Integrated farming is an effective multiple water use system to enhance the livelihood security of small and marginal farmers: A review

Abstract

The agriculture sector faces numerous challenges like increasing population, decreasing per capita land, fragmented land holdings, land degradation and climate change in 21st Century. The downtrend of per capita land availability poses a severe threat to the sustainability and profitability of agriculture. This issue is severe for small and marginal farmers as they face many problems sustaining single farm enterprises. The global assessment on water scarcity indicates that about 66 % of the global population live under severe water scarcity conditions. Increasing land and water productivity for enhancing livelihood security of rural poor is the challenge for various stakeholders of agriculture and allied sectors. Larger numbers of integrated farming system models have been developed and demonstrated across the globe. In most cases, integrated farming systems combine crops and livestock components. However, water component is rarely included in a few integrated farming system models and needs to be upscaled its research and demonstration on a larger scale. Hence, it is the right time to review the existing integrated farming system models and analyze the research gap on multiple water-use integrated farming systems to derive a future road map. This systematic review analyzed all available integrated farming systems' prospects and retrospects and their impacts on production and productivity. The reviews proved that crop and livestock based integrated farming systems are outperforming and enhancing farmers income, employment opportunities and fulfilling the family's nutritional requirements by optimizing the farm's resources. However, the role of harvested water and its effect on the integrated farming system is rarely studied. Hence, the research on multiple water use based integrated farming systems needs to be developed and demonstrated in all agro-ecological regions of different countries. The water productivity functions for multiple water use-based integrated farming systems need to be derived and tested to understand the role of harvested water in multiple water use scenarios.

Keywords: Integrated farming system; Livestock based IFS; Poultry based IFS; Fish based IFS; Multiple water use

Introduction

The development of the agricultural sector is the primary concern for all the developing countries as agriculture is an essential sector in action for food production (1). However, increasing population, fragmented land holdings, decreasing per capita land, land degradation and climate change are challenging agricultural development. Our country's growing population and shrinking land resources leave no scope for further land expansion for agricultural purposes and poses a severe threat to the sustainability and profitability of Agriculture (2). Though small and marginal farmers constitute 85% of the Indian farming community, they share only 44% of the total agricultural land (3). Nevertheless, farmers face challenges to generate adequate income and year-round employment with a single commodity (4). Hence, integrating water resources, agriculture, horticulture, fishery, duckery and other livestock components at the farm level with suitable technologies is the best way to maintain land productivity and increase farmer income while protecting the environment. In the climate change scenario, water is becoming a scarce commodity worldwide. The water scarcity problem can be managed by runoff water harvesting at the farm level and put into multiple uses for agriculture and allied activities. This multiple water use based Integrated Farming system is a systematic approach to use low external inputs for crops and livestock production (5) consisting of various interrelated components (6). This can be a sustainable alternative to commercial farming systems, particularly for small and marginal farmers, to reverse the resource degradation (7). Integration of various farm enterprises with harvested water, recycling crop residue and farm-based by-products surely enhance farm income (8) and provide opportunities for maintaining and extending biodiversity (9).

Multiple water use based IFS provides an opportunity to increase the income per unit area by adopting diversification of crops and livestocks with integration of water. There is much scope for water and nutrient recycling within the system to economize and sustain the entire system and minimizes the dependence on off-farm and fossil fuel-based chemical inputs in farming (10). Traditionally IFS is effectively undertaken by farmers of Indonesia, China, Malaysia, Vietnam, Rwanda and Thailand (11). However, these ancient systems have been gradually replaced by single commodity based intensive farming systems (12). In recent days, the crops and livestock-based IFS are being adopted by farmers to increase net income using river or canal or well water. But, the awareness for integrating harvested rainwater with crops and livestock is being followed to a limited extent and needs to be upscaled in a wider range. This review aims to analyze the research gap on multiple water use integrated farming system to derive a future road map.

Comprehensive Integrated Farming System

IFS aim to sustain the productivity, efficient recycling of farm wastes, better resource utilization, employment generation and risk reduction while maintaining environmental harmony (13, 14). Whereas multiple water use based IFS aims for a sustained increase in agricultural production and water use efficiency. Crop components, horticulture, dairy, livestock, and other subsidiary enterprises are all part of the agricultural system method (15, 16,17). Increasing organic inputs by way of farming system has a crucial role for increasing carbon content (18). Intensive agricultural systems change the properties of organic matter and induce carbon losses (19) and lead to the low organic matter in soil.

Farming systems significantly affect soil organic matter's quantity and quality (20,21). No single farm enterprise is likely to sustain the small and marginal farmers without integrated farming system (22). IFS is a combined economic-environmental model (23) and entrepreneurial orientation model (24) where by product / waste from one component becomes an input to another (25,26,27,28). IFS was defined by various authors differently like it is an agricultural system that is integrated with livestock (29), an integrated farming system that introduces the changes in the farming system, system for waste recycling with increased input efficiency (30), no-cost farming with increased income (31) and a mixed agricultural system (32).

Integrated farming system models

Various IFS models developed and demonstrated have been reviewed, and impacts on various aspects were analyzed. In any IFS model all the components are interdependent and the resources are recycled in the total farming system. This makes the farmer self-sufficient in inputs and balanced diet of the family. This interaction among the different components were explained by Behera and Mahapatra (33).

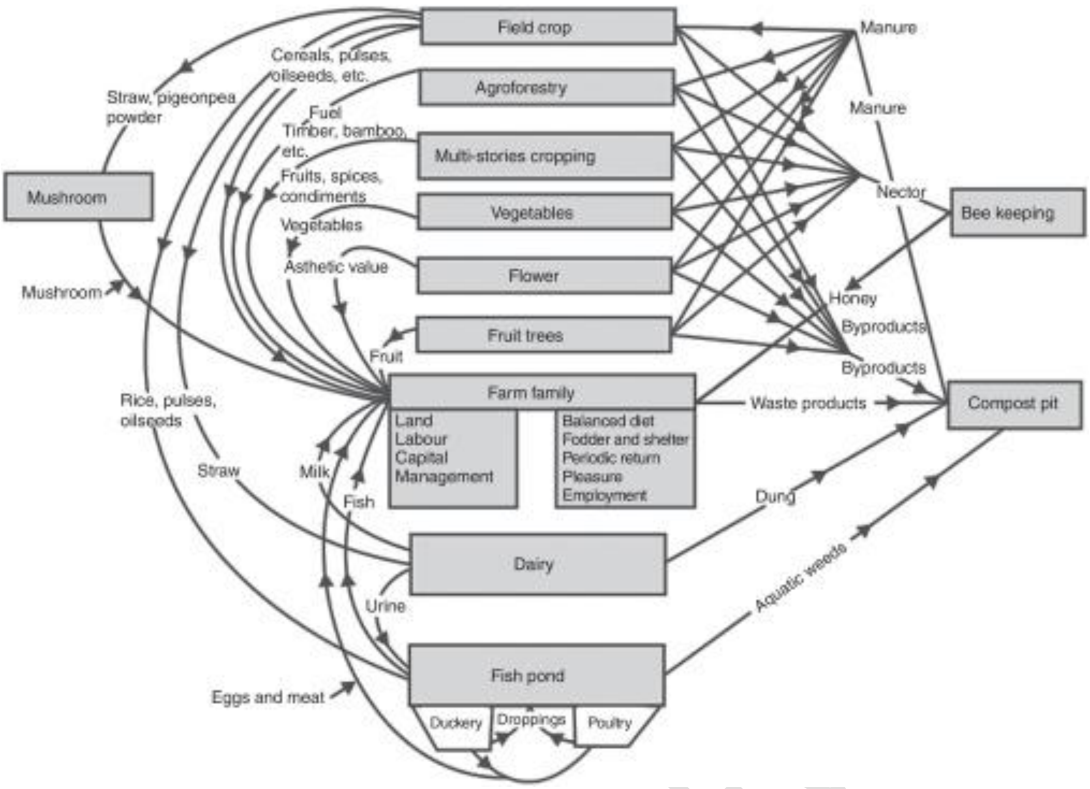

Fig 1. Interactions among different components of an IFS.

Source: Behera and Mahapatra (1998).

Livestock based Integrated Farming System

The interaction of soil, water, plant, animal and environment enables the system to be more viable and profitable than the arable farming system. The method of integrating livestock with perennial crops must be comprehensive, considering all system components (34). Livestock based Integrated farming systems offer optimizing resource utilization rather than maximizing individual elements in the system (9). Live stock based IFS was described as a mixed animal crop system that often raises the animal component on agricultural waste products (35). On the other hand, the animal is used to cultivate the soil, provide manure and fuel (36) and have better food security and higher income (37).

The advantages of livestock crop integration are in the following perspectives: (a) Agronomical (b) Economical (c) Ecological (d) Nutritional and (e) Social. Plants and livestock interact to create synergy (34).

Fig 2. Advantages of Livestock based IFS

Kumar *et al.,* (38) found that a combination of crop + duck + fish + goat had produced a good quantity of manure, poultry 2.3 t yr^{-1}, duck 1.6 t yr^{-1}, goatry 2.9 t yr^{-1}, cattle 14.0 t yr^{-1} and plant residue 11.3 t yr^{-1} whereas crop + dairy + sheep + rabbit + hen + quails, generated 750 man-days of employment (39). Strategies should thus incorporate links with existing networks and institutional arrangements in designing crop-livestock integration beyond the farm level (40). Integration of goats (41) and bovines (42) in IFS would rapidly increase the family income in case of reduced landholding pattern due to disintegration of the family in addition to high protein feeds to goats. Similarly, goat dung can be highly recycled into organic manure that can fertilize the soil and increase the growth of plants (43). Cattle and pigs are also a cornerstone element for promoting local recycling of nutrients (44) and increasing the farm income (45) through abundant cattle manure (46).

Integrating pig, goats or sheep with the plantation crops will reduce the greenhouse gas emissions (47) in addition to augmenting the quality of life of the farmers (48). Live stock based IFS is a zero waste approach (49) that prevents wasting residuals (50) to minimize agricultural production costs (51). Cattle with maize, sugarcane and oil palm IFS (52,53,54) enhances the soil quality by the decomposing capacity of crop residues and earthworms improvement as bioindicator of soil fertility (55,56,57) in addition to increasing soil moisture.

Fish Integrated Based farming systems

Fish based integrated farming systems plays an essential economic and ecological role, particularly in Asia, by recycling waste and by-products from other production systems (58,59) that maximize productivity through optimized resource use (60) and reduced input costs (61,62). Production of fish in ponds, with pigs, duck or chicken rearing in pens, beside or over the ponds constitutes continuous organic fertilization of the pond and increases the efficiency and rentability of livestock and fish culture (63). Fish farming is an income-generating activity for a few farmers, like other household activities (64,65) which is lower yield than fish based IFS (66). Integrated fish farming is a zero-waste, low-cost, and low-energy production method in which by-products from one business are recycled as inputs into another (67), resulting in increased family food consumption (68). Manure wastes from pigs used as a source of nutrients for polyculture of carps, channel catfish and largemouth bass produced maximum fish yield (69). Intensive fish culture with chicken droppings increased the fish yield by 21 per cent and decreased the feed conversion rate by 0.4 (70). Integration of animal-fish farming can increase the returns from a limited land area and reduce risk by diversifying crops (71). The gap between supply and demand can be achieved faster through integrated fish farming enhanced with organic matter, nitrogen, phosphorus, and micronutrients collected in pond (72,73,74).

Integration of aquaculture with agriculture has significant potential to contribute to sustainable intensification and nutrition security goals, reducing local environmental impacts associated with sediment disposal and increasing agricultural production (75,76). Fish based IFS depending on the financial capacity of the farmer (77) could create horizontal integration of crop production by maximizing their workforce and cash flow that produce large fish at low cost, in line with the local market and consumers' expectations. The low stocking density allows for the use of natural pond productivity, ensures enough food for optimal fish growth and optimizes fish yield (78). The leading adopter of rice-fish farming system in China has devoted 15 per cent of its rice-suitable farmland to this type of farming, producing 1.2 million tons of fish and other aquatic organisms annually (79). Rice-fish farming has been advocated in Korea to improve resource efficiency and safeguard the environment (80) and grain yield was significantly higher (4.92 t ha^{-1}) with fish (81). Rice-fish farming in rainfed lowland increases the organic carbon content of soil by 7 per cent and exchangeable ammonium by 25 per cent, besides a 6 per cent increase in the available phosphrous (82). However, rice-fish farming systems inevitably demand significant labour, resulting in high production costs in developed countries (83).

Integrated farming of fish, poultry and vegetables has experimented with a practical approach for sustainable production, income generation and employment opportunity for resource-poor rural households (84). No supplementary feed was provided to the fish under integration throughout the culturing period. The product of Adama red onion (*Allium cepa*) grown in the plot (260m^2) integrated with the poultry and fish components was estimated to be 10, 800kg ha^{-1}. The obtained yield was ranked to a better production level when compared to the product obtained using chemical fertilizers (85).

Duck-based integrated farming system

The IFS model of fish culture + duck farming + azolla + pulses, given three times more income than conventional farming and in a sustainable manner (86). The benefit-cost ratio in IFS model is 2.28 compared to the traditional model. The total Global Warming Potential (GWP) of integrated rice–duck farming was 13.3 per cent less than the conventional rice cultivation (87). The rice duck system can protect and enhance natural resources, ensure food security, and improve the economy (88). Duck integrated farming is becoming more popular as a source of income for people in rural and urban areas and is one option for meeting community demands for nutritious food that is more disease resistant and develops quicker than native chicken become the foundation of life for most individuals who live in agro-ecosystem wetland areas (89). Ducks were fed agricultural waste with high crude fibre (90). In the integrated rice–duck farming (IRDF) system, rice paddies provide food (weeds and pests) for ducks, and ducks play a role in fertilizing rice plants (91).

Poultry based integrated farming system

IFS involving crop + poultry + dairy + piggery enterprises had a positive advantage in terms of economic returns (92,93). Incorporation of poultry manure and FYM positively affected the plant growth parameters and yield contributing characters and thus resulted in the highest grain and straw yield of rice (94). The gross return and gross margin from poultry and vegetables exhibited an additional income that remarkably contributed to the households' increased income. Furthermore, unlike other livestock, poultry and chickens play an essential role in the smallholder farming systems in developing countries. Local poultry stocks often serve as a significant source of animal protein to the poor since they are accessible even to landless households (95,96). Integrated farming of fish, poultry and vegetables has experimented with a practical approach for sustainable production, income generation and employment opportunity for resource-poor rural households (84). The fish were feeding upon the planktons and other organisms harboured in the integrated pond with the aid of poultry waste; poultry waste is either eaten directly by fish or fertilizes pond water to support the plankton community used by fish as natural organic feed (96).

Rice and cattle - fish integrated farming system

An integrated farming system of rice, cattle and fish is an improved system for paddy productivity that is combined with livestock. The selection of rice and cattle in farming is based on reciprocity relationships, where rice provides straw and bran for cattle feed. Conversely, cattle produce faeces as organic fertilizer. In rice, plants can improve soil structure, encourage absorption, better humidity, reduce power absorbency, and prevent surface soil crusting (97). The rice, cattle and fish farming system helped to improve the land productivity, water and air quality and created harmony between the socio-cultural environment of the local community (98). Intensification and efficiency gains in animal production result in less greenhouse gas emissions per unit of milk and more milk per unit of water (99). This system produces grain and animal protein simultaneously, generating additional income sources and reducing the adverse effects of agriculture on the environment (100).

Table 1 The Benefits of livestock components with crop reported by various researchers

S.No	Livestock Components	Direct benefits	Indirect benefits*	Researchers
1.	Duck + fish + goat	Manure production	Soil health and reduced external inputs	Kumar *et al.,* 2017, Mowa *et al.,* 2017
2.	Dairy + sheep + rabbit + hen + quails	Employment Generation	Poverty alleviation	Govardhan *et al.,* 2018
3.	Pig, goats or sheep	Greenhouse gas emissions	Reduced global warming potential	Rati *et al.*, 2016
4.	Fish + chicken	Increased fish yield	Increased Economic status	Rappaport and Sarig, 1978
5.	Rice+ Fish	Increased rice yield	Crop productivity and income	Poonam *et al.*, 2016
6.	Rice+ Fish	Increased organic carbon exchangeable ammonium, available phosphorus in soil	Soil fertility	Sinhababu *et al.,* 1998
7.	Poultry + fish	Increased onion yield	Increased Economic status	Desaleng and Aklilu, 2003
8.	Fish + duck +	Increased income	Livelihood security	Mitra *et al.,* 2018

	azolla			
9.	Rice+duck	Reduced global warming potential	Environmental sustainability	Xu *et al.*, 2017
10.	Poultry + dairy + piggery	High economic returns	Livelihood security	Mukherjee, 1995; Ravishankar *et al.*, 2007
11.	Rice+ Poultry	Nutritional security	Improved family health	Weigend *et al.*, 2004; Endabu *et al.*, 2016
12.	Rice + cattle + fish	Land productivity	Increased Economic status	Suwandi, 2005; Gupta *et al.*, 2012

*The indirect benefits are reviewed and synthesized by the authors from various sources

Impact of IFS on farm income

Water use productivity of IFS model (Crop + horticulture + dairy + poultry + fishery) was high at Rs. 991 ha cm compared to conventional farming (soyabean+wheat+ fallow), which was Rs. 406 ha cm. Higher net returns of 284 and 176 percent through the pig and duck-based multiple uses of pond water through diversified farming (crop, fruit, livestock and fishery) than the farmers' practice (without integration), respectively (101). Integration of cattle and rice can increase the value of the BC ratio to 6 compare to BC ratio of 4 in traditional farming system (102). The income of farmers with the integrated farming system was Rs. 9,086,867 for 1 ha land and two cattle or Rs. 4,543,433 for 1 ha land and one cattle with an BC ratio of 1.56 (103). However, Multiple water use based IFS has the immense potential to emerge as an effective tool for obtaining maximum income and profitability from available resources (104).

Multiple water use based integrated farming system

Harvest of surface runoff during the rainy season enhances the opportunity for diversification in space and time dimensions. Water productivity is enhanced by about one to two times due to multiple uses of pond water compared to farmers' practice of rainfed crops (101,105). Meeting the food demand, a farming system approach should be used to reduce risks and uncertainties, increase food production, and improve living standards (106). According to Islam and Mandal (107) adding 6 cm of additional irrigation to rainfed rice improved productivity by 59 per cent. It was projected that a pond the size of 5 per cent of the total cultivable land might hold enough water for supplemental irrigation. Multiple water use based IFS increase the efficiency of all the available resources of the farm and optimize the use of harvested rain water. It also enhances the water productivity and water harvesting efficiency that resulting in increased system productivity. A water harvesting pond at the downstream side of the farm land will harvest the runoff water from the entire farm. According to the slope, the catchment area needs to be treated with soil conservation measures like bunding and bench terracing to check soil erosion. Grassed waterways also help direct the water flow towards the pond inlet. Multiple use of harvested rainwater includes crop cultivation, plantation, fishery, livestock, poultry, duckery and small scale industries. Crops and livestock can be selected based on the local conditions and need. Various studies found that the Multiple water use based IFS can improve the economic level of farmers, employment opportunities and fulfil the family's nutritional requirements by optimizing the farm's resources.

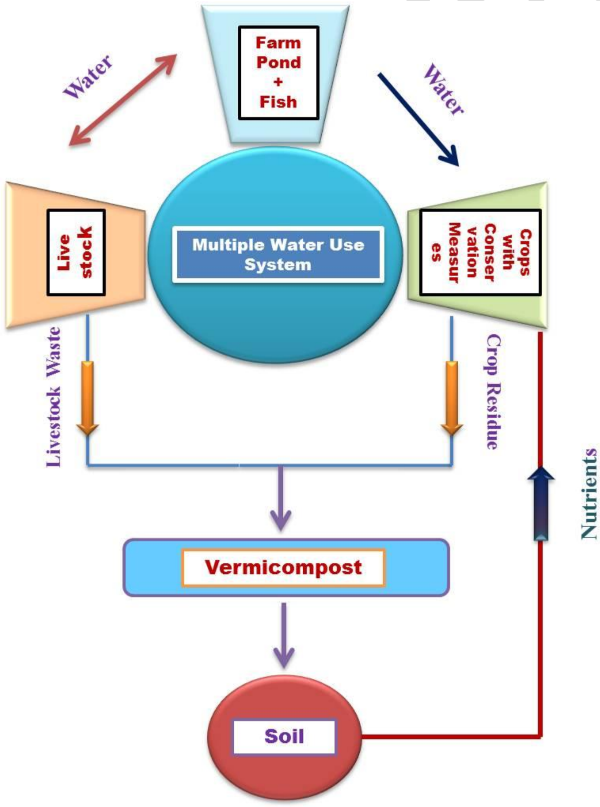

Fig 3. Schematic representation of Multiple water use based IFS

The following components of multiple water use system found to be effective.

- Farm pond – Water, Fishery, Duckery
- Crop components – Annual crops, Plantation crops, Agro forestry, Fodder crops
- Livestock components – Dairy animals, Sheep & Goat rearing, poultry, piggery, Sericulture, Rabbitry, Pigeon rearing

- By product based components - Vermiculture, Compost production, Apiary Mushroom cultivation (108).

Conclusion and future perspective

Sustainability through an integrated farming system is environment friendly, socially accepted by farmers and economically viable. IFS helps to maintain agricultural income by lowering production costs, creating a lot of job opportunities, and showing the way to the resilience of the farm productivity. Overall, an integrated farming system achieves multiple objectives: making farmers self-sufficient by ensuring a balanced diet for family members, raising the standard of living by maximizing total net returns and creating more jobs, reducing risk and uncertainty, and maintaining environmental harmony. Adequate IFS models have been developed by various stakeholders involving crops, livestock, fish, poulty and ducks and found to be highly productive and profitable. It can be advocated for small and medium farmers for enhancing their livelihood securtity. Impacts of IFS on soil health, production, productivity, nutrient recycling, income, waste recycling and crop growth have been reported in sizable quantities. However, the studies on IFS with harvested rainwater is lacking and only limited model has been reported. Hence, the following areas needs to be addressed for understanding the role of harvested rainwater in integrated farming system.

- Hydrology and water balance studies on integrated farming systems and its effect on supplemental irrigation
- Water productivity functions of multiple water use system incorporating crops, livestock and fish components
- Nutrient balance studies on various livestock, fish and crops based IFS models
- Role of IFS models and its impact in climate resilence agriculture

Declaration of competing interest

The authors declare that they have no conflict of intrest.

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