Indian Journal of Agronomy **56** (1): 1—19 (March 2011)

Rice (*Oryza sativa*)-based farming systems for livelihood improvement of Indian farmers

I.C. MAHAPATRA[1] AND U.K. BEHERA[2]

Received: April, 2009

ABSTRACT

Farming system research is a multi-disciplinary holistic approach to solve the problems of small and marginal farms. Small and marginal farmers are the core of the Indian rural economy constituting 80% of the total farming community but possessing only 36% of the total operational land. The declining trend of per caput land availability poses a serious challenge to the sustainability and profitability of farming. Under such conditions, it is appropriate to integrate land-based enterprises, *viz.* dairy, fishery, poultry, duckery, apiary, field and horticultural crops within the farm, with the objective of generating adequate income and employment for these small and marginal farmers and thereby improved livelihoods. The production system adopted during Green Revolution has been explorative and the natural resources like soil and water were subjected to immense pressure beyond carrying capacity. As a result sustainability of agricultural production system and the farming system is in crises. This suggests the urgent need of integrated farming system development where the various components of the farming system may be integrated to improve productivity and profitability as well as resource conservation along with maintenance of the environment. Rice (*Oryza sativa* L.) occupies a position of overwhelming importance in Asian agriculture and it constitutes the bulk of the Asian diet. For many people in the poor countries, rice is the main source of energy, and it plays an important role in providing livelihood to the Asian population. It is largely grown in Asia (90% area) under diverse conditions of soil, climate, hydrology and topography. Rice farming is the single most important source of employment and income for the majority of rural people in these regions. Among the various farming system options in rice ecologies, rice – fish farming has great potential particularly in eastern India in view of the resources, food habits and other socio-economic conditions. Rice–fish diversified farming system with the integration of compatible components, such as improved varieties of rice, fish, prawn, pulses, oilseeds, horticultural crops, agroforestry, mushroom, poultry, duckery, goatery, floriculture, apiculture etc. can increase the farm productivity, besides farm employment over traditional rice farming. There exist chain of interactions and flow of resources among the different enterprises in a integrated farming system. To make farming profitable and improve resource use efficiency at the farm level, the synergy among interacting components of farming system needs to be exploited. In this paper focus is on different aspect of rice-based farming system involving methodology, determinants, and forms of rice-based farming systems and their impact on livelihood of farming communities.

Key words: Farming systems, Fish, On-farm research, Resource use efficiency, System modeling,

Specific agricultural systems created, shaped and maintained by generations of farmers, on the basis of the diverse species and their interactions and using locally adapted, distinctive and often indigenous combinations of management practices and techniques. Rice-based farming systems evolved in South-east Asia over 6,000 years ago is a sustainable form of agriculture, for subsistence farmers. However, this beneficial cultivation system was gradually abandoned due to population pressure and the Green Revolution, which emphasized high-input monoculture using high-yield rice varieties, pesticides and herbicides. The production system adopted during Green Revolution was explorative and the natural resources like soil and water were subjected to immense pressure beyond carrying capacity (Mahapatra *et al.,* 2007). This leads to degradation of not only the crop system but also to the life-supporting environment as whole. As a result sustainability of agricultural production system and the farming system has faced crisis (Dent, 1990). This suggests the urgent need of integrated farming system development where the various components are integrated to improve productivity and profitability as well as resource conservation as a part of the maintenance of the environment.

With the view of predominance of small farmers, there

Corresponding author E mail: ukbehera2008@yahoo.com)
Present address: [1]Former Vice Chancellor, OUAT, Bhubaneswar, Usha Villa, 211, Aerodrome Area, Bhubaneswar, Orissa 751 020; [2]Associate Dean, College of Agriculture, OUAT, Chiplima, Orissa 768 025

is hardly any scope for horizontal expansion of land for food, feed and fiber production. Vertical expansion alone is possible by integrating appropriate farming components requiring lesser space and time, and ensuring periodic income to the farmers. The integrated farming system assumes greater importance for sound management of farm resources to enhance the farm productivity, to reduce environmental degradation, and to improve the quality of life of resource poor farmers and maintain the sustainability. This is the approach in which interactions among different enterprises in the system are taken into consideration, while going for a technological intervention (Pant *et al.,* 2005); the by product of one enterprise becomes the input for other (Behera and Mahapatra, 1998; and Behera *et al.,* 2008), and the systems are managed in response to physical, biological and socioeconomic environments and in accordance with farmers goals, preferences and resources (Shaner *et al*., 1982).

Rice occupies a position of overwhelming importance in Asian agriculture and it constitutes the bulk of the Asian diet. Effective per caput demand of rice ranges from a low of about 60 kg/year in Japan to 208 kg/year in Myanmar. For many of the people in the poor countries, rice is the main source of energy that enables them to execute their daily chores. It accounts for about 50% of the annual per capita calorie intake in the region, reaching more than 70% in Bangladesh, Cambodia and Myanmar. Equally important is rice's role in providing livelihood to the Asian population. Rice farming is the single most important source of employment and income for the majority of rural people (FAO, 2001b). Rice-based production systems and their associated post-harvest operations employ nearly 1 billion people in the rural areas of developing countries and about four-fifths of the world's rice is grown by small-scale farmers in low-income countries. This explains the relatively large contribution of rice to agricultural production.

Cropping systems vis-a-vis farming system approach

A cropping system signifies the sequence of crops grown over a specific piece of cultivated land over a period of time and seeks to increase the benefits from the available physical resources. Therefore, the basic approach in an efficient cropping system leading to higher production and better economic returns suggests efficient utilization of inputs (Yadav *et al.,* 1998). The latter includes selection of suitable crop varieties having their growth duration fitting in the frame of the rotation and their adaptability to the growing conditions. Further, tillage practices, planting methods, plant population, crop interaction, effect of crop combinations and cropping sequences on pest incidence, efficient use of fertilizers and irrigation water, and utilization of farm power are the other management inputs affecting success of cropping system. Socio-economic factors like size of holding and its consolidation, timely and adequate input availability, farmers' demand for a part of the produce for self consumption, nearness to the centres of disposal of the farm produce and above all economic returns of marketable surplus influence the decision for including specific crops in a cropping system. The increased use of chemical fertilizers coupled with the introduction of short-duration high-yielding varieties and improved irrigation practices have resulted in spectacular increases in the yield of crops and thereby added a new dimension to the productivity of the land. Cropping systems research over the last few decades have led to identification of system-based production technologies, which have made a visible impact in enhancing crop productivity. System-based approach emphasizes on integration of component technologies to provide stable farm income, low-cost farm technology, high productivity, low risk, better utilization of available resources, complementarities to existing cropping programme and additional employment generation (Devendra and Thomas, 2002).

During the last 4-5 decades of agricultural research and development in India, major emphasis has been given to component and commodity based research projects for developing animal breed, farm implement and crop variety, mostly conducted in isolation and at the institute level (Behera *et al.,* 2008). This component, commodity and discipline based research has proved largely inadequate in addressing the multifarious problems of small farmers (Jha, 2003). Due to such approaches, several ills have appeared in Indian farming, such as decreasing factor productivity, resource use efficiency, and declining farm profitability and productivity (Chopra, 1993; and Sharma and Behera, 2004). Environmental degradation including groundwater contamination and entry of toxic substances into the food chain has become a significant problem (Behera *et al.,* 2007). To tackle such problems, farming systems approaches to research has been widely recognized (Behera, 2007).

Farming system refers to particular arrangement of enterprises that are managed in response to physical, biological and socio-economic environment and in accordance with farmer's goals, preferences and resources. In farming system approach to research the whole farm rather than single farm enterprise is taken in to consideration, while decisions are taken for technology adoption and production activities. In this approach the whole farm is viewed as a system and interactions among the various components are taken in to considerations (Mahapatra and Behera, 2004).

To meet the multiple objectives of poverty reduction, food security, competitiveness and sustainability, several researchers have recommended a farming systems approach to research and development (Norman, 1978; Byerlee *et al.,* 1982; and Shaner e*t al.,* 1982). Farming system research is a multidisciplinary wholefarm approach and is effective for solving the problems of small and marginal farmers (Gangwar, 1993, and Devendra, 2002). The approach aims at increasing income and employment from small-holdings by integrating various farm enterprises and recycling crop residues and by-products within the farm itself (Behera and Mahapatra, 1999; and Singh *et al*., 2006). Under the gradual shrinking of land holding, it is necessary to integrate land based enterprises such as dairy, fishery, poultry, duckery, apiary, field crops, vegetable crops and fruit crops etc. within the bio-physical and socio-economic environment of the farmers to make farming more profitable and dependable (Behera *et al*., 2004).

Major focus in farming system

In the past few decades farming system research (FSR) has emerged as a popular and major theme in international agricultural research (Sands, 1986). Yet despite the widespread use of the term FSR, substantial ambiguity persists about its meaning and the types of research concepts, objectives, approaches, activities and methods to which it should be applied. The FSR integrates the following key activities and concepts into a coherent research process designed to overcome the perceived weaknesses in mainstream agricultural research.

It is problem solving: The FSR is an operational research which first identifies technical, biological and socio-economic constraints for improved production in farming systems. It then endeavours to develop solutions those are appropriate for the management conditions of that system (Biggs and Stephen, 1995).

Farmer-oriented: The FSR views small farmers as clients for research and technology development. Therefore, its fundamental objectives are to generate technologies relevant to their goals, needs and priorities. Several mechanisms are employed to attain these objectives: (i) farmers are integrated in to research process, (ii) the existing farming system is studied before proposing technological solutions, and (iii) technologies are adapted to local circumstances and needs of a specific group of farmers (Rhoades and Booth, 1982; and Chambers and Ghildyal, 1985).

System oriented: The FSR views the farm in a holistic manner and focuses on interactions between components. In practice the whole farming system serves as the framework for analysis, but specific components, sub-systems or interactions are targeted for interventions.

Interdisciplinary: The FSR, by nature, cuts across conventional, commodity and disciplinary boundaries. Biological and social scientists must collaborate in order to understand the conditions under which small farmers operate, to diagnose constraints and to develop appropriate and improved technologies (Rhoades and Booth, 1982; and Mahapatra and Behera, 2004).

Complements mainstream commodity and disciplinary agricultural research; it does not replace it. The FSR draws on the "body of knowledge" of technologies and management strategies, generated by discipline and commodity research and adapts them to the specific environment and socio-economic circumstances of a target group of relatively homogeneous farmers (Sands, 1986).

On-farm research is central to FSR approach: On-farm research provides the context for collaborations between farmers and researchers (Chambers and Ghildyal, 1985). Researchers get a deeper understanding of the farming system and the decision making context of the farm family. It revolves round the basic principle that successful agricultural research and development efforts should start and end with the farmers (Rhoades and Booth, 1982). Farmer participation is ensured at different stages of technology generation and transfer processes such as system description, problem diagnosis, design and implementation of on- farm trials, and providing feedback through monitoring and evaluation.

Bottleneck in conventional system of research, extension and development

There has been a demand for holistic approach for technology generation and dissemination instead of traditional component approach in piecemeal and isolation (Behera *et al.,* 2008). There is no mechanism either with the researchers or with the line department to construct a whole farm model and present the same for farmers (Mahapatra and Behera, 2004). Projection of a whole farm scenario of farm income based on integrated farming system is lacking either through development agencies or extension functionaries. This projection has been more relevant in rice-based farming system, where rice crop alone yields meager profit and involves high levels of risk (Behera *et al.,* 2008).

In our extension and development programme, the respective agencies generally give a variety of advice in isolation and in piece meal to the farmers (Black, 2000; Ridley, 2005; and Jha, 2003). That creates confusion among these farmers. But nobody puts a clear-cut whole farm scenario of his farm income, employment generation and also expenditure, and other input requirement for different enterprises involved at the farm level into consideration.

This is due to non-availability of a simpler technique to project a whole farm scenario of farm activities and enterprise combinations (Mahapatra and Behera. 2004). Hence, there is a great demand for construction of whole farm model using suitable computer software and forwarding the same to the farmers.

The dominant model for technology transfer is based on the assumption that new agricultural technologies and knowledge are typically developed and validated by research scientists, and that the task of extension agencies is to promote the adoption of these technologies by farmers, there by increasing agricultural productivity (Chambers and Ghildyal, 1985; Norman and Mediakgotla, 1990; and Black, 2000). Such an approach is quite failure to disseminate the technologies where there are constraints at the farm level. In this process farmers have no say about their need, constraints and available resources with them rather they are forcibly asked to adopt an unrealistic technology (Chambers and Ghildyal, 1985; Abhby, 1986; and Johnson and Claar, 1986). Such efforts are needed to be improved.

Potential approaches to deal with rice-based farming system

Holistic approach: The problems of Indian agriculture call for a holistic approach to research and development effort (Behera *et al.,* 2008). It has been largely recognized for a changed vision of agricultural research in the country that the commodity and component based research effort at an institute level need to be shifted to farmer-centric research and development effort (Mahapatra and Behera, 2004). The crop and cropping system based perspective of research needs to make way for farming systems based research conducted in a holistic manner for the sound management of available resources by small farmers (Gangwar, 1993; and Jha, 2003). Integrated farming systems are often less risky, because if managed efficiently, they benefit from synergisms among enterprises, a diversity in produce, and environmental soundness (Lightfoot, 1998; and Pullin, 1998). On this basis, IFS models have been suggested by several workers for the development of small and marginal farms (Rangaswamy *et al.,* 1996; and Behera and Mahapatra, 1999).

In this context, construction and application of whole farm model by using linear programming and Multi-Criteria Decision Making (MCDM) techniques is very important for resource allocation and enterprise selection point of view (Behera *et al.,* 2008). These models will be development model (*vis-à-vis* the existing model for comparison) and address employment generation (to check migration) and income round the year (to push up farmers above poverty line), (Behera *et al.,* 2008); and reorganize farm activities that will also rejuvenate lost farm ecologies and agro-resources.

Participatory 'bottom-up' approaches: Failure of 'top-down' model of technology transfer led to formulation of alternative models 'bottom-up' approach (Gartner, 1990; and Black, 2000). Instead of starting with the knowledge, problems, analysis and priorities of scientist, it starts with the knowledge, problems, analysis and priorities of farmers and farm families. Instead of research station as main focus of action, it is now the farm. Instead of scientist as the central experimenter, it is now the farmer, whether woman or man, and other members of farm family. Advantages claimed for participatory 'bottom-up' approach of experimentation, learning and action include the followings:

(i) Participatory approaches recognize the importance of local ways of knowing and drawing upon the accumulated knowledge and experiences of farming community (Cornwall *et al*., 1993).
(ii) They "support local innovation and adaptation, accommodate and augment diversity and complexity, enhance local capabilities, and so are more likely to generate sustainable processes and practices" (Pretty and Chambers, 1993).
(iii) They are consistent with ethical principle that there should be stakeholder involvement in any research that is likely to have social and financial impacts on the farming community (Marsh, 1998).
(iv) They acknowledge the value of farmers sharing ideas and information among themselves rather than relying simply on direction or advice from government agencies or professionals (Carr, 1997).

Technological interventions: There is urgent need to generate low cost holistic farm technologies involving agricultural diversification focusing enterprises like crop (crop diversification with drought resistance crops/varieties and remunerative crops), dairy, goatary, apiary, agroforestry and agro-processing etc. driven by market demand and opportunities (Lightfoot *et al.,* 1993; Prein *et al.,* 1995).

Many researchers advocated farming system analysis and multi-disciplinary research for the development of small farms (Devendra, 2002; Prein, 2002; Lawrence and Pearson, 2002; and Keating and McCown, 2001). Hence, development of suitable IFS models for the small farmers in different agro-ecological regions of the country is of major importance. The basic aim of IFS is to derive a set of resource development and utilization practices, which lead to substantial and sustained increase in agricultural production. The Farming system studies involving a number of enterprises and taking the physical, socio-economic and bio-physical environments into consideration are very complicated, expensive and time-consuming (Mahapatra and Behera, 2004). There exists a chain of interactions among the components within the farming systems and it becomes difficult to deal with such inter-linking complex systems (Behera and Mahapatra, 1999; and Shekinah *et al.*, 2005). This problem can be overcome by construction and application of suitable whole farm models (Dent, 1990).

Methodologies of conducting farming system research

Collinson (1987) while considering procedures of farming system research has suggested that farming system adaptive research is a better approach for allowing better decision making on recommendation to farmers and on priorities for technical research. In less developed countries the majority of the farmers (70%) are small farm-holders with holding size of 0.5 ha. Bhatia and Venugopal (1991) reported that the farming system approach is needed in integrating trees, livestock and fisheries with the agriculture in formulating synergetic "mixed farming" models, appropriate to different agro-climatic regions and on-farm situations for a total uplift and sustainability of output from the millions of small and marginal farms which account for a major share in Indian agriculture. In FSR, small farmers are considered to be clients for agricultural research and development of technology, the farm as a whole is viewed in a holistic manner and focus is on interactions between components and also considered to be problem solving operational research. Instead of a lengthy trial and error process to test innovation on the farmers' field, a wide range of experimental pattern could be pre-screened for compatibility with the existing farm resources and the community social and economic structure (Chambers and Ghildyal, 1985; and Norman and Mediakgotla, 1990).

With the development of the modelling approach to farming systems research with due verification and validation etc. using computer software, followed by on farm experimentation, provides a sound base for agricultural research in developing and less developed countries. The most important contribution of FSR is that it provides a focus for all the disciplines involved in agricultural research and development and that it attempts to classify farmers into relevant categories for agricultural research and policy, while involving them in an active way (Fresco, 1984). Moreover, FSR is an effective way of improving the focus of scientists on problems faced by farmers. Therefore, FSR is a systematic approach to agricultural research. Its conduct will have a definite impact and relevance to generate research results which can quickly enhance agricultural productivity.

Sands (1986) reported that FSR by nature is a farmer oriented system research (takes the holistic view) which cuts across the disciplinary boundaries (interdisciplinary), centred to on-farm research, problem solving operational approach complements main stream commodity research and also provides a feedback from farmers. Most farming system activities are associated with the use of teams comprised of bio-physical and socio-economic scientists such as Agronomist, Soil scientists, Entomologists, Pathologists, Horticulturists, Sociologist, Economists, Animal Production scientists etc. This approach involves interdisciplinary cooperation between the above mentioned scientists in close association with other production specialists and farmers in a collaborative and integrated ways (Collinson, 1987). Generally farming system research is conducted by the following three possible ways: FSR : On-farm Adaptive Research (OFAR); FSR : On-station research; and FSR: Study of farming system by modeling, using suitable computer soft ware.

On-farm adaptive research: **Details procedure of conducting OFAR is reviewed by Mahapatra and Behera (2004). However, few important aspects relevant to RBFS are presented as follows:**

Genesis of "On Farm Trials": The farmers have either not adopted or have partially adopted technologies recommended by Research Stations/Centres/Institutes often because the technologies are not consistent with their situations (Norman and Mediakgotla, 1990). The farmers vary in many socio-economic parameters such as farm size, farm resources, farm labour, farming skill, literacy level, managerial ability, land tenure system, applicability and acceptability of the attributes of new technology relevant to socio-economic and bio-physical parameters of the target areas etc. (Sands, 1986). The technology has, therefore, to be tested by taking into account the realistic environment and with farmers' participation through 'On Farm Adaptive Research' approach in specific recommendation domain, characterized by relatively homogenous farming system associated with similar agro-climatic conditions (FAO, 1995).

General Principles of OFAR: The adaptive research has two components – (a) technology refinement research, and (b) technology adoption research. In the technology refinement research, the research scientist himself moves to a more realistic environment of a problem on which he is working. For instance, if a scientist is interested in striga control research in sorghum, maize or upland rice, he may select a suitable site in the striga endemic areas instead of creating artificial striga infestation at the experimental station (where it is not an important problem). The scientist himself manages the trial in the most appropriate areas under controlled conditions for the refinement of technology for striga control or assesses the resistance of the crop varieties against striga infestation. The research institutes/ agricultural universities have established regular substations in the appropriate environment or choose a specific site either on farmers' fields or government land to temporarily work on a location specific problem until a solution is arrived at. Many scientists confuse this situation with On-Farm Adaptive Research (OFAR). Merely locating replicated field experiment on farmers' field (because of appropriate and realistic environment) and managed by the scientist does not mean that an OFAR trial has been conducted. It is an integral and essential component of adaptive research (Farrington, 1988; and Norman and Mediakgotla, 1990). However, distinction has to be made between technology refinement adaptive research managed by the researcher (even though on farmers' field) and researcher designed farmers' managed on farm adaptive research.

In the design of the OFAR our target is the small farmers who are extremely variable in socio-economic parameters, and are subjected to enormous bio-physical constraints. It is for this reason that the objective selection of the farmers and fields should be done so as to be representative of the most realistic situation in which a crop variety or a production technology should be tested and evaluated and conclusions drawn on the basis of stratification with reference to agro-climatic zone, soil and fertility levels, rainfall pattern biophysical constraints, management levels and socio-economic parameters of the farmers**.** For this reason not only the data on the test varieties and production technology should be collected but the full description of the climate, soil, farm, farmers and his management practices should be made (of the target trial sites and farmers) to be able to analyse and correlate the information for working out the appropriate recommendations.

Objectives of OFAR: The primary objectives of on-farm research is to improve the well being of individual farming families by increasing the overall productivity of the farming system in the context of both private and social goals, given the constraints and potentials imposed by factors that determine the existing farming system (FAO, 1995; and FAO, 1989). However, broadly OFAR is carried out with the following specific objectives in view: (i) to reduce the yield gap between the experimental stations and farmers' fields; (ii) to measure the impact of technology under varying bio-physical and socio-economic constraints, (iii) to identify the key components of technology which can help to increase farm income?, (iv) to characterize and quantify the factors responsible for yield gap; (v) to measure the extent of acceptability of technology by the farmers; (v) to study the applicability of the technology under wide range of conditions; (vi) to study the stability in production and profitability from a given technology; (vii) to determine the scale neutrality of the technology; (ix) to refine the technology suiting to the local conditions; and (x) to identify and resolve location specific problems through diagnostic survey.

The specific objectives, however, shall depend upon the nature of technical programme agreed upon to be executed for solving the location specific problems.

Steps in OFAR: So far, in the formulation of research programme either for "On station" or "On Farm" trials, there has been a "top-down" approach. But the strategy for "On farm Adaptive Research" has to be a "bottom-up" approach. In OFAR the following four steps are involved for effective execution of OFAR (Norman and Collinson, 1985; Mahapatra, 1994, FAO, 1995; and Behera, 2007).

i) Description of existing farming systems, and diagnosis of production constraints in the existing cropping systems/farming system of the target areas.
ii) Design (relevant technology)
iii) Testing
iv) Extension

The research-extension linkage is a vital component of agricultural development process and this has to be at the grass root level.

(a) For this purpose, **a diagnostic survey** has to be conducted at micro-level as against the macro-level, that was conducted in the past in broad agro-climatic zones. To understand the farming systems that are being practiced in the selected target areas, (to begin with) a team of senior research/ extension/social scientists knowledgeable in the identification of production constraints, belonging to various disciplines should go to the target area with low productivity but high spread of the crops/cropping system to pin-point and prioritize the factors limiting production. Only then it would be possible to formulate a meaningful location specific and problem solving research programme. The farming system will be differentiated by both technological and human elements within target area. The diagnostic stage, therefore, should yield the basis for dealing with heterogeneity in farming population.

(b) In the design stage**,** "improved technologies" thought to be relevant to overcome and remove the constraints identified and these technologies are considered for on-farm testing in this stage. The body of the knowledge, the cumulative store of information resulting from other research, is obviously an important source ideal for potential improved technology that might be appropriate. The new "technological break through" may have to be sought to address certain constraints; as there may be nothing "on the shelf" that will work.

(c) The objective of the testing stage is to evaluate a few of the more promising technology arising from the design stage on the farmers' fields.

(d) In the extension stage technology found during the design and testing stages to overcome the constraints delineated in the descriptive and diagnostic stages should be widely extended to other farmers. This stage should also be the beginning of the next cycle of the farmers' 'feed back' and input into the research process. Problems in extension stage should be monitored-perhaps overlapped with a new round of descriptive and diagnostic work.

On-station FSR: FSR is considered as highly farmers' participatory and conducted on the farmers' fields by the inter-disciplinary group of scientists. Farmer participation is ensured at different stages of technology generation and transfer processes such as system description, problem diagnosis, design and implementation of on-farm trials, and providing feedback through monitoring and evaluation (Rhoades and Booth, 1982). On-station experiments on farming system perspectives are also conducted at the research station by taking into consideration the farmers problems, resource availability with farmers such as land, labour, capital etc. and farm constraints (physical and biophysical) into consideration (Rangaswamy *et al.,* 1996; and Behera and Mahapatra, 1999). Number of on-station rice-based farming system studies on integration of different enterprises: lowland rice-cum-pisciculture farming system, rice-poultry-fish-mushroom integrated farming systems for low land, alternate system of land use through diversification of rice-based farming system etc. were conducted in different parts of the country just by simulating the small and marginal farm situations (Rangaswamy *et al.* 1992; Rangasamy *et al.,* 1996; Behera and Mahapatra, 1999, Behera *et al.,* 2004, and Rautary *et al.,* 2005). In these studies, different farming system models were developed for small and marginal farmers with the combinations of different enterprises in order to generate adequate income, employment for the farm family members thereby checking periodic migration, providing balanced diet, with the overall objective to improve their livelihood. The central emphasis in these studies are based on the criteria of economics only. The enterprise selections are on *adhoc* basis and needs scientific and systematic approach.

Experiments conducted are mostly non-replicated. However, efforts have been made to conduct replicated trials under few cases (Murgan and Kathiresan, 2005). Conducting replicated trials seems to be difficult due to involvement of number of enterprises and huge expenditure and time. Besides, the techniques for extrapolating the on-station studies to the similar farmers' environment need to be explored (Mahapatra and Behera, 2004).

Objectives of rice-based integrated farming systems: The rice-based farming system studies both at on-station and on-farm are conducted with the prime objectives of generating adequate income and employment for the farm families, as well as meeting the family requirement of food and balanced diet. Besides, specific objectives are targeted to achieve as follows: (i) maximization of yield of all component enterprises to provide steady and stable income at higher levels; (ii) rejuvenation/amelioration of system's productivity and achieve agro-ecological equilibrium; (iii) control the build up of insect-pests, diseases and weed population through cropping system management and keep them at low level of intensity; (iv) reducing the use of chemical fertilizers and other harmful agro-chemicals and pesticides to provide pollution free, healthy produce and environment to the society at large; and (v) to make farm economy more sound by decreasing dependency on outside inputs through efficient management of farm resources and recycling of all farm wastes and crop residues and thus reduced cost of production.

Farming system modeling

A model is a simplified abstraction of the real world. It simulates the behaviour of a real system. Modeling begins with the analysis of the systems, its circumstances and purposes. Defining the model gives insight into the working of the system. So far the farming system research has been rather inadequate or slow, particularly in less developed countries. Perhaps the only way by which improvement can be achieved is by the construction and application of suitable whole farm models (Dent, 1990). Recent computer software development may provide the basis for a start in modeling of whole farm systems even with incomplete conceptual understanding and data sets.

Number of rice-based integrated farming system studies both on-station and on-farm were conducted by several researchers (Rangaswamy *et al.*, 1992; Sinhababu and Venkateswarlu, 1995; Rangaswamy *et al*., 1996; Behera and Mahapatra, 1998; Behera and Mahapatra, 1999; Behera *et al*., 2004; Samra *et al.*, 2003; Rautaray *et al*., 2005; Gill *et al*., 2005; Singh *et al*., 2006; and Ravisankar *et al*., 2007). In these studies the enterprises are integrated with the objectives of generating additional farm income and employment to improve the socioeconomic condition of small and marginal farmers. These studies also partly included the farm constraints and resource availability. However, no scientific tool (optimization technique) was used for optimal combination of enterprises. These researchers also faced the problems to extrapolate the finding to large-scale with varying constrains and resource availability from farm to farm. On the other hand, system analysis techniques such as optimization proved useful for efficient resource allocation under various constraints

(Taha, 2005). Optimization models optimize the use of farm resources, costs/profits or determine the optimum requirements for specific farm income, and can analyse farm response to policy change in an effective way (Loucks *et al*., 1981). Among available, Linear Programming (LP) is one of the most applied solution methodology in agricultural planning to determine the optimal policy (Loucks *et al.*, 1981; Raju, 1995; and Medulla and Mujumdar, 2005) in single and multiple objective framework. However, their application to IFS is limited (Mahapatra and Behera, 2004)

System analysis using models: With the increased use of simulations, it is often possible to take advantage of previous modeling work and even to build simulations by assembling modules already available. In some instances, general purpose modules have been established which require a user to simply enter data and make appropriate connections. Many models of a given system are possible. The choice between various models depends on the purpose behind simulation, the relative ease with which the simulation can be achieved, and the circumstances surrounding the system. To observe the system behaviour *via* simulation, the model should be written to include significant causes of that behaviour and yet be as simple as possible. System behaviour should accept any and all simplifications that aid in translating the model into simulation without causing unacceptable divergence between real and simulated behaviour. The model does not duplicate the system; rather, it is an abstraction of reality, using mathematics as language to express the cause-effect relationship that determine system behaviour (Mitchell and Gauthier, 1981).

Interactions in rice-based farming systems

Farming system in many of the developed world has become an issue of managing a set of individual enterprises. Individual farm enterprises driven by advancing technology have developed almost in isolation. Industrial inputs in to farming have almost broken the subsystem (enterprise) interaction in farming systems. Certain dependencies between enterprises, of course remain; these are related to the need to distribute scarce resources within the farm business. The management of farm as a system has been neglected to resource acquisition and an allocation problem between (almost) independent enterprises (Dent, 1990).

The farming systems in India and other developing countries are mostly subsistence in nature. The enterprises are existed more in a natural form based on their complimentarity. For example, in fish-duck farming system, a lot of complementarities is observed between duck enterprise and pond ecosystem. The on-station study conducted by Behera and Mahapatra (1998) involving enterprises such as crop, fishery, poultry, duckery, apiary and mushroom production revealed that there is chain of interaction among these enterprises. The byproduct of one enterprise may be effectively utilized for the other enterprise, thus ensuring higher and efficient resource use efficiency. A close examination of resource recycling (Fig.1) indicated the interdependence of the different components of the total farming system to make the farmer self-sufficient in terms of ensuring the family members a balanced diet for leading healthy life and also making farm self sufficient through recycling of by products/wastes. The by product of dairy (cowdung) forms a major raw material for bio-gas plants. Digested slurry of bio-gas forms a major part of feed of pisciculture for increasing plankton growth as well as supplying valuable manure to raise the productivity of field crops/enrich the soil. The by product of field crops like paddy straw forms a major raw material for mushroom cultivation. Straw after use in mushroom production is utilized as cattle feed and compost preparation. Similarly, the poultry droppings form an important ingredient of pisciculture for increasing the plankton growth as well as increasing the fertility of land. Even apiary played a role of improvement in pollination, apart from giving a wholesome product like honey to farmers. Therefore, it is dangerous to deal separately in such linked agricultural system. The integrated farming system revolves round better utilization of time, money, resources and family labourer of farm families. The farm family gets scope for gainful employment round the year, thereby ensuring good income and higher standard of living.

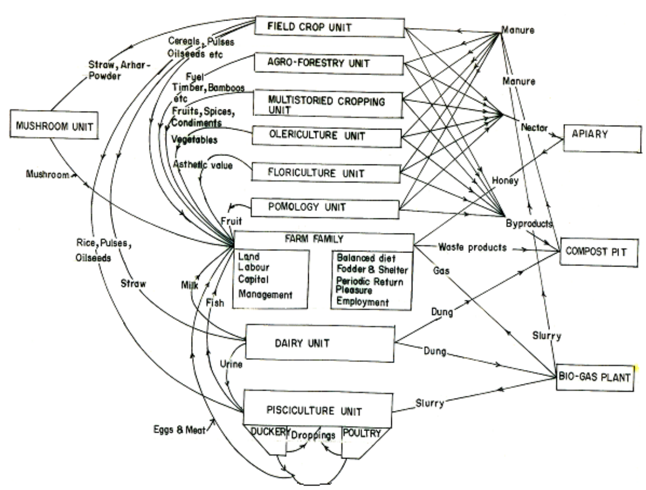

Fig. 1. Interactions among different components of the farming systems.
(*Source* : Behera and Mahapatra, 1998)

Types of rice-based farming systems

Rice- fish farming in rainfed lowlands: Many farmers in coastal and inland low-lying areas have diversified their farm enterprises to minimize risk (Rautaray *et al*., 2005; and Behera *et al.,* 2008*).* Rice (*Oryza sativa* L.) is a semi-aquatic plant, whereas fish and prawn are aquatic in nature. Therefore, integration of aquaculture with rice farming in flooded paddy augments farm output and also benefits rice by improving its environment. This system was found to be economically beneficial, besides reducing pest infestation (Sinhababu and Venkateswarlu, 1995). Further, rice-fish/prawn-horticulture/silviculture systems provided more returns and help in maintaining ecological balance. In a rice-fish integrated farming system, a gross return of Rs 44,382 and net returns of Rs 11,226 was obtained from 0.5 ha area (Rautaray *et al*., 2005), besides generating employment of around 350 man-days (Table 1). The total expenditure for the first year including cost for farm construction was Rs 33,156. Compared to this, the income from the same field through traditional rice farming (only one crop) was Rs 4,000. Adoption of this rice-fish farming thus provided a 2.8 –fold-higher income in the first year, which is again expected to increase in the subsequent years from the produce of fruit plants (*viz.,* coconut, arecanut, plantain, papaya, guava etc.) and agroforestry crop. In North-Eastern Hills Region, the income could be further increased through incorporation of some other components like duckery, poultry and piggery as reported by Sinhababu and Venkateswarlu (1995) in rainfed lowlands in Eastern India. The study revealed that rice-fish technology could be a viable and environment friendly farming option for considerable increase in farm productivity, income and employment in lowland of Assam and also, in other states of north-eastern Region.

For successful rice-cum-fish farming, the fields are made to hold water for longer periods with strong and raised bunds to avoid over-flowing of flood water and a suitable fish refuge/trench system. Fish rearing requires additional inputs such as organic manure and fish feed, whereas rice farming remains essentially the same as in monocropping system, except avoidance of toxic pesticides. Raising of marketable fish and prawn in rainfed lowlands including coastal saline areas (brackish-water bodies) along with rice was accomplished in West Bengal, Orissa and Andhra Pradesh. In shallow lowlands, 500 to 700 kg/ha of fish or prawn and 5 to 6 t/ha of rice can be obtained under such mixed cropping systems (Lipton, 1983; Mukhopadhyay, 1992; Mandal *et al.,* 1990; and Sinhababu and Venkateswarlu, 1995). In deepwater situations where water remains in the field for longer periods, the yield of fish/prawn may go up to 2,000 kg/ha, although the yields of rice are lower under such conditions. Cultivation of vegetables and horticultural crops on bunds raised around the field with the soil excavated from the trenches further increase the land productivity to a great extent (Sinhababu *et al.,* 1998).

Table 1. Return on expenditure from different components in first year from rice-fish system.

Items/Crops	Operational cost including labour (Rs)	Gross returns (Rs)	Net returns (Rs)
Farm construction	6,000*	-	
Rice	17,106	25,387	8,281
Fish	8,650	17,180	8,530
Vegetables and horticulture crops	1,400	1,825	425
Total	33,156	44,382	11,226

*10% of the cost of construction + interest on total cost is taken as the depreciation cost.

The coastal saline lands which grow *kharif* rice or remain barren as unproductive wetlands provide ample scope for development of rice-fish/prawn production system. Rice-fish system in these areas involved growing of salt tolerant rice varieties and fresh water fish/prawn during *kharif* and sole cropping of salt water fish/prawn in sequence during *rabi*. These wetlands can produce fish/prawn amounting to 400 to 600 kg/ha during three months of *rabi,* and another 500 to 600 kg/ha during the monsoon season in an integrated rice/fish/prawn culture (Ghosh, 1992). Rice-fish integrated farming has proved to be viable technology in the low-lying rice fields in Assam, West Bengal and Kuttanad region of Kerala, lying below the mean sea level. The coastal regions receive high rainfall and excess rainfall stored in the ponds/tanks would help in raising a second crop after rice and also for providing protective irrigation to rice during *kharif*. The construction of farm ponds on 1/5th of area has the advantage of raising fish in them and a part of the land can be elevated with the soil excavated from the ponds which provided better land situation for raising a good crop of rice having lower salt concentration and shallower depth of standing water than the original fields. The coastal saline soils generally remain flooded throughout the crop growth period. In bunded fields where the brackish-water does not enter, fish can be successfully grown with rice. In highly saline conditions, where saline water regularly enters the ponds from estuarine/creeks, the main consideration is not for raising rice crop but for prawn and brackish-water fish because these areas do not support a successful crop of rice (Sinhababu and Venkateswarlu, 1998).

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 (Lightfoot *et al*., 1993; and Cagauan 1995). The rice yields increase through the inclusion of fish (dela Cruz *et al*., 1992; and Cai *et al*., 1995). As the price of rice has fallen considerably in recent decades, the value of the produced fish can be higher than that of the crop and thereby of great importance for additional cash generation by farmers.

Types of rice-fish integration: Rice-fish farming systems can be broadly classified as "capture"or "culture" systems, depending on the origin of the fish stock. In the capture system, wild fish enter the rice fields from adjacent water-bodies and grow and reproduce in the flooded fields. In the culture system, on the other hand, rice fields are deliberately stocked with fish either simultaneously or alternately with the rice crop (Prein, 2002). The rice fields may be used for the production of fingerlings or table fish. Technical details of the few physical modifications (bunds, trenches, water inlets and outlets) required to make the rice field suitable for fish farming. Several physical modifications were devised over the years in order to make the rice field better suited for fish culture (dela Cruz *et al.,* 1992; dela Cruz, 1994; Halwart, 1994; Cai *et al.,* 1995; and Yap, 2001).

(a) Rice-fish capture

The earliest and still most widely practised system involves the uncontrolled entry of fish and other aquatic organisms into the rice field, this method is called the captural system of rice-fish culture." (Guan and Chen, 1989). This can only be considered a rice-fish culture system if the fish are prevented from leaving once they have entered the rice field. In this system, the organisms often depend wholly on what feed is available naturally in the field, although it is not uncommon for farmers to provide some type of supplementary feeds. This system is often practised in rainfed areas and plays an important role in many rice-producing countries, for example in Thailand where rainfed areas constitute 86% of the country's rice area, the transition from a pure capture system and a capture-based culture system is gradual and was described as a continuum (Pant *et al.*, 2005).

(b) Rice-fish culture

The stocking and growing of fish in a rice field is basically an extensive aquaculture system that mainly relies on the natural food in the field. The benefits of rice-fish culture as a low investment entry-level technology for resource poor farmers was demonstrated in Bangladesh (Gupta *et al.,* 1998); Indonesia (IIRR and ICLARM, 1992), the Philippines (IIRR and ICLARM, 1992; Horstkotte-Wesseler, 1999) and Vietnam (Rothuis, 1998). Presently, rice-fish culture is being disseminated on a large scale in Bangladesh. A recent achievement is the control of the golden apple snail, a rice pest by the common carp (Halwart, 1998). On-farm resources are cheap, readily available feedstuffs are often provided as supplementary feeds, particularly during the early part of the growing cycle (Guttman, 1999). For the management of the rice crop, compromises are made with respect to the application of fertilizer, which is done judiciously. Fish-rice culture may be concurrent or rotational (Kang min, 1996). Fish stocking in these systems may range from fewer than 500 to 5 000 fish/ha in high intensity systems, with about 3 000 fish/ha being optimal. Rice fields in Asia in varying combinations constitute about two-thirds of the fish species used in aquaculture. More fish species are cultured in lowland humid tropical than in temperate rice fields, and in freshwater than in brackish water rice fields.

(c) Rotational culture

During the season of flooding, the land is used for fish culture. In the dry season, the areas reverted again to individual management of modern rice varieties (Dey and Prein, 2001; and Prein and Dey, 2001). The seasonally flooded areas are also managed by group and benefits are also shared by the group involved. Raising fish during the fallow period or as a winter is practised to make use of the rice field when it otherwise would not be used. In China it is practised but does not seem to be as widely practised as concurrent culture (Langhu, 1995).

(d) Rice and fish with livestock

Carrying the concept of integration one-step further, livestock rearing may also be integrated with rice-fish systems. This has been tried in many areas but is not as common as the integration of livestock with pond culture. The most common form of integration is the rice-fish-duck farming. Integrated livestock fish-farming, as commonly defined, includes the direct use of fresh livestock manure in fish production. The livestock may be confined over the fishpond and wastes drop continuously through slats into the pond or the livestock may be housed adjacent to the pond from where wastes can be easily washed down or scraped into the pond (Rangaswamy *et al.*¸ 1996). A wider definition includes the use of manures moved from their site of production to use for fish culture, bagged poultry manure and pig slurry from collection tanks. The use of livestock manure and processing wastes as either direct fertilizers or feeds, or as a substrate to produce live feeds for fish, may also be included in a broader definition. Cultured fish, or fish products are also used as ingredients in livestock feeds and this is an undeveloped but potentially important linkage with global supplies of fish meal being dependent upon static or declining marine capture fisheries. Aquaculture is a highly competitive option for recycling these wastes through "conventional" integrated livestock-fish farming systems, providing that sufficient land is available for pond construction.

Rice-duck system: Rice-duck farming system is a traditional practice in some of the Asian countries (Sinhababu and Venkateswarlu, 1998; and Sinhababu, *et al.,* 1998*).* Duck farming is closely associated with wet land rice farming (Panda, 2004; and Farrelt, 1997). It is a traditional practice in south India, Philippines, Indonesia, Thailand and Vietnam. The swampy areas with canals, ponds and rice fields provide optimum condition and environment for ducks. The ducks enhance the rice yield, reduce the labour cost, maintain the soil and water for healthy growth of rice crops. There is additional income from the sale of duck eggs and meat. It provides cheap animal protein and balanced diet. The small land holders are benefited by integration of ducks in rice farming systems and their number is increased day-by-day. The duck integration in rice field increases the rice yield by reducing weed growth, insect population,, increasing soil physical properties with better root system and tillering. It increases the dissolved oxygen content in rice field. However, ducks in rice farming reduces the green house effect; prevent the release of methane gas, important to check global warming.

Rice - Fish + Azolla system

The dual culture method of growing *Azolla* with rice has gained widespread adaptability because standing water is available in rice field from seedling to panicle maturity in lowland rice fields and is effectively used for *Azolla* as biofertilizer. *Azolla* can accumulate up to 2 to 4 kg of nitrogen/ha/day. The use of *Azolla* has been a part of rice cultivation in Vietnam and China for centuries and its performance was tested in other rice growing countries, including India (Singh, 1979; and Singh *et al.,* 1991). *Azolla* cultivation in rice field can improve the fish food. Fish culture in rice fields loosens the soil as a result of their free movement in water body and thus aerating the soil, enhances the decomposition of organic matter and promotes release of nutrients from soil (Balusamy, 1996). The excreta of fish directly fertilize the water in rice fields leading to increase in utilizable source of N to the rice crop. Integration of allied components like *Azolla* + fish with rice in lowland farming could provide wider scope for bioresources recycling.

The field experiments were conducted at agricultural research station, Bhavanisagar in Tamil Nadu to develop an integrated N management practices for rice – fish - *Azolla* farming in wetland. Farming systems consisted of rice - rice + fish and rice - rice + *Azolla* + fish and two levels of N (100 and 75% recommended) with and without green leaf manure (*sesbania rostrata*) applications. In the rice-fish system, rice and fish crops were raised together (*synchronous* system) in rice field. Field trenches were provided with 1.0 m depth and 1.5m width occupying 10% of the rice area, for sheltering the fish, *Azolla microphylla* was grown in rice field throughout the cropping period.

Rice-rice- *Azolla* + fish farming with 75% recommended N as well as incorporation of green leaf manure resulted in higher productivity with increased economic returns and improved the soil fertility through recycling of organic resides. The quantum of organic residue addition and N added through recycling were higher in rice-rice-*Azolla* + fish farming with *Sesbania rostrata* incorporation (Table 2). The unutilized fish feed, decayed *Azolla* and fish excreta settled at the fish trench bottom had a higher nutrient value, which can be recycled to enrich the soil (Balusamy, 1996).

Other forms of rice-based farming systems

Rice-based integrated farming system model for marginal farmers in Tamil Nadu: Rice-poultry-fish-mushroom integration on-station studies were conducted between

Table 2. Nitrogen added through recycling of organic residue (kg/ha).

Treatments	*N applied through residue recycling*					
	Fish trench	I crop	II crop	*Azolla*	GLM	Total
Rice-Rice	0	9.2	9.9	0	0	19.1
Rice-Rice+Fish+100%N	12.9	8.7	9.6	0	0	31.2
Rice-Rice+*Azolla*+Fish+100%N	16.9	9.0	10.5	102.2	0	138.6
Rice-Rice+Fish+GLM+100%N	13.4	9.2	11.1	0	19.4	53.1
Rice-Rice+*Azolla*+Fish+GLM+100%N	17.3	9.2	11.3	107.5	19.4	164.7
Rice-Rice+Fish+75% N	12.4	6.8	7.5	0	0	26.7
Rice-Rice+*Azolla*+Fish+75%	16.5	8.0	11.1	0	19.4	52.1
Rice-Rice+*Azolla*+Fish+GLM+75% N	17.0	9.1	11.2	106.3	19.4	163.0

Source: Balusamy (1996).

1987-1992 (Rangaswamy *et at.,* 1996) taking the marginal farmers' situations *i.e.* problems and opportunities in to considerations. Economic analysis of the study of the system under lowland ecosystem of Tamil Nadu in India revealed that a net profit of Rs 11,755/year was obtained from rice-poultry-fish-mushroom integrated farming system (IFS) in 0.4 ha area while in conventional cropping system (CCS) with rice-rice-green manure/pulses gave a net income of Rs 6,334/year (Table 3) from the same area. Integrated farming system increased the net income and employment from the small farm holding and providing balance diet for the resource poor farmers.

Table 3. Economics of rice based farming systems for a marginal farmer (0.4 ha) under low land ecosystem in Tamil Nadu (mean of 1987-1992).

Component	Expenditure (₹)	Gross return (₹)	Net return (₹)
Integrated farming system			
Crop	11,398	19,076	7,678
Poultry	1,944	2,861	917
Fishery	1,486	3,568	2,082
Mushroom	5,078	6,156	1,078
Total	19,906	31,661	11,755
Conventional cropping system(CCS)	7,202	13,536	6,334
Additional income in IFS over CCS			5,421

Source: Rangaswamy *et al*. (1996).
Mean of 5 years.

Another such rice-based integrated farming system study conducted by Murugan 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 yield, economic indices and soil fertility status. The highest net returns of ₹1,55,920/ha and ₹2,28,090/ha during the first and second season, respectively were obtained with integrated rice + fish + poultry farming systems. The same also recorded the highest grain yield of rice (5.67 tonnes/ha and 5.25 tonnes/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.

Rice-based integrated farming system model for small farmers in Orissa: On-station studies were conducted by Behera and Mahapatra (1999) to develop IFS model for small farms by taking into consideration their resource availability and farm constraints. To bring self sufficiency in farmers' requirement of food and cash; increased income and employment opportunity; recycling of farm-wastes and byproducts and increasing resource use efficiency through efficient management of resources a study was conducted considering the situations of farmers in Orissa. 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 social and economic upliftment. The philosophy of such integrated farming system revolved around better utilisation of time, money, resources and family labourers of farm-families. The farm family gets scope for gainful employment around the year thereby ensuring good income and higher standard of living. The economic analysis of such studies revealed that from a small farm piece of 1.25 ha area, a net return of Rs 58,367 could be realised from an investment of Rs 49,286 generating 573-man-days of employment (Table 4) and with a resource use efficiency of Rs 2.18/Rs invested. Similar rice-based integrated farming studies were conducted at farmers' field taking marginal farmers situation into consideration revealed that farm an area of 0.4 ha, a gross income of Rs 19,500 was generated with the expenditure of Rs 20,000 (Behera *et al.,* 2004; and Mahapatra, 1994).

Integrated rice-based farming system for north-eastern plain zone: Singh *et al.,* (2006) revealed that rice-pea-okra was the most remunerative cropping sequence with highest rice equivalent yield (17.88 t/ha) and net return than rest of sequences (rice-wheat, rice-berseem-sorghum, rice-wheat-moong, rice-pea-onion, rice-mustard-sorghum, sorghum-berseem-maize). The rice-based integrated farming system comprising of crop components (Rice-Pea-Okra and Sorghum-Berseem-Maize), dairy, poultry and fishery was the most suitable and efficient farming system model giving the highest system productivity and net return under irrigated agro-ecosystem of eastern Uttar Pradesh. This model generated significantly higher levels of employment than the rice-wheat system only.

Integrated rice based farming systems for north-western plain zone: Study conducted in farmer's field in Ludhiana revealed that rice based integrated farming systems involving rice-wheat + poultry + dairy + piggery + poplar + fishery produced significantly higher rice equivalent yield and net return (Rs 73,973/ha) when compared with conventional practice of rice-wheat, where a return of Rs 53,221 was obtained, Gill *et al.,* (2005). Integrated rice-based farming system also generated an additional employment of 48-man-days/ha was recorded in comparison to rice-wheat. The additional income and overall profitability of the system was due to the synergistic effect of integration of different enterprises within the system.

Table 4. Rice-based farming system for increasing income and employment of small farmers through enterprise diversification (1.25 ha farmland) at Bhubaneswar, Orissa

Components	Employment generation (man days)	Total expenditure (₹)	Net return (₹)	Return/rupee invested (₹)
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	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

Source: Behera and Mahapatra (1999)

Potential contribution of rice-based farming system to the livelihoods of farmers

The rice-based farming system contributes to the livelihoods of the poor through improved food supply, employment and income. Many small-scale farmers have small land holdings in areas of complex, diverse and risk prone agriculture in mainly rainfed and undulating land on the fringes of lowlands or in uplands. The immediate beneficiaries of the production of fish and often improved rice yield in rice-fish farming are the farmers who adopt the technology. Models developed using linear programming techniques on a 2.3 ha farm in Guimba, Nueva Ecija, Philippines showed that the adoption of rice-fish farming technology can generate an additional 23% more farm income by raising fish as well rice. This increases to 91% if the entire 2.3 ha area is stocked with fish, even if rice production remains constant and farm requirements for cash and labour increased by 22% and 17%, respectively (Ahmed *et al.,* 1992). In rice-based farming system, risk is reduced due to diversification of system with low risk-enterprises like fish and vegetable cultivation (Behera *et al*., 2008). Rice-fish farming system not only increases the farm income, but also gives nutritional security to the family of the rural farmers through providing foods. Further the system also ensures integration of other compatible agricultural and animal components suiting to the regional needs and increasing the farm income.

Improved nutrition and benefit to the poor: The fish and other aquatic organisms from rice fields provided a very important component of the daily diet of farming community (Halwart, 2003). The nutritional contribution extends from micro-nutrients and proteins to essential fatty acids that are needed for visual and brain development. Recognizing this, the XX session of the International Rice Commission recommended its member countries to pay increased attention to the nutritional value of fish and other aquatic organisms from rice fields (FAO, 2002). Similarly the cultivation of vegetables such as cucurbits, tomato, okra etc. and fruits such as papaya, coconut etc. not only serves for better nourishment of the farm family but also helps in providing regular farm income round the year.

Considerable benefits result to the farmers due to practice of rice-based farming systems, either from direct consumption of fish by the producing households or from gains in income which lead to the purchase of other cheaper foods, which nevertheless lead to household food consumption (Ruddle and Prein, 1998, Ahmed and Lorica, 1999; Thilsted and Roos, 1999, Thompson *et al.,* 1999; Prein and Ahmed, 2000; and Sultana, 2000). The high nutritional value of fish, particularly for vulnerable groups such as infants and pre-school children, pregnant and lacting women is widely known (Edward, 2000). Further 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. 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 an industry providing work on fish farms and related services; the sharing of investment in community managed common pool resources such as water-bodies in water storage in farm ponds; and in integrated pest management in rice-fish culture (Edward, 2000).

Public health: There are two public health vectors against which fish have been employed: mosquitoes and snails. Mosquitoes are known carriers of malaria and dengue fever. Certain species of freshwater snails serve as hosts to trematodes (*Schistosoma* spp.) that cause histosomiasis. A third aspect is that rice-fish culture may reduce the use of agricultural chemicals that pose a health hazard to humans. Despite the fact that some pesticides are considered safe to use in rice-fish farming due to their low toxicity, low tendency to bioaccumulation, and short half-life, pesticides are still poisons and may be carcinogenic or harmful in other ways. In rice-fish system, fish are potentially a good herbicide and insecticide and can greatly reduce, if not completely eliminate the need for using chemical pesticides. The presence of fish discourages farmers from applying pesticides. The reduction or elimination of the need to apply chemicals cannot but result in an environment that is safer and healthier for the people.

Impact on the environment

Intensification of rice cultivation with an associated increase in chemical pesticide use is reducing bio- diversity. Since rice-fish farming often reduces the need to use chemicals for pest control, this assists in preserving a diverse rice field biota. Utilizing the existing native - species for rice-fish culture serves to actively preserve the biodiversity. Fish are a non-consumptive user of water, and while they can degrade the water they do not use it up. If cleaned, the same water can be returned and reused by the fish. The culture of fish in rice fields can enhance the sustainability of rice farming, since indications are that the presence of fish makes the rice field ecosystem more balanced and stable. With fish removing the weeds and reducing the insect pest population to tolerable levels, the poisoning of the water and soil may be curtailed.

Macro-economic impact: There are three macro-economic issues on which the widespread adoption of rice-based farming system technology could impact: food security, employment generation, and national income. It can be said that fish culture in rice fields is technically an almost ideal method of land use, combining the production of both vegetal and animal proteins. Its further development is important, as it may contribute to a guarantee of the world food supply. Widespread adoption of rice-fish farming as a strategy to substantially narrow the gap between the protein supply and demand is a potential option for any major rice-producing country.

Prospects, constraints and issues

Prospects: The prospects are enumerated here:

(i) Substantial progress has been made in the development of rice-based farming system in Asia. Considerable potential exist for further integration of rice with livestock system in the region, which will contribute to poverty reduction and improvement in the livelihoods of the rural small-scale farmers**.**

(ii) The lowland rice farmers get a nominal return from their rice crop and still continues rice cultivation as there is no alternative use of this lands. To make these lands more remunerative, diversification of the system for fish as well as other crops (fruits, seasonal vegetables, agroforestry etc.) and animal components with modification of the lowland system is required.

(iii) There is a growing recognition of the need to “work with” rather than “against” nature. Integrated pest management (IPM) is being promoted in the place of extensive use of pesticides, and fish have been found to be an effective pest control agent. Promotion of rice-fish system in the low land situation can help in improving the ecologies in these region.

(iv) Fresh water is a limited resource and the integration of fish with rice is one way of using water more efficiently by producing both aquatic animals and rice. Besides, new land suitable for aquaculture is limited and the culture of fish together with rice is an effective way of utilizing scarce land resources.

Constraints: The constraints are as follows:

(i) Rice-fish system is based on the principle of maximizing the use of organic manures and the inorganic fertilization (Ayyappan *et al*., 2004). Again the chemical fertilizers are to be used basally for the whole crop with restricted or no topdressing, which is otherwise required for the rice crop, particularly during panicle initiation stage. Although rice pest and disease incidence in such system is low (Sinhababu *et al*., 2003), in an outbreak of rice borer and diseases like bacterial leaf blight, sheath blight etc.; fish being in the rice field restricts the use of pesticides and insecticides. Though use of insecticides at low level partially cures the disease, it causes a reduction of fish yield (CRRI, 1994).

(ii) Water requirement in rice-fish culture may be more than rice culture alone. One has to properly plan and visualize the water availability situation before going for rice-fish system.

(iii) Trenches must be dug about 40 to 50 cm below the paddy bottom. However, this makes drainage difficult in many places. Rice yield per area is usually reduced because paddy area used for trenches is not planted with rice.

(iv) Field preparation will demand a large initial investment of time, labour and money. As this system requires additional labour input in large-scale adoption, the system may create labour scarcity.

(v) Development of self-sustaining rice-based farming system providing enough income and employment and meeting needs of the house is important.

Issues: The issues are as follows:

(i) There is a demand for a holistic approach in rice-based farming systems to technology generation and dissemination, apart of the traditional component approach. Projection through development or extension agencies of a whole farm scenario for farm income based on IFS is lacking (Mahapatra and Behera, 2004). In this context, construction and application of whole farm models by using optimization techniques are valuable for resource allocation and enterprise selection. In extension and developmental programmes in most of the developing countries, the respective agencies generally go to farmers and give a variety of advice in an adhoc manner. Few appear to put a clear-cut whole farm scenario forward for consideration (Mahapatra and Behera 2004, and Behera *et al*., 2008). In the context of present challenges to make small farms profitable not only in India, but also in most of the Asian and other developing countries, it is necessary to place an overall scenario for farm income and employment generation and other associated benefits before the small and marginal farmers to motivate them towards farming.

(ii) An institutional commitment to demand-led research that is multidisciplinary and farming system oriented is required.

(iii) Research programme must acknowledge current concerns on poverty elimination, food security, environment, equity gender and sustainability. Research and developmental efforts should adhere to holistic “Developmental model” for improvement of rural livelihoods and poverty alleviation.

Past research efforts in India and other countries in Asia have tended to target specific commodities such as crop, variety, milk, machines, and disciplines such as agronomy, plant physiology, animal nutrition etc. In these efforts, there has been an overwhelming emphasis on research to achieve food security.

CONCLUSION

The integrated rice-based farming system is extremely important for the efficient management of available resources at the farm level to generate adequate income and employment for the rural poor, and improvement of their livelihoods in a sustainable manner. The synergistic interactions of the components of farming systems need to be exploited to enhance resource use efficiency and recycling of farm by-products. Rice-based farming offers tremendous potential for food security and poverty alleviation in rural areas. It is an efficient way of using the same land resource to produce both carbohydrate and animal protein concurrently or serially as well as meeting the vitamins and mineral requirement through cultivation of vegetables and fruits in dykes and bunds, thus providing balanced diet to farm family, reducing hunger and malnutrition. Integrating aquaculture with rice farming results in an efficient nutrient use through byproduct recycling, eradicating weeds, some insect pests; an important side effect is a cleaner and healthier rural environment. Processing and marketing of fish and fish products and value addition of other farm produces generate additional employment. However, that the adoption rate of rice-fish farming is very low. To popularize rice-fish culture, the concept should become part of the agricultural system rather than the fisheries system.

The farming system approach to agricultural research and development efforts will accelerate agricultural growth and thereby provide leverage for transforming poverty-prone rural India into a prosperous India.

REFERENCES

Ahmed, M. and Lorica, M.H. 1999. Improving developing country food security through aquaculture development: socio-economic and policy issues. Paper presented at *World Aquaculture* 1999, the Annual International Conference and Exposition of the World Aquaculture Society, 26 April - 2 May. Sydney, Australia.

Ahmed, M., Bimbao, M.A.P. and Sevilleja, R.C. 1992. The economics of rice-fish in Asian mixed farming system - a case study of the Philippines. (In:) *ICLARM Conference Proceedings 24 on rice-fish research and development in Asia*. dela Cruz, C.R., Lightfoot, C. Costa-Pierce, B.A. Carangal, V.R. and Bimbao, M.P. (Eds.).

Ashby, J.A. 1986. Methodology for participation of small farmers in the design of on-farm trials. *Agricultural Administration* **22**: 1–9.

Ayyappan, S., Sarangi, N, Sinhababu, D.P., Das, P.C. and Jena, J.K. 2004. Rice-Fish Farming: An economic enterprise for low land rice farmers. (In:) Proceedings The National Symposium on *Recent Advances in Rice-based Farming Systems*, Panda, D., Sasmal, S., Nayak, S.K., Singh, D.P. and Saha, S. (Eds.).17-19 November 2004, pp. 190–201. Central Rice Research Institute, Cuttack, Orissa.

Balusamy, M. 1996. Studies on Nitrogen management in low land rice - fish - azolla integrated farming system. Ph.D. Thesis, TNAU, Coimbatore.

Behera, U.K. 2007. Development of eco-friendly technology through farming system research. (In:) *Proceedings The National Symposium on Sustainable Pest Management for safer environment*. Society for Plant Protection and environment. Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, 06-7 December, 2007, pp. 92–102.

Behera, U.K, Jha, K.P. and Mahapatra, I.C. 2004. Integrated management of available resources of the small and marginal farmers for generation of income and employment in eastern India. *Crop Research* **27**(1): 83–89

Behera, U.K. and Mahapatra, I.C. 1998. Income and employment generation for small and marginal farmers through integrated farming systems. *Indian Farming* **48**(3): 16–28.

Behera, U.K. and Mahapatra, I.C. 1999. Income and employment generation of small and marginal farmers through integrated farming systems. *Indian Journal of Agronomy* **44**(3): 431–439.

Behera, U.K., Sharma, A.R. and Mahapatra, I.C. 2007. Crop diversification for efficient resource management in India: Problems, Prospects and Policy. Journal of Sustainable Agriculture **30:**(3), 97–217.

Behera , U.K., Yates, C.M., Kebreab, E. and France, J. 2008. Farming systems methodology for efficient resource management at the farm level: an Indian perspective. *Journal of Agricultural Sciences, Cambridge* **146**: 493–505.

Bhatia, P.C. and Venugopal, K. 1991. Farming systems researches in Indian context with special reference to humid Tropics. (In:) *Proceedings of Symposium on Farming systems for Sustained Productivity in Humid tropics,* Gangwar, B. and Rao, G.C. (Eds.) pp. 14–21.

Biggs and Stephen, D. 1995. Farming system Research and Rural Poverty: Relationship between context and content. *Agricultural Systems* **47:** 161–174.

Black, A.W. 2000. Extension theory and Practice: a review. *Australian Journal of Experimental Agriculture* **40**: 493–502.

Byerlee, D., Harrington, L. and Winkelman, D.L. 1982. Farming system research: issues in research strategy and technology design. *American Journal of Agricultural Economics* **64**(5): 897–904.

Cagauan, A.G. 1995. Overview of the potential roles of pisciculture on pest and disease control and nutrient management in rice fields. (In:) *Proceedings* An International Seminar on The Management of Integrated Freshwater Agro-Pisciculture Ecosystems in Tropical Areas, 16-19 May 1994, Brussels, Belgium, *Symoens*, J.J. and Micha, J.C. (Eds.) pp. 203–244. Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, Holland and the Belgian Royal Academy of Overseas Sciences (ARSOM), Brussels, Belgium.

Cai, R.K., Ni, D.S. and Wang, J.G. 1995. Rice-fish culture in China: the past, the present and the future. (In:) *Rice-Fish Culture in China*, MacKay, K.T. (Ed.). IDRC, Ottawa, Canada pp. 3–14.

Carr, A. 1997. Innovation and diffusion: Landcare and information exchange. (In:) *Critical Land care*, Lockie, S. and Vanclay, F. (Eds.). Centre for Rural Social Research, Charles Sturt University, Wagga Wagga pp. 201–215.

Chambers, R. and Ghildyal, B.P. 1985. Agricultural research for resource-poor farmers: the farmer-first and last model. *Agricultural Administration* **20**: 1–30.

Chand, Ramesh, 2003. 'Government intervention in foodgrain markets in the New Context'. Policy paper 19. National Center for Agricultural Economics and Policy Research, New Delhi pp.

Chand, Ramesh. 2002. *Trade liberalization, WTO and Indian Agriculture: Experience and Prospects*. Mittal Publications, New Delhi pp.

Chopra, K. 1993. Sustainability of agriculture. *Indian Journal of Agricultural Economics* **48**(3): 527–535.

Collinson, M.P. 1987. Farming system Research: Procedures for technology development *Experimental Agriculture* **23**: 356–386.

Cornwall, A, Guijt, I and Wellbourn, A. 1993. 'Acknowledging process: challenges for agricultural research and extension methodology. Institution of Development Studies', Discussion paper 333, Brighton, U.K.

CRRI .1994. *Rice-fish in rainfed lowland.* Central Rice Research Institute, Cuttack, India pp.

Dehadrai, P.V. 1992. Fisheries for food, nutrition and employment in the north-east regions. *Indian Farming* **42**(8): 3–4.

dela Cruz, C., 1994. Role of Fish in Enhancing Ricefield Ecology and in Integrated Pest Management. In: *ICLARM Conference Proceedings 42*. ICLARM, Manila, Philippines.

dela Cruz, C.R., Lightfoot, C., Costa-Pierce, B.A., Carangal, V.R. and Bimbao, M.P., 1992. Rice-Fish Research and Development in Asia. (In:) *ICLARM Conference Proceedings 24*. ICLARM, Minila, Philippines pp.

Dent, J.B. 1990. *Systems Theory Applied to Agriculture and the Food Chain.* Elsevier, Amsterdam pp.

Devendra, C. 1997. Crop residues for feeding animals in Asia: technology assessment and adoption in crop/livestock systems. In: *Crop Residues in Sustainable Mixed Crop/Livestock Farming Systems,* Renard, C. (Ed.). CAB International, Walling ford, U.K pp. 241–267.

Devendra, C. 2002. Crop-animal systems in Asia: Implications for research. *Agricultural Systems* **71**: 169–177.

Devendra, C. and Thomas, D. 2002. Crop-animal interactions in mixed farming systems in Asia. *Agricultural Systems* **71**: 27–40.

Devendra, C. Thomas, D., Jabbbar, M.A. and Zerbini, E. 2000. *Improvement of livestock production in crop-animal system in crop-animal systems in agro-ecological zones of South Asia*. ILRI, Nairobi, Kenya.

Dey, M.M. and Prein, M. 2001. Participatory research at landscape level: floodprone ecosystems in Bangladesh and Vietnam. (In:) Proceedings The NRM Scientists' Meeting, 1-3 September 1999. Ashby, J. and Braun, A. (Eds.). NRI, Chatham, United Kingdom.

Edward, P. 2000. Aquaculture, Poverty Impacts and Livelihoods. ODI Natural Resource Perspectives 56. ODI, London, United Kingdom

Esther Shekinah, E., Jayanthi, C. and Sankaran, N. 2005. Physical indicators of sustainability - a farming systems approach for the small farmer in the rain-fed vertisols of western zone of Tamil Nadu. *Journal of Sustainable Agriculture* **25**(3): 43–65.

FAO. 1995. The Farming Systems Approach to Development and Appropriate Technology Generation. Rome, Italy: Food and Agriculture Organisation of the United Nations.

FAO. 1989. *Farming Systems Development: Concepts, Methods, Applications*. Agricultural service Division, FAO, Rome, Italy.

FAO. 2001. Farming systems and poverty: Improving farmers' livelihoods in a changing world. FAO and World Bank, Rome and Washington DC.

FAO. 2001b. Integrated agriculture-aquaculture. FAO Fisheries Technical Paper 407. Rome.

FAO. 2002. Report of the International Rice Commission, Twentieth Session. Bangkok, Thailand,23-26 July 2002.FAO, Rome

Farrelt, D.J. 1997. Integrated wet land rice and duck production systems in humid tropics of Asia: Current and Future Trends. In: XIth *European Symposium Waterfowl,* 8-10 September 1997, pp. 483–489. Nantes, France.

Farrington, J. 1988. Farmer participatory Research. *Experimental Agriculture* **24**: 269–279.

Fresco, L.D. 1984. Issues in farming systems research. *Netherlands Journal of Agricultural Science* **32**: 253–261.

Gangwar, B. 1993. Farming systems research for accelerating agricultural development in less developed countries – a review. *Agricultural Reviews* **14**(3): 149–159.

Gartner, J.A. 1990. Extension Education: Top(s) Down, Bottom(s) UP and other things. (In:) *Systems Theory Applied to agriculture and the Food Chain*, Jones, J.G.W. and Street, P.R. (Eds.). Elesevier Applied Science, London pp. 325-348.

Ghosh, A. 1992. Rice – fish farming development in India: past, present and future. (In:) *ICLARM Conference Proceedings on Rice-fish Research and Development in Asia*, dela Cruz, C.R., Lightfoot, C. Costa-Pierce, B.A., Carangal, V.R. and Bimbao, M.P. (Eds.) pp. 27–43.

Gill, M.S., Samra, J.S. and Singh, G. 2005. Integrated farming system for realizing high productivity under shallow water table conditions. *Research Bulletin, Punjab Agriculture University, Ludhiana*.

Guan, R.J. and Chen, Y.D. 1989. Reform and Development of China's Fisheries. *FAO Fisheries Circular 822*, AO, Rome, Italy.

Gupta, M.V., Sollows, J.D., Mazid, M.A., Rahman, A., Hussain, M.G. and Dey, M.M. 1998. Integrating Aquaculture with Rice Farming in Bangladesh:Feasibility and Economic Viability, Its Adoption and Impact. *ICLARM Technical Report 55*. ICLARM, Penang, Malaysia.

Guttman, H.1999. Rice field fisheries – a resource for Cambodia. Naga. *The ICLARM Quarterly* **22**(2): 11–15.

Halwart, M., 1994. Fish as Biocontrol Agents in Rice: The Potential of Common Carp, *Cyprinus carpio* (L.), and Nile Tilapia, *Oreochromis niloticul* (L.), Tropical Agro-ecology No. 8, Margraf Verlag, Weikersheim, Germany.

Halwart, M. 2003. Rice field fisheries and rice-based aquaculture underestimated and under valued resources. In: *FAO Inland Water Resources and Aquaculture Service*. FAO Fisheries Circular. 942(1). Rome.

Halwart, M.1998. Trends in rice-fish farming. *FAO Aquaculture Newslettr* **18:** 3–11.

Horstkotte-Wesseler, G., 1999. Socioeconomics of Rice-Aquaculture and IPM in the Philippines: Synergies, Potentials and Problems. *ICLARM Technical Report 57*. ICLARM, Manila, Philippines. ICLARM, 2000. Food for the rural poor through integrated aquaculture-agriculture. *ICLARM Focus for Research* **3**(1): 1–6.

IIRR, ICLARM, 1992. Farmer-Proven Integrated Agriculture-Aquaculture: *A Technology Information Kit*. ICLARM, Manila, Philippines and IIRR, Silang, Cavite, Philippines.

Jha, D. 2003. An overview of farming systems research in India. *Annals of Agricultural Research* **24**(4): 695–706.

Johnson, S.H. and Claar, J.B. 1986. FSRE: Shifting the intersection between research and extension. *Agricultural Administration* **21**: 81–93.

Kang min, Li.1996. A review of rice –fish culture in China. http:fao.org/docrep/field/003/ac221e/ ac221e00.htm [Accessed on 12.07.2008].

Keating, B.A. and McCown. 2001. Advances in farming systems analysis and intervention. *Agricultural Systems* **70**: 555-579.

Langhu, Wu 1995. Methods of rice-fish culture and their ecological efficiency. (In:) *Rice –fish culture in China*. Mackay, K.T. (Ed.). pp. 240.

Lawrence, P.R. and Pearson, R.A. 2002. Use of draught animal power on smalled mixed farms in Asia. *Agricultural systems* **71**: 99–110.

Lightfoot, C. 1998. Integration of aquaculture and agriculture: a route to sustainable farming systems. Naga, *The ICLARM Quarterly* **13**(1): 9–12.

Lightfoot, C., Bimbao, M.P., Dalsgaard, J.P.T. and Pullin, R.S.V. 1993. Aquaculture and sustainability through integrated resources management. *Outlook on Agriculture* **22**(3), 143–150.

Lipton, A.P. 1983. Prospects of paddy-cum-fish culture in the north-eastern regions of India. *Seafood Expert Journal.* **15**(9): 25–30.

Loucks, D. P., Stedinger, J. R., and Haith, D. A., 1981. *Water Resources Systems Planning and Analysis*, Prentice-Hall, Englewood Cliffs, New Jersey.

Mahapatra, I.C. 1992. Farming systems research challenges and opportunities. *Eastern Indian Farming System Research and Extension Newsletter* **6**(4): 3–10.

Mahapatra, I.C. 1994. Farming system research – A key to sustainable agriculture. *Fertilizer News* **39**(11): 13–25.

Mahapatra, I.C. and Behera, U.K. 2004. Methodologies of farming systems research. (In:) *National Symposium on Recent Advances in Rice-based Farming Systems,* 17-19 November 2004, Panda, D., Sasmal, S., Nayak, S.K., Singh, D.P. and Saha, S. (Eds.). Central Rice Research Institute, Cuttack, Orissa pp. 79–113.

Mahapatra, I.C., Roy, J.K., Sinhababu, D.P. and Behera, U.K. 2007. Rice-based farming system for livelihood improvement of Indian farming. (In:) *Extended Summaries of National Symposium on Research Priorities and Strategies in Rice Production System for Second Green Revolution*, 20-22 November 2007, Association of Rice Research Workers, CRRI, Cuttack, India pp. 16–18.

Mandal, B., Das, C.S. and Bhaduri, B. 1990. Sustainable rice-based farming systems in rainfed low lands of coastal West Bengal. *Indian Farming* **40**(9): 21–23.

Marsh, S. P. 1998. What can research do to encourage the adoption of sustainable farming systems?

Paper presented at the CLIMA/ASSI (WA Branch) Forum on Sustainability of Farming Systems with a Focus on Future Management of Water and Nutrients, CSIRO, Perth, Western Australia, August 13–14.

Medulla, S and Mujumdar, P.P. 2005. *Water Resources Systems, Modelling Techniques and Analysis*, Tata Mcgraw-Hill Publishing Company Limited, New Delhi.

Mitchell, E.L. and Gauthier, J. 1981. *Advanced Continuous Simulation Language*. User Guide/Reference Manual, 3rd Edition, Mitchell and Gauthier, Associates, Concord, MA.

Mukhopadhyay, B. 1992. On-farm research in deep water rice-fish culture on West Bengal, India. (In:) *ICLARM Conference Proceedings 24 on rice-fish research and development in Asia,* dela Cruz, C.R., Lightfoot, C. Costa-Pierce, B.A.

Carangal, V.R. and Bimbao, M.P. (Eds.) pp. 255–272.

Murgan, G. and Kathiresan, R.M. 2005. Integrated rice farming systems. *Indian Farming* **55**(5): 4–6.

Norman, D. and Collinson, M. 1985. Farming system Research in Theory and practice. In: *Proceedings (Proceedings No. 11, 89 p) of an international workshop on Agricultural systems research for developing countries*, Remenyi, J.V. (Ed.). Hawkesbury Agricultural College, Richmand, N.S.W., Australia, ACIAR pp. 16–30.

Norman, D. and Modia Kgotla, E, 1990. Ensuring farmer input into research process within an institutional setting. *The case of semi-arid Botswana. Odi Network Paper* **16**: p. 29.

Norman, D.W. 1978. Farming system research to improve to livelihood of small farmers. *American Journal of Agricultural Economics* **60**(5): 813–818.

Panda, B.K. 2004. Rice-duck farming system- A profitable enterprise. In: *Recent Advances in Rice-based Farming Systems*, 17-19 November 2004, Panda, D., Sasmal, S., Nayak, S.K., Singh, D.P. and Saha, S. (Eds.). Central Rice Research Institute, Cuttack, Orissa pp. 202–208.

Pant, J., Demaine, H. and Edwards, P. 2005. Bio-resource flow in integrated agriculture-aquaculture systems in a tropical monsoonal climate: a case study in northwest Thialand. *Agricultural Systems* **83**: 203–219.

Patanaik, N. 2007. Farmers' indigenous traditional knowledge for pest management. Proceedings National Symposium on Sustainable Pest Management for safer environment. 06-7 December, 2007, Society for Plant Protection and environment. Department of Entomology, College of Agriculture, OUAT, Bhubaneswar pp. 72–74.

Prein, M. 2002. Integration of aquaculture into crop-animal systems in Asia. *Agricultural Systems* **71**(1-2): 127–146.

Prein, M. and Dey, M.M., 2001. Rice and fish culture in seasonally flooded ecosystems. (In:) *Resource Book on Small Scale Aquaculture Technologies in Asia*. IIRR, IDRC, ICLARM, FAO and AIT (Eds.). International Institute of Rural Reconstruction, Silang, Cavite, Philippines.

Prein, M., Lightfoot, C. and Pullin, R.S.V. 1995. ICLARM's approach to the integration of aquaculture into sustainable farming systems. In: *Global Agenda for Livestock Research,* Devendra, C. and Gardiner, P. (Eds.). ILRI, Nairobi, Kenya.

Prein, M. and Ahmed, M. 2000. Integration of aquaculture into smallholder farming systems for improved food security and household nutrition. *Food and Nutrition Bulletin* **21**(4): 466–471.

Pretty, J.N. and Chambers, R.1993. Towards a learning paradigm: new professionalism and institutions for agriculture. Institute of Development Studies, Discussion Paper 334, Brighton, United Kingdom.

Pullin, R.S.V. 1998. Aquaculture, integrated resources management and the environment. (In:) Proceedings The workshop on Integrated Fish Farming, 11-15 October 1994, Wuxi, Jiangsu Province, China, Mathias, J.A., Charles, A.T. and Baotong, H. (Eds.). CRC Press, Boca Raton, Florida, USA pp.19–43.

Raju, K. S.1995. 'Studies on Multicriterion Decision Making Techniques and Management of Irrigation Systems'. *Ph.D. Thesis*, Indian Institute of Technology, Kharagpur.

Rangaswamy, A, Venkataswamy, R., Premsekhar, M. and Palaniappan, S.P., 1992. Sustainable agriculture for rice (*Oryza sativa*) based ecosystem, *Indian Journal of Agronomy* **37**(2): 215– 219.

Rangaswamy, A. Venkitaswamy R. Purushothaman and Palaniappan, Spp.1996. Rice-Poultry – Fish – Mushroom integrated farming systems for lowlands of Tamil Nadu. *Indian Journal of Agronomy* **41**(3): 344–348.

Rath, S. and Bhanja, P.K. 2007. Crop protection through ITK for sustainable agriculture and food security. Proceedings The National Symposium on Sustainable Pest Management for safer environment. 06-7 December, 2007. Society for Plant Protection and environment. Department of Entomology, College of Agriculture, OUAT, Bhubaneswar pp. 58–71.

Rautaray, S.K., Das, P.C. and Sinhababu, D.P. 2005. Increasing farm income through rice-fish based integrated farming system in rainfed lowlands of Assam. *Indian Journal of Agricultural Sciences* **75**(2): 79–82

Ravisankar, N., Pramanik, S.C., Rai, R.B., Nawaz, S., Biswas, T.K. and Bibi, N. 2007. Study on integrated farming system in hilly upland areas of Bay Islands. *Indian Journal of Agronomy* **52**(1): 7–10.

Rhoades, R.E. and Booth, R.H. 1982. Farmer-back to back farmers: a model for generating acceptable agricultural technology. *Agricultural Administration* **11:** 127–137.

Ridley, A.M. 2005. The role of farming system group approaches in achieving sustainability in Australian Agriculture. *Australian Journal of Experimental Agriculture* **45**: 603–615.

Rothuis, A., 1998. 'Rice-fish ulture in the Mekong Delta, Vietnam: Constrant analysis and adaptive research'. *Ph.D. thesis*. Katholieke Uniersiteit, Leuven, Belgium.

Ruddle, K. and Prein, M. 1998. Assessing the potential nutritional and household economic benefits of developing integrated farming systems. (In:) *Proceedings of a Workshop on Integrated Fish Farming*, 11-15 October 1994, Wuxi, Jiangsu Province, China, Mathias, J.A., Charles, A.T., Baotong, H. (Eds.). CRC Press, Boca Raton, Florida, USA pp. 111–121.

Samra, J.S., Sahoo, N. Chowdhury, Roy, Mohanty, S., Rajeeb K., Jena, S.K. and Verma, H.N. 2003. Sustainable Integrated Farming System for Waterlogged Areas of Eastern India. *Research Bulletin No. 14.* Water Technology Centre for eastern Region (ICAR) Chandrasekharpur, Bhubaneswar, Orissa, 751023, India.

Sands, M.D. 1986. Farming systems research: clarification of terms and concepts. *Experimental Agriculture* **22**:84–104.

Schueller, J.K. 1997. In: *Precision Agriculture,* Stafford, J.V. (Ed.). Bloss Scientific Publisher Ltd. pp. 33–44.

Shaner, W.W., Philipp, P.F. and Schmehl, W.R. 1982. *Farming Systems Research and Development: Guide for Developing Countries*. West View Press, Colorado, USA.

Sharma, A.R. and Behera, U.K. 2004. Fertiliser use and option for diversification in rice-wheat cropping systems in India. *Fertilizer News* **49**(12): 115–131.

Singh, K, Bohra, J.S., Singh, Y. and Singh, J.P. 2006. Development of farming system models for the north-eastern plain zone of Uttar Pradesh. *Indian Farming* **56**(2): 5–11.

Singh, P.K. 1979. Nitrogen and Rice. International Rice Research Institute, Los Banos, Philippines: pp. 407–418.

Singh, P.K., Singh, D.P., Manna, A.B., Singh, R.P. and Bisoyi, R.N. 1991. (In:) *Biological Nigrogen Fixation Association with Rice Production*, Datta, S.K. and Sloger, C. (Eds.). Oxford and IBH Publishers, New Delhi pp. 95–108.

Sinhababu, D.P., Das, P.C., Rautray, S.K. and Singh, B.N. 2003.

Possibility of rice-fish-horti-duck farming system in rainfed low land. (In:) Proceedings The workshop on Integration of fish bio-diversity conservation and Development of Fisheries in North Eastern Region through community participation, Mohanta, P.C. and Tyagi, L.K. (Eds.). Lucknow, India pp. 140–145.

Sinhababu, D.P., Jha, K.P., Mathur, K.C. and Ayyappan, S. 1998. Integrated farming system: rice-fish for low land ecologies. (In:) Proceedings The International Symposium on Rainfed Rice for Sustainable Food Security, 23-25 September, 1996. Central Rice Research Institute, Cuttack, Orissa, India pp. 203–222.

Sinhababu, D.P. and Venkateswarlu, B. 1998. Modern Frontiers of rice-fish systems. (In:) *Advances in fisheries and fish production*, Ahmed, S.H. (Ed). Hindustan Publishing Corporation, New Delhi. pp. 206–228 and p. 309.

Sinhababu, D.P. and Venkateswarlu 1995. Rice – Fish in rainfed lowlands. *CRRI Bulletin,* Central Rice Research Institute, Cuttack, India p. 14.

Sultana, P. 2000. Household fish consumption and socio-economic impacts in Kapasia. Paper presented at the Workshop on Aquaculture Extension: Impacts and Sustainability, 11 May 2000, Dhaka, Bangladesh. ICLARM, Penang, Malaysia and the Department of Fisheries, Dhaka, Bangladesh, p. 7.

Taha, H.A. 2005. *Operations Research: An Introduction*. Prentice-Hall of India Private Limited, New Delhi.

Thilsted, S.H. and Roos, N. 1999. Policy issues on fisheries in relation to food and nutrition security. (In:) *Proceedings 60 Conference on Fisheries Policy Research in Developing Countries: Issues, Priorities and Needs,* Ahmed, M., Delgado, C., Sverdrup-Jensen, S. and Santos, R.A.V. (Eds.). ICLARM, Penang, Malaysia pp. 61–69.

Thompson, P., Sultana, P., Nuruzzaman, M. and Fiooz Khan, A.K.M. 1999. An analysis of production facators in carp farming in Andhra Pradesh, India. *Aquaculture Research* **30**(11/12): 805–814.

Yadav, R.L.,Prasad, Kamata, Gangwar, K.S. and Dwivedi, B.S. 1998. Cropping system and resource use efficiency. *Indian Journal of Agricultural Sciences* **68**: 548–558.

Yap, F., 2001. *Culture of Fish in Rice fields*. FAO Role, Italy and ICLARM, Penang, Malaysia.