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Multiple Water Use Protocols in Integrated Farming System for Enhancing Productivity

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Abstract Agriculture is the largest consumer of water in world. Due to demand of water for industrial and drinking purposes, the share of available water resources in agriculture sector is reducing substantially in near future. However, the food, fodder, fuel, and fibre production for satisfying the demands of enhanced population requires more water. In this scenario, increasing water productivity through diversified farming system has been identified as one of the viable options. Diversified farming, otherwise also called integrated farming system (IFS), represents integration of various enterprises such as cropping systems, horticulture, animal husbandry, fishery, agro-forestry, apiary etc. for optimal utilization of farm resources besides water. Integrated farming, a judicious mix of cropping systems suited to given agro-climatic conditions and socio-economic status of the farmers, shall be able to generate additional employment and income for the small and marginal farmers under both rain-fed and irrigated environment. Although, IFS was mainly initiated in Asian agriculture, it is being introduced in almost all the countries of world. Such a system results in more rationale use of water with judicious distribution among different users. In this paper, different aspects of multiple uses of water for higher productivity and future strategies for enhancing water productivity are discussed.

Keywords Multiple water use · Water scarcity · Farming systems · Water productivity

1 Introduction

Water plays a vital role for providing food security, poverty alleviation through increased and sustainable livelihoods, improved health through better nutrition and environmental

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security, maintenance of water related-ecosystem and biodiversity. The relentless pressure of ever-increasing population and demand for food, fodder, fuel, fibber, flower and fish has led to over exploitation of natural resources, particularly on finite water resources (Fasakhodi et al. 2010). Considering the wide spatial and temporal variation of water availability within a country, several regions of the world are already facing a severe water crisis. A majority of the farmers, particularly those located in tropical regions, still as adopts cultivation of a variety of crops on a single piece of land for their food and income (Vandermeer et al. 1998; Sethi et al. 2002). Those systems, which are often without synthetic inputs but based on integrated management of local natural resources and rational management of biodiversity, offer numerous ecological advantages.

Rice-fish integration is an old age practice. The occurrence of fish, freshwater prawns and crabs, snails, mussels and frogs is natural in flooded rice fields. These were regularly caught or collected and have played an important role in the diet of the rural farm households. The family members share these in a meal during readily available period (during the rice growing season). In some societies selected species of fish, molluscs and crustaceans have been stocked intentionally to augment the availability and production of protein from rice fields (Prein 2002). In floodplain conditions, trap ponds in rice fields, in which wild fish accumulate in the dry season, have been used to extend the holding period of fish with modest feeding (e.g. rice bran) in order to avoid a bulk harvest (Guttman 1999). In modern times, with the use of pesticides and larger amounts of inorganic fertilisers, the natural occurrence of these aquatic resources has been reduced considerably. However, the intentional stocking and culture of fish in rice fields has increased in some developing countries like China, Vietnam, etc. (Guan and Chen 1989). Numerous designs and experiences in experimentation and implementation are available for such integration (De la Cruz 1994). The integrated fish-in-paddy field system functions through the feeding of fish on organisms (particularly insects and other possible rice pests) and weeds, and the stirring of the sediment through their foraging action which leads to nutrient resuspension (Cagauan 1995; Mishra and Mohanty 2004). It has been observed frequently that rice yields increase through the inclusion of fish (Mishra and Mohanty 2004). In recent years, this integration has taken as a commercial mode. The farmers are excavating a farm pond near to the rice field and commercially taking pisciculture and duckery in the pond (Srivastava et al. 2004; Behera et al. 2004). Side-by-side, they grow vegetables and fruit crops on the embankment of the pond. They also use the harvested rainwater in the pond to rice field in drought period, ultimately enhancing the productivity of the system.

Poverty, hunger and malnutrition remain amongst the most devastating problems facing the world's poor and needy (FAO 2002). To meet the multiple objectives of poverty, food security, competitiveness and sustainability, farming system research and its implementation has been recognized as a potential tool (Shaner et al. 1982; Behera et al. 2008). This is a multi-disciplinary holistic approach which aims at increasing income and employment from small holding by integrating various farm enterprises and recycling farm wastes and by-products in an efficient manner among different enterprises for enhancing overall farm productivity (Behera and Mahapatra 1999; Singh et al. 2006). Under gradual shrinking of land holding in country like India, it is essential to integrate land based enterprises, like fishery, poultry, duckery, apiary, field and horticultural crops etc. within the bio-physical and socio-economic environment of farming community. No single farm enterprise is likely to be able to sustain small and marginal farmer without integrated farming system (IFS). The most reliable source of protein for many is fish, yet millions of people who depend on fish are facing the fear of food shortage (Choo and Williams 2003). Integrated fish farming is a diversified and coordinated way of farming with fish as the main target along with other farm products, such as rice, vegetable, and fruits (Sinhababu and Venkateswarlu 1995; Ayinla 2003). Thus, there is the need for a suitable agricultural system to meet the increasing demand for food, and also maximizing the utilization of the available limited resources without much wastage.

Rain-fed agro-ecosystem, which constitutes around 70 % of total cultivated area in India, contributes about 40 % of the total food grain production in the country (ARDB 2009). Yields under this eco-system are low and highly unstable due to the vagaries of monsoon. Out of 42 million ha of rice cultivated land in India, about 20 million ha is suitable for adoption of rice-fish integrated system. However, only 0.23 million ha area is presently under rice fish culture. If these lands were brought under integrated rice-fish system, it would enhance the use of land and water resources without bringing any environmental degradation. Rice-fish culture has attracted renewed interest over the past decade as a potentially viable means of producing additional food, particularly protein, and increasing the overall incomes from an integrated farming system. The integrated fish farming system is already well developed in China, Taiwan, Malaysia, Hungary and certain other European countries. However, little attention has been given in India. If the area under integrated rice–fish and rice–vegetable–fish production system will increase, it would compensate the economic losses in rice production caused by natural calamities and also enhance the use of land and water resources without bringing any environmental degradation. This necessitates the demand for development of profitable IFS model either equivalent or superior to rice-wheat and rice-rice system (Behera 2010). This situation has compelled the researchers, planners and water users to invest in research and development to improve crop water productivity. With increasing pressure from the burgeoning human population, only vertical expansion is possible by integrating appropriate farming components which requiring lesser space and time, and ensuring periodic income to the farmer. Irrigation water supply projects provide water for multiple uses such as domestic, fisheries, and livestock as well as wildlife habitat, and environmental preservation and enhancement besides irrigation. Different water consuming sectors have benefitted significantly due to multipurpose river valley projects.

2 Concepts, Issues and Importance

2.1 Water Scarcity: A Driver for Increasing Water Productivity

Although globally there are adequate water resources to meet the needs of the current and future world population, locally there are many areas experiencing water scarcity (Clarke 1993; Postel 1993, 1999; Haileslassie et al. 2009). Water scarcity exists when the demand for water exceeds the supply and it can be classified as: (a) physical water scarcity in which water availability is limited by natural availability; (b) economic water scarcity when human and financial resources constraints availability of water; (c) managerial water scarcity where availability is constrained by management limitations; (d) institutional water scarcity where water availability is constrained by institutional shortcomings; and (e) political water scarcity where political forces debar people from accessing available water resources (Molle and Mollinga 2003). These types of scarcity can occur concomitantly, increasing both the severity and impacts of water scarcity. Molden et al. (2003) estimated that by 2020 approximately 75 % of the world's population will live in areas experiencing physical or economic water scarcity. Most of these areas happen to be where most of the poor and food insecure people reside. Meeting their food needs with locally produced food will face enormous challenges. Hence, there is a need to increase water productivity in agriculture in water scarce regions.

2.2 Multiple Uses of Water

Agricultural sector in India has been and is likely to remain the largest consumer of water. The share of water allocated to irrigation is likely to decrease by 10% to 15 % in the coming decades (CWC 2010). Hence, more focus should be on sustainable management of water resources for optimal agricultural production. It is essential to increase the efficiency of each component of irrigation system and crop production, preventing wasteful and ecologically injurious use of water. In view of these considerations, it is largely emphasized for enhancing water productivity through multiple uses. In general, multiple use of water is not a new concept. There are examples of several water resource projects simultaneously planned for electricity generation, irrigation, and meeting rural, urban and industrial uses and also naval and transport purposes (Bakker et al. 1999). At the farm level, water can be judiciously applied for multiple uses such as drinking, irrigation, livestock, fisheries etc. to optimize water productivity. Integrated farming system (IFS) based on multiple uses of water, comprising of crop, fishery, duckery, poultry, piggery, agro-forestry etc. are in practice not only in India but also in other Asian countries. Such a system results in more judicious use of water resulting in higher water productivity and also improving livelihood of resource poor farmers (Sharda and Juyal 2007; Gill et al. 2005).

In addition to use of water in crop production, many of the other uses such as fishing or bathing are non-consumptive, while others such as drinking, watering livestock, and brick making consume relatively small amounts of water compared to field irrigation. Because they draw water directly from irrigation system (canals and tanks) or indirectly (wells through groundwater recharge), there are complementarities between these uses and field irrigation. When water is available in the tanks and canals, it is also available for gardens, fishing, lotus production, bathing, livestock production, curd pot making, brick making, laundering and household cleaning (Penning de Vries 2007). At the household level there are complementarities between crops and livestock, because water in the irrigation system makes water available for animals as well (Nayak and Panda 2001). There are considerable complementarities between irrigation and fishing. The reservoir, tanks and canals of the irrigation system provide the environment for fish production, and fishing provides a fallback during difficult times. Under dry-land situations, there is more conflict between irrigation and drinking uses when availability and quality of water is a problem. Again in irrigated agro-ecosystems, water sometimes becomes unsafe for drinking due to agro-chemical runoff and leaching of minerals as water seeps and percolate from paddy field (IFPRI 1999).

2.3 Multiple Objectives of an Agricultural Producer

A farming system comprises of a complex and highly diverse agricultural production system in developing countries like India, whose outputs include crop, tree, livestock and fish and a vast multitude of ecological goods and services. The bio-physical, socio-economic and institutional settings under which the production system operates and the multiple and sometimes conflicts goals of the producers present additional challenges. The decisions made by agricultural producers and managers of water systems determine the levels of technical and allocation efficiency of the water resources available in the water harvesting structures. The farmers' decisions are also influenced by the policy and regulatory instruments. Therefore, increasing water productivity is a shared responsibility. Agricultural producers have multiple objectives upon which they assess the performance of their production systems, namely the productivity (ratio of output to input that serves as a measure of the relative suitability of a farming system or an activity within the system); profitability (net benefit accruing from the farming system); stability (the absence or minimization of season-to-season or year-to-year fluctuations in the level), diversity (risk minimizing strategy associated with: (a) diversification of the farming system i.e. crop, livestock, trees, fisheries on a given farm; (b) diversity of outputs from a given farming system *viz.* milk, meat and draft power from cattle production; (c) diversity of the ways that the produce is used i.e. consumed, sold, stored, processed; and (d) diversity of income sources, and time-dispersion (i.e. the degree to which production inputs, output and income are spread over time) (McConnell and Dillon 1997). The relative importance of each of these objectives depends on whether their production system operates at subsistence level and is partially or fully commercial. The most important objective for a commercial farmer is to maximize profit. Productivity, stability, diversity and time-dispersion may be important underlying factors for achieving higher levels of profitability but are generally not taken as desirable objectives in themselves. Farmers view productivity as a necessary condition to achieve higher profits but not as a sufficient condition in itself (McConnell and Dillon 1997). Along with higher profit, the consistent availability of water in space and time is vital for sustainable agricultural production. The decision on the farming system components plays a greater role in balancing the expense and availability of water for farming.

2.4 Water Productivity and Saving

Output in terms of biological yield per unit of water is termed as water productivity. It varies with scale as well as the purpose for which it is being quantified. The definition of water productivity varies with the background of the researcher or stakeholders involved (Bastiaanssen et al. 2003), as described in Table 1. Water productivity at field level is the amount of crop output in physical terms i.e. crop yield divided by amount of water consumed (i.e. the crop evapo-transpiration) or monetary terms i.e. crop yield multiplied by its price divided by amount of water used. The water productivity is therefore a function of price, which a produce fetches in the market. Productivity may be assessed for the whole system or parts of it. It accounts for all or one of the inputs of the production system giving rise to two productivity indicators: (i) total productivity i.e. the ratio of total tangible outputs divided by total tangible inputs; and (ii) partial or single factor productivity i.e. the ratio of total tangible output to input of one factor within a system (Molden 1997). In farming systems, the factors could be water, land, capital, labour and nutrients. Like land productivity, water productivity is also a partial-factor productivity that measures how the systems convert water into goods and services (Molden et al. 2003). Its generic equation is:

$$\text{Water productivity} = \text{Product output} / \text{water input} \tag{1}$$

Water saving is defined as the process of reducing non-beneficial use of water and utilizing saved water in a productive way. In situations where water is scarce, reducing non-beneficial uses becomes one of the main ways for reducing water scarcity. Improving water productivity seeks to get the highest benefits from water and hence can be viewed as a major contributor to water saving. Water saving by reducing non-beneficial depletion can be accomplished through reducing flows to sinks and reducing non-beneficial evaporation. For example, improving irrigation efficiency is considered to be the most appropriate way to reduce non-beneficial depletion and save water. Before this can be done, it is important to understand the water pathways and its dynamics of non-beneficial water use and re-use. For example, seepage losses may be the main way in which shallow groundwater aquifers used

Table 1 Definition of water productivity as per the researcher and stack holder involved

Stack holder	Definition	Scale	Target
Plant physiologist	Dry matter/transpiration	Plant	Utilize light and water resources
Nutritionist	Calorie/transpiration	Field	Healthy food
Agronomist	Yield/evapotranspiration	Field	Sufficient food
Farmer	Yield/supply	Field	Maximize income
Irrigation Engineer	Yield/irrigation supply	Irrigation scheme	Proper water allocation
Ground water policy maker	Money earned per unit quantity of ground water extraction	Aquifer	Sustainable extraction
Basin policy maker	Money earned per unit quantity of evapo-transpiration	River basin	Maximize profit

Bastiaanssen et al. (2003)

for downstream irrigation and domestic water supply are recharged. By failing to consider a basin perspective when planning and implementing water interventions, the risk of not achieving real water saving and of having a negative impact on water quality, drinking water supply, groundwater balance, and downstream human and ecological users are encountered.

Guerra et al. (1998) noted that in most cases the arguments regarding water saving do not address other important factors that determine water saving such as the cost of water development and recovery. Increasing water productivity often requires greater use of other resources such as labour, capital and management etc. Hence, at the basin level it is imperative to address the following key questions:

i) What happens to the water that is lost through runoff and deep percolation?
ii) What is the effect on systems that were dependent on the water due to reduction in non-beneficial use?
iii) What happens to the water that is saved through reduced runoff and deep percolation losses?
iv) How the aquifer system gets contaminated due to unaccounted irrigation in intensive agricultural regions?

3 Enhancing Water Productivity Through Integrated Farming System (IFS)

There exists a plethora of methods by which considerable saving of water is possible. Multiple uses of water are best possible through diversification of farming systems. Integrated farming system provides a better scope for most effective use of water by putting the same water for several uses like producing crop, fish, dairy, mushroom, poultry, duckery etc. simultaneously within a farm (Singh and Gautam 2002). A number of case studies on integration of different enterprises: rice-cum-pisciculture farming system, rice-poultry-fish-mushroom integrated farming systems for lowland situation and alternate system of land use through diversification of enterprises had been conducted in different parts of the country by simulating the small and marginal farms situations (Rangaswamy et al. 1992, 1996; Mahapatra 1992; Behera and Mahapatra 1998; Rautaray et al. 2005).

The water productivity and farm income was higher in rice-fish system in comparison to the sole system of any of these two independent methods (Sinhababu and Venkateswarlu

1995). Integration of rice-fish with vegetables in pond dykes or farm pond bunds further increased the water productivity (Samra et al. 2003). Sinhababu (1996) described rice-fish system as micro-watershed for effective land and water uses. The system explored synergy leading to increased grain yield of rice by 5–15 %, enrichment of organic matter and nutrients. This system promoted gainful linkage between rice, fish, prawn, duck, vegetable and horticultural enterprise, resulting in better resource utilization as well as conservation of the ecosystem, generating year round employment in the farm and increased total farm income. A diversified integrated farming system model using harvested pond water was developed by Behera and Mahapatra (1999) taking into consideration of small farmers' resource availability and farm constraints into consideration of Orissa in Eastern Indian, with the objectives to bring self-sufficiency in farmers' requirement of food and cash; increase income and employment opportunity; recycling of farm wastes and by-products and increase resource use efficiency including water. The land-based enterprises such as dairy, poultry, fishery, mushroom, biogas etc. were included to complement the cropping programme to get more income and employment, thus leading to higher socio-economic upliftment. The economic analysis of such studies revealed that from a small farm piece of 1.25 ha, net returns of Indian rupee, INR58,360 could be realised from an investment of INR49,286 generating 573 mandays of employment and with a resource use efficiency of INR 2.18 per rupee invested (Table 2).

Rice–based integrated farming system model developed for marginal farmers in Tamil Nadu revealed that a net profit of INR 11,755/year from rice– poultry– fish– mushroom in 0.4 ha area, while in conventional cropping system (CCS) with rice– rice– green manure/ pulses, a net income of INR 6,334/year was obtained from the same area. Thus, integrated farming system increased the net income and employment from the small farm holding and provided balance diet for the resource poor farmers and helped in efficient use of water in different enterprises. Another such farming system study conducted by Murgan and Kathiresan (2005) revealed that among the different farming enterprises compared for integration along with lowland transplanted rice, *viz*. fish culture, rabbit rearing, and poultry rearing performed significantly superior. Positive interactions among these enterprises resulted in higher crop

Table 2 Integrated farming system model and its economics for small farmers situation at Bhubaneswar, Orissa

Components	Employment generation (man-days)	Total expenditure (Rs)	Net returns (Rs)	Returns/Rs invested (Rs)
Field crops	98.2	3315	5638	2.70
Multistoried cropping	87.0	3831	9089	3.37
Pomology	18.4	900	1466	2.63
Olericulture	96.4	3812	8302	3.18
Floriculture	4.0	125	100	1.80
Pisciculture	31.0	3722	16603	5.46
Poultry	23.0	9240	981	1.11
Duckery	23.0	5387	713	1.13
Mushroom cultivation	180.0	18184	12856	1.70
Apiary	1.0	170	1180	7.94
Biogas	11.0	600	1431	3.38
Total	573.0	49,286	58,360	2.18

Behera and Mahapatra (1999)

yield, economic indices and soil fertility status. The highest net returns of INR 155,920/ha and INR 228,090/ha during the first and second season, respectively were obtained with integrated rice+fish+poultry farming systems. The same system also recorded the highest grain yield of rice (5.67 and 5.25 t/ha during first and second season, respectively). The highest post-harvest soil nutrient status with regard to N, P, and K was also observed with rice+fish culture+poultry farming system.

Singh et al. (2006) in their efforts to develop sustainable integrated farming system models for irrigated agro-ecosystem of Eastern Uttar Pradesh of North-Eastern plain zone revealed that rice-pea-okra cropping sequence was the most remunerative with highest rice equivalent yield of 17.88 t/ha and net returns than the conventional rice-wheat sequence. The rice-based integrated farming system comprising of crop components, dairy, poultry and fishery was the most suitable and efficient farming system model giving the highest system productivity and ensured the multiple uses of water. This model generated significantly higher levels of employment than rice-wheat system (Singh et al. 1999; Gill et al. 2009).

An integrated farming system (IFS) in Punjab under shallow water table conditions, the water productivity increased by 56–86 % under IFS in comparison with only rice-wheat system (Gill et al. 2005). On-farm studies in the same situations, revealed that integration of fishery and piggery gave maximum water productivity (net returns of INR 5.67/m^3, 1.23 kg grain of rice/m^3 of water). The corresponding values for fishery only were net returns of INR 3.36/m^2 or 0.94 kg grain of rice/m^2 of water against net return of INR 2.60/m^2 or 0.6 kg grain of rice/m^2 of water in rice-wheat system (Table 3). Similarly, under Eastern Indian situations in a pond-based integrated farming system, it was observed that IFS (fish+vegetable+rice) gave the highest water productivity, followed by vegetables and irrigated rice (Samra et al. 2003).

The technologies *viz.* adoption of furrow irrigation instead of check basin or boarder method of irrigation, raised bed planting technology, pressurized irrigation system, laser land levelling etc. are suitable under diversified farming systems and lead to considerable amount of saving in water use. These techniques can be explored in a farming system perspective to improve productivity and water economy.

4 Interaction of Farm Water with Other Enterprises

Pattern of resource flow among enterprises in an integrated farming system also varies between rain-fed and irrigated ecologies. The number, type and magnitude of flow of resources indicate the degree of integration in the system. As the degree of integration is determined by bio-physical, socio-economic and institutional factors, these also largely

Table 3 Water productivity in different farming systems under western Indian situation

System	Evapotrans-piration/ Depth of water used (mm)	Rice equivalent yield(t/ha)	Fish yield (t/ha)	Net returns (Rs/ha)	Water used (m^3)	Productivity	
						(Rs/m^2)	(kg/m^2)
Rice–wheat	2050	12.4	3.92	53,220	20500	2.60	0.60
Fishery	1760	16.6	3.92	59,132	17600	3.36	0.94
Fishery+piggery	1760	19.7	3.92 +1.62[a]	99,719	17600	5.67	1.12

[a] Piggery yield converted into fish equivalent yield;

Gill et al. (2005)

influence farmers' decision making on enterprise composition and pattern of input use (Pant et al. 2005). A study in Thailand revealed that majority of rice-based irrigated systems comprised four major enterprises *viz*. paddy, fruit vegetables and aquaculture. A strong linkage between fruit and pond, vegetables and pond was reported. Rice by-products, particularly broken rice, were often applied as a pond input. However, virtually no linkage was observed among rice, fruits and vegetables. Overall irrigated system was weakly integrated as most of the enterprises functioned independently. Since on-farm nutrient recycling was limited, household in this system relied almost entirely on external inputs, particularly chemical fertilizers to enhance production.

Integration in rain-fed agro-ecologies is rather complex as compared with the irrigated system. In addition to rice, fruits, vegetables and ponds, enterprise composition of majority of rain-fed systems include livestock and field crops. Flow of resources among enterprises in rain-fed system indicates a relatively high degree of integration among the enterprises. The pond plays a central role in rain-fed systems, as it is essentially the only source of water supply in majority of farms. Households in rain-fed systems regularly irrigate fruits and vegetables using pond water and occasionally rice, particularly during transplanting stage when rainwater is inadequate to puddle the field (Mohanty et al. 2004). There is a strong linkage in pond-water use between fruits and vegetables. Livestock plays a vital role in majority of rain-fed systems. Livestock are fed or grazed on weeds and grasses on the farm lands. Manure is an important by-product from the livestock sub-system, as it is often used to fertilize fruit trees and vegetables, and occasionally used to line the pond to prevent seepage.

Residues as by-products from various crop enterprises in rain-fed agro-ecologies also have multiple uses e.g. vegetable wastes, residues from orchard and field crops and rice by- products could either be fed to fish or to livestock. Household in rain-fed systems are more rational in making efficient use of these resources. Likewise, judicious and balanced use of pond water for irrigated crops and stocking fish is also essential in rain-fed eco system.

Based on a study conducted in Western zone of Tamil Nadu under dryland situation, the linkages between enterprises within different farming systems, *viz*. FS_1: cropping alone; FS_2: crop+pigeonpea+goat+agroforestry+farm pond; FS_3: crop+pigeon+buffalo+agroforestry+farm pond; FS_4: crop+pigeon+goat+buffalo+agroforestry+farm pond have been presented by Shekinah et al. (2005). The last farming system model comprising of crop (0.8 ha) fertilized with buffalo manure produced on the farm with pigeonpea (10 pairs 0.01 ha), goat (5:1 female: male on 0.02 ha), buffalo (2 milking buffaloes+1 calf on 0.03 ha), agroforestry (0.1 ha) and farm pond 0.04 ha) was the most profitable combination. This system also facilitated maximum recycling of resources and residues generated on the farm among the enterprises. The output and waste of one enterprise served as input to the other. The nutritive value of the system in terms of carbohydrate, protein and fat was also highest with these enterprise combinations.

The status of integrated agriculture-aquaculture in Asia was reviewed (Prein 2002). The importance of nutrient recycling of otherwise unused waste materials as an important element and a benefit of integration was emphasized. In comparison to other enterprises, the pond offers relatively greater potential of integration on farm, and for flows of nutrients to and from the new enterprises. Behera et al. (2008), in a study pertaining to a pond based integrated farming system in Eastern India with crop–animal–fish–duck–biogas–poultry interactions (Fig. 1) revealed a strong interactions between pond (fishery) and animal production, pond-duck and biogas and pond system with input from one sector being supplied to others.

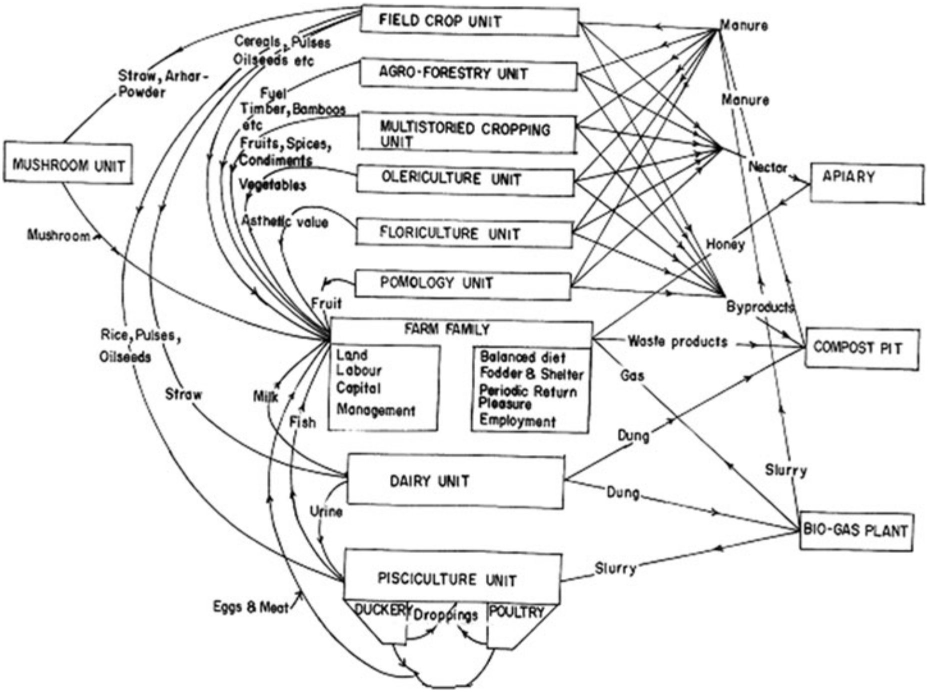

Fig. 1 Interactions among different components of the integrated farming systems (IFS). Source: Behera (2010)

4.1 Integration Fishery with Other Enterprises

Integrated fish farming provides the farmer with a steady source of income all year round arising out of various farm products. For example, in poultry–cum–fish farming before the harvesting of the fish, which may take some months, the farmer can sell the eggs which will generate money. Apart from this, money can also be generated from the vegetables or the crops that may be combined in the integrated fish farming. This corroborated the submission of Nnaji et al. (2003) that integrated fish farming is more profitable than unitary system of farming. There is evidence from many independent studies that fish farming increases rice yields by 5–30 %, in addition to providing a second source of income from fish (De la Cruz et al. 1992; MacKay 1995). An important factor in profitability of rice-fish farmers' has been the reduced use of fertilizers and pesticides for which prices have increased at a disproportionate rate as compared to other commodities (Fernando and Halwart 2000). Aquaculture in irrigation structures may improve the cost-benefit ratio of agriculture and aquaculture. Raising fishes in irrigation ditches adds substantial amounts of nutrients (metabolic by-products of fish production) to water and may decrease the need to purchase commercial fertilizers for the field crop (Balusamy 1996). Data indicate that using water from fish cultures on vegetables, rice, and mulberry may eliminate the need for commercial fertilizers.

Integration of fish culture into farming systems has been developed in areas where ponds were essential to diversification of rice-dominant systems and livestock were relatively few and feed limited. This has also occurred in flood-prone areas, often where rice yields were low and land was raised to make dikes for planting perennial or upland crops (Ruddle and

Zhang 1988). The ponds excavated in farm areas, generally called on-farm reservoirs serve primarily for storing water and recycling the stored water for intensification of cropping. On-farm reservoirs (OFRs) are often used for fish production. In situ conservation of rainwater in the dyked cropped field and in the on-farm reservoir (OFR), harvesting of excess rainwater from the field in the OFR, use of harvested water for supplemental irrigation (SI) and diversified cropping (fish culture) are some of the options for rainwater storage and recycling processes for increasing the overall agricultural productivity of a region (Pandey et al. 2006). For the selection of appropriate rainwater management strategies, water balance simulation model followed by field experimental verification were carried out during the monsoon season for sustainable production of rice (O*ryza sativa,* MW-10 Variety) and fish varieties such as rohu (*Labeo rohita*)*,* catla *(Catla catla)* and mrigal *(Cirrhinus mrigala)* in the polyethylene lined and unlined OFRs with different weir heights (0, 5 and 10 cm) maintained at the inlet point of the excess rainwater from the field into the OFR. The average (1994–2003) volume of runoff generated from the rice field area (720 m^2) through the weir heights of 0, 5 and 10 cm were 170.51, 127.88 and 92.84 m^3, respectively. The average depth of storage required for the lined and unlined OFRs (10 % of the rice field area) with 1:1 slope was 2.46 and 1.99 m, respectively. Hence, the constructed storage depth of the OFR was kept as 2.4 m for both the lined and unlined systems including the settlement allowance. The benefit cost ratio (BCR) obtained from rice-fish integration with the lined OFRs are 1.54 for 0 cm and 1.65 for 5 cm and 1.80 for 10 cm weir heights. Similarly, for unlined OFR system, the BCR are 2.83 for 0 cm, 2.70 for 5 cm and 2.66 for 10 cm weir heights. The pay back periods obtained for the lined OFR with 0, 5 and 10 cm weir heights are 21, 20 and 19 years, respectively, whereas for the unlined OFR system with 0, 5 and 10 cm weir heights, the pay back periods are 12, 13 and 13 years, respectively. The study revealed that rice-fish integration in the unlined OFRs is technical feasible and economically viable as compared to lined system for increasing the agricultural productivity during the monsoon season of rain-fed ecosystem (Pandey et al. 2005).

A runoff harvesting tank-based integrated farming system model with catchment-command ratio of 3:1 has been developed for the plateau area of eastern Orissa, India (Srivastava et al. 2004). In this system, fish and prawn was grown in pond. The free board area of the embankment of the pond was planted with two rows of papaya (*Arica papaya*) and one row of banana (*Musa paradisica*) in inward slope. It has been reported that the benefit-cost (BC) ratio of the system was 2.2 with crop alone, which increased to 2.66 when horticulture was added and it further rose to 3.28 with inclusion of aquaculture (Table 4). It was also marked that fish productivity was higher as the water will be less turbid. In irrigation systems, particularly in shallow reservoirs and rice fields, there is a high potential for the capture and culture of fish. The capture of wild fish is usually a traditional practice, returning low yields. The farming of fish requires the use of highly productive fish species. It is evident that the runoff recycling is beneficial even with irrigation to crop alone. However, with multiple uses, the B: C ratio rose beyond 3.0. It is also evident from table that additional benefit from allied activities of fish and horticulture ranged from INR 4500 to 7800 which is almost equal to the total annual cost of system. Thus, with multiple use of the water in the tank, the cost of irrigation becomes minimum.

In order to increase the productivity from a unit volume of rainwater, a two-stage rainwater conservation technique was conceptualized and tested (Mishra and Mohanty 2004). In this system, a part of the rainwater was conserved in rice field up to the weir crest level and the remaining in a refuge for rearing of fish (*Catla catla, Labeo rohita, Cirrhinus mrigala* and *Cyprinus carpio*) and prawn (*Macrobrachium rosenbergii*) was conducted in Bhubaneswar, India. Weir height of 12.5 cm, provision of peripheral trench on three sides of

Table 4 Economics of crop production in tank-based irrigation command at Bhubaneswar, Orissa

Commodity	Additional production from command area	Irrigation water use efficiency		Addition gross benefit from command area (Rs)	Addition cost of production in command area (Rs)
		kg/ha. mm	Rs/ha.mm		
Rice	1.22 t	12.33	67.82	7198	500
Mustard	0.39 t	8.12	97.44	3850	2000
Groundnut	0.49 t	6.07	72.82	5880	2800
Watermelon	0.4 t	14.81	29.62	800	100
Papaya	450 kg	–	–	1800	100
Banana	100 dozens	–	–	600	300
Fish	100 kg	–	–	3000	1000
Prawn	16 kg	–	–	1600	1000
Return from land occupied by tank	–	–	–	–	650
Pumping cost (Rs)	–	–	–	–	2500
Total				24,728	10,950
Net return in tank irrigation over rain-fed				Rs 13,778	

Srivastava et al. (2004)

rice fields (0.5 m width and 0.3 m depth), a refuge occupying 9 % of field area and fish stocking density of INR 25,000/ha were found suitable for this system and resulted in rice equivalent yield of about 4.4 t/ha without application of pesticides. A net higher profit of INR 10,781/ha was obtained from this rice—fish production system over only rice cultivation.

The coastal areas of India suffer from floods during monsoon and lack of water in winter season. With groundwater being saline, there is little scope of irrigation development. However, working in supercyclone ravaged areas it was found that properly designed and constructed Subsurface Water Harvesting Structure (SSWHS) will mitigate the early drought in monsoon season and provide irrigation during post-monsoon and summer season (Sahoo et al. 2005). Fresh water was available at 0.5–3.0 m depth from the ground surface underlain with saline water body in coastal water logged areas. Fresh water is due to seepage of high rainfall in this region. The SSWHS has been designed in the form of excavated tank. The depth of SSWHS in this area varied from 3 to 4 m, based on available fresh water depth and area depends upon the water requirement and seepage rate of sub-surface material in fresh water zone. Such structure is capable to harvest surface runoff in the rainy season and to harvest sub-surface seepage water in the post-monsoon. To extract water from these structures, pump up to 2 hp is suitable to avoid saline water ingression in to fresh aquifer. To increase the returns from these SSWHS, aquaculture was integrated in the system. The fish crop income ratio varied from 1: 1.85 to 1: 3.16 in different SSWHS. Income from fish per cubic metre capacity of SSWHS varied from INR 2.96 to 12.23. The total income from SSWHS varied from INR 12.93/m^3 to INR 47.20/m^3 in the first year itself. Low income from crop is sustained by high income from fish as the SSWHS is being fed continuously by sub-surface seepage water in coastal waterlogged area. The net return per unit of rupee invested varied from 0.98 to 3.43 in the first year itself. Water productivity varied from INR 15.84/m^3 to INR 80.43/m^3 with an average of INR 36.20/m^3 (Sahoo et al. 2003; Sahoo and Verma 2003).

There is immense scope of integration of fishery and livestock in a water body, as the crop–livestock system is a rule rather than exception for a hill farmer (Bhatt and Bujarbaruah 2011). It is evident from Meghalaya state, India, which is a part of the North Eastern Himalayan region of the country that large livestock population with pigs being 53/100 persons (all India average 1/100) and poultry birds at 63/100 persons (all India average 24/100) in the state (Bujarbaruah and Bhatt 2006). The technologies of pig-cum-fish farming, poultry-cum-fish farming and duck-cum-fish farming can be utilized for multiple uses of water and this requires less input with high rate of return (Bhatt and Bujarbaruah 2005). However, some modifications are required for achieving multiple use of water. Water supply to ponds in hills generally depends on rainfall, run-off water, springs or wells. Water can also be fed from stream, river or lake depending on the site of location. The soils are generally acidic in nature and need proper management during the construction of ponds or tanks for fish culture. The various types of ponds which can be excavated or constructed in hill slopes are barrage ponds, diversion ponds, recirculation ponds and running water channels. Construction of ponds in hills or converting water bodies to fish culture practices needs special attention with regard to building of proper drainage system, sealing of pond bottom with clay/polythene or plastic sheet or other sealing materials and putting wire net etc. in sluice gate to prevent escape of fish (Behera and Mahapatra 1998) . The composite fish culture using six species of fish with three Indian major carps is quite profitable in the lower altitudes with warmer climate and the results were very encouraging (Nayak and Mandal 1989).

Tube-well based multiple water use is adopted largely by farmers in Punjab plains of India. Groundwater can be used for multiple uses before irrigating crops and this has been effectively illustrated by innovative farmers, who have adopted the concept of integration of agriculture–fishery–horticulture–agroforestry–livestock on their farm at village *Haiyatpura*, Ludhiana (Punjab). They developed their own system to irrigate field crops, orchards and forestry with the fishpond water. Innovatively, they developed floating fish feed dispenser and aerator (Pant et al. 2005). With mixed fish culture and multiple harvesting, also uses pigs and poultry droppings to fertilize the fishpond. They harvested 5–6 tha^{-1} fish along with 2.2–3.0 tha^{-1} rice and 1.8–2.5 tha^{-1} wheat along with other earnings from piggery, poultry, and dairy (Bhatnagar 2004). The system for utilizing groundwater for fish culture before its delivery to the field has immense potential. However, its design parameters for various pump sizes and command area need to be standardized. Under a similar system, Gill et al. 2005, reported an income of INR 72,000/ha in IFS as against INR 53,200 in rice-wheat system. The multiple use of water in IFS not only improved the farm income but also resulted in ensuring diversified product from the farm. The aquaculture in canals also has tremendous potential of generating higher economy for farmers. However, the present technology base is insufficient to harness this potential. A sustained and systematic research effort should be initiated to develop technology suitable for various flow conditions. If a suitable technology could be developed for utilizing this water, it can serve as a tool of increasing the number of stakeholders in canal system while involving landless people in the enterprise (Fernando and Halwart 2000). The effect of multiple uses on hydraulics of the canal also needs to be studied in detail. Groundwater-based multiple use system was also designed at Patna, Bihar, India (Bhatnagar 2004). A secondary reservoir was integrated with tube-well to minimize the effect of uncertainties on irrigation water availability on crop production and improving the irrigation performance in command area.

Since the financial performance of irrigation projects in developing countries is frequently less than anticipated, accounting for multiple uses of irrigation water can significantly bolster the identified contribution of the project to the local economy and provide a rationale for increased project investments. Besides this, the water quality is an important consideration because many non-irrigation uses require better quality water than that required for agriculture. Fish farming has been shown to be a viable enterprise in all different components of the irrigation system. The world's most productive reservoir fishery is found in large shallow reservoirs, which are abundant in Sri Lanka (De Silva and Maughan 1994). Fish farming in irrigation systems can and should be integrated in such a way that all the habitats created by irrigation and the accompanying agricultural activities are put to use in fish farming. Any system adopted must have the flexibility to incorporate new technologies depending on local conditions.

4.2 Multiple Uses through Integration of Fishery and Agroforestry

The cultivation of multi-storeyed agro-forests around small water reservoirs allows the combined management of vegetation and water resources (Wagachchi and Wiersum 1997). The ponds are primarily used for storing water, regulating stream flow, arresting sediments and wallowing of water buffaloes. The inclusion of the ponds increases the multifunctional nature of the forest gardens, especially in relation to water, erosion and sedimentation management and animal husbandry, and thus optimizes the complementary nature of forest gardens in the total farming system. The increase in height and stem base area was significantly greater ($P<0.001$) in mesquite trees irrigated with water from the fish culture facility than in mesquite trees irrigated with well water. Resultantly, trees irrigated with well water took double time over trees irrigated with fish pond water to reach a marketable size (De Silva and Maughan 1994).

5 Benefits of Multiple Use of Water

Irrigation water is used for many purposes other than irrigating field crops. The importance and value of multiple uses of irrigation water are often under-estimated. According to Bhatia (1997), direct economic benefits to the farmer (from crop output) reflect only a small proportion of the total benefits to the community of using water in irrigated agriculture. An irrigation infrastructure provides non-irrigation benefits to other user sectors and ignoring these benefits will result in a serious under-estimation of the benefits available from the volume of water that is diverted for irrigation. The valuing of water for multiple uses should ensure that the full range of values placed on water in competing uses is taken into account when water allocation decisions are made (Pigram 1997).

5.1 Livelihood Improvement

Multiple uses of water contribute to the livelihoods of the poor through improved food supply, employment and income (Sinhababu 1996). Many small-scale farmers have small land holdings in areas of complex, diverse and risk-prone agriculture. Practice of rice-fish diversified system under lowland flood-prone ecologies is not only a viable alternative option to rice cultivation for utilization of land and water resources, but also to increase farm income and provide nutritional security to the family of the rural farmers (Mishra and Mohanty 2004). Further the system also ensures integration of other compatible agricultural and animal components suiting to the regional needs. Direct benefits from rice-based integrated farming system aside from increased household nutrition and income are local availability of fresh fish, meat, fruits and vegetables, and the provision of employment for household members (Srivastava et al. 2004; Rautaray et al. 2005). Indirect benefits are the increased availability of these products to local and urban market, thus meeting the local and regional requirement of these products, increased employment benefits through development of industry on fish farms and related services and sharing of investment in community-managed common pool resources (Edward 2000).

5.2 Economic Development

Irrigation water has a social value in the sense that it creates opportunities for development. Without irrigation these opportunities do not exist. For instance, the employment generated in irrigated agriculture is much higher than the non-irrigated agriculture. Similarly, a multi-enterprise farming system due to multiple use of water can create much higher level of employment opportunities (Behera et al. 2004). It creates direct job opportunities in the field as well as indirect jobs that are linked with agricultural business and services (Behera and Mahapatra 1999). Under drought or dry farming situation as prevalent in states like Rajasthan, India, the job opportunities are less. Under such circumstances, the trend of migration from rural to urban areas results in social conflicts. Besides employment generation and social consistency, multiple uses of water in agriculture contribute to food security (Balusamy et al. 2003; Gill et al. 2009).

5.3 Environmental Values

Multiple use of water in farming system has environmental value. Under rain-fed lowland and flood-prone areas, practice of multi-farm enterprises such as fishery, crop, vegetables, fruits, duck, mushroom etc. helps in preservation of the ecology of the wetlands (Sinhababu 1996; Gill et al. 2009; Sen 2009) Besides, recycling of by-products and farm wastes within the farming system helps in improving the surrounding environment.

6 Constraints in Adoption of Multiple Use System

An analysis of different systems showed that although multiple use of water has tremendous potential in farming system diversification, increasing income manifold and above all productivity of available water, there are several constraints in its wide spread adoption. For multiple use, especially aquaculture, duckery and vegetables on pond embankment, the water body has to be near the homestead for better management and security (Srivastava et al. 2004). The community based water bodies pose greater challenges to put them under multiple use. Although the farmers are a bit aware of options of multiple use and their benefits, they lack adequate skills to design and operate appropriate systems (Sinhababu 1996). Multiple use system is capital-intensive and invariably there is lack of adequate funds for initial investment especially among the resource poor groups. The multiple uses through aquaculture, duckery etc. is limited to the water bodies, which are near to homestead. For spreading it to other water bodies, there is need for exploring other crops/systems that can survive even in poor management conditions. Makhana (*Euryle ferox*) and water chestnut (*Trapa bispinosa*) are two such crops which are less prone to poaching. Aquaculture with specific type of fishes can be integrated with these aquatic crops. Due to thorny spread of these crops, the catching of fish will not be very easy (Mahapatra 1994). However, the cultivation of these crops is on a very limited scale and there is need to develop technology for integrating these crops with other systems. In plateau regions, where water availability is up to March, two approaches can be adopted *viz.* a) design the pond in such a way so that there is additional water available in a small refuge during dry season or b) pump water from the well to maintain desired water level or harvest it at earlier stage and sell it as fingerling (Mishra and Mohanty 2004). Alternatively, a system of one small tank adjacent to big tank can be developed for fish production. The smaller tank can be lined and filled up with the water pumped from the well. This will maintain fingerlings of 50–100 g during summer and can be stocked during succeeding monsoon (Mohanty et al. 2004).

7 Strategies for Improving Farm Water Productivity Through Multiple Water Uses

- Interventions to enhance water productivity should not be pursued in isolation. A system approach is required which integrates improved resource management (land, livestock and water) and agronomic practices. However, the potential complementary between irrigation uses and different farm enterprises in a farming system need to be explored which are quite often overlooked.
- The water productivity in terms of yield per unit volume of water consumed or economic benefits per unit quantity of water used should be evaluated for different enterprises or combination of enterprises involved in IFS schemes in different agro-ecoregions.
- Irrigation scheduling in a whole-farm basis using efficient irrigation system such as micro-irrigation will help in water economy. Technologies such as laser land levelling, furrow-irrigated raised-bed (FIRB) planting, surge-flow irrigation, pulsating, partial root zone drying, pitcher irrigation and soil moisture deficit based surface irrigation scheduling etc. are also useful in bringing water economy at farm level.
- Diversion of roof water to the storage tank and its use for multiple purposes should be emphasized.
- Selection of low water requiring and high value crops for enhanced water productivity is desirable.
- Creation of secondary reservoir fed by available canal water and canal seepage and utilizing the water in efficient way including IFS, to maximize the profit is necessary.
- On upland/hilly terrain, where construction of big pond is not possible, storage of rain water in small tanks is an alternative option for establishment of horticulture/off season vegetables and introduction of livestock, poultry etc. with crop.
- Explore the possibility of fish trenches-cum raised bed for growing fruits+vegetables at moderate depth of water logging.
- Creation of awareness and capacity building through training, sensitization meeting, leaflet, poster etc. on multifunctional role of water and eco-friendly farming.

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