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AICRP on Integrated Farming Systems : Salient Achievements and Future Directions

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Abstract

Simple Fertilizer Trials (SFTs) were initiated on cultivators' fields in the year 1952-53. These underwent changes over the time as per need and contributed significantly in ushering the country into the Green Revolution by way of developing and demonstrating the usefulness of fertilizers to the farmers through experiments on their fields, famously termed as the Experiments on Cultivators Field (ECF). This made the Government of India develop suitable fertilizer policy for improving the productivity of major production systems, such as rice-wheat, rice-rice and maize-wheat, which meet around 72% of the Indian calories requirement. The scheme developed the component production technologies for the emerging cropping systems in the form of All India Coordinated Agronomic Experiments Scheme during 1968-69 which resulted in percolation of agronomic management packages developed both at the states and national level. Further, the cropping systems research carried out from 1989 to 2010 significantly contributed in increasing the cropping intensity of the country by 25% (current cropping intensity of India is 142%) since independence. Long-term nutrient management strategies identified for cereal-cereal cropping systems have helped in sustaining the productivity of rice-wheat and rice-rice systems. Besides, other production practices developed such as tillage and planting methods, site-specific nutrient management (SSNM), sustainable production model etc. have also contributed in improving the productivity of crops and cropping systems besides enhancing the input use efficiency. Documentation of nutrient response of crops and cropping systems in 96 districts of the country helped in estimating the production potential based on balanced nutrient application. Currently the scheme is operating as All India Coordinated Research Project (AICRP) on Integrated Farming Systems (IFS) through which 45 science-based IFS models have been developed; these give scope for doubling the farmers' income by March 2022 besides meeting the household level nutrition requirement of human, livestock and soil. The 63-farmer participatory refinement of farming systems and also documentation of 81 success stories of farmers have resulted in effective dissemination of component technologies of cropping and farming systems through various sources. The IFS models have been found to be emission- negative or low GHG emitters, paving the way for promotion of climate-friendly farming in India. The future direction for research includes vertical farming, climate-smart precision farming systems, and improving the quality and sustainability of the farming systems especially of the under-privileged farm households.

Key words: AICRP on Integrated Farming Systems, salient achievements, future directions

Introduction

Although 84% of farm households in India have crop and dairy together, their recycling is very low (< 25%) and depend for markets for their farm inputs including meeting the family's food and nutritional requirements. Declining partial factor productivity, deteriorating soil health, increase in cost of production due to higher input cost, reduced rate of recycling within the farm and failure of crops due to frequent aberrant weather conditions are the major problems which affect agriculture in general and the farmers' income in particular. Around 38 types of farming systems exist in India having number of components ranging from 2 to 7; their income and livelihood do not commensurate with inflation mainly due to the poor linkage among different components in the farming system. The existing farming systems are not able to meet the household demand of food, feed, fodder, fertilizer and fuel. Hence, the existing farming systems need to be scientifically studied and validated for better output. Generating sustainable and regular income (round the year) from farm is a major challenge for the farmers in the present day context. *Union Government has declared to double the farm income by 2022 which is possible by adopting scientifically designed diversified Integrated Farming Systems (IFS). National level coordinated research on IFS is essential and a must for framing policy guidelines and central sector schemes for doubling the income of farmers.* The experiences in context of

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small and marginal farmers from across the states and regions have clearly evinced the fact that income from crop production or livestock alone is hardly sufficient to sustain the household needs. Therefore, farmers' income and food requirements would have to be augmented and supplemented by adoption of efficient and optimized secondary/ tertiary enterprises like animal husbandry, horticulture (vegetables/ fruits/ flowers/ agro-forestry/ medicinal and aromatic plants), apiary, mushroom cultivation, fisheries, farm-waste recycling, on-farm processing/ value addition and non-conventional agriculture methods *etc* by scientifically integrating them with main stream agriculture. With the growing challenges of attaining livelihood security for the country's millions of the farmers (around 14 crore farm holdings), especially small and marginal ones, who constitute more than 86% of farm households, it has become almost essential (certain) to shift to the approach of integrated farming system (IFS) for their livelihood. The IFS approach of farming, especially by small and marginal farmers, will give answer to many of the vital questions being raised today in agriculture, *viz.*, vulnerability of small farmers and agriculture-dependent rural masses to food and nutritional insecurity, employability, their livelihood security, natural resources sustainability and their use efficiencies, slow rate of component technology transfer and global issues of climate change etc.

Genesis of the Scheme

Based on a report submitted to the Government of India by Dr A.B. Stewart of Macaulay Institute of Soil Research, Aberdeen (U.K.), during 1947 a scheme called "Simple Fertilizer Trials on Cultivators' Fields" was started during 1952-53. It led to the popularization of fertilizer use and substantial increase in crop productivity during those days. Subsequently in 1956, the 'Model Agronomic Experiments' were added to the project and the scheme started as "All India Coordinated Agronomic Experiments Scheme" as an ICAR Project. In 1968-69, the scheme was reshaped as "All India Coordinated Agronomic Research Project (AICARP)" with two components viz.; 'Model Agronomic Experiments' and 'Simple Fertilizer Trials'. The objectives of Model Agronomic Experiments were broadened to encompass studies on the response of high yielding varieties of cereals to intensive use of different factors such as fertilizer, irrigation, weed control, liming etc.; production potential of crops for different agro-climatic conditions of the country; and appropriate cropping patterns and fertilizer responses under rainfed conditions. The AICARP contributed for development of package of agronomic management practices for the newly introduced high yielding varieties and played a critical role in bringing about Green Revolution in India.

Although, the system-based research was initiated during early seventies, but it was only during the VII Five Year Plan that to strengthen all the aspects of research in cropping systems, the AICARP was upgraded into the "Project Directorate for Cropping Systems Research (PDCSR)" with "All India Coordinated Research Project on Cropping Systems (AICRP-CS)" as one of the Plan schemes. The PDCSR was established at Modipuram (Meerut) in April 1989. The Directorate was mandated to undertake and coordinate country-wide system-based basic and applied research in cropping systems perspective by adopting approach of 'On-Station (basic and applied) Research' at its headquarters as well as at main and sub-centres of AICRP-CS, and 'On-Farm (farmers' participatory) Research' at on-farm research centres of AICRP-CS. During XI Five-Year Plan the mandate of PDCSR was further expanded to cover the whole gamut of farming systems. Accordingly, the PDCSR and AICRP-CS scheme were renamed as "Project Directorate for Farming Systems Research" and "AICRP on Integrated Farming Systems", respectively (Anonymous, 2017). In the XII Five Year Plan, the Directorate was renamed as ICAR-Indian Institute of Farming Systems Research. Milestones of changes that happened over time are presented in **Table 1**.

Operation of the AICRP on Integrated Farming Systems

All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS), a plan scheme initiated from 2010-11 operates currently with 75 centres (25 on-station main, 12 on-station sub, 32 on-farm and 6 ICAR Institute-based voluntary centres) covering all the 15 agro-climatic regions (ACR). The scheme is in operation at 34 State Agricultural Universities (SAU's), 2 General Universities and 6 ICAR Institutes and also covers 23 States and 2 Union Territories. During the year under report, four experiments namely, i) development of region specific IFS models (32 locations), ii) identification of need-based cropping systems for different agro-ecosystems (37 locations), iii) permanent plot experiment on long-term nutrient management in cereal-based cropping systems (13 locations), and iv) development of

Table 1. Progression of the scheme

Name of the Project	Starting year	Completion year
Simple Fertilizer Trials on Cultivators' Fields	1952-53	1954-55
All India Coordinated Agronomic Experiments Scheme	1955-56	1966-67
All India Coordinated Agronomic Research Project (AICARP)	1968-69	31 March 1989
All India Coordinated Research Project on Cropping Systems	1 April 1989*	22 February 2010
AICRP on Integrated Farming Systems	23 February 2010	Continuing

* Shifted to Modipuram from Bengaluru

organic farming package for system-based high value crops (8 locations) were undertaken at on-station and voluntary centres while 3 experiments namely i) on-farm crop response to plant nutrients in predominant cropping systems (768 farm households in 192 villages in 64 blocks of 32 districts in 21 states), ii) diversification of existing farming systems under marginal household conditions (768 farm households in 192 villages in 64 blocks of 32 districts in 21 states) and iii) on-farm evaluation of farming system modules for improving profitability and livelihood of small and marginal farmers (384 farm households in 192 villages in 64 blocks of 32 districts in 21 states) and FLDs on farming systems involving oilseeds (125 no's) were undertaken through on-farm research centres. Spatial distribution of centres is depicted in **Figure 1 (A&B)**.

Components of the Scheme

The scheme is operating with two major components of research such as on-station research addressing the basic and technological development and on-farm research focusing mainly on farmer participatory refinement of technologies. The current objectives of the scheme are given below:

On-Station Research

1. To undertake applied and adaptive research on IFS, especially on production technologies for improving system productivity and resource use efficiencies.
2. To develop efficient, economically viable and environmentally sustainable IFS models for different zones, with special reference to small

Figure 1 (A&B). A - Locations of on-station centres of AICRP on IFS (2018). B-Locations of on-farm centres of AICRP on IFS (2012-2017)

and marginal farmers.

3. To undertake capacity building and human resource development in IFS.

On-Farm Research

1. To characterize the existing farming systems for identification of production constraints and problem prioritization.
2. To undertake on-farm testing and refinement of system-based farm production technologies.
3. To optimize on-farm integration of enterprises for enhanced farm incomes, resource/ input use efficiencies, and employment opportunities, with special reference to small and marginal farmers.

Salient Achievements

The major research themes on which the scheme has been carried out research are IFS, cropping systems, nutrient management and other production-related constraints being faced by cultivators which are of national importance. Accordingly, the salient achievements of the scheme are presented thematically.

1. Integrated Farming Systems (IFS)

Farming System Characterization

Analysis of farming systems in marginal households indicates the presence of 38 types of enterprise mixing and marginal households having up to 5 components [crop + dairy + goat + poultry + fish in West Bengal]. In the country, 59% of marginal households are having 2 or less components (**Figure 2**) integration whose annual net income is only Rs 0.57 lakh yr^{-1} from 0.82 ha area while the remaining 41% households are having more than 3 components integration whose income was found to be Rs 1.61 lakh yr^{-1} from 0.84 ha area. This clearly implies that greater opportunity exists for intensification and diversification of farming systems in 59% of the marginal households. Even if a bare minimum of 3 persons per household is considered, 1095 man/ woman days (8 hrs in a day) work is available per household which is sufficient to take up the farming in the tiny holdings. Hence, marginal farms offer a greater scope for agricultural diversification.

Establishment and Study of Region-specific IFS Modules and Models

IFS approach can be described as "a judicious mix of two or more components using cardinal principles of minimum competition and maximum

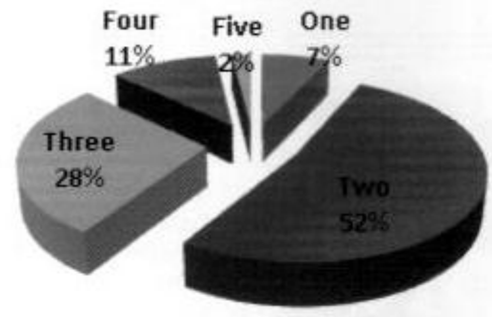
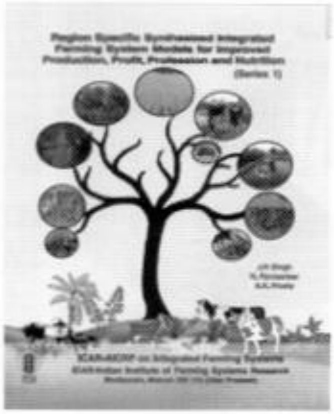


Figure 2. Number of farming system enterprises practiced by marginal households (Benchmark data of OFR experiment 2 under AICRP on IFS)

complementarity with advanced agronomic management tools aiming for sustainable and environment-friendly improvement of farm income, family nutrition and ecosystem services". Preservation of bio-diversity, diversification of cropping/farming system(s) and maximum recycling is the base for success of the farming systems approach (Singh and Ravisankar, 2015). Forty-five on-station IFS models (38 under AICRP on IFS and 7 Integrated Organic Farming Systems under All India NPOF) in 15 agro-climatic regions (ACR) for research, extension, education and business (bankable projects) were established. Similarly, sixty-three existing IFS through on-farm farmer participatory research in 14 agro-climatic regions (ACR) were refined. The details are given in **Table 2**.

Table 2. Agro-climatic region wise establishment and refinement of integrated farming system models through on-station and on-farm research programmes

Agro-climatic region	Number of integrated farming systems (IFS)	
	On-station (IFS)	On-farm farmer participatory refined (IFS)
Western Himalaya	4	3
Eastern Himalaya	3	6
Lower Gangetic Plains	1	9
Middle Gangetic Plains	5	3
Upper Gangetic Plains	2	4
Trans Gangetic Plains	2	1
Eastern Plateau and Hills	2	7
Central Plateau and Hills	1	5
Western Plateau and Hills	3	4
Southern Plateau and Hills	5	6
East Coast Plains and Hills	2	4
West Coast Plains and Hills	9	4
Western dry	2	-
Gujarat Plains and Hills	2	6
Islands	2	1
Total	**45**	**63**



The major components of the IFS models include location-specific cropping systems + livestock components (cow/buffalo/poultry/duck/goat/pig) + fisheries + horticulture (fruit orchard intercropped with vegetables) + complementary/supplementary enterprises such as apiary, mushroom, bio-gas + compulsory integration of kitchen garden, boundary plantations and vermicompost. These models provide 1.5 to 2.7 times higher income than the existing farming systems besides meeting the household demand of food, fodder, fuel completely with fibre and fertilizer to the extent of 65-80% (Panwar et al., 2018; Ravisankar et al., 2014; Ravisankar and Panwar, 2018; Singh et al., 2016).

Family Farming Model for Nutrition and Round the Year Income (Bihar) : A one hectare area with 5 member family farming model comprising of diversified cropping systems (0.78 ha) + horticulture (0.14 ha)+ dairy (2 cows) + goat (11 no's) + fish (0.1 ha) + ducks (25 no's) + boundary plantation (*subabul*, 225 plants and moringa, 50 plants) developed for the South Bihar Alluvial Plain zone (BI-3) in Middle Gangetic Plains region provides round the year income which ranges between Rs 13,160 (September) to 51,950 (April) ha^{-1} $month^{-1}$ (**Figure 3**). The diversified cropping systems [rice - wheat – green gram (grain + residue incorporation), rice - maize + potato - cowpea (fodder), rice - mustard - maize (grain) + cowpea (fodder), sorghum + rice bean – berseem / oat- maize + cowpea (fodder) and seasonal vegetables (brinjal, tomato, cauliflower, cabbage, vegetable pea, *okra*, lettuce) grown in 0.78 ha area could meet the full family requirement of 1100, 95, 125, 185 and 640 kg of cereals, pulses, oilseeds, fruits (guava and papaya) and vegetables and livestock requirement of 29.5 and 6.6 t of green and dry fodder per annum. The model also meets the milk, egg and fish requirement of 550 litres (L), 900 no's and 120 kg, respectively. Besides meeting the family and livestock requirement, the model produced marketable surplus of 4810, 986 and 35 kg of cereals, vegetables and fruits with surplus of milk, egg and fish of 4243 L, 950 numbers and 124 kg, respectively which resulted in generation of round the year income. The model also ensured fuel wood availability of 4 t yr^{-1} for the family and could add 4 t of enriched vermicompost and 2.3 t of manure to improve the soil health. The value of recycled products and by-products model works out Rs. 1.29 lakh which reduces the total cost (Rs. 3.1 lakh) of the model by 42%. The family labour (730 man days) contributed to save 37% of the cost. Hence, only 21% (Rs 0.68 lakh) of total cost is involved in the form of inputs purchased from the market. A total net return of Rs. 3.14 lakh is 3.2 times higher than the existing pre-dominant crop + dairy system of the zone. Benefit: cost (market inputs only) ratio of the model stands at 4.6 Rs. Re^{-1} (Gangwar and Ravisankar, 2014).

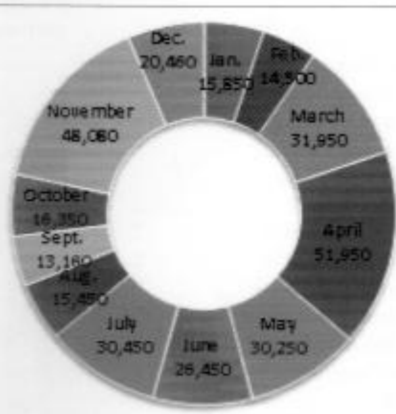


Figure 3. Round the year net income farming system model at Sabour (Bihar)

Resource Recycling in Crop + Horticulture + Dairy + Poultry + Fish Model: IFS model of 1 hectare developed for Vindhyan zone (UP-8) in Eastern Himalayan region comprises the components of diversified cropping systems (0.81 ha) + horticulture (0.06 ha) + dairy (6 cows) + poultry (200 numbers in 6 batches) + fishery (0.10 ha). The diversified cropping systems (rice – wheat – green gram, rice – barley – green gram, rice – mustard –black gram, bottle gourd – cabbage - sponge gourd, Sudanchari - berseem+mustard - Sudanchari, pigeon pea+pearl millet - sudanchari) was planned in such a way that better recycling of products happens besides meeting the 100% requirement of food and fodder. The model also had the boundary plantation (*karonda*, 200 numbers and banana, 50 plants), mushroom (only button during winter) and vermicompost production as income supplementing activities. Recycling of products and by-products studied for the system indicated that Rs. 1.92 lakh value of products are recycled into the system which reduce the cost of the model by 39%. The value of marketable surplus after meeting the household need of 7 member family stands at Rs

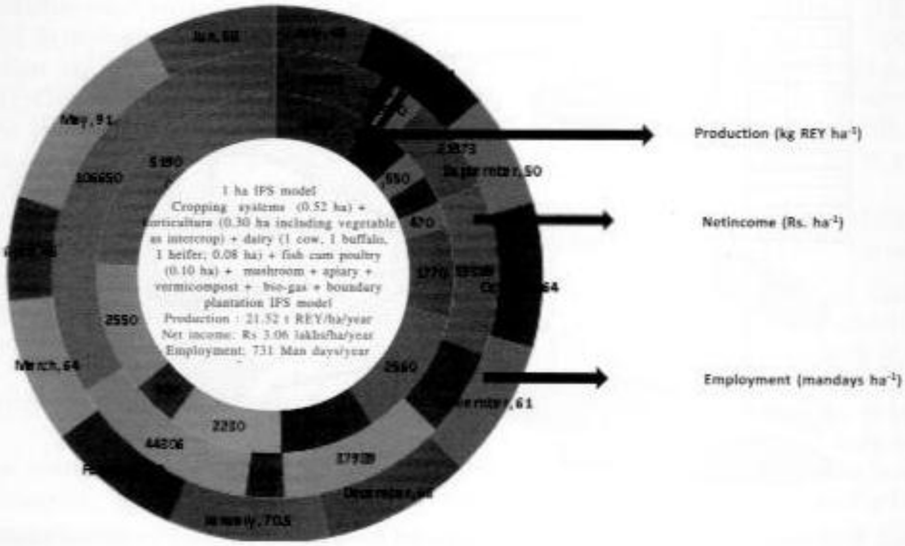


Figure 4. IFS model for round the year production (kg REY ha^{-1}), profit (Rs ha^{-1}) and employment (mandays ha^{-1}) of the farm family at Jammu (Jammu and Kashmir)

1.97 lakhs per annum. A net return of Rs. 2.59 lakh ha^{-1} yr^{-1} can be obtained from the model by recycling the wastes as input into the components. The model recorded 3.2 times higher net income than the prevailing farming system (crop + dairy) of the region.

Integrated Farming System Model for Round the Year Production, Profit and Profession:

One hectare (IFS) model comprising of cropping systems (rice – wheat – green gram, rice –potato – black gram, rice – mustard – green gram and berseem+oat - maize+sorghum with hybrid napier on bund) in 0.52 ha + horticulture (guava as main crop, lemon and mango (Amarpali) as boundry crop and broccoli, knol khol, cabbage, cauliflower, radish, okra as intercrops) in 0.32 ha + dairy (1 cow, 1 buffalo, 1 heifer) including bio-gas and vermicompost unit in 0.08 ha + fish-cum-poultry in 0.1 ha) + mushroom (*dhingri* and button) developed for the mid to high altitude plain zone (JK-1) in Western Himalayas provides ***round the year*** production (21.52 t REY yr^{-1}), profit (Rs. 3.06 lakh yr^{-1}) and employment (731 mandays yr^{-1}). The maximum production and profit was realized in June (**Figure 4**) while employment was in May month signifying the work even during lean period. The model also meets around 85% of inputs required for different enterprises within the farm, besides providing all the commodities (cereals, pulses, oilseeds, vegetables, fruits, mushroom, milk, egg, and fish) required for the farm family (**Figure 5**).

Green House Gas (GHG) Emission in IFS: **A** user-friendly IIFSR-AICRP-IFS-IFS-GHG estimator in excel platform following the emission coefficient of IPCC (2007) was developed. This tool is used for estimation of GHG from different farming system components and also from individual farm households/farms. This is simple and user-friendly tool for any Indian farming situation to identify climate-resilient farming system components to mitigate the ill-effects of climate change impacts on agriculture. Based on one-year assessment the IFS model is evaluated in respect of carbon dioxide equivalent (CO_2-e) in which the livestock component was found to be more emitter of GHGs whereas the agroforestry and recycling of plant nutrient component was found to be an effective tool for the sink of GHG emissions from the IFS model. Out of 45 IFS models developed scientifically, most of the models are found to be emission-negative indicating the climate-friendly nature of the farming systems.

Farmers' Participatory Improved Integrated Farming Systems

Location-specific household-centric farmers' participatory improved IFS were designed and implemented on 192 small (1.00-1.52 ha)/ marginal (0.31-0.92 ha) farm households, spread over 12 states namely, Himachal Pradesh (Kangra district), West

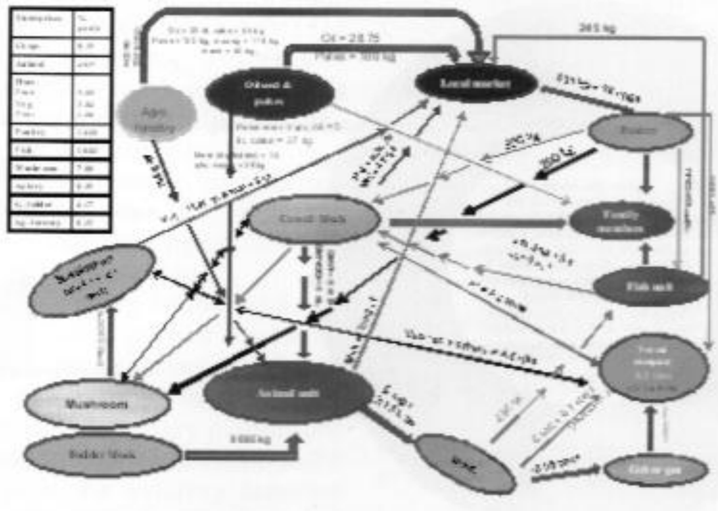


Figure 5. Recycling of inputs and output in the IFS model developed at Jammu (Jammu and Kashmir)

Bengal (South 24 Paragnas district), Rajasthan (Chittorgarh district), Chhattisgarh (Kabirdham district), with crop+dairy as pre-dominant farming systems. Technological interventions in existing farming system components (crops/ animals) along with resource-based introduction of optional components such as primary processing/ value addition of farm produce, scientific grain storage, nutritional kitchen garden, composite fish culture, backyard poultry with improved breeds, mushroom production and vermi-compost led to 6.8 times increase in net returns over variable cost. The total mean cost of interventions in all the modules was found to be Rs. 7774 for 0.92 ha area of the household. The total cost of interventions in all the modules ranged from Rs. 616 to 8220 per household at various locations and the total net returns over variable cost of intervention were found to vary from Rs. 8235 to as high as Rs 38,860 (**Figure 6**). The increase in value of household consumption (produced within the farm) and per day profit was found to be 51.4 and 69.2%, respectively. Additional employment of 53.6 mandays yr^{-1} was also created.

On-Farm Evaluation of Farming System Modules for Improving Profitability and Livelihood of Small and Marginal Farmers: On-farm interventions made in farming systems perspective at various locations of the country (Varghese et al., 2018, Gangwar et al., 2016) through on-farm centres of AICRP-IFS indicated that the profitability can be enhanced to as high as 2-3 times with low cost interventions. The total cost of interventions in all the modules

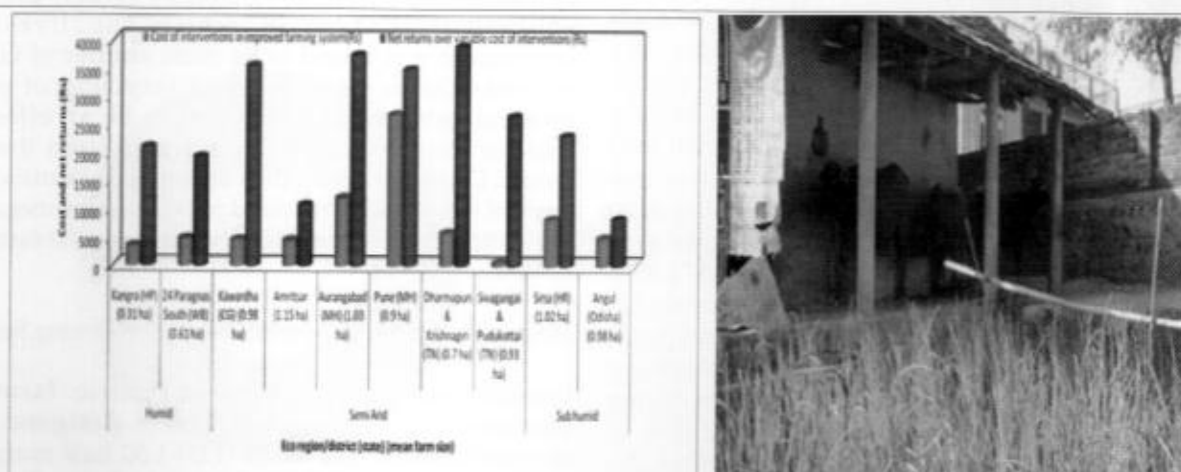


Figure 6. Cost of interventions and net returns over variable cost of improved farming systems in different ecoregions and buffalo component and onion in kitchen garden at Kangra (Himachal Pradesh)

was found to be Rs. 7774 for 0.92 ha area. Increase in the net returns over variable cost of interventions in improved farming systems was found to be 6.8 times. Value of the household consumption increased 51.4% due to improvement in the farming system. The per day profit of marginal and small households can be increased by 69.2% through low cost interventions in the farming systems perspective. An additional employment of 53.6 mandays yr^{-1} can be generated through interventions in various modules such as crop, livestock, processing and optional in the farming system mode.

Documentation of Farming Systems Success Stories

Eighty-one number of geo-referenced farming system success stories were studied and documented from on-farm farming systems research in 19 states. Some of the successful models practiced by farmers with slight improvement promise 4 to 6 times higher net income to farmers over the existing farming systems (Ravisankar et al., 2015).

Impact of Integrated Farming Systems Research

Many states such as Kerala, Jammu and Kashmir, Bihar, Tamil Nadu and Maharashtra have developed the state plan schemes for promotion of IFS. Besides, in certain states, the developed modules and models have been included in the state level production packages for upscaling.

Farmers' income can be doubled easily by addressing critical farm-oriented technology constraints in farming systems perspective. With low-cost interventions in farming systems perspective (Rs.10,000 per marginal farm household) the net financial gains up to 3 times can be achieved. The study deserves to be up-scaled at a large scale. One successful example on on-farm farming systems research is given below.

Improved Variety of Kharif *Maize for Higher Grain and Fodder Yield in Crop + Dairy Farming System*

In Panchmahal district of Gujarat, mixed farming is practiced by farmers which includes field crops (rice and maize) + livestock (cow, buffalo, poultry). Majority of the farmers adopt maize - maize and paddy - maize cropping system. Farmers' white seeded local varieties was replaced by Godhra Maize-6 (GM-6) composite under cropping system diversification module of the farming systems. GM-6 is extra early composite (75-80 days), drought escaping and white flint grained variety. It is also resistant to Maydiys leaf blight, brown stripe downy mildew and curvularia leaf spot. Adoption of improved composite variety of maize in place of local variety increased the average grain yield of maize to 2021 kg ha^{-1}. Fodder yield of maize also increased from 1982 to 2434 kg ha^{-1}. Additional grain and fodder yield of 995 and 456 kg ha^{-1}, respectively was obtained. The average net income of farmers also increased by Rs. 5006 ha^{-1} and it replaced the local *kharif* variety in almost 45% area within 2 years.

2. Cropping Systems

Cropping System Atlas of India

Atlas of cropping systems in India was developed. Maps of state-wise distribution of cropping systems for 17 states and maps of agro-climatic zone wise distribution of cropping systems for 14 zones have been developed. Pre-dominant (First) cropping systems of India are shown in **Figure 7**.

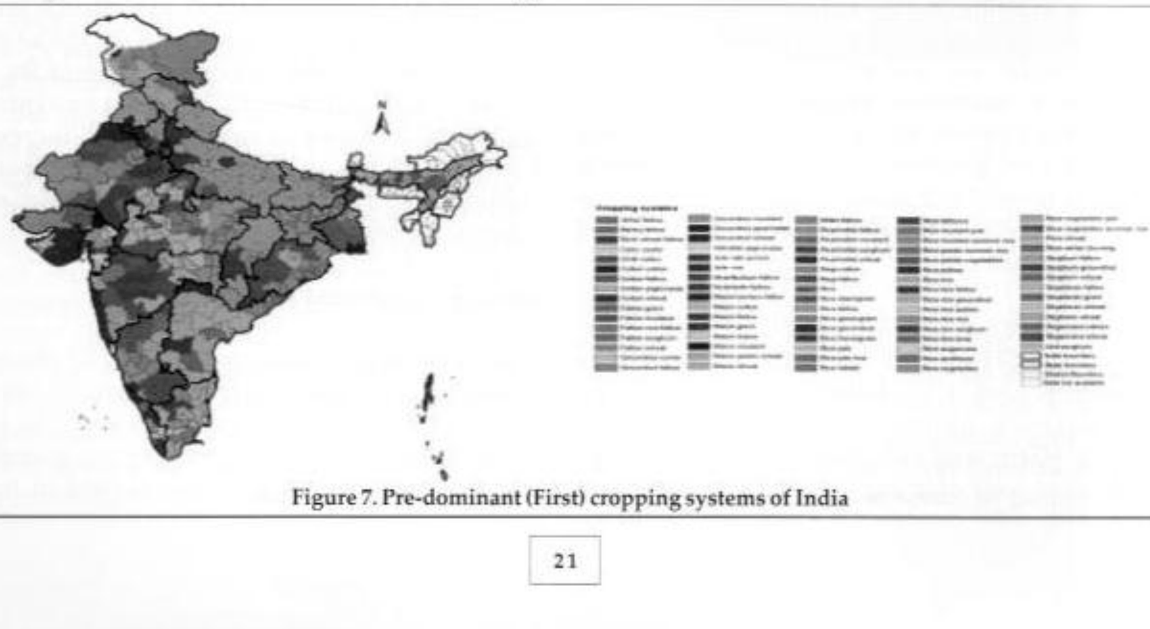


Figure 7. Pre-dominant (First) cropping systems of India

Table 3. Identified high productive systems for selected locations under irrigated condition

Locations	Prevailing system			High productive system		
	System	System yield (REY) (t ha^{-1})	Net returns (x10^3 Rs. ha^{-1})	System	System yield (REY) (t ha^{-1})	Net returns (x10^3 Rs. ha^{-1})
Jammu, J&K	Rice-wheat	11.3	68.6	Rice-marigold-French bean Rice-potato-onion	30.1 29.5	168.0 148.5
Ludhiana, Punjab	Rice-wheat	13.2	59.7	Maize-potato-onion Groundnut-potato-*bajra*(F)	27.9 23.3	125.0 111.8
Modipuram, Uttar Pradesh	Rice-wheat	12.9	32.2	Maize-potato-sunflower Rice-wheat-*moong*	24.2 15.9	68.2 40.3
Sabour, Bihar	Rice-wheat	11.0	43.0	Rice-potato-onion Rice-wheat-maize	29.0 15.7	83.7 54.1
Bhubaneswar, Odisha	Rice-rice	6.7	41.3	Rice-maize-cowpea Rice-maize-green gram	17.4 14.8	69.0 50.8
Coimbatore, Tamil Nadu	Cotton-sorghum-finger millet	4.1	48.2	Beet root-green gram-maize+cowpea Chillies+onion-Sunhemp-okra+coriander	7.1 6.6	93.1 85.2
Thanjavur, Tamil Nadu	Rice-rice-sesame	13.7	78.0	Rice-rice-brinjal DS rice-rice-maize+black gram	18.3 17.4	108.2 110.3
S.K. Nagar, Gujarat	Groundnut-wheat-fallow	4.1	65.4	Groundnut-wheat-sesame Groundnut-onion-green gram	7.0 5.0	125.1 81.4
Bangalore, Karnataka	Hybrid cotton-sunflower	7.0	12.8	Maize-groundnut Maize-sunhemp-sunflower	12.2 11.3	44.1 40.8
Hyderabad, Andhra Pradesh	Rice-rice	7.9	22.9	Maize-onion Maize-tomato	12.3 12.1	59.6 48.1
Mean	-	**9.2**	**47.2**	-	**16.9**	**85.8**

Identification of Alternative Efficient Cropping Systems: Based on multi-location studies at 37 on-station and 31 on-farm centres, efficient alternative cropping systems were identified, documented and recommended for different agro-climatic zones having potential productivity ranging from 16 to 35.2 t ha^{-1} yr^{-1} (Gangwar and Singh, 2011). As a result of adoption of the identified alternative systems, the cropping systems intensity of the country could be enhanced by 25% since independence. Identified alternative systems for selected are given in **Table 3**. Twenty-six alternatives to rice-wheat for 11 zones of 9 states, pearl millet-based for 4 zones of 4 states and maize-based systems for 5 zones of 5 states were identified for large scale adoption.

On-farm Evaluation of New Diversified Cropping Systems: The on-station evaluated alternate systems have been experimented in the farmers' fields for testing their efficiency under farmers' management conditions (Gangwar and Ravisankar, 2013). The yield increase over existing systems with alternate efficient cropping systems was found to be 40 to more than 300% in various agro-climatic zones. Rice – potato - onion was found to be better alternative for rice - wheat in Western Himalayas whereas adding *okra* in the sequence of maize - wheat in Central Plateau region was found to be more remunerative.Across the locations and systems, the diversified system registered net returns and total calories of Rs. 1,17,156 ha^{-1} and 29,158 x1000 kcal ha^{-1} compared to the existing system of Rs. 60,634 ha^{-1} and 24,498 x1000 kcal ha^{-1}). On an average, the net return and total calories could be increased by 93.2 and 19.0% through the diversification of existing cropping systems. Gains in yield and net returns are given in **Figure 8**.

Impact of Cropping Systems Research

A study on impact assessment of AICRP on cropping systems research indicated improvement in productivity of systems ranging from 2 to 154% in different agro-climatic regions of the country. The cropping systems research also helped in reducing

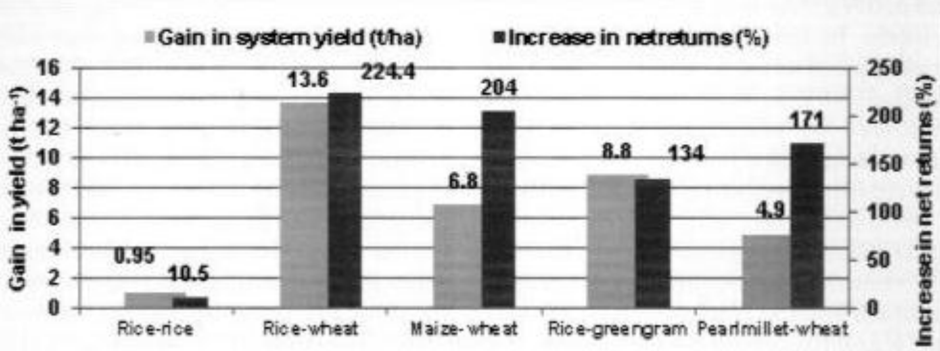


Figure 8. Gain in yield and net returns due to diversification of major systems

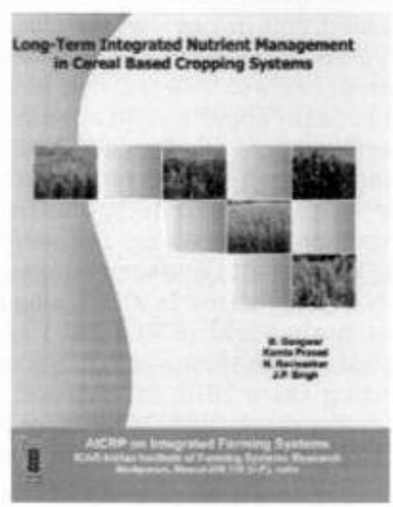
the cost of production of different crops. As a result of cropping systems research and development of component technologies, the cropping intensity could be increased by 2.5% at national level, besides an enhancement of farm income by 1.5 to 2 times over the years. The factor productivity of nutrients could be improved by 25%. The system's approach enhanced the resource recycling by 25-30% with an increase in rural employment by 25-30%. Alternative efficient cropping systems developed by the AICRP on IFS have given good impact in all the regions. One such example is given below.

Alternate Efficient Cropping System (Rice - Maize for Rice - Rice in Southern Telangana Zone of Andhra Pradesh): Rice occupies largest area of 3.95 Mha in Andhra Pradesh and is mostly grown in lowland irrigated puddled ecosystem to the extent of 2.58 Mha in *kharif* season and 1.37 Mha in *rabi* season. Water is increasingly become scarce, especially in the *rabi* season. Diversification option was explored under AICRP on IFS and accordingly rice - rice system was diversified with many systems including rice - maize. Although many other systems which were having vegetables are profitable, rice - maize was found to be most dependable (low risk and market price fluctuations) and sustainable cropping system having the maximum sustainability index of 0.82 with rice equivalent yield of 7.95 t ha^{-1}. Net returns were higher (30%) in rice - maize. Net return per rupee invested was found to be Rs. 1.11 in rice - maize against Rs. 0.76 in rice - rice. The production efficiency and water use efficiency were higher in rice - maize system (31.20 kg REY ha^{-1} day^{-1} & 43.59 kg REY ha^{-1} cm^{-1}, respectively) compared to rice-rice system (28.26 kg REY ha^{-1} day^{-1} & 32.73 kg REY ha^{-1} cm^{-1}, respectively). As a result of the technology developed and on-farm participatory research with constant extension mechanism, rice - maize system is being currently practiced in 4.5 lakh ha (0.45 Mha) in Andhra Pradesh.

3. Nutrient Management

Long-term Nutrient Management Strategies for Cereal-Cereal Cropping Systems

A long-term experiment on integrated nutrient management (INM) in cereal-based cropping systems was initiated in *kharif* 1985 to understand



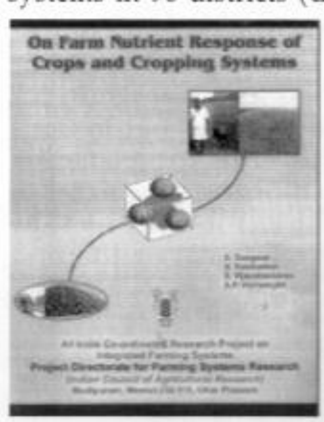
the dynamics of INM practices with substitution approach in six cereal-cereal systems namely, rice - wheat (12 locations), rice - rice (4 locations), rice - maize (1 location), pearl millet - wheat (4 locations), maize – wheat (1 location) and sorghum - wheat (3 locations). The experiment was continued for 22 to 28 years with reduced application of nutrients through chemical fertilizers up to 50% and substituting 50% with organic sources like FYM, paddy straw and green manuring during *kharif*. In *rabi* crops,no substitution was done with organic sources. Irrespective of the systems and locations, continuous use of FYM, crop residue and green manuring in partial substitution of chemical source significantly improved the soil properties, plant growth and yields. In initial period of 3 years (stabilizing period), yield of crops was higher under 100% recommended NPK to both the crops which was closely followed by substitution up to 25% through organic sources. However, after stabilizing period and in a long-term period (around 22 cycles), the system productivity was higher with substitution up to 50% with organic sources during *kharif* and 100% chemical fertilizers to *rabi* crops. Leguminous residues such as mung bean straw and green manures were found to be better among different organic sources. Maximum negative soil potassium balance was noticed under farmers' practice due to gap in crop demand and supply. Study revealed that substitution of 25-50% N with FYM or green manure in rice-wheat system increased the system's productivity by 4%. In rice - rice system, green manuring increased the yield by 3.6%. Application of organic manures (at least once in each crop cycle) is a must for realizing the sustainable yield in predominant cereal-cereal food systems like rice - rice, rice - wheat and rice - maize (Gangwar et al., 2015).

System-based Site-specific Nutrient Management (SSNM): Results showed that in rice - wheat more than 13 t ha^{-1} grain yields of rice + wheat are achievable. The contribution of rice was 58% and that of wheat 42%. The SSNM brought about a yield advantage of 39% over farmers' nutrient use practices and 31% over the state recommended dose of fertilizers (RDF). Among the secondary- and micro- nutrients, S and Zn had prominence over others and were followed by B, Mn, Fe and Cu in that sequence. Under precision N management in rice - wheat system, the highest grain yield (6.21 t ha^{-1}) of rice was recorded under green seeker-based N management practice during *kharif* 2010. In each soil and plant analysis development (SPAD) threshold value, N split at 30 kg ha^{-1} gave highest yield in comparison to other doses of N split. Nitrogen use efficiency (NUE), defined as kg grain kg^{-1} N, was highest (28.7%) under green seeker-based N application. The SSNM brought about a grain yield advantage of 2.4 t ha^{-1} over farmers' nutrient use and by 1.6 t ha^{-1} over state RDF. Use of 150 kg N, 60 kg P_2O_5, 100 kg K_2O and 40 kg S ha^{-1} under SSNM schedule gave yield gain of 3.32 t ha^{-1} for rice and 2.29 t ha^{-1} for maize over the farmer's practice. In groundnut – wheat system, application of 25 kg N, 60 kg P_2O_5, 120 kg K_2O, 30 kg S, 40 kg zinc sulphate, 20 kg copper sulphate and 40 kg iron sulphate had the highest productivity (1.9 t ha^{-1}and 6.2 t ha^{-1}) of groundnut and wheat. This treatment out-yielded the state recommendation by 36 and 18%, respectively. Per hectare use of 30 kg S, 40 kg zinc sulphate, 20 kg copper sulphate and 40 kg iron sulphate gave an additional yield gain of 327, 275, 386 and 309 kg, respectively for groundnut and 165, 414, 317 and 325 kg for wheat crop over the treatment kept devoid of it. In groundnut – potato – pearl millet, application of 25-50-60 kg NPK to groundnut, 250-150-200-45-40-40 kg N-P-K-S-Zn-Fe to potato and 100-50-60 kg N-P-K ha^{-1} to pearl millet recorded the highest pearl millet equivalent yield (20.27 t ha^{-1}) which was higher by 142% over without N (8.38 t ha^{-1}), 26% without P (16.12 t ha^{-1}), 23% without K (16.51 t ha^{-1}), 14% without Fe (17.84 t ha^{-1}), 13% without S (17.91 t ha^{-1}) and 11% without Zn (18.42 t ha^{-1}). On-farm evaluation of SSNM in rice-based cropping system revealed that rice grain yield varied from 6.76 to 8.92 t ha^{-1} under different crop establishment practices and nutrient management options. Residue recycling under transplanted rice crop had the highest yield gain as compared to the direct seeded or zero till rice crop. Response to K+S and Zn application was also modified in the presence of residue and the magnitude was 1.00, 0.90 and 0.53 t ha^{-1}, respectively for K+S and Zn under transplanted rice (TPR), direct seeded rice (DSR) and zero tillage rice (ZT) (Gangwar et al., 2012).

Integrated Nutrient Management under Organic Systems: High yields to the tune of 12-20 t ha^{-1} could be achieved in the organically managed maize - onion system at Rajendranagar, rice – onion system in Bihar, baby corn - Chinese *sarson* - onion system in Himachal Pradesh, rice – potato – lady's finger system at Bhubaneswar and Chiplima (Odisha), and maize – potato - onion system in Kanpur (Uttar Pradesh).

Documentation of the On-farm Nutrient Response of Crops and Cropping Systems

On-farm nutrient response of crops and cropping systems in 96 districts (Gangwar et al., 2014) was



documented. The average response to NPK application in different cropping systems was 8-12 kg rice equivalent yield kg^{-1} of any of the major plant nutrients like N, P or K with mean economic response of Rs. 7-10 Re^{-1} invested on N, Rs. 4 Re^{-1} invested on P and Rs. 6-8 Re^{-1} invested on K.

Among the zones, Eastern, Southern Plateau and Hills Regions and East Coast Plains and Hills region recorded higher yields. However, the partial factor productivity (PFP) and agronomic efficiency (AE) of N in these zones were lower compared to the Eastern Himalayas, Lower Gangetic plains and West Coast plains and Ghat regions indicating on the need to enhance the use efficiency of N in the eastern and southern regions. Wheat equivalent yield (WEY) of rice-wheat system in Trans-Gangetic plain was higher followed by Western Himalayas, Central Plateau and Hills regions and Middle Gangetic plains compared to other zones. Unlike rice-rice system, PFP and AE of N of rice - wheat system was higher in the same zones where the yield levels were higher. Lowest NUE was recorded in Western

On-Farm experiment at Paiyur (Tamil Nadu)

Plateau and Hills region. Maize equivalent yield (MEY) of maize - wheat system was higher in Eastern and Central plateau and Hills regions than Western Himalayas. Maize - wheat system in Western Himalayas, rice - groundnut and rice – green gram in Eastern Plateau and Hills region and rice - brinjal and okra - rice in Southern Plateau and Hills region recorded higher PFP and AE of N compared to other systems. The yield gap between farmers' package and recommended dose of fertilizer + micronutrient(s) in major cropping systems indicates existence of higher yield gap in major systems with farmers' package recording lower yields (**Figure 9**) (Gangwar et al., 2013; Singh et al., 2017; Ravisankar et al., 2014). Partial factor productivity (PFP) of N can be increased by 54.6, 33.9, 35.7 and 55.6% in rice - rice, rice - wheat, rice – green gram and maize - wheat systems, respectively by applying N with P and K compared to N alone. Similarly, PFP of P can be increased by 21.1, 10.9, 17.5 and 14.4% in the respective systems by applying it with NK rather than with N alone. The PFP of K increased by 23.8, 21.9, 13.6 and 34.4% in the respective systems when K was applied with N and P instead of with N alone. Agronomic efficiency (AE) of N could be enhanced by 239, 113, 168 and 141% in rice - rice, rice - wheat, rice – green gram and maize - wheat systems, respectively by application of NPK together instead of N alone. Phosphorus and K also recorded the similar trend. Agronomic efficiency (AE) of P was found to be higher in rice – green gram system (54.5 kg REY kg^{-1} of P) while AE of K was found to be higher in maize-wheat system (91.5 kg REY kg^{-1} of K) compared to other cereal-based systems. Marginal return of N was 426, 254, 339 and 476% for rice - rice, rice - wheat, rice – green gram and maize - wheat systems when N was applied with P and K. Application of N alone recorded lower marginal returns ranging from 180 to 325% only.

4. Addressing of the Other Production-related Constraints

System-based Resource Conservation Technologies and Crop Residue Management

Mechanized transplanting of rice by self-propelled

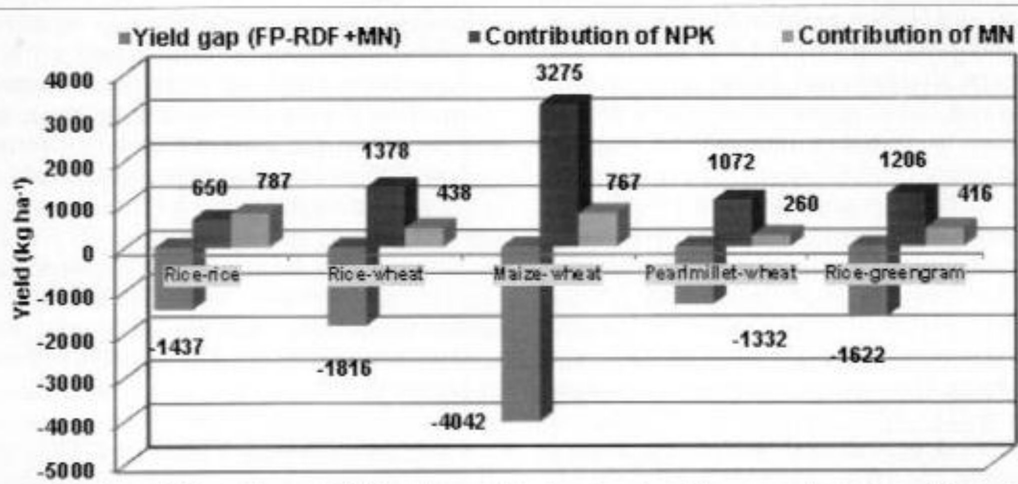


Figure 9. On-farm yield gap between RDF + micronutrient treatment and farmer package along with contribution of macro and micro nutrients to yield gap in the major cropping systems

transplanter was found to be more efficient (9.3%) compared to manual transplanting. Zero, strip and rotary till drills and bed planter saved 65 to 86% time, labour, diesel cost and energy; provided higher wheat yields (4-9%), net returns (9-13%), cost effectiveness (11-13%) and energy efficiency (20-24%); and reduced *Phalaris minor* (44-77%) and other weeds (61-73%), compared to conventional sowing. *In-situ* incorporation of wheat straw provided 6.22 t rice yield ha^{-1} which was 13 and 9% higher than the residue retrieval and burning. *In-situ* incorporation of rice straw provided 6.0 t wheat yield ha^{-1} which was 8 and 5% higher than the residue retrieval and burning. Also, the net returns and B: C ratios were 11 and 5% and 2 and -1% higher but energy output: input ratio was 5 and 8% lower. Studies conducted at the IFS centres revealed that mechanical transplanting provided the highest grain yield of rice (6.34 t ha^{-1}), rice equivalent yield (12.47 t ha^{-1}), net monetary return (Rs. 55,652 ha^{-1}) and benefit: cost ratio (1.57 Rs. Re^{-1}) in Bihar. Sprouted wet seeded rice sown by the 8 row drum seeder or establishment of rice by the paddy hand trasplanter gave better yield than the rice establishment through hand transplanting in Jammu region and Madhya Pradesh, bed planting of rice - rice system with yield gain of 28%, and saving of 27% irrigation time and 21% labour in Odisha while in West Bengal, SRI method recorded maximum yield gain (4.76 t ha^{-1}) during *boro* season.

On-farm Agronomic Management Practices for Sustaining the Production of Cropping Systems

Yield gap of 1.5 to 2.7 t ha^{-1} exists in rice between farmers and recommended practice in Eastern, Southern Plateau and Hills regions and West Coast plains and Ghat region while it ranges between 1 to 1.3 t ha^{-1} for maize in Western Himalayas and Eastern Plateau and Hills regions in *kharif* season. In *rabi* season, yield gap ranges from 1.1 to 1.3 t ha^{-1} for rice in Southern Plateau and Hills regions and Gujarat plains and Hills regions while yield gap of wheat is higher in Western Himalayan region. Higher yield increase of 64.4% over farmers' practice was observed in Eastern and Western plains and Hills regions with addressing of the constraints of improved variety, plant population and nutrient application. In Western Himalayas and Trans-Gangetic plains, nutrient application and weed management recorded yield increase of 48.5 and 32.3%, respectively. The yield increase in other zones ranged from 6.3 to 35% due to addressing of constraints related to cultural and management practices. Among the two constraints addressed, nutrient plus pest management recorded higher yield increase of 35.8% followed by nutrient and weed control practices (26.7%). Across the locations and crops, the yield increase due to adoption of recommended package was 47% over farmers' practice, thus giving scope to increase the yield and profitability of crops in all the locations simply by giving thrust to the transfer of technology and adoption of recommended scientific packages by farmers. The yield gap between recommended package and farmer's method was found to be 40.4, 36.6 and 39.3% in *kharif, rabi* and summer seasons, respectively in various existing pre-dominant cropping systems.

Other Significant Achievements

- Farmers' perception on climate change and integrated farming systems as adaptation measure towards changing climate by involving 1260 farm households was studied and documented. Results revealed that the adaptation index was higher for the field crops/ cropping systems and livestock than that for the horticulture crops (Shamim et al., 2015).
- Online data submission, analysis and report generation process for on-farm nutrient response experiments from farmer's field (http://expert.iasri.res.in/onfarm/) was developed. Database has the information on nutrient response of crops and cropping systems from 96 districts spread in 21 states.
- On an average, annually 170 front line demonstrations on 14-19 oilseed-based cropping systems and 47 front line demonstrations on 8 pulses-based cropping systems were conducted on farmers' fields through 32 on-farm research centres. In these FLDs, improved practice has an average 37% yield advantage amounting to 1 t mustard equivalent yield ha^{-1} over the farmers' practice in oilseed-based cropping systems. Improved practice in the pulses-based cropping systems has 42% yield advantage equivalent to 0.87 t gram equivalent yield ha^{-1}.
- *National level information on oilseed-based cropping systems:* Issues and technologies were documented which paved way for commercialization of innovative technologies to farmers.
- Component technologies for cropping systems management including site-specific nutrient management, sulphur balanced nutrition; farm

mechanization; precision farming; and tillage and crop establishment were developed.

- The AICRP on IFS also contributed in capacity building of farmers in cropping and farming systems. A total of around 700 training programmes at farmers' fields were organized during last 5 years, in which a total of around 17,500 farmers including farm women received the training. An assessment of impact of 3-days duration training on *kharif crop* production technologies revealed that there was about 30% gain in overall knowledge of the participant farmers. It was also realised that training should be targeted more on younger group of farmers because age is a negative factor.

Future Directions

Looking into the emerging issues of agriculture such as sustainability, climate-related risks, retaining youth, shrinking of holdings, reduced availability of man power and investment, diverse requirements of commodities due to change in economic conditions, and also market-led agriculture, the following dimensions of research need to be integrated into the scheme for achieving the goal.

***Information Technology-enabled Farming System Typology and FarmDesign Applications*:** Emphasis on development of system characterization software for existing situations with minimum datasets for its further application in devising suitable modules for integration into farming systems for sustainable productivity and profitability is essential by integrating the components of farming systems typology and FarmDesign.

***District/Village-specific Sustainable Integrated Farming System Models and Modules*:** Multiplicity of farming systems existing in the country gives scope for developing district- and village- specific farming systems. Geo-referenced location-specific IFS modules and models will hold key to make farming practice sustainable by small and marginal households in future scenario in combating the climate adversaries.

***Farming Systems Diversification/Intensification*:** Scope exists to intensify and diversify with various components of farming systems as 59% of the small holders have only two or less components. Short duration pulses, oilseeds and other high value crops will find their definite niche as sequential or intercrops, rather than replacing the major cereal crops having higher yield stability.

***Vertical Farming Systems*:** Land is constant so vertical farming shall help in meeting the food and other demands of the rapidly growing urban population. Building low-cost vertical soilless system (hydroponics) for production of small vegetable and fruit crops can be a viable option for small farmers in the pre-urban area. Vertical farming will facilitate organic farming with no use of pesticides and will have conservation of natural resources. Poultry + paddy + fish in the same piece of land in different layers is a good example for the low-cost vertical farming system.

***Specialized Farming Systems*:** Harnessing power of science in enhancing farming system's productivity, profitability, resource use efficiency, cost-effectiveness, value addition and improving quality of food through blending of scientific and traditional knowledge is essential. Specialized farming system components like protected agriculture, better management of dairy, poultry especially broiler in batches, high value vegetables in poly houses, floriculture in suitable areas, multi species multipurpose boundary plantations etc. need to be promoted in small holder farms for enhanced profitability and producing more from less resources.

***Cluster and Social Farming*:** Organizing the small holders' farm clusters for meeting the social, domestic and global goals will be critical. Some of the case studies are One Village One Product (OVOP) in Japan and Local Competitive Advantage (LOCA) in Sri Lanka. Farmer's clusters comprise of contiguous group of minimum 10 or more villages where in multi-disciplinary interventions can be made to make all the farms and clusters self-sustainable.

***Climate Smart Farms and Systems*:** Resilience starts with reducing vulnerabilities and farming system by nature having integration of components has this feature. However, building further resilience by way of incorporating the appropriate components is essential. The concepts of 4Rs (reduce, recycle, reuse and recovery) applied in farming systems are in favour of creation of better resilience to climatic adversities. Reduction in greenhouse gas emissions and the agricultural carbon footprint is essential, which calls for changes of practices, including more resource efficiency, use of clean energy and carbon sequestration.

***Precision Farming for Higher Input Use Efficiency*:**

Management of field by considering spatial and temporal variations by using Information Technology (IT) tools like Global Positioning System (GPS), Geographical Information System (GIS) and Simulation Modelling for Decision Support Systems (DSS). We can't use whole technology as such in the Indian conditions but can definitely use some low cost tools.

***Integrative Simulation Modelling*:** Integrative (bio-physical or socio-economical) simulation modelling including artificial neural network (ANN) is a promising tool in farming systems research, which will help in unravelling the complex and dynamic interactions and feedbacks among bio-physical, socio-economic and institutional components across scales and levels and is a useful tool for taking decisions to foster sustainable farming systems.

***Empowerment of Women through IFS*:** Women play a very important role in household management including agricultural operations. This is especially true for hilly and tribal areas. There is a vast scope to improve the household profitability by judiciously utilizing their time using innovative practices and ensuring multiple uses of various household resources. This is possible through women's empowerment through location-specific trainings. Development of need-based women-centric farming system models will be a real challenge as men are migrating to the rural non-farm sectors.

Conclusions

Looking into the achievements, contributions and achievements of the scheme for technology development in the field of Agronomy are highly significant. The technologies have resulted in a regional-level improvement in productivity of many crops and cropping systems and also sharing technologies and products among co-operators such as State Governments, State Agricultural Universities and also other schemes. The IFS models developed at various locations are going to define the path of climate-friendly agriculture in the country. Further strengthening of research in the areas of climate- smart farming systems and vertical farming are essential to achieve the desired goals.

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