous scope in West Coast of India due to availability of water and difficulties in fishing during monsoon season. Despite the envisaged benefits of mixed cropping systems, an understanding of agro-ecosystem is most important for developing efficient farming systems with less dependence on external inputs. The information on the resource use and economic impact of integrating livestock components in perennial crop systems is scanty in India. With this background, the study on arecanut based mixed farming system was initiated with a primary objective to develop suitable models for different land holdings based on assessment of resource use efficiency, interdependencies, soil fertility and economic sustainability over a period of time.

2. Materials and methods

2.1. Details of experimental site

The research work was carried out at Regional Station of ICAR-Central Plantation Crops Research Institute, Vittal, Karnataka, India (12° 15'N latitude and 75° 25'E longitude, 91 m above sea level) during 2007–2014. The average rainfall per annum at this location is 3670 mm. The annual rainfall varied from 2600 mm to 3950 mm during the experimental period. South-west monsoon contributes about 80% of the total rainfall during June–September. Mean temperature ranges from 21 °C (minimum) to 36 °C (maximum). The average relative humidity varies between 61 and 94%. The soil of the experimental site is sandy clay loam (laterite) with a pH of 5.2–5.6 and high soil organic carbon (>2% in arecanut plantations) at 0–30 cm soil depth. The soil organic carbon status is less than 1% in hard laterite soils. The mixed farming model was established with components like arecanut sole, fodder sole, arecanut + fodder, dairy and fishery in a phased manner as initiation of complete model at a time would be difficult for small and marginal farmers. Fodder sole was included as a measure to ensure continuous fodder supply and to utilize hard laterite soils. The topography is undulating in humid tropics and hard laterite soils are seen in pockets that are formed due to heavy rainfall leading to continuous erosion and hardness of both surface and subsurface. The layout of arecanut based farming system model with different components is depicted in Fig. 1.

2.2. Arecanut component

Arecanut plantations of different age groups (2.7 m X 2.7 m spacing) with the presence of shade trees on South-west side were selected for the study. Arecanut needs shade on South-west side to avoid damage due to sun scorching. In 2007, 21-year-old arecanut plantation with an area of 0.24 ha (plantation 1 with 328 palms) was selected for studying the performance of Napier Bajra hybrid (NBH). Simultaneously another plantation of the same age and area (plantation 1_A with 328 palms) was also selected for only screening different fodder crops in 2007. In 2008, new arecanut plantation was established in 0.22 ha (plantation 2 with 300 palms) on a plot with slope of 3–10% and equal area was delineated for intercropping of fodder and sole crop situations. Fodder crop was intercropped simultaneously in plantation 2. It was contemplated to select another plantation with higher light availability for intercropping of fodder crop based on the results obtained from plantations 1 and 2. In 2012, 14-year-old arecanut plantation (0.21 ha, plantation 3 with 288 palms) with the presence of *Casurina* shade trees was selected. About 15 random sampling units were selected in each plantation for comparing yield and other parameters between sole arecanut and arecanut intercropped with fodder. For sampling purpose, two rows of arecanut palms on either side of the fodder crop in intercropped system and single row of arecanut in sole system were considered. Thus, the number of palms varied in sampling units of sole arecanut and arecanut + fodder system. In plantations 1 and 3, each random sampling unit consisted of 14 palms in intercropped situation and 6 palms in sole cropped situation. In plantation 2, each sampling unit consisted of 10 palms in both cropping situations.

Standardized management practices were followed for arecanut (Bhat and Sujatha, 2004). Farm Yard Manure (FYM) was applied @ 12 kg per palm every year before initiation of experiment. The nutrient composition of FYM was estimated as 0.5% N, 0.12% P and 0.45% K. However, the quantity of FYM application to the palms was adjusted with recycling of cow dung manure from dairy after initiation of the experiment. Arecanut was irrigated with sprinklers equivalent to 100% pan evaporation (E_p) during post monsoon season and thus there was

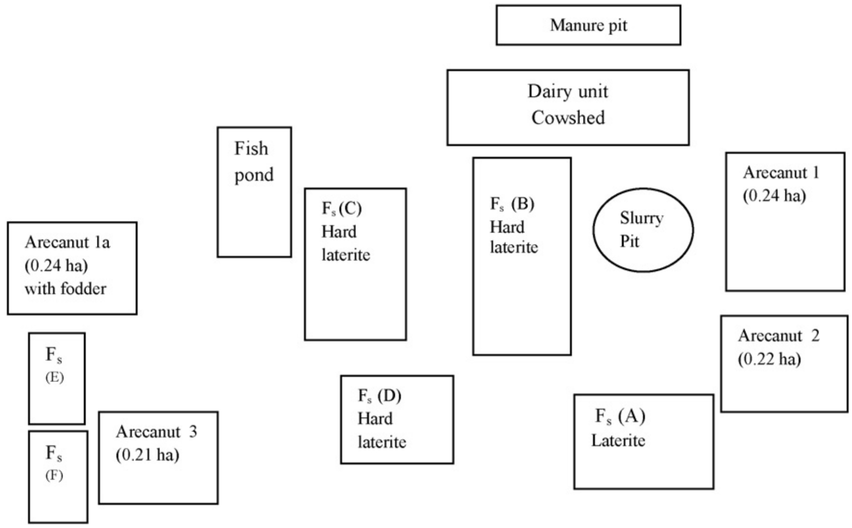


Fig. 1. Layout of different components in mixed farming system.

no need to provide separate irrigation facility to fodder crop. Bordeaux mixture (1%) was sprayed on bunches in May–June to prevent fruit rot incidence caused by *Phytopthora palmivora* and second spray was given after 45 days. Ripe nuts of arecanut were harvested during October–March every year, sun dried, dehusked and expressed as kg dry kernel per hectare. Light availability was measured using LI-6200 Portable Photosynthesis System (Li-Cor Inc., Nebraska, USA).

2.3. Fodder component

Before establishing dairy unit, several fodder crops were screened. Initially fodder crops such as guinea grass (*Panicum maximum*), Guatemala grass (*Tripsacum laxum*), rhodes grass (*Chloris gayana*), Napier Bajra hybrid (*variety* CO_3) and fodder maize (*Zea mays*) were intercropped in arecanut (plantation 1_a) in 2007 because of their importance in the livestock diet. The establishment of all these fodder crops except Napier Bajra hybrid (NBH) was not satisfactory in arecanut. Napier Bajra hybrid was planted as intercrop in arecanut (plantation 1) as well as sole crop (A) in June, 2007. Two rows of fodder crop were planted at a recommended spacing of 60 cm × 60 cm in inter-row interspaces of arecanut. It implies that fodder crop utilizes 44% of the space in arecanut plantation. Two or three budded cuttings were planted in slanting position on the ridges during September–October. Based on the fodder requirement, staggered planting of Napier Bajra hybrid (CO3) was done both as sole and intercrop in arecanut. Fodder crop was managed as per standard package. Intercropping was done in arecanut plantations of different ages. About 0.24 ha area of arecanut was planted with NBH initially in June, 2007 with the assumption that fodder crop performs better under arecanut as aromatic grasses are successfully grown in arecanut (Sujatha et al., 2011a). About 360 m^2 area of sole fodder was maintained for comparison. Legume fodder (*Styolosanthes hamata*) was also tried.

Napier Bajra hybrid was intercropped during 2007–2010 in plantation 1, 2008–2012 in plantation 2 and 2012–2014 in plantation 3. Sole fodder crop was also maintained simultaneously. Sole fodder area (m^2) was demarcated in to different plots of A (360), B (950), C (420), D (180), E (200) and F (180). In sole fodder crop, each plot was divided in to 15 random sampling units and the size of each unit varied between 10 and 60 m^2 depending on the total area of each plot. In intercropped fodder, yield samples were estimated from sampling unit of 72.9–102 m^2 i.e., inclusive of arecanut area. The area utilized by fodder accounts for 44% of the total area under arecanut. For recycling purpose, the plot B was maintained near the slurry pit for recycling of cow shed washings and the plot C near the fish pond for recycling of pond water. The blocks E and F represented CO3 and CO4 cultivars of NHB grass, respectively. Different treatments like recycling of fish pond water and recycling of cowshed washings were imposed to sole fodder from 2012 to 2014. Cow dung manure @ 10 t per ha was applied before planting in hard laterite soils. As a basal dose, 125:125:100 kg of NPK per ha was applied. Nitrogen @ 75 kg ha^{-1} in the form of urea was applied after each cut with gentle raking of the soil in initial years of establishment and whenever dairy wastes could not be recycled. The quantity of N was adjusted or skipped when the cow dung manure/ cow shed washings were applied. Irrigation was given through sprinklers once in 7 to 15 days interval during post monsoon season. The fodder grass was cut once in 45–60 days interval after planting. Green fodder yield was quantified daily on unit area basis. Sometimes, calves and heifers were fed with locally available para grass to supplement for fodder deficit. Initially sole fodder was maintained for comparison with intercropped fodder, but the results highlighted the need for increasing the area under sole fodder to meet the requirement. For comparing the green fodder yield between sole and intercropped systems, we used the *t*-test.

2.4. Dairy component

Two small cowsheds were constructed scientifically with recommended space per animal, and feeding and water troughs, sufficient light and hard floor with required slope. The cost incurred on construction of cowsheds was Rs. 2, 02, 400. The dairy unit was established with 3 milching cows initially in 2007–2008 and 4–6 cows (Holstein Friesian, Jersey and Gir breeds) were maintained under this system from 2010 onwards to ensure milk production from 3 animals throughout the year. Jersey breed was maintained for only one year. The animals varied in lactation, milk production and body weight. Necessary care was taken for pregnant cow before and after the delivery. Male and some female calves were disposed through auction. Stall feeding was adopted to have greater control over the feed quantity and valuable manure output. On an average 25–30 kg green fodder was given daily to each cow based on the availability. Chaff cutter was used to cut fodder in to small pieces to increase fodder intake efficiency. Cattle feed concentrate was given as per recommendations. The concentrate feed mix was prepared by purchasing raw material viz., cereal flour (maize and finger millet), bran (rice and wheat), oil cake (groundnut, sesame and coconut), husk of black gram (*Vigna mungo*), mineral mixture and salt. Cattle feed concentrate of 100 kg was prepared by mixing 50% cereals, 25%

oil cakes + black gram husk, 23% bran and 1% each of mineral mixture and salt. For milking animals, 1 kg mix for every 2.5 to 3.0 l of milk and 2 kg paddy straw was given. For pregnant animals, 2.5 kg mix and 2 kg paddy straw was given from the 7th month onwards. For calves and heifers, 1–1.5 kg feed mix and 1 kg paddy straw were given. Manure output was quantified once in a month from all the cows, heifers and calves. Milk yields were recorded daily for all cows. The lactating dairy cow produced about 24–30 kg of fresh manure per day. The moisture content in fresh manure was estimated at 75–80% based on gravimetric method. Slurry pit of closed type with dimensions of 2.5 m diameter and 2.75 m depth was constructed near cowshed to collect all the cowshed washings in to the pit. Slurry pump (1 HP) was used to recycle these wastes to fodder crop at regular intervals.

2.5. Fishery component

A fishpond with dimensions of 22 m length, 12 m width and 1.5 m depth was constructed in 2010. Due to porous nature of the soil, the pond was lined with silpaulin polyethylene sheet of 250 GSM to curtail percolation loss and covered with plastic net to avoid problems due to birds and wild animals. The construction cost of fish pond with silpaulin lining was Rs. 60,000. The entire silpaulin lining sheet needs to be replaced after 10 years. Laterite soil was filled up to 10 cm at the bottom of the pond to facilitate natural recycling of the food material and to arrest the temperature fluctuations during hot days. An outlet pipe was provided at 1 ft below the embarkment to drain excess water from the pond. Both the outlets and the drain pipes were fixed with strainers. Instead of using aerator that would be costly for small farmers, pond water was recycled at frequent intervals with the help of 0.5 HP motor to fodder crop and the water level was maintained with pumping of fresh water to maintain the aeration in the pond. Composite fish culture of Indian major carps and exotic carps was followed as per recommendations in India. The technology of composite fish culture involves raising of different fish species of complimentary feeding habits and behavior to realize high production. It refers to exploitation of available different ecological niches of the pond effectively by the chosen cultivable fish species. The growth of aquatic plants was nil due to frequent exchange of water. The three Indian major carps such as catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) contribute to 72% of the total production of fresh water aquaculture in India. Composite fish culture included 3 or 4 species, two indigenous (Catla, Rohu) and one or two exotic (common carp and grass carp). It was practiced mostly as three (Catla: Rohu: Common carp in 4: 3: 3) except in 2013 with four species combination (Catla: Rohu: Common carp: Grass carp in 3: 3: 2: 2). The feed for grass carp (*Ctenopharyngodon idella*) was NHB grass. Initially, grass was given daily @ 15% of the body weight and was gradually reduced to 3%. Feed in the form of rice bran and groundnut oil cake was given daily @ 1–3% of the body weight of fish.

2.6. Analysis of soil, manures and effluents

Soil samples were collected from the basins of arecanut and fodder blocks at 30 and 60 cm depths. Soil organic carbon (SOC) was estimated following the modified method of Walkley and Black. Soil nutrient analysis was done using standard procedures (Jackson, 1973). The total N was analyzed using micro-Kjeldahl digestion method (Jackson, 1973). Estimation of K, Ca, Mg and micronutrients like Cu, Zn, Fe and Mn was done in Atomic Absorption Spectrophotometer (AAS). The effluents from dairy and fishery, cow dung manure, vermicompost and irrigation water were analyzed at regular intervals using standard procedures.

2.7. Estimation of carbon stocks

Above ground biomass (trunk, leaf, kernel and husk) and growth parameters like trunk height, girth and number of leaves were recorded every year. Standing trunk biomass (Y) was estimated using regression equation, $Y = 0.01435\ h + 0.3442\ g - 1.0017$ (h = height of the trunk and g = girth of the trunk). Five leaves from each plot were collected and oven dried to estimate leaf biomass. Average leaf biomass was multiplied with number of leaves to arrive at total leaf biomass per palm. The biomass of leaf, dry kernel and husk was added to trunk biomass to arrive at total. Root biomass was estimated indirectly from above ground biomass using estimated root/shoot ratio of 0.20 to 0.21 from destructive sampling of five palms and previous studies. Root–shoot ratio in fodder was estimated by destructive sampling and a ratio of 0.26 was considered though it varied from 0.25 to 0.28. The estimated carbon in arecanut by combustion method (Balasimha and Naresh Kumar, 2013) was considered in this study. Carbon stocks were calculated by multiplying above ground biomass with 0.40 in old plantations and 0.44 in young plantations and below ground with 0.5 (Albrecht and Kandji, 2003; Glenday, 2006). Carbon in above ground standing biomass and root biomass were summed to calculate total carbon storage in biomass in the trial. The carbon storage in soil was estimated using the following formula.

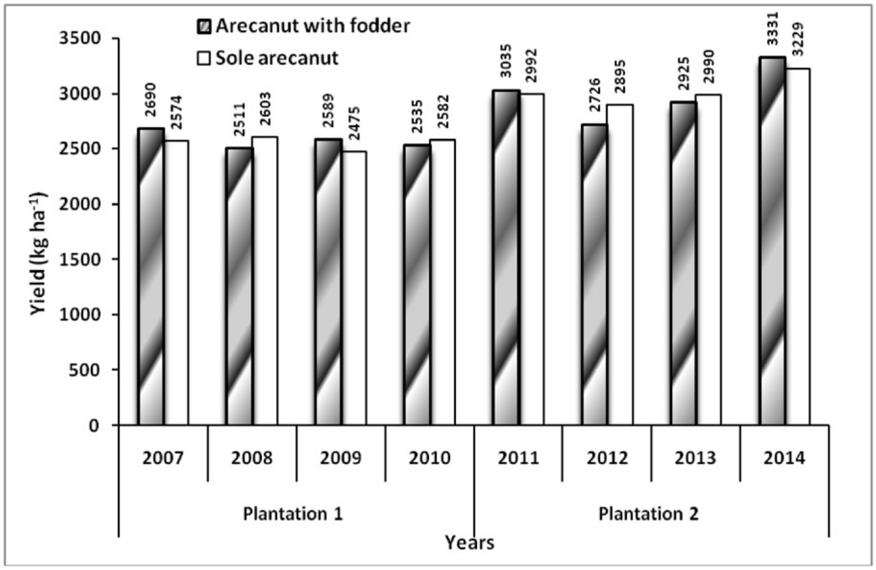
Carbon t per ha = Soil organic carbon (%) × soil bulk density (Mg/m^3) × depth of soil (cm).

2.8. Estimation of water use

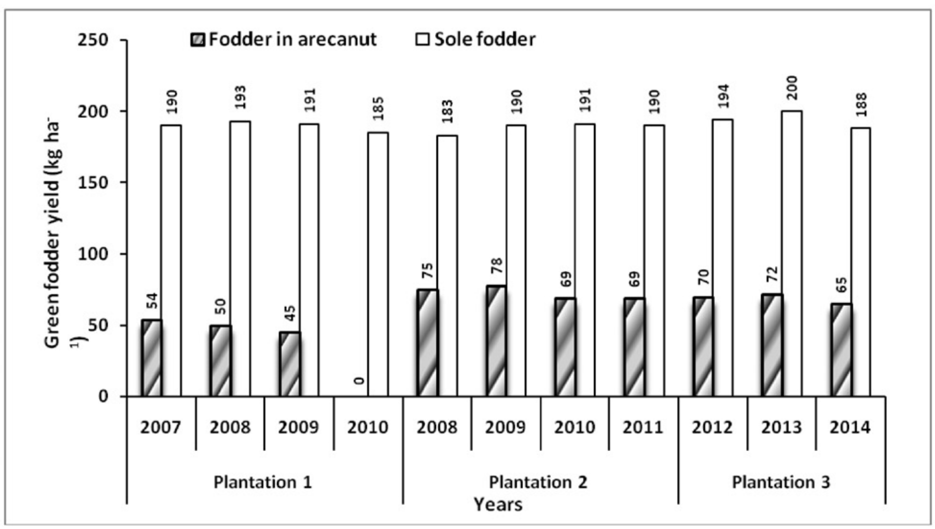
Water use by arecanut was quantified every year based on irrigation requirement. Arecanut requires irrigation equivalent to pan evaporation during post-monsoon season from December to May (Bhat and Sujatha, 2004; Bhat et al., 2007). Daily water use in dairy was quantified once in 3 months at regular intervals and then total water use per year was estimated. Water exchange in fish pond was considered as water use by fishery unit as fish pond was filled with rain water during monsoon season. Water use by fodder was quantified based on number of irrigations given as per recommendation after excluding recycled water from dairy and fish pond to fodder crop.

2.9. Economic and statistical analysis

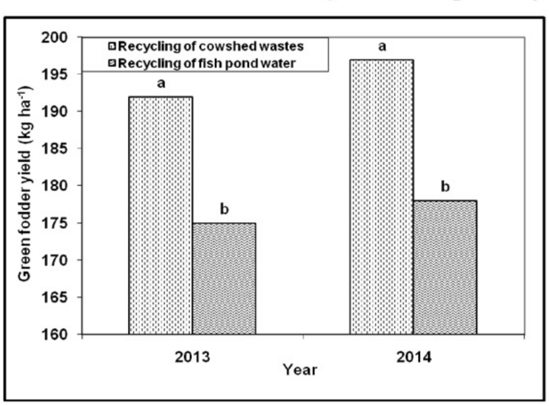
For economic analysis of mixed farming system, both cash flow technique and annuity value approach (Gattinger, 1981) were adopted. The establishment cost on each component such as arecanut, dairy and fishery was amortized separately into an annuity value bearing 10% interest rate. In arecanut, the entire expenditure incurred during pre-bearing stage was considered as establishment cost. In livestock components, establishment cost covered expenditure on construction of cowshed and fish pond with silpaulin lining. The annuity value on each component was a fixed cost and was added to cash inflows of each component every year to arrive at total cash inflows/cost of production. For economic analysis, the cash inflows and outflows were maintained for all the years from the initiation of this study. Cash inflows included expenditure on inputs, labour, cattle insurance, veterinary care, maintenance of calves and heifers and fingerlings. The cost incurred on purchase of cattle was also added to inflows in the initial years and afterwards the herd was increased by self-renewal. Income from dairy unit was estimated using milk production, manure production and livestock sold. An additional income can be obtained from recycling of organic wastes from arecanut plantation by vermicomposting. It was given separately. Local market and farm gate prices were considered for computing cash inflows and outflows. Though local market price per unit was higher in case of livestock products such as milk and fish, the farm gate price was considered for economic analysis. The yields of crops and other parameters were compared statistically using *t*-test. Standard error was given for parameters, wherever *t*-test was not possible.



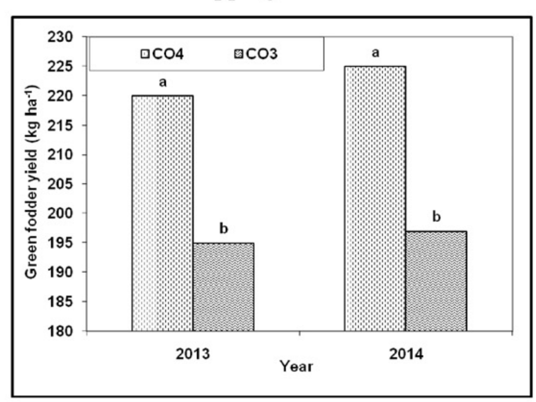
a. Kernel yield of arecanut in different years



b. Green fodder yield of Napier Bajra hybrid in different cropping situations



Recycling of waste water



Cultivars of Bajra Napier hybrid

c. Green fodder yield as influenced by recycling of waste water and cultivar in sole crop situation

Fig. 2. Yields of arecanut and fodder crop as influenced by cropping situation. a. Kernel yield of arecanut in different years. b. Green fodder yield of Napier Bajra hybrid in different cropping situations. Recycling of waste water. Cultivars of Bajra Napier hybrid. c. Green fodder yield as influenced by recycling of waste water and cultivar in sole crop situation.

3. Results

3.1. Output of economic products from ABFS

3.1.1. Kernel yield of arecanut

Arecanut registered similar kernel yields in both sole and intercropped systems in all years in yielding plantations 1 and 3 (Fig. 2). The total biomass of arecanut palms was also similar in both sole and intercropping cropping situations in young plantation 2. In plantation 1, the yields varied between 2511 and 2690 kg ha^{-1} in intercropping situation and 2445–2603 kg ha^{-1} in sole cropping situation during the experimental period. In pre-bearing plantation 2, the total standing biomass of arecanut varied between 4.2–4.3, 7.0–7.6, 14.9–15.5 and 18.2–18.7 kg per palm in 2008, 2009, 2010 and 2011, respectively. Plantation 3 registered higher kernel yields than plantation 1. The kernel yields (kg ha^{-1}) remained the same in sole (2895–3229) and intercropping (2726–3331) situations in different years in plantation 3. For economic analysis, the kernel yields obtained from unit area of plantations 1 and 3 are given in Table 1.

3.1.2. Green fodder yield and land use (m^2 per each cow)

The sole NBH recorded significantly higher green fodder yield than intercropped NBH in plantations 1 and 3 (Fig. 2). On unit area basis, intercropped fodder registered a yield reduction of 35–47% in plantation 1 and 15–21% in plantation 3 over sole fodder. In young plantation 2, there was yield reduction of only 5–18% in intercropped NBH over sole NBH. About 9.5–10 t of green fodder is required for each cow per year. Based on the yield trends of fodder crop in both cropping situations, the land use to meet fodder requirement of each cow was estimated at 550–650 m^2 in sole NBH and 1400–2000 m^2 in intercropped NBH. Seasonal fluctuations in green fodder yields were observed during monsoon and post-monsoon periods in 2012 and 2014. In sole NBH, the green fodder yields in August (32 t ha^{-1} per cut) and March (23 t ha^{-1} per cut) harvests showed significant differences. But, fodder yields remained the same in August (13.2 t ha^{-1}) and March (12.5 t ha^{-1}) harvests in intercropped NBH due to less evaporation rate and higher humidity in arecanut plantation leading to moderation in microclimate. Green fodder yields were quantified at 94–101 t ha^{-1} and 195–197 t ha^{-1} on hard laterite and laterite soils, respectively. Hard laterite soils can be utilized successfully for cultivation of fodder crop as the yields on these soils were 48 to 51% of yields obtained on laterite soils and higher than intercropped fodder yields in arecanut. Improved cultivars have been evaluated in the mixed farming unit. In sole crop situation, CO4 cultivar of NBH (220–225 t ha^{-1}) registered 14% higher green fodder yield than CO3 cultivar (195–197 t ha^{-1}) (Fig. 2). Recycling of cowshed wastes (192–197 t ha^{-1}) resulted in higher green fodder yields of NBH than recycling of fish pond water (175–178 t ha^{-1}) with limited irrigations (Fig. 2). The dry matter varied from 16 to 18% of green grass and total Nitrogen concentration in fodder ranged from 1.4 to 1.6%.

3.1.3. Milk production and fish yields

Table 1 shows the number of milching cows and the year wise milk output from dairy component. The milk yields from 3 milching cows varied between 8730 and 9022 L in the initial years of 2008 and 2009. With scaling up of milching cows (4–6) in dairy unit, higher milk yields were realized during the study period and total milk yields varied between 12,458 and 20,689 L. Indigenous breed of Gir registered milk yield of about 3880–4282 L per lactation. The milk yield ranged from 4500 to 6988 L per lactation for HF breed. Purchased HF breeds produced milk yield of 4500 to 5000 L per lactation, while heifers raised at the dairy unit produced milk yield of 6120–6988 L per lactation. In general, the milk yields and fat content in milk remained the same in all seasons. The fat content in milk ranged from 3.5 to 4.0% and the Gir breed registered higher fat content of 4–5%. In 2014, it was contemplated to reduce the feed cost due to sharp increase in prices of commercial concentrates and surplus availability of green fodder during rainy season. The animal feed diet of two HF cows during peak lactation period was altered from the regular diet of 6 kg feed mix + 30 kg green fodder to new diet by reducing the feed mix and increasing the green fodder (4 kg feed mix + 40 kg green fodder). Similar milk yields (22.5–24.0 L day^{-1}) were noticed in both diets. The feed cost was considerably reduced by Rs. 44 per day per cow in case of 4 kg feed mix + 40 kg green fodder. This feed diet of 4 kg concentrate + 40 kg green fodder was adopted for all milching cows in 2015 up to September. There was a saving of Rs. 41,000/− on feed cost due to adoption of this diet in dairy unit.

Alternate feed options for cattle in arecanut ecosystem were explored as commercial cattle feed accounted to 45–56% of the total inflows in dairy unit. During 2012–13, arecanut leaf sheath powder was used to supplement for 10% of the cattle feed mix. The results indicated that it was possible to reduce the feed cost by Rs. 1.5 per kg mix without reduction in milk yield. A possibility to cultivate protein-rich fodder such as *Stylo* in arecanut ecosystem was explored during 2013–2014. But the performance of *Stylo* was not satisfactory in both sole and intercropped situations. The results indicated that it was not economical to cultivate *Stylo* due to high labour and maintenance cost, and poor green fodder production of about 1.5–2.0 kg m^{-2} $yr.^{-1}$. The fish yields from fishery component ranged between 162 and 182 kg in different years (Table 1). Maximum weight of the fish varied from 550 g to 950 g depending on the variety after one year. The weight ranged from 550 g in Catla to 950 g in common carp.

3.2. Impact on resources

3.2.1. Soil fertility status

In ABMS, the soil organic carbon was analyzed in all three arecanut plantations and fodder crop blocks at the beginning as well as at the end of experimental period. The variation in SOC in arecanut was not significant between sole and intercropped situations. But, the yearwise variation in the SOC status was significant in all arecanut plantations

Table 1
Output from different farming activities in ABMS and sole arecanut.

Year	ABMS				Net income from sole arecanut (Rs./0.25 ha)
	Arecanut (kg kernel per 0.16 ha)	Milk (L)	Fish (kg)	Fresh cow dung (t $yr.^{-1}$)	
2007	455	2363(2)	–	4.5	31,367
2008	425	9022 (3)	–	36.6	30,835
2009	365	8729 (3)	–	43.8	27,926
2010	438	12,458 (3–4)	–	54.8	44,034
2011	515	17,594 (4–5)	181	55.8	73,935
2012	461	20,689 (5–6)	162	60.8	102,889
2013	563	19,240 (5–6)	160	61.7	132,275
2014	616	19,824 (5–6)	180	63.2	126,190

Note: Figures in parenthesis indicate number of milching cows.

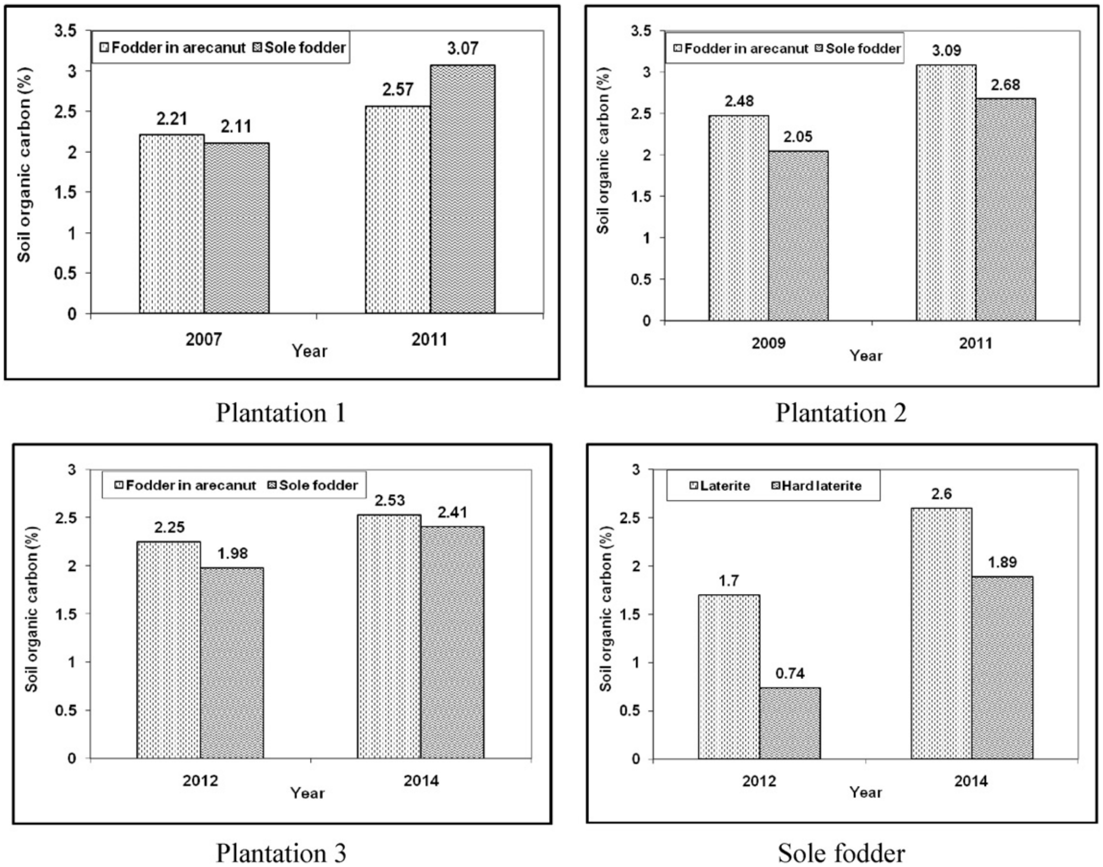


Fig. 3. Influence of fodder grass cultivation on soil organic carbon in sole and intercropping situations. Plantation 1. Plantation 2. Plantation 3. Sole fodder.

irrespective of cropping situation. In plantation 1, the SOC status varied between 2.45 and 2.50% in 2007 and 2.64–2.71% in 2011. In plantation 2, the variation in SOC was marginal both in 2009 (2.70–2.72%) and in 2011 (2.85–2.91%). In plantation 3, the SOC level ranged between 2.30–2.33% in 2011 and 2.47–2.52% in 2014. The variations in soil organic carbon in fodder component are depicted in Fig. 3. Fodder grass cultivation for a period of three to four years significantly enriched the SOC status both in intercropped and sole crop situations. The SOC status varied significantly in laterite and hard laterite soils during the experimental period (Fig. 3). In sole fodder, soil organic carbon status increased from 0.74 to 1.89% and 1.7 to 2.6% in hard laterite and laterite soils, respectively.

In crop components of arecanut based mixed farming system, the soil test P levels were low during the experimental period (2–3 mg kg^{-1} P). The soil test K levels were maintained during the same period (66–82 mg kg^{-1}) in both cropping situations during 2007–2011. Both sole NBH and intercropped NHB maintained significantly higher soil test Ca (1397–1531 mg kg^{-1}) in 2011 than in 2007 (1060 mg kg^{-1}). But, the soil test Mg registered significant reduction during the same period from 112–137 to 29–56 mg kg^{-1}.

3.2.2. Carbon stocks

In general, the soil carbon stocks were higher than aboveground carbon stocks in arecanut and fodder (Table 2). Higher soil organic carbon levels in arecanut and fodder (Fig. 3) indicate higher sequestration of carbon by soil in ABMS. The soil carbon stocks were 6–8 times higher than aboveground carbon stocks in yielding arecanut and fodder. In young arecanut plantation 2, the soil carbon stocks were 12–13 times higher than aboveground carbon stocks. Root carbon stocks were found similar in arecanut and fodder. The total carbon stocks in all three plantations were significantly higher in arecanut + fodder system (210–228 t ha^{-1}) than arecanut sole and fodder sole (Table 2). The total carbon stocks (t ha^{-1}) in arecanut sole and fodder sole were similar in all plantations (153–169 in plantation 1, 129–137 in plantation 2 and

Table 2
Carbon stock assessment in different land use systems (t ha^{-1}) at 0–30 cm soil depth.

Arecanut system	Parameter	Arecanut + fodder	Arecanut sole	Fodder sole
Plantation 1	Root	6.69 ± 0.29	5.24 ± 0.32	4.69 ± 0.06
(25 yr. old) in 2010	Above ground	26.56 ± 0.29	20.99 ± 0.31	18.03 ± 0.23
	Soil C	186 ± 4.1	127 ± 4.2	147 ± 3.0
	Total	219.3 ± 3.7	153.2 ± 3.2	169.7 ± 2.3
Plantation 2	Root	4.35 ± 0.12	2.52 ± 0.2	4.66 ± 0.06
(4 yr. old) in 2011	Above ground	17.1 ± 0.30	10.1 ± 0.33	17.9 ± 0.24
	Soil	207 ± 4.5	137 ± 3.1	129 ± 2.9
	Total	228.5 ± 3.5	149.6 ± 3.0	151.6 ± 2.1
Plantation 3	Root	7.06 ± 0.61	5.34 ± 0.66	4.79 ± 0.09
(16 yr. old) in 2014	Above ground	26.94 ± 0.31	19.92 ± 0.32	18.43 ± 0.40
	Soil	176 ± 3.9	119 ± 4.9	116 ± 3.2
	Total	210.0 ± 3.0	144.3 ± 3.1	139.2 ± 2.0

Table 3
Nutrient composition of organic manures and effluents produced from mixed farming unit.

Nutrient	Macro and secondary nutrients (%) and micronutrients (mg kg^{-1})			Nutrients (mg L^{-1})		
	Vermicompost	Arecanut husk	Cow dung manure	Fish pond effluent	Cowshed effluent	Irrigation water
N	2.0–2.2	0.9–0.94	2.03	2.8	39–296	10–20
P	0.5–0.6	0.09–0.11	0.48	0.23	1.0	0.2–0.3
K	0.9–0.96	1.10–1.18	0.22	2–3	3–5	3–7
Ca	1.8–2.0	0.20–0.23	1.4	15–36	1–2	25–40
Mg	0.63–0.68	0.08–0.10	0.82	–	–	4–7
Cu	62–72	61–66	7.7	–	–	0.005
Zn	320–360	70–90	440	–	–	0.1–0.7
Fe	4000–5400	850–880	1146	–	–	0.16
Mn	490–550	30–40	367	–	–	ND

139–144 in plantation 3) implying that grasses sequester carbon efficiently in a short time.

3.2.3. Recycling potential

Table 3 illustrates the nutrient composition of organics and effluents generated from ABMS. Manures like vermicompost, cow dung manure and cowshed effluents except fish pond water were rich in N and calcium. Arecanut husk contained higher K than other recyclable manures or effluents. The cow dung manure was rich in nitrogen (2%) and phosphorus (0.48%) but contained less K (0.22%). On an average, the estimated nutrient supply from one tonne of cow dung manure was 20 kg N, 4.8 kg P and 2.2 kg K. The total N in dairy effluent varied from 112 to 269 mg L^{-1} and fresh washings contained higher N than stored washings in slurry pit. The fish pond effluent contained 2.8 mg L^{-1} N. Table 4 summarizes the estimates of recyclable organic matter/wastes from arecanut and dairy units of ABMS during 2012–14. On an average, combined recycling potential of arecanut and dairy was estimated at 13.7 t of organics ha^{-1} and dairy unit alone contributed to 87% of the manure production. About 0.41 t of leaf sheath biomass and 0.355 t of husk was obtained from 0.16 ha of arecanut plantation. On an average, about 1.8–2.4 t dry cow dung manure per cow per year was obtained and one tonne of fresh cow dung was priced at Rs. 1875 in the local market. Total nutrient supply from ABMS after recycling to the system was estimated at 218 kg N, 51.8 kg P and 33 kg K that can meet N and P demand of 1.7 and 2.2 ha of arecanut, respectively (Table 4).

Table 5
Total water use in arecanut sole (0.5 ha) and ABMS (0.16 ha arecanut with fodder +0.23 sole fodder +0.11 ha livestock) averaged over years.

System	Water use (m^3)
ABMS with drip for arecanut and sprinkler for fodder	1178 ± 6.4
Sole arecanut with drip system from Dec to May	2340 ± 7.2
ABMS with sprinkler for arecanut and fodder	1546 ± 10.2
Sole arecanut with sprinkler system from Dec to May	3280 ± 15.5

3.2.4. Efficient water use

Table 5 shows the estimated water use by sole arecanut and ABMS under different irrigation systems. It is obvious from Table 5 that mixed farming resulted in efficient use of water. Total water use was 47 to 50% higher in arecanut sole (2340–3280 m^3) compared to ABMS (1178–1546 m^3) in both sprinkler and drip irrigation systems. Total water use in dairy unit was 182 m^3 in a year and about 135 m^3 of cow shed washings was recycled during post monsoon season to sole fodder. Initially, pond was filled with rain water during monsoon season. The pond water filled by rain was quantified at 253 m^3 in a year. Recyclable water from fish pond at each exchange/refilling up to 5 cm depth was 13.2 m^3 and the total water available for recycling was estimated at 238 m^3 during post monsoon season.

3.3. Economic benefits

Table 6 lists the estimated cash flows in arecanut based mixed farming system. It is obvious from the data that the mixed crop–livestock system had positive effect on gross and net profits. The variations in cash inflows were due to variations in prices of inputs and labour. The estimated annuity value on establishment cost of cowshed and fish pond with silpaulin lining was Rs. 15,000 and Rs. 8000, respectively (Table 6). On an average the production cost for one kg of fish without and with inclusion of annuity on establishment of fish pond worked out to be Rs.30 and Rs.70, respectively. The local market price varied from Rs.150 to 200 per kg fish. In this study, the gross profits were calculated using farm gate price of Rs.80 per kg fish. The gross returns from sale of fish varied from Rs. 13, 200 to 14, 880. The arecanut based mixed farming system accrued higher net income of Rs. 33, 865 than sole arecanut due to 17% saving in input cost (Table 6). This 8-year-study revealed that the net income from ABMS gradually increased from negative in the initial year to more than Rs.2, 40,000 in 6th year. Arecanut based mixed farming registered maximum net returns of Rs. 2, 88,999 in the 8th year. Mixture of crop and livestock enterprises

Table 4
Organic matter production and nutrient recycling potential of arecanut (0.16 ha) and dairy unit (2012–14).

Activity	Quantity	N (kg)	P (kg)	K (kg)
Recyclable leaf waste from arecanut	930 ± 24 kg			
Recyclable leaf sheath waste from arecnut	410 ± 9 kg			
Recyclable husk waste from arecanut	355 ± 7 kg			
Recovery of vermicompost from leaf waste of arecanut	700 ± 16 kg			
Value of vermicompost @ Rs. 5.00/kg	Rs. 3500			
Value of earthworms multiplied (2.5 kg @ Rs. 500/kg)	Rs. 1200			
Leaf sheath waste as cattle feed @ Rs. 7.5 per kg	Rs. 3075			
Total cow dung produced from dairy with 4–6 cows	12 ± 0.12 t			
Total recycled cow dung to ABMS (arecanut −0.9 t; fodder −1.0 t; fishery-0.1 t)	2.0 t			
Total production of organic matter from arecanut and dairy	13.7 t			
Surplus organic manure production from arecanut and dairy	10.7 t			
Nutrients required to meet the demand of one ha of arecanut	–	130	23.4	152
Nutrient supply from cow dung manure (12 t)	–	240	57.6	26.4
Nutrient supply from cow dung manure (10 t) after recycling to ABMS	–	200	48	22
Surplus cow dung sufficient to meet nutrient demand of arecanut	–	1.5 ha	2.1 ha	0.14 ha
Nutrient supply from 0.7 t of vermicompost and arecanut husk	–	18	4.16	10.5
Total nutrient supply potential of the system	–	218	51.8	33
Total manure sufficient to meet nutrient demand of arecanut	–	1.7 ha	2.2 ha	0.22 ha

Table 6
Cash flows (Rs.) in arecanut based mixed farming system (0.16 ha arecanut + fodder (sole and intercrop) + dairy + fishery).*

Year	Arecanut		Dairy + fishery	Annuity on establishment of dairy and fish pond	Dairy	Fishery	Total		Net return	Additional net return from recycling arecanut wastes
	Inflows	Outflows	Inflows	Inflows	Outflows	Outflows	Inflows	Outflows		
2007	9900	31,850	77,800	15,000	37,355	–	102,700	69,205	−33,495	7000
2008	11,000	29,750	146,000	15,000	152,326	–	172,000	182,076	10,076	7500
2009	11,000	25,550	155,361	15,000	173,119	–	181,361	198,669	17,308	7500
2010	11,000	39,420	227,860	15,000	269,387	–	253,860	308,807	54,947	7500
2011	13,200	61,800	305,870	23,000	355,714	14,880	342,070	432,394	90,324	7500
2012	22,000	82,980	373,963	23,000	598,119	14,560	418,963	695,659	276,696	8000
2013	24,200	120,000	468,800	23,000	622,900	13,200	516,000	756,100	240,100	8000
2014	24,200	135,520	536,070	23,000	722,349	14,400	583,270	872,269	288,999	8000
Total (2014)	126,500	526,870	2,291,724	152,000	2,931,269	57,040	2,570,224	3,515,179	944,955	
Total (2011–14)	83,600	400,300	1,684,703	92,000	2,299,082	57,040	1,860,303	2,756,422	896,119	

* The inflows for fishery unit was included in dairy inflows due to combined feed and labour cost.

resulted in reduced variation in annual farm returns from the 4th year onwards. When compared to the economic benefit from sole arecanut (Table 1), the net returns were negative in ABMS in initial year of 2007 due to costs incurred on purchase of cows and miscellaneous items as part of the establishment of a dairy unit. In 2008 and 2009, there was marginal increase in net returns due to income from arecanut crop. From 2010 onwards, ABMS registered 22–169% increase in net income per unit area. Overall, the contribution of livestock to total outflows was high (82 to 87%) during 2008 to 2014 except in the establishment year of dairy unit (54%).

3.4. ABMS models for different land holdings

Based on the compiled results of this long-term trial, mixed farming models for small and marginal land holdings were formulated by quantifying average output per each unit (Table 7). The quantifications were average fodder yield per 1000 m^2 in sole (19 t) and intercropped situations (5–7 t), kernel yield per palm (2 kg) and milk yield per cow (3650 L). The inflow and outflow per each palm/cow were estimated based on rates of 2014 to arrive at expected benefits for different land holdings. The average cost of production per palm was Rs. 120 in mixed farming system and Rs. 145 in sole crop situation. Based on the results of this trial, the average inflow and outflow per cow per year was estimated at Rs. 73,000 and 1, 20, 450/—, respectively. The fodder availability and sufficiency for number of cows were estimated for different land holdings. Different scenarios were formulated by varying the area for three important components in which the intercropped area of fodder was restricted or increased or nil in arecanut. In scenarios 1 and 2, expected profits were increased by as much as 90% in small holdings by adopting mixed farming system over sole arecanut. The profits were reduced with decreased contribution of dairy and increased size of land holding in ABMS.

4. Discussion

The major farming activity in humid tropics of India is cultivation of commercial crops such as arecanut, coconut, cocoa, rubber and cashew. Agricultural activity alone is not sufficient to sustain farm families as arecanut farmers face recurring problems due to stagnant productivity, soil fertility imbalances, proliferation of diseases, price fluctuations and climate change. Due to predominance of small and marginal holdings (<2 ha), other livelihood options for farm families are essential for food and nutritional security, and sustainable profits. Adoption of cropping/farming approach is appropriate for plantation ecosystem to increase resource use and profits (Sujatha et al., 2011b; Bhat and Sujatha, 2011). This study discusses the impact of ABMS on ecosystem services and productive aspects like economic output, resource use, recycling potential, profits and soil fertility in an integrative way.

There is potential for improved land use through pasture cultivation in the perennial systems in Southeast Asia (Shelton and Stur, 1991). The non-competitive and efficient land use for fodder production is inevitable for higher milk yields in arecanut based mixed cropping system.

Table 7
Arecanut based mixed farming models for different land holdings and expected benefits over sole arecanut.

Land holding (ha)	Land use for different components (ha)				Expected benefits as per 2014 rates				
					Green fodder yield (t)	Fodder sufficiency (no. of cows)	Net profit (Rs.)		
	Arecanut + fodder	Fodder sole	Dairy unit	Fishery unit			ABMS	Arecanut sole	% increase
Scenario 1: Model with restricted fodder area in arecanut									
0.25	0.2	0.025	0.025	–	19–23 [1]	2	182,000	95,875	90
0.5	0.3	0.1	0.075	0.025	34–40	3–4	282,000–321,300	191,750	47–72
1.0	0.75	0.1	0.1	0.05	56–72	5–7	585,000–646,000	383,500	53–69
1.5	1.0	0.2	0.2	0.1	88–108	8–10	817,000–917,000	575,250	42–59
2.0	1.5 [2]	0.2	0.2	0.1	88–108	8–10	1,042,000–114,000	767,000	36–49
2.5	2.0 [2]	0.2	0.2	0.1	88–108	8–10	1,253,000–1,348,000	958,750	31–41
Scenario 2: Model with entire arecanut area intercropped with fodder									
0.25	0.2	0.025	0.025	–	19–23	2	182,000	95,875	90
0.5	0.3	0.1	0.075	0.025	34–40	3–4	282,000–321,300	191,750	47–72
1.0	0.75	0.1	0.1	0.05	56–72	5–7	585,000–646,000	383,500	53–69
1.5	1.0	0.2	0.2	0.1	88–108	8–10	796,000–890,000	575,250	38–55
2.0	1.5	0.2	0.2	0.1	113–143	11–14	1,146,000–1,288,000	767,000	49–68
2.5	2.0	0.2	0.2	0.1	138–178	13–17	1,449,000–1,639,000	958,750	51–71

Note: [1] – Based on age of arecanut plantation; [2] – Only one hectare of arecanut with fodder crop.

Inter-row interspaces in plantations provide opportunity for cultivation of perennial fodder crops. Arecanut canopy permits 32.7–47.8% of incident radiation to penetrate down to the ground (Balasimha, 2004). The results indicated that the yield of arecanut is not affected by intercropping of fodder grass (Fig. 2) and the yearwise variations in yield are due to alternate bearing and fruit rot problems. This can be attributed to positive impact of intercropping on microclimate in arecanut (Bhat and Sujatha, 2011; Sujatha et al., 2011b). But, the green fodder yield of intercropped NBH is reduced by 5–47% over sole NBH (Fig. 2) due to reduced light availability. The light availability to intercrops in this study varied from 515 to 748 μmol m^{-2} s^{-1} in different arecanut plantations. Other possible reason for reduced fodder yields in intercropped situation might be heavy dripping during monsoon season and decay of few tillers. Considering these different influencing factors, it is understandable that the green fodder yield in intercropping system is influenced by light availability despite optimum soil moisture and SOC levels in the system (Fig. 3). Few reports in the literature indicate the better performance of fodder crops in the presence of trees (Garrett et al., 2004; Moreno et al., 2007), while some reports highlight the negative effect of trees on intercrops due to light stress (García-Barrios and Ong, 2004; Moreno, 2008). Overall, our study suggests that fodder yields are dependent on light availability and there is a need to delineate area for sole fodder. Thus, it is advisable either to delineate area for sole fodder or to plant arecanut in wider/paired rows to ensure sufficient fodder supply in ABMS. It is unlikely that farmers will cultivate fodder on laterite soils. Farmers prefer cultivation of remunerative crop like arecanut and use local grasses available in arecanut plantation as fodder. Hard laterite soils, which are not suitable for cultivation of arecanut, are seen in few pockets with the presence of sparse vegetation in humid tropics. The results of this long-term study give option for arecanut farmers to cultivate fodder grass successfully on these soils by applying locally available arecanut husk at the time of planting to loosen the soil and conserve moisture.

The milk yields in this study are 4 to 6 times higher than average milk production of less than 1000 kg per lactation in India. The average milk yields are also comparable to yields in Europe (4500 kg) and United States (7000 kg). Local breeds of cattle and inadequate supplies of quality feed and fodder are the major reasons for less milk yields in India. This study highlights that on-farm availability of green fodder and efficient feed use are important for profitable dairy management in humid tropics. Replacement of livestock by raising heifers from the dairy unit has also contributed to higher and sharp increase in milk yields. Thus, small herds are ideal for small and marginal farmers initially to contain fixed costs. It is advisable to scale up dairy unit gradually by self-renewal. There is a need to reduce the competition for available feeds by increasing the availability of alternate animal feeds (Renard, 1997; Thomas et al., 2002). Commercial concentrate mixtures and forage legumes increase the protein content of livestock diet (Klapwijk et al., 2014). But, majority of the farmers are unable to invest in costly feed concentrates and there is a need to find out locally available feed sources. Several options were explored in this study for improving economic benefits from dairy component in ABMS and the efforts made in this direction have yielded positive results. In arecanut-based cropping system, there is scope for utilizing non-conventional feed resources like arecanut leaf sheath, suckers and pseudo-stem of banana, and cocoa pod husk as cattle feed. Leaf sheath of arecanut can be used as cattle feed by supplementing up to 40% of the commercial feed mix (NIANP, 2011). But, the sudden change in feed diet by supplementing leaf sheath in large quantities was avoided in this study. Due to supplementation of commercial feed mix with arecanut leaf sheath up to 10%, the feed cost is reduced considerably. The performance of *Stylo* is not satisfactory in arecanut due to high rainfall and more shade. It is cheaper to purchase black gram husk rather than cultivation of *Stylo* in the limited land available to the farmer in humid tropics.

From the trends of inflows and outflows of dairy unit, it is clear that the key determinant of profit is total cost of production and the right balance between input use and milk output is essential for increased profits. It is obvious from the results that maintenance of dairy unit with minimum 4 milching cows is necessary to sustain small and marginal farmers unless family labour is involved in dairy management. An additional income of Rs. 5000–10,000 per year can be obtained through disposal of male calves and excess female calves. About 70% of the livestock is in the hands of small and marginal farmers and landless laborers in India. Most of the farmers prefer low cost cowsheds that are constructed with arecanut stem and palm leaves and involve family labour in dairy management. Thus, government support in the form of subsidy for cattle feed mix and construction of scientific cow shed would be useful for small farmers to avoid income loss in the initial years.

Many forms of integrated aquaculture are dominated by resource-rich entrepreneurs in Asia (Little and Edwards, 2003; Nhan et al., 2007). Aquaculture in small-holder systems is aimed at improving the livelihoods of the rural poor, enhancing food security and generating employment opportunities in rural areas (Jayaraj et al., 2008). Despite availability of resources, freshwater inland aquaculture is not popular in the West-coast of India due to availability of marine fish. In recent years, the role of small-scale aquaculture in poverty alleviation and household food security is recognized as part of rural development program. In this study, we intended to use hard laterite soils for fishery unit and the results indicated that the inclusion of small scale aquaculture unit in ABMS is beneficial to meet the local demand during heavy monsoon season. The fish yields in this trial (6.2–7.2 t ha^{-1} $yr.^{-1}$) are two times higher than the national average of 2.9 t ha^{-1} $yr.^{-1}$ from still-water ponds in India (ICAR, 2013). Heavy monsoon rains from June to September and the availability of good quality water during post-monsoon season are the added advantages to fill and refill the pond in these regions. The pond is filled with rain water and the charges incurred on fuel and labor to fill the pond can be saved. In view of the huge export demand, community approach to fish farming in small land holdings would enable farmers to earn higher profits. The vermicompost produced from arecanut leaf wastes can also be used for fish culture instead of cow dung from dairy. Small ponds, which facilitate effective control of environment, are preferable as reconversion of ponds to agricultural practices is not possible. The positive impacts of Integrated Agriculture–Animal husbandry–Aquaculture farming on the livelihoods of the poor in terms of improved food supply, employment and income generation are reported (Prein, 2002; Karim, 2006). This study shows that fish pond construction with silpaulin lining is costlier and the fish culture accounts for only 30–40% of the total inflows in a year. The fish pond construction without lining would reduce the establishment cost, but it would be difficult to refill the pond daily in water scarcity conditions as hydraulic conductivity is high in laterite soils (0.01 cm s^{-1}).

Soil enrichment is the key component of ecosystem services (Syswerda and Robertson, 2014). Well-managed mixed farming systems enhance the organic matter content through nutrient cycling and organic matter use, and sustain the agro-ecosystem (Schiere et al., 2002; Watson et al., 2005; Petersen et al., 2007; Russelle et al., 2007; Wilkins, 2008; Hilimire, 2011). Pastures store over 90% of their carbon and nitrogen below-ground as soil organic matter. Enrichment of soil organic carbon is noticed in crop components of arecanut based mixed farming system. The results in Table 2 indicate that grasses sequester carbon efficiently in short time than perennial arecanut. Grasslands provide essential ecosystem services by absorbing negative environmental impacts resulting from the intensification of agriculture (Lemaire et al., 2005). In fodder grass, root production varied from 1.2 to 1.6 kg per plant after the third year of planting. Arecanut husk application at the time of planting and in situ root decay might have contributed to improvement in carbon stocks. The contribution of grasslands is often under emphasized because most storage is in soil organic matter rather than in aboveground biomass (de Groot, 1990). Grassland ecosystems may accrete equivalent amounts of organic matter as forests and are considered a general sink for carbon dioxide (CO_2) due to litter deposition as dead leaves and roots with high C:N and lignin:N ratios (Corre et al., 2000; Rasse et al., 2005). In young plantation (2), soil carbon stocks are high due to planting in virgin soil after clearing sparse vegetation. These results highlight that the carbon stocks in all land use systems like arecanut + fodder, arecanut sole and fodder sole are high in above and below ground biomass as well as soil. This can be attributed to factors like reduced soil temperatures, slow decomposition rate of organic matter, continuous in situ root decay and heavy rainfall leading to profuse growth of vegetation in humid tropics. Overall, the contribution of soil carbon stocks to total carbon storage is very high compared to carbon stocks in the above ground biomass. This study shows that arecanut based mixed farming system on a small scale do not lead to problem of P accumulation. But, the available soil P is low in this study due to P fixation and high organic P in laterite soils.

Water availability during summer is crucial for growth and yield of arecanut, which requires irrigation equivalent to pan evaporation in humid tropics (Bhat and Sujatha, 2004; Sujatha and Bhat, 2010; Sujatha et al., 2011b). Water harvesting is a major problem in laterite soils due to faster infiltration rate, poor moisture retention capacity and high hydraulic conductivity. Thus, agricultural technologies/practices that improve water productivity are critical. It is obvious from Table 5 that mixed farming results in efficient use of water due to recycling of water from livestock component to crop component. Recycling of cow shed washings to sole fodder during post-monsoon season along with cow dung manure saved critical inputs like fertilizer and water. Recycling of fish pond water to fodder and refilling of the pond help in maintaining required aeration besides water saving. Thus, the farmers have option to divert water from sole arecanut to dairy and fish pond to improve water productivity. Due to less and poor distribution of rainfall in 2012, water shortage was experienced in April–May, 2013. Recycling of water from livestock components to crop component helped to sustain ABMS during this period. Further studies are required on recycling of water from livestock component to arecanut.

Nitrogen surplus and total gross margin are the two evaluation indicators that represent the sustainability components of mixed crop–livestock farms (Ryschawy et al., 2012). These two components are discussed here in detail. The results in Table 4 indicate that nutrient surplus is five times higher than utilization in ABMS. This study indicates that the farming system makes the farmers less dependent on external input and helps in minimizing cost of production. Field studies are required to evaluate the recycling potential of nutrient surplus from ABMS. It is necessary to optimize the farming system for reducing nutrient losses in the whole dairy farm (Aarts et al., 2000). Immediate recycling of wastes and proper storage of manures/effluents is ensured to reduce nutrient losses in different components of ABMS. This is evident from the data on nutrient composition of manures/effluents. Fertilizer recommendations for fodder should not be altered when pond water is used for irrigation as enrichment of pond water is insufficient to meet nutrient demand.

Bell and Moore (2012) pointed out lack of studies on reduction in income variability due to adoption of mixed farming systems/mixed crop–livestock farms. Livestock activities are more stable than agricultural crops (Pacín and Oesterheld, 2014). This is evident in the present study when a dairy unit is maintained with more than three milching cows. The net returns are negative only during initial years of 2007 to 2009 in ABMS. Thus, a short period of 2 years is needed for successful conversion to mixed farming and to make it cost effective. The contribution of these livelihood activities to farm income shows variations among different components. The results of this study also illustrate that the livelihood strategies of ABMS are generally dependent on three major income sources: income from crop production, livestock and recycling of wastes as value added products. The cash outflows and the net returns from arecanut based mixed farming (Tables 6 and 7) reveal that livestock can become the main source of income generation and can compensate for the yield loss in arecanut due to alternate bearing, fruit rot and weather vagaries. Due to assured year round employment opportunity in mixed farming systems, the problem of manpower availability can be addressed effectively compared to less man day requirement in sole arecanut (180 days). The economic benefit of ABFS models is better realized when the price of the main crop is low (Jayasekhar, 2011). It is obvious that inclusion of livestock components would be highly beneficial in arecanut ecosystem for nutritional security of rural households besides increasing profits.

The envisaged ABMS models for 0.25 to 2.5 ha holdings would help farmers to take strategic and tactical decisions, and to determine the degree and kind of integration among enterprises. Monocropping of arecanut under climate change scenario is risky and might contribute to ecological imbalance, ground water exploitation, increased incidence of pests and diseases, decline in productivity and reduced income. Though several opportunities exist, the adoption rate of mixed farming in humid tropics is slow due to cultivation of remunerative crops such as plantation crops, banana, cocoa and black pepper in more than 90% of land holdings. Large scale adoption of mixed farming systems requires policy support from government for establishment of dairy and construction of fish pond mainly to benefit small and marginal farmers. The results of the present study confirm several reports that mixed farming systems are sustainable, environment friendly and economically viable compared to only crop-based agricultural systems (Tittonell et al., 2005; Russelle et al., 2007; Wilkins, 2008; Ryschawy et al., 2012; Lemaire et al., 2014). Thus, crop–livestock integration in small size farms is an effective measure to improve ecosystem services in perennial arecanut. This prospective study also identifies future technical directions for improving the sustainability of mixed crop–livestock systems.

5. Conclusions

Arecanut-based farming system is efficient in terms of ecosystem services like yield and economic benefits, enrichment of SOC, carbon sequestration and water use. The benefits were directly associated with increased productivity, increased income and improved sustainability. Overall, the interrelationships among different components of arecanut-based mixed farming in terms of resource flows suggest that the system can be made interdependent, economical and self-sustainable in laterite soils of humid tropics due to on-farm availability of green fodder and efficient resource use. Utilization of hard laterite soils for dairy and fish pond is also an ideal option for arecanut farmers. Livestock provided fast and efficient route to income intensification and stability for small and marginal-holders in perennial crop system. Adoption of ABMS is a better management strategy in view of climate change and ecological imbalance in humid tropics. Strengthening mixed farms through technical innovations and government support is the most important.

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