Food, nutrition and energy security of small and marginal farmers through integrated agriculture

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Food security and environmental sustainability are threatened by the degradation of natural resources in India's rice-based agricultural systems. On-farm and on-station experiments on the integrated farming system (IFS) were carried out at ICAR-Indian Agricultural Research Institute, New Delhi, to develop a productive, profitable and long-term resource-conserving alternative agricultural system that secures the food, nutrition and energy requirements of small farmers. IFS helped in making the farming system sustainable through different cropping, biodiversity and ecosystem services. It provided food and nutrition security to the farmer family through the production of diversified food commodities such as cereal, pulses, oilseeds, vegetables, fruits, eggs, milk, fish, meat, etc. Dairy–biogas integration offered a promising win–win opportunity to improve crop production while, at the same time, meeting the fuel needs of the farmer families. Field application of slurry reduced fertilizer burden on the farmers, besides improving the sustainability of their fields. Ecosystem services such as pollination of crops, run-off water harvesting, prevention of soil erosion, carbon sequestration by plants and soil, cultural services, etc. are vital for the sustainable supply of food and fibre. The experiment was conducted for three consecutive years (2015–18), and was observed that the IFS model generated net returns of INR 378,784 and employment of 628 mandays which are more than the conventional rice–wheat system. In the Indo-Gangetic Plains, IFS leads to sustainable intensification besides food security and poverty alleviation.

Keywords: Biodiversity, food security, integrated agriculture, nutrition and energy security, resource recycling, sustainable intensification.

THE domination of smallholders is one of the noticeable elements of the changing structure of Indian agriculture. In India, out of 145.72 million landholders, 68% are marginal farmers who own less than 1 ha, and 18% are small farmers with holdings of 1–2 ha (ref. 1). The proportion of small and marginal farmers will increase in the future as well since land fragmentation is inevitable in nuclear households. It is difficult for small farmers to transition from traditional to scientific farming because of the tiny savings from these small holdings[2]. Rice–wheat cropping system (RWCS) in the Indo-Gangetic Plains (IGP) has led to the destruction of natural resources, loss in farm profitability, factor productivity and environmental security[3,4]. Moreover, the conventional monoculture practice and disciplinary approach is incapable of meeting the food and nutritional security as well as the livelihood of smallholders on a sustainable basis[5]. Since farm business income is dependent on farm size, land reforms in favour of the small farmers are helpful in increasing the income[6]. It is easy to take up land reforms on small farms that increase small farmers' income. Due to the low purchasing capacity of small and marginal farmers, it is difficult for them to maintain an optimum level of nutritive food intake, leaving them undernourished. It is a hard truth that farmers who supply the main part of agricultural produce are the poorest and most hungry population group in the developing countries[7]. According to Rawal *et al.*[8], 39% of Indian population is undernourished, mostly in rural areas. The integrated farming system (IFS) provides nutrition security to a farmer's family through the production of diversified food commodities such as cereals, pulses, oilseeds, vegetables, fruits, eggs, milk, fish, meat, etc. Moreover, the energy security of these families is ensured due to the integration of additional components like biogas within the farm[9]. The higher returns from IFS were not only due to higher productivity but also due to lower cost of production, as by-products of various components are recycled within the system[10]. In India, farming systems research has been largely focused on enhancing production, productivity and profitability without much emphasis on nutritional and energy outcomes[11].

Considering the above facts, an effort has been made in this study to: (i) develop an IFS model that can ensure the food, nutritional and energy security for smallholders and (ii) quantify the by-products generation from different IFS components for recycling within the system to make it self-reliant and less dependent on external inputs.

A field experiment was carried out on IFS during 2015–18 at the Research Farm of ICAR-Indian Agricultural Research Institute (IARI), New Delhi, to study the performance of the interlinked system with different components involving crops, dairy, fishery, duckery, poultry, biogas plant, fruit trees and agro-forestry, and its potential to secure food, nutrition and energy requirements of the small farmer household. The climate of the study area was semiarid, with dry, hot summers and cold winters. The soil of the experimental site was sandy clay loam (26.4% clay, 11.9% silt and 61.7% sand), very deep (>3.5 m) and well-drained, belonging to order Inceptisol of Udic Ustochrepts.

The study was conducted on IFS encompassing crops, dairy, fishery, duckery, poultry, biogas plant, fruit trees and agro-forestry in 1.0 ha area (Figure 1). The details of each component are given below.

Crop component: Five cropping systems, i.e. maize–pea–okra, maize–mustard–green gram, cotton–wheat, bottle gourd–onion and okra–wheat were accommodated in

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0.625 ha and were evaluated to identify the efficient cropping system.

Dairy: Three crossbred cows (two Holstein Friesian and one Jersey) were maintained. Feed and water troughs were constructed inside the shed. Next to the dairy unit, a dung tank (1 m^3) and urine tank (0.5 m^3) were constructed to collect drained dung and urine.

Biogas: A biogas plant of Khadi and Village Industries Commission (KVIC) model of 2 m^3 capacity was established near the dairy. Cow dung from the dairy unit of about 45–50 kg, and 50 litre of water (1 : 1) were fed to the biogas unit from which bio-digested slurry and biogas were collected through their respective outlets.

Fishery: A fish pond was constructed in 1000 m^2 area (50 m × 20 m) with a depth of 2 m. Four species, viz. catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*) and grass carp (*Ctenopharyngodon idella*) of different feeding habits were stocked together in the ratio 3 : 4 : 3 : 2. Stocking density was 12,000 fingerlings/ha.

Poultry: A low-cost poultry house was constructed on the fish pond with the help of iron pillars (Figure 1). Fifty poultry birds, viz. Aseel-12, Kadaknath-14, Ankleswar-12 and Nikobari-12 were reared in it.

Duckery: A duck shed was constructed on the pond embankment using wooden and bamboo poles (Figure 1). Thirty-five ducklings of eight-month-old Khaki Campbell breed were reared for eggs.

Fruit trees: Thirty seven kinnow (*Citrus reticulata*), 30 lemon (*Citrus limon*) and 15 banana (*Musa paradisiaca*) plants were grown all along the farm boundary with 4 m spacing between plants. Ten guavas (*Psidium guazava*) and ten mangoes (*Mangifera indica*) trees were planted on the fish pond dyke for fruit production. The entire 1.0 ha farm was protected with a barbed wire fence. Country bean (*Lablab purpureus*) and *Basella rubra* were sown along the fence.

Agroforestry: Twenty-one moringa (*Moringa oleifera*) trees were planted on one side of the boundary. The spacing between the trees was 4 m. They were pruned every year for a good flush.

Figure 1. Integrated farming system (IFS) model in 1.0 ha area with different components.

To explore the synergies among the components, the by-products of each component were quantified and reused as input in the other components. Besides the economic yield from crops, crop residues like wheat straw, maize stover, legume straw and weed biomass served as feed for cows, thus reducing the feed cost of the dairy unit. Similarly, cattle dung from the dairy was used as an input for the biogas plant. Slurry application in the crop field reduced the production cost by cutting fertilizer costs. Likewise, by-products of all the components were quantified, by which we can infer how well they are interdependent.

The IFS model was developed considering the resources available and family needs of various items, including modern forms of energy (biogas). The optimization was done in such a way that the resources of the system could be efficiently utilized without causing environmental problems. Three units of dairy cows produced around 50 kg of cow dung, which was fully utilized by the 2 m^3 biogas plant. If the biogas plant is smaller (1 m^3), the generated cow dung will be in excess and cause an environmental problem. If it is larger, the digester of the biogas plant will be underfed. Similarly, for a fish pond of 1000 m^2 area, 32–35 ducks are optimum for aeration of the pond, and excreta release and food availability for the ducks too will be sufficient from the pond. A poultry unit of 50 birds for the 1000 m^2 pond area is ideal and may not result in NO_3 load in the pond water, which is detrimental to fish growth. Overall, the planning was made to properly utilize the by-products and waste generated in the system.

Besides generating a year-round income of INR 378,784 with INR 1040 per day farm income, IFS helps make the farmer family self-sufficient in food and fodder (Table 1).

According to the dietary guidelines for Indians by ICMR-National Institute of Nutrition, Hyderabad[12], for a balanced diet, a small family with two adults and three children needs 1450 g of cereals, 300 g of pulses, 1600 g of vegetables, 2100 ml of milk and 500 g of fruits daily (Table 2). In the present study, IFS produced diverse food products, i.e. two cereals (wheat, maize), two pulses (green gram, pea), one oilseed (mustard), one fibre crop (cotton), six vegetables (okra, onion, bottlegourd, brinjal, spinach, bean), and five fruits (guava, mango, mandarin, acid lime, banana). Inclusion of vegetables and fruits in IFS is more remunerative than the cereal-based cropping systems[13]. Annual milk yield from the three dairy cows was 11,553 litres, with 30 litres of production per day. A total of 7864 eggs, 5059 from duckery and 2805 from poultry, were produced annually, of which the requirement of the farmer's family was 1500 eggs per year. Annual meat production from IFS was 160 kg (live birds weight). The total fish biomass production was 759 kg from 0.1 ha area of the pond. The farmer's family gets an excellent quality protein from fish and meat, which they would not have been able to purchase from the market due to the low purchasing power of the

Table 1. Cost–benefit analysis of different components of the integrated farming system (IFS) model

Enterprise	Area (ha)	Expenditure (INR) Fixed cost	Expenditure (INR) Variable cost	Total expenditure (INR)	Income (INR) Main product	Income (INR) By-products	Gross income (INR)	Benefit : Cost ratio
Field crops	0.625		72,156	72,156	165,354		165,354	2.29
Dairy	3 cows	57,098	273,384	330,482	462,120	30,000	492,120	1.49
Fishery	0.1	15,400	38,392	53,792	91,080	–	91,080	1.69
Duckery	35 birds	12,610	18,069	30,679	50,590	10,500	61,090	1.99
Poultry	50 birds	4,390	24,388	28,778	28,050	25,000	53,050	1.84
Fruit production	0.05	2,958	5,700	8,658	19,900	–	19,900	2.30
Agroforestry	0.012	231	1,100	1,331	4,560	–	4,560	3.43
Biogas	KVIC (2 m^3)	4,000	–	4,000	5,000	4,000	9,000	2.25
Country bean	Fence area	–	2000	2,000	10,000	–	10,000	5.00
Total				531,876			906,154	1.70

Table 2. Sample meal of an individual per day[12]

Individual	Cereals (g)	Pulses (g)	Vegetables (g)	Milk (ml)	Fruits (g)
Adult male	310	60	400	300	100
Adult female	300	60	300	300	100
Boy (10–12 yrs)	300	60	300	500	100
Girl (10–12 yrs)	240	60	300	500	100

Table 3. Annual production and surplus of farm produce in IFS

Produce	Annual production	Annual family requirement (kg)	Annual surplus (kg)
Cereals	1,444 kg	654 (45)	790 (55)
Pulses	150 kg	109 (73)	41 (27)
Vegetables	2,045 kg	584 (29)	1,461 (71)
Fruits	802 kg	182 (23)	620 (77)
Oilseeds	113	36 (32)	77 (68)
Milk	11,553 litre	766 (7)	10,787 (93)
Egg	7,864 nos	1,500 (23)	7,864 (77)

Note: Values in paranthesis indicate the percentage of total production.

Table 4. Volume ($V = \pi r^2 h$) of daily biogas production

Month	Mean daily biogas production (m^3/day)	Methane production (per/day from a single burner)	Mean monthly temperature (°C)
January	0.31	3 h	13.7
February	0.33	3 h 10 min	16.4
March	0.39	3 h 30 min	20.5
April	0.51	4 h 45 min	28.9
May	0.55	4 h 55 min	31.6
June	0.57	4 h 40 min	31.7
July	0.58	5 h	30.7
August	0.55	4 h 50 min	28.7
September	0.51	4 h 40 min	28.7
October	0.48	4 h 20 min	25.6
November	0.39	3 h 30 min	20.1
December	0.36	3 h 15 min	15.1

farmer. The high nutritional value of egg, fish, milk and meat help overcome the undernourishment of vulnerable groups such as infants, pre-school children, as well as pregnant and lactating women[14]. Table 3 indicates that out of the total production of cereals, vegetables, fruits, oilseeds and milk, 55%, 71%, 77%, 68% and 93% respectively is marketable surplus. An IFS is more secure in the supply of food as it has a diversified/greater number of food species than the commercial farming system[15,16]. Farmers could 'grow everything they eat and eat everything they grow',

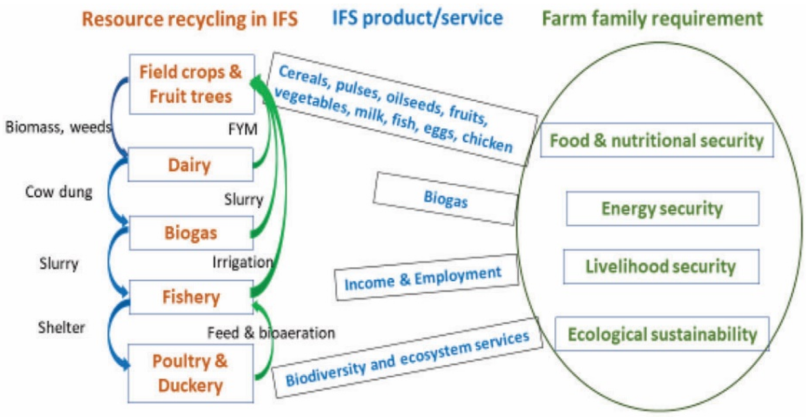

Figure 2. Resource flow among different components and their role in IFS.

Table 5. Physico-chemical composition of biogas slurry

Parameters	Range	Average ± standard deviation
pH	7.9–8.2	8.0 ± 0.16
Total nitrogen (%)	2.04–2.36	2.2 ± 0.16
Total phosphorus (%)	0.99–1.18	1.1 ± 0.07
Potassium (%)	0.92–1.1	0.98 ± 0.13
Fe (ppm)	0.34–0.36	0.35 ± 0.03
Cu (ppm)	0.004–0.007	0.005 ± 0.01
Mn (ppm)	0.085–0.093	0.089 ± 0.01
Zn (ppm)	0.023–0.025	0.024 ± 0.00

which imitates King's philosophy of self-sufficiency. The added benefits of IFS are local availability of fresh products and year round employment for the farmers.

A biogas provides clean and cheap energy, which also produces a good organic fertilizer for sustainable crop production. Table 4 indicates that daily biogas production is more during the summer months (March–September) and decreases during winter months (October–February) due to low temperatures. Even though the volume of gas produced during winter was comparatively less, it was sufficient for the kitchen needs of a small family with two adults and three children. A distinct advantage of biogas is the use of organic waste and by-products of IFS for energy production, which is environmental-friendly and the cleanest of all cooking technologies[17,18]. It not only alleviates the financial burden on households in countries that do not subsidize LPG and kerosene but also reduces household air pollution, which causes 2.8 million deaths worldwide each year[19]. Field application of slurry reduced fertilizer burden on farmers, besides improving the sustainability of their fields.

IFS has shown the potential to manage farm resources to decrease production costs by synergetic recycling of by-products of various components within the system (Figure 2). The integration was made in such a way that the product of one component is the input for another with a high degree of complementary effects on each other.

Crop–dairy–biogas interaction: The crop component with five cropping systems generated 1012, 1640, 336 and 167 kg stover of maize, wheat, pea and green gram respectively and weed biomass of 5280 kg. The green fodder requirement (16 kg cow^{-1} day^{-1}) of three cows was 16,500 kg yr^{-1}, of which the crop component produced 50% (8450 kg), saving 25% of the total feed cost. The biogas unit generated around 5 tonnes of biogas slurry equivalent to 105 : 55 : 50 kg N, P and K, which helped cut down 60–70% of chemical fertilizers (Table 5). It offers a promising win–win opportunity to improve crop production, at the same time reducing the harmful environmental effects of waste disposal[20,21].

Poultry–fish–duck integration: In the present study, fishery was integrated with duckery and poultry. Duck droppings (1.35 tonnes yr^{-1}) and poultry droppings (0.6 tonnes yr^{-1}) were diverted for fish production. Besides, the daily spilled feed of birds of about 700–800 g of serves as fish feed in ponds or as manure; else it would have been wasted. The manurial value of birds droppings and decomposed aquatic vegetation promotes plankton growth, which in turn helps in higher fish biomass production. From this, it is evident that a small farmer who integrates poultry and duckery with the fishery unit gains a good profit. This integration cut down 40% of fishery feed costs apart from supplying household members with a balanced and nutritious diet like fish, egg and meat for a decent living.

Pond as a water harvesting structure: A fish pond was dug having a water storage capacity of 1,000,000 litres. The run-off rainwater of nearly 6.0 lakh litres was collected in the pond, which helped in meeting around 30% of its water requirement[22]. When the nitrogen content in pond water exceeded 2.5–3.0 ppm, the water was used for irrigating the crops. This nutrient-rich water aids in manuring the crops grown in the system, allowing for multiple uses of water, which reduces the need for manure in crop production and increases water productivity[23].

Following are the major points emanating from the three-year field study that indicates the potential of IFS to improve the livelihood of small farmers by ensuring food, nutrition and energy security besides making the system sustainable.

IFS produced diverse food products, i.e. six field crops, six vegetables, five fruits, milk, egg, meat and fish. Out of the total production of cereals, vegetables, fruits, oilseeds and milk, 45%, 29%, 23%, 32% and 7% were family requirement and the rest 55%, 71%, 77%, 68% and 93% were marketable surplus respectively. IFS makes farmers self-sufficient in ensuring their family members a balanced diet for leading a healthy life and making the farm self-reliant through recycling of by-products and waste. Further direct benefits from IFS, besides increased household nutrition and income, are local availability of fresh products and employment provision for household members throughout the year.

Among different components, crop–dairy–biogas interaction was the most prominent, where crop components produced 50% of green fodder, thus saving 25% of the total dairy feed cost. Cow dung from the dairy unit served as input in the biogas unit, through which fuel energy requirement of the household was met. Biogas is a clean and cheap alternative energy for small farmers, and the field application of about 5 tonnes biogas slurry reduced 60–70% fertilizer burden and improved soil health. The net return from this interaction was about INR 259,836, which constitutes 68.5% of the total returns of the system.

IFS ensures biodiversity conservation through adoption of diversified crops and agri-allied enterprises. IFS leads to sustainable agricultural development, which is fundamental to food security and poverty alleviation, especially in developing countries like India. Such a multi-enterprise model also has the potential to attract the rural youth to adopt it as an entrepreneurship/self-employment vocation. High start-up costs might constrain farmers from switching to integrated farming and from exploiting the benefits of resource integration. Under such situations, farmers can take up the components one by one instead of all at one time.

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