The Bioscan 12(0): 00-00, 2017
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.com

SUSTAINABILITY THROUGH RESOURCE RECYCLING, SOIL FERTILITY AND CARBON SEQUESTRATION FROM INTEGRATED FARMING SYSTEMS IN WEST COAST INDIA

B. L. MANJUNATH[1], V. PARAMESH[2*], G. R. MAHAJAN[2], BAPPA DAS[2], K.VISWANATHA REDDY[3], E. B. CHAKURKAR[2] AND N. P. SINGH[4]

[1]ICAR-Indian Institute of Horticultural Research, Hessaraghatta, Bengaluru - 560 089, Karnataka
[2*]ICAR-Central Coastal Agricultural Research Institute, Old Goa - 403 402, Goa
[3]ICAR-Central Tobacco Research Institute, Rajahmundry -533105, Andhra Pradesh
[4]ICAR-National Institute of Abiotic Stress Management, Baramati - 413 115, Maharashtra
e-mail: parameshagron@gmail.com

KEYWORDS
Carbon stock
Contrast analysis
Integrated farming system
Resource recycling
Sustainability

Received on :
11.03.2017

Accepted on :
25.07.2017

***Corresponding author**

ABSTRACT

A lowland integrated farming system model was studied for the productivity, profitability, inter-dependency and sustainability in West coast of India for four years. The model included rice based cropping systems (0.4 ha) *viz*., rice-cowpea, rice-groundnut, rice-brinjal and rice-sweet corn integrated with dairy and forage crops grown on the bunds of the field. The results indicated that rice-sweet corn + dairy was productive (32.6 t ha^{-1}) and profitable system while rice-brinjal + dairy generated higher employment (256 man-days $year^{-1}$) throughout the year. Dairy was found economical due to on-farm generated green fodder (6.7 tonne) throughout the year and efficient use of crop by-products, about 30-35% of the gross return contributed from the dairy except during 2014-15. The lowland [illegible]ing system facilitated maximum recycling of nutrients through composting, on an average 101.2 kg of N, 18.2 kg of P and 61.9 kg of K were recycled every year. Significantly higher carbon sequestration was noticed in rice-groundnut system (28.6 Mg C ha^{-1}). The study concluded that integrated farming system including cereals, pulses, oilseeds and vegetables integration with dairy were productive, sustainable, climate resilient and economically viable for west coast region of India.

INTRODUCTION

West coast region of India, recognized by the planning commission as the 12th agro-climatic zone of the country, runs about 1600 km. The region comprising parts of Gujarat, Maharashtra, Goa, Karnataka, Kerala, Lakshadweep, Daman and Diu covers. Soils of the region are lateritic, alluvial, coastal saline, clay and sandy types. Most of these soil's cover is made up of laterites which are rich in ferric aluminium oxides and reddish in colour (Manjunath *et al*., 2017). In this region, nearly 65% of the farmers are small and marginal farmers and these depend on agriculture and livestock for livelihood security. During *Kharif* due to higher rainfall, cultivation of rice is predominant in lowland and during *rabi* the field is left as fallow or cultivate short duration crops like moong, groundnut and cowpea (Manjunath and Korikanthimath, 2009). The cultivation of vegetable crops such as tomato, okra, chili, brinjal and leafy vegetables are restricted to irrigated areas in small area for local market. These marginal farmers maintain livestock in the form of cattle or pigs, ducks or poultry birds for household consumption and income (Manjunath *et al*. 2017).

The agricultural production system of this region is influenced by many problems relating to climate change, natural resources degradation, endemic pests and diseases, price fluctuations and changing government policies. It is imperative to develop management strategies to overcome these challenges to achieve sustainability. In this regard farming system approach is a holistic tool to address the problems of complex, diverse and risk-prone agriculture in small and marginal land holdings and for natural and human resource management in developing countries (Magdoff, 2007). The farming system aims at increasing employment and to reduce the adverse environmental effect by integrating various farm enterprises and recycling crop residues and by-products within the farm itself (Behera and Mahapatra, 1999).

Adoption of [illegible] with improved package of practices like cultivation of improved varieties, crop diversification, integrated nutrient management and adoption of improved animal breeds would solve the problem of food and nutritional insecurity (Behera *et al*. 2008). Sahoo *et al*. (2015) reported that system productivity, net return and soil properties were improved significantly with IFS system involving cropping, fishery, poultry and mushroom over rice-moong system. IFS model developed at Punjab, India including crop, dairy, fishery and horticulture produced a net return of 1 . 380308/ha with B:C ratio of 1.08 which were three times more than the rice-wheat cropping system (Walia *et al*., 2016). With this background, we hypothesised that IFS models will provide food and nutritional security, improves soil fertility, generates year round employment and income to the farm family. The primary objective of the study was to develop suitable IFS models for small and marginal land holdings based on assessment of resource use, interdependencies, soil fertility and economic sustainability over a period.

MATERIALS AND METHODS

Details of the experimental site

The study was carried out at the experimental farm of ICAR-Central Coastal Agricultural Research Institute, Goa, India. Being in the tropical zone and near the Arabian Sea, has a hot and humid climate for most of the year with moderate temperature variation between 17 to 35°C. Goa receives heavy precipitation (2500 to 3200 mm) and most of its annual rainfall is received through South West monsoon which lasts till late September to early October. The experiment was conducted for four years from 2011-12 to 2014-15. The region has a warm humid tropical climate. The soil of the experimental site is sandy clay loam (laterite) with a pH of 6.01. An IFS model involving rice, pulse, oilseed, vegetables, etc. in different possible crop combinations integrated with livestock for a family size of six members in an area of 0.45 ha was established.

Crop component

During rainy season, the heavy rainfall (3000 mm) situation of Goa is not supporting variety of crops other than rice under lowland conditions. Due to this reason, we selected rice as a base crop followed by different crops depending on nutritional requirement, household feasibility and market demand. The rice based cropping system selected for study were rice-cowpea, rice-groundnut, rice-brinjal and rice-sweet corn in an area of 0.1 ha each with a total area of 0.4 ha. The rice (variety - Jyoti) crop was sown in nursery beds during the first fortnight of June after the onset of rainfall and transplanted in the main field by the second week of July. Farmyard manure (FYM) was applied at the rate of five tonnes per hectare one month before transplanting and puddling was taken with appropriate soil moisture and transplanting of 25 days old seedlings were done. A basal dose of fertilizer was applied at the time of transplanting and remaining fertilizer was applied at maximum tillering and panicle initiation stage. Once the crop attained physiological maturity, the water from the main field was drained and harvesting was done. After the harvest of rice crop, the field was prepared thoroughly. The brinjal (variety local selection) seedlings were raised in a nursery and transplanted in the main field with a spacing of 60 x 30 cm. The groundnut (variety TAG 24), cowpea (variety DU 3) and sweet corn (variety S 75) weresown with a spacing of 60 x 30 cm. All the recommended practices were followed according to the crop requirement. Cowpea and groundnut were raised in the residual moisture available in the soil during the period as per the local practice. Sweet corn and brinjal were irrigated based on soil moisture requirement to meet the crop demand. The grain yields of rice, grain and pod/seed yields of cowpea and groundnut, cob yield of sweet corn and brinjal fruit yields were determined annually. The data of five replicate measurements (1 m^2 each) from each of the plot was recorded and converted to per hectare basis. The yields of non-rice crops were converted into rice equivalent yield (REY) using the equation (1) to compare the system productivity of component crops in the cropping system (Anjeneyulu *et al.* 1982).

$$\text{REY (t ha} = \frac{\text{Yield of component crop (t ha}^{-1}\text{) x Price of component crop (?. t}^{-1}\text{)}}{\text{Price of Rice (?. t}^{-1}\text{)}} \quad \text{................(1)}$$

Dairy component

One low-cost small cowshed was constructed in an area of 24 m^2 scientifically with recommended space per animal. The cowshed has sufficient light and hard floor with required slope and feeding and water troughs. The dairy unit was established with one milchingcross breed cow (Red Sindhi x Jersey) initially in 2011. The animals varied in lactation, milk production and body weight. Necessary care was taken for a pregnant cow before and after the delivery and the male calf was disposed through auction. Stall feeding was adopted to have greater control over the feed quantity and valuable manure output. On an average 20-25 kg, green fodder was given daily to each cow based on the availability. The fodder was chopped using sickle to increase the palatability. Cattle feed concentrate was given as per the recommendations. The concentrate feed was prepared using materials *viz*., cereal flour (maize), rice polish, oil cake (groundnut), soybean powder, mineral mixture (Agrimin Forte) and salt. Cattle feed concentrate of 100 kg was prepared by mixing 50% cereals, 25% rice polish, 25% soybean powder + oilcake and 1% each of mineral mixture and salt. Manure output was quantified through periodical weighing from cow and heifer. Milk yields were recorded daily for all cows. The lactating dairy cow produced about 24–30 kg of fresh manure per day. FYM pit was constructed near the cowshed and all the waste from the dairy unit were composted and recycled quantifying periodically.

Fodder component

To meet out the fodder requirement of the dairy unit, fodder crop Napier bajra hybrid (variety Co-3, Co-4 and IGFRI-3) were planted all along the bunds of the field in an area of 360 m^2. Three rows of fodder crop were planted at a recommended spacing of 60 cm × 60 cm. Fodder crop was managed as per standard cultivation practices. The fodder crop was harvested first time at 90 days up to the ground level and subsequent harvest was done at an interval of 45 days after previous cutting.

Analysis of soil and manures

Soil samples were collected from the field after the completion of each sequence at 0-30 cm and analysis was carried out. Modified Walkey and Black method was followed to estimate the soil organic carbon (SOC). Soil nutrient analysis was done using standard procedures. The available N was determined using alkaline potassium permanganate method (Subbiah and Asija, 1956), available phosphorus (P) by spectrophotometer (Bray and Kurtz, 1945) and available potassium (K) through flame photometer (Hanway and Heidel, 1952).

Carbon Stock

The carbon storage from0-30 cm soil depth was estimated using the following formula.

$$\text{Carbon Mg C ha - 1} = \text{Soli Organic carbon (\%) x Soli bulk density (Mg m - 3) x Depth of soli (cm)} \quad \text{.........(2)}$$

Economical and Statistical analysis

For economic analysis of IFS system, indicators such as gross return, net return and benefit-cost ratio (B:C ratio) were calculated for all the components. The cash inflows and outflows were maintained using farm gate prices for all the years of this study. Cash inputs included expenditure on purchase of off-farminputs, labour, cattle feed, veterinary care, maintenance of calves and heifers. Income from the dairy unit was estimated using milk production, manure production and calves sold. Additional income obtained from the recycling of organic wastes from the IFS system through composting was quantified. The data were statistically analyzed using ANOVA technique by following SAS (Version 9.3).The treatment means were compared at $P < 0.05$ level of probability.

RESULTS AND DISCUSSION

Mono-cropping of rice under changing socio-economic scenario particularly in the West coast of India is leading to increased incidence of weeds and pests, decline in soil productivity, yield stagnation and reduced income. The study was conducted to assess diversification of rice based cropping systems including pulse (cowpea), oilseed (groundnut), vegetable (brinjal) and commercial crops (sweet corn) so as to bring in the concept of sustainability. A set of key variables were used to quantify REY, residue recycling, employment potential, soil fertility and economic returns to compare the different cropping systems over a period of four years.

Productivity of lowland IFS model

The data (Table 1) revealed that the REY was found significantly higher in rice-sweet corn system followed by rice-brinjal and rice-cowpea and the lowest REY was observed with rice-groundnut system during all the years of study. The higher REY in rice-sweet corn and rice-brinjal system was due to higher tonnage yield of sweet corn and brinjal compared to groundnut and cowpea. Higher REY in rice-sweet corn system was a consequence of more crop productivity of sweet corn under protective irrigation and higher market price for the produce as compared to other crops. The increasing trend of REY in all the cropping systems may be attributed to improved soil fertility (Singh *et al*. 2011). These results are in agreement with the Fageria and Baligar, (2005); Cazzato *et al*. (2012); Rahman *et al*. (2014) who reported that improved soil fertility by inclusion of legumes and root biomass added from the component crops in the cropping system will increase the yield of the subsequent crops considerably.

Performance of dairy animals

The fodder produced and the milk yield from one cross breed cow from the IFS unit are depicted in Table 2. The green fodder yield ranged from 6.29 to 7.55 tonnes during the study period from the available bund area of 360 m^2 in IFS unit. The grass was established with staggered planting under protective irrigation which resulted in the mean yield of 1258 kg fodder/ harvest. On an average five harvests were found possible in a year. The amount of dry fodder available from the experimental field varied from 4.09 to 4.91 t ha^{-1}, which also includes crop residues from different cropping systems. The milk yield varied between 608 to 2388 litres/year. During 2014-15, the milk yield was found lower due to dry period of the cow. In general, the milk yield relatively remained the same in first three years of experimentation. The milk yields in this study are two times higher than average milk production of less than 1000 kg per lactation in India (Table 2). On-farm

Table 1: Year wise rice equivalent yield of different cropping systems under lowland situations of Goa

Cropping system	Rice equivalent yield (t ha^{-1}) 2011-12	2012-13	2013-14	2014-15	Average
Rice-cowpea	10.5^{c*}	9.6^{c}	12.8^{c}	14.7^{c}	11.9
Rice- groundnut	9.5^{c}	7.2^{c}	10.1^{d}	13.2^{c}	10.0
Rice- brinjal	16.4^{b}	19.8^{b}	26.2^{b}	30.2^{b}	23.2
Rice- sweet corn	19.8^{a}	37.2^{a}	35.3^{a}	37.9^{a}	32.6

*The values indicated by different alphabets differed significantly

Table 2: Year wise milk and fodder yield from the lowland integrated farming system

Year	Green fodder (t)	Dry fodder (t)	Milk yield (litres)
2011-12	6.29	4.09	2041
2012-13	7.55	4.91	2388
2013-14	6.79	4.42	2358
2014-15	7.04	4.58	608

Table 3: Year wise organic matter production and potential nutrient recycling from lowland IFS model

Year	Residues from cropping system (kg)	Cow Dung (kg)	Cow Urine (lit.)	Others (kg)	Recycled N (kg)	Recycled P (kg)	Recycled K(kg)
2011-12	10379	4852	2715	284	96.2	18.6	63.0
2012-13	10878	3948	3458	275	101.2	18.1	63.7
2013-14	11328	4359	3646	256	106.9	19.1	66.6
2014-15	8497	5318	3710	212	100.3	16.8	54.2
Average	10271	4619.3	3382.3	256.8	101.2	18.2	61.9

availability of green fodder, dry fodder and efficient feed management with mineral mixture helped in productive and profitable dairy management (Barataud *et al*., 2015). Sujatha and Bhat (2015) also observed that sufficient fodder availability and proper feed management will increase the animal health and milk yield proportionately in areca-dairy mixed farming system.

Nutrient recycling

The total quantity of residues from different cropping systems and dairy as well as nutrient from the lowland IFS was depicted in Table 3. Residues from cropping system included weeds, crop residues left after meeting the animal requirement, fodder waste and leaf litter. The amount of biomass produced from crop component was found higher compared to dairy component during all the years of study. The biomass produced from the IFS unit was composted and recycled within the unit. The potential usable residue produced from the IFS unit were recycled and used in the system efficiently (Table 3). The amount of NPK recycled in the system reduced the external purchase of fertilizers. Thus, it is clear that the The farming system enhances the residue and nutrient cycling thereby sustains the agro-ecosystem (Petersen *et al*., 2007; Watson *et al*., 2005). Shekinah *et al*.(2005) reported that the nature of the biomass produced in the mixed farming system coupled with the suitability of the crops and cattle to the warm humid tropical climate resulted in the higher availability of residue for recycling through composting. Foliar spray of cow urine helped to save in fertilizer and plant protection cost. Gliessman, (2007) highlighted that inclusion of livestock unit in farming system facilitate the residue recycling, crop growth, improves the soil fertility and reduces the pest and disease incidence.

Soil fertility status

The fertility of soil after each crop cycle was evaluated and the soil nutrient status of four continuous cycles of cropping indicated that there were significant changes in the soil nutrient availability. The NPK balance was found positive in different cropping systems during all the years of study. Continuous cropping of cowpea and groundnut after rice each year for four years in fixed plot found to increase the soil N availability significantly as compared to sweet corn and brinjal. This increase can be attributed to atmospheric N-fixation ability of legume crops and their quick decomposition might have improved the N availability in the soil. The P balance varied significantly due to cropping systems and its availability was found higher in rice-cowpea and rice-groundnut systems during the study period. The available P was found lower in rice-sweet corn system during all the four years of crops cycle. However, the K balance was found significantly higher in rice-sweet corn system followed by rice-cowpea and rice-groundnut, while in the rice-brinjal system the K balance was found negative compared to initial soil K values (Table 4).These results are in agreement with the findings of Singh *et al*. (2014)who reported the positive balance of NPK in rice-wheat rotation. The contrast analysis revealed the effect of cropping system on nutrient availability in the soil (Table 5) which indicated that legumes have a clear advantage over non-legumes with respect to N availability, it is proved from the contrast of RC v/s RS (0.0035), RG v/s RB (0.0182) and RG v/s RS (0.0048).P availability was not significantly affected by different contrasts of the cropping systems. The high probability in the contrast analysis of K availability in RC v/s RB (0.0038), RG v/s RB (0.0033) and RB v/s RS (0.0002) systems indicated the negative balance of K in rice-brinjal system. Chatterjee *et al*. (2014) revealed that balanced nutrition improves the productivity of rice-moong-potato sequence and sustains the soil fertility.

Soil fertility enrichment is the key component of IFS (Syswerda and Robertson, 2014). Enrichment of soil nutrients was noticed in crop components of IFS (Table 4).The N and P balance in

Table 4: Nutrient availability under different cropping systems after four cycles from 2011-15

Nutrient	Cropping system	2011-12	2012-13	2013-14	2014-15
Nitrogen (kg)	Rice-cowpea	187.6^{ab}	188.7	198.5	199.6^{ab}
	Rice-groundnut	195.2^{a}	202.6	208.5	212.3^{a}
	Rice-brinjal	178.3^{b}	185.7	194.0	195.3^{b}
	Rice-sweet corn	175.9^{b}	187.1	193.1	196.1^{b}
Phosphorus(kg)	Rice-cowpea	34.8^{a}	32.4	39.3^{a}	28.7
	Rice-groundnut	35.7^{a}	31.1	36.2^{ab}	27.5
	Rice-brinjal	37.0^{a}	31.1	31.9^{bc}	28.7
	Rice-sweet corn	28.5^{b}	30.1	27.8^{c}	26.2
Potassium(kg)	Rice-cowpea	193.8^{ab}	201.2	209.5^{a}	210.8^{a}
	Rice-groundnut	191.4^{ab}	202.6	208.6^{a}	211.6^{a}
	Rice-brinjal	177.2^{b}	176.8	177.5^{b}	174.7^{b}
	Rice-sweet corn	210.7^{a}	218.1	224.0^{a}	227.8^{a}

Note: Initial values of N - 154.9 kg ha^{-1}, P - 21.1 kg ha^{-1} and K- 188.0 kg ha^{-1}

Table 5: Probability level of significance for contrast analysis of available soil nutrients

Source	Nitrogen	Phosphorus	Potassium
RC v/s RG	0.8732	0.3175	0.9413
RC v/s RB	0.3797	0.9873	0.0038
RC v/s RS	0.0035	0.0573	0.1175
RG v/s RB	0.0182	0.3103	0.0033

Note- RC-Rice-cowpea; RG-Rice-groundnut; RB-Rice-brinjal &RS-Rice-sweet corn

Table 6: Effect of different cropping systems on the soil organic carbon, bulk density and soil organic carbon stock after four years

Cropping system	Soil organic carbon (%)	Bulk density (Mg m^{-3})	Soil carbon stock (Mg C ha^{-1})
Rice-cowpea	1.05^{b}	1.19^{b}	25.0^{b}
Rice-sweet corn	0.90^{c}	1.29^{a}	23.2^{c}
Rice-brinjal	0.86^{c}	1.29^{a}	22.4^{c}
Rice-groundnut	1.20^{a}	1.19^{b}	28.6^{a}

Table 7: Employment generated (Man-days $year^{-1}$) from lowland integrated farming system model

Farming System	2011-12	2012-13	2013-14	2014-15	Average
Rice-cowpea + dairy	150	157	161	154	156
Rice-groundnut + dairy	181	186	192	184	186
Rice-brinjal + dairy	252	260	254	256	256
Rice-sweet corn + dairy	207	219	213	211	213

the soil after every crop cycle was found positive which may be attributed to the addition of leaf fall, slow decomposition rate of organic matter, root biomass, heavy rainfall and recycling of organic manure produced from the IFS unit (Rasse *et al*.,2005). The apparent K balances were negative in rice-brinjal cropping system indicating that the K fertilizer recommendations for brinjal were insufficient to meet the requirement of the cropping systems which calls for revisiting the fertilizer recommendations for brinjal crop in the region. These results are supported by contrast analysis of different cropping system with respect to available soil nutrients (Table 5).

Carbon stock

The table 6 summarizes the SOC, bulk density (BD) and soil carbon stock in lowland IFS. The results revealed that significantly higher soil organic carbon level and reduced BD was observed with rice-groundnut and rice-cowpea systems indicating higher carbon sequestration of 28.6 and 25 Mg C ha^{-1}, respectively. The results highlighted the importance of leguminous crop in replenishment of SOC and to improve the soil physical environment. Kumar *et al*. (2006) reported that legumes reduce atmospheric carbon by absorption and translocating these carbon to soil through leaf fall and higher root biomass. The carbon inputs from crop residues and quick ground cover ability of cowpea and groundnut might have contributed for improvement of carbon stocks. The lower carbon sequestration was observed in rice-brinjal system (22.4 Mg C ha^{-1}) which will explain the nutrient exhaustive nature of the rice-brinjal system. Wilkins, (2008)and Hilimire, (2011) reported that well managed mixed farming system including cereal, legumes and livestock enriches soil organic matter to achieve sustainability. Our study indicated that, inclusion of legume crops in IFS system would sequester 3-5 Mg more carbon per hectare compared to cereal-vegetable and cereal-cereal system.

Employment potential

With the increase in cropping intensity through double cropping in rice based crops either under residual soil moisture or protective irrigation, the employment potential was increased substantially (Table 7). The higher employment generation was observed with rice- brinjal-dairy system followed by rice-sweet corn-dairy system. The increased labour intensity with the rice-brinjal cropping system involving additional work for crop production activities extended in the second season accounted for additional man days. The labour intensive operations involved in brinjal production including nursery raising, weeding, earthing up, plant protection and harvesting contributed to this increase. It is pertinent to note that this labour involvement was spread throughout the year with potential for additional wages. Further, this employment potential spread throughout the year reduces the pressure for peak labour requirement and engages farm family for most part of the year (Devendra, 1999; Hamadeh *et al*., 1999). Tarai *et al*. (2016) who reported that IFS model involving crops and livestock creates an employment opportunities of 845 man days for males and 250 man days for females from various enterprises from two hectare. The results thus proved that IFS would address the problem of unemployment and migration of small and marginal farmers due to crop failure.

It can be concluded from the study that rice based lowland integrated farming system is efficient in terms of ecosystem services like production, enrichment of soil nutrients, residue recycling and employment generation. The direct benefits of the farming system were associated with increased productivity per unit area, increased income and sustainability. Establishing the complementarity among different components of rice based integrated farming system in terms of resource flow suggested that the system can be made self-sustainable in the West coast of India due to on-farm availability of green fodder and efficient resource use. Livestock would be an efficient route to income intensification and stability in field crop system. Adoption of rice based integrated farming system is a better management strategy in view of changing socio-economic situations for small and marginal-holders in Westcoast of India. Large scale adoption of integrated farming system requires policy support from government for establishment of dairy and construction of shed through subsidy mainly to benefit small and marginal farmers.

ACKNOWLEDGMENT

Authors would like to thank Indian Council of Agricultural Research, New Delhi and ICAR-Indian Institute of Farming System Research, Modipuram, India for providing financial support to carry out the research.

REFERENCES

Allen, V.G., Brown, C.P., Kellison, R., Segarra, E., Wheeler, T., Dotray,

P.A., Conkwright, J.C., Green, C. J. and Acosta-Martinez, V. 2005. Integrating cotton and beef production to reduce water withdrawal from the Ogallala Aquifer in the Southern High Plains. *Agron. J.***97**: 556–567.

Anderson, V. and Schatz, B. 2003. Biological and economic synergies, and methods of integrating beef cow and field crops enterprises. Unified Beef Cattle Range Res. Rep. 3.

Anjeneyulu, V. R., Singh, S.P. and Pal, M. 1982. Effect of competition free period and technique and pattern of pearl millet planting on growth and yield of mung bean and total productivity in solid pearl millet and pearl millet/mung bean intercropping system. *Indian J. Agron.* **27**: 219–226.

Barataud, F., Foissy, D., Fiorelli, J. L., Beaudoin, N. and Billen, G. 2015. Conversion of a Conventional to an Organic Mixed Dairy Farming System: Consequences in Terms of N Fluxes. *Agroecol. Sustain. Food Syst*. **39**: 978–1002.

Behera, U. K. and Mahapatra, I.C. 1999. Income and employment generation for small and marginal farmers through integrated farming systems. *Indian J. Agron.***44**: 431–439.

Behera, U. K., Yates, C. M., Kebreab, E. and France, J. 2008. Farming systems methodology for efficient resource management at the farm level: a review from an Indian perspective. *J. Agric. Sci.***146**: 493–505.

Bell, L.W. and Moore, A.D., 2012. Integrated crop–livestock systems in Australian agriculture: Trends, drivers and implications. *Agric. Syst.***111:** 1–12.

Bray, R. H. and Kurtz, L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci*. **59**: 39–46.

Cazzato, E., Laudadio, V., Stellacci, A. M., Ceci, E. and Tufarelli, V. 2012. Influence of sulphur application on protein quality, fatty acid composition and nitrogen fixation of white lupin (Lupinus albus L.). *Eur. Food Res. Technol*. **235**: 963–969.

Chatterjee, S., Sit, B. R., Saha, P. K., Ghosh, D. and Debnath, A. 2014. Relative performance of rice-potato-green gramsystem in red and lateritic zone of west bengal underorganic, inorganic and integrated nutrientmanagement. *The Bioscan*. **9(4)**: 1411-1418.

Devendra, C. 1999. Goats: Challenges for increased productivity and improved livelihoods. *Outlook Agric*. **28**: 215–226.

Devendra, C. 2002. Crop-animal systems in Asia: future perspectives. *Agric. Syst*. **71:** 179–186.

Fageria, N.K. and Baligar, V.C. 2005. Enhancing Nitrogen Use Efficiency in Crop Plants. pp. 97–185.

Gliessman, S.R. 2007. Agroecology: the ecology of sustainable food systems 2nd Edition CRC Press. Boca Ratón.

Hamadeh, S. K., Zurayk, R., El-Awar, F., Talhouk, S., Ghanem, D. A. and Abi-Said, M., 1999. Farming System Analysis of Drylands Agriculture in Lebanon: An Analysis of Sustainability. *J. Sustain. Agric.* **15**: 33–43.

Hanway, J. J. and Heidel, H. 1952. Soil analysis methods as used in Iowa state college soil testing laboratory. *Iowa agric.***57**: 1–31.

Hilimire, K. 2011. Integrated Crop/Livestock Agriculture in the United States: A Review. *J. Sustain. Agric.* **35**: 376–393.

Kumar, R., Pandey, S. and Pandey, A. 2006. Plant roots and carbon sequestration. *Curr. Sci.*885–890.

Kundu, D.K. and Ladha, J.K.1995. Efficient management of soil and biologically fixed N2 in intensively-cultivated rice fields. *Soil Biol.Biochem*. **27:** 431–439.

Lemaire, G., Franzluebbers, A., Carvalho, P. C. de F. and Dedieu, B. 2014. Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agric. Ecosyst. Environ.* **190**: 4–8.

Magdoff, F. 2007. Ecological agriculture: Principles, practices, and constraints. *Renew. Agric. Food Syst*. **22**: 109–117.

Manjunath, B.L., Paramesh, V., Mahajan, G. R., Viswanatha Reddy, K., Chakurkar, E. B., Das, S. K., Sreekanth, G. B. and Singh N. P. 2017. Rice based integrated farming system for low land agroecosystem of Goa. *Technical bulletin*.**61:** 1-55.

Manjunath, B.L. and Korikanthimath, V.S. 2009. Sustainable rice production through farming systems approach. *J. Sustain. Agric*. **33**: 272–284.

Pacín, F. and Oesterheld, M. 2014. In-farm diversity stabilizes return on capital in Argentine agro-ecosystems. *Agric. Syst*. **124**: 51–59.

Petersen, S. O., Sommer, S. G., Béline, F., Burton, C., Dach, J., Dourmad, J. Y., Leip, A., Misselbrook, T., Nicholson, F., Poulsen, H. D., Provolo, G., Sørensen, P., Vinnerås, B., Weiske, A., Bernal, M. P., Böhm, R., Juhász, C. and Mihelic, R., 2007. Recycling of livestock manure in a whole-farm perspective. *Livest. Sci.***112:** 180–191.

Place, S.E. and Mitloehner, F.M. 2010. Invited review: Contemporary environmental issues: A review of the dairy industry's role in climate change and air quality and the potential of mitigation through improved production efficiency. *J. Dairy Sci.***93**: 3407–3416.

Rahman, M.M., Islam, A.M., Azirun, S.M. and Boyce, A.N. 2014. Tropical legume crop rotation and nitrogen fertilizer effects on agronomic and nitrogen efficiency of rice. *Sci. World J.* **2014:** 1-11.

Rasse, D.P., Rumpel, C. and Dignac, M. F. 2005. Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. *Plant Soil*.**269**: 341–356.

Ryschawy, J., Choisis, N., Choisis, J. P., Joannon, A. and Gibon, A. 2012. Mixed crop-livestock systems: an economic and environmental-friendly way of farming? *Animal*.**6:** 1722–1730.

Sahoo, H. K., Behera, B., Behera, U. K. and Das, T. K. 2015. Land productivity enhancement and soil health improvement in rainfed rice (Oryza sativa) farms of Odisha through integrated farming system. *Indian J. Agron*. **60:** 485–492.

Shekinah, D. E., Jayanthi, C. and Sankaran, N. 2005. Physical Indicators of Sustainability—A Farming Systems Approach for the Small Farmer in the Rainfed Vertisols of the Western Zone of Tamil Nadu. *J. Sustain. Agric*. **25**: 43–65.

Singh, R. K., Bohra, J. S., Nath, T., Singh, Y. and Singh, K. 2011. Integrated assessment of diversification of rice-wheat cropping system in Indo-Gangetic plain. *Arch. Agron. Soil Sci.* **57**: 489–506.

Singh, S., Bhatz. A. and Rehman, H. U. 2014. Influences of organic and integrated nutrient management on physico-chemical properties of soil under basmati-wheat cropping sequence. *The Bioscan*. **9(4)**:1471-1478.

Subbiah, B. V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.***25**: 259–260.

Sujatha, S. and Bhat, R. 2015. Resource use and benefits of mixed farming approach in arecanut ecosystem in India. *Agric. Syst*. **141**: 126–137.

Tarai, R. K., Sahoo, T. R. and Behera, S. K. 2016. Integrated farming system for enhancing income, profitability and employment opportunities.*Inter.J.Farm Sci*.**6**: 231-239.

Walia, S. S., Aulakh, C. S., Gill, R. S., Dhawan, V. and Kaur, J. 2016. Intensive Integrated Farming System Approach-A Vaccination to Cure Agrarian Crisis in the Punjab. Indian J. Econ. Dev. 12, 451. doi:10.5958/2322-0430.2016.00104.9

Watson, C. A., Oborn, I., Eriksen, J. and Edwards, A. C. 2005. Perspectives on nutrient management in mixed farming systems. *Soil Use Manag.* **21**: 132–140.

Wilkins, R. 2008. Eco-efficient approaches to land management: a case for increased integration of crop and animal production systems. Philos. *Trans. R. Soc. B Biol. Sci.***363**: 517–525.