Indian Journal of Agronomy (Special Issue) **57** : 171—181 (2012)

Agronomic research on cropping systems in India

B. GANGWAR[1], N. RAVISANKAR[2] AND KAMTA PRASAD[3]

Project Directorate for Farming Systems Research, Modipuram, Meerut, Uttar Pradesh -250 110

ABSTRACT

Cropping systems with differential requirement and contribution in modifying the rhizosphere by different crops provide newer challenge as well as opportunity for management to achieve higher input productivity for water and nutrients. Although, more than 250 double cropping systems are adopted in the country, the major contribution to food basket remains with the few cereal based systems such as rice-wheat, rice-rice, rice-gram, rice-sorghum, maize-wheat, maize-gram, soybean-wheat and sugarcane-wheat due to their extent of cultivation. Agronomic research conducted at on and off farm with these systems brought out a significant change in terms of productivity and profitability besides enhanced input use efficiency. Alternate efficient cropping systems for the existing predominant cropping systems involving replacement and substitution principles developed for 15 agriculturally important agro-climatic regions at both on-station and on-farm have contributed for significant improvement of the regions. Cropping systems, which are ably planned and executed show promise for better efficiency of water, nutrient and weed control. Besides, careful selection of crops in the system, management practices such as tillage, residue management, nutrient, water and weed plays critical role in deciding the overall make up and output of the system. In order to achieve the targeted food production of 450 to 500 mt in 2050, cropping systems research has to play a vital role of enhancing the land use efficiency as per capita availability of agriculture land is decreasing at a fast rate (0.48 ha in 1951 to 0.14 ha in 2001). Cropping systems will continue to form as a major module in farming systems management which are pursued to provide sustainable livelihood for about 90 % of land holdings consisting of small, marginal and semi-medium categories of farm house holds.

Key words : Cropping system, Farming system, On farm research, Resource management

Concept of cropping system is as old as agriculture in India. Multiplicity of cropping systems has been one of the main features of Indian agriculture and it is mainly attributed to prevailing socio-economic situations of farming community. The term cropping system essentially represents a philosophy of maximum crop production per unit area of land within a calendar year or relevant time unit with minimum natural resource degradation. Cropping systems remain dynamic in time and space, making it difficult to precisely determine their spread using conventional methods, over a large territory. However, it has been estimated that more than 250 double cropping systems are followed throughout the country. Based on rationale of spread of crops in each district in the country, 30 important cropping systems have been identified for irrigated conditions. These are; rice-wheat, rice-rice, rice-gram, rice-mustard, rice-groundnut, rice-sorghum, pearlmillet-gram, pearlmillet-mustard, pearlmillet-sorghum, cotton-wheat, cotton-gram, cotton-sorghum, cotton-safflower, cotton-groundnut, maize-wheat, maize-gram, sugarcane-wheat, soybean-wheat, sorghum-sorghum, groundnut-wheat, sorghum-groundnut, groundnut-rice, sorghum-wheat, sorghum-gram, pigeonpea-sorghum, groundnut-groundnut, sorghum-rice, groundnut-sorghum and soybean-gram. (Das, 2010). However, the systems those are considered to be themajor contributors to national food basket are: rice *(Oryzasativa* L.)-wheat *(Triticum aestivunl* L. emend. Fiori & Paol.) (10.5 million ha), rice-rice (5.9 million ha) and coarse grainbasedsystems (10.8 million ha). Out of all these systems, share of 'rice-rice' and 'rice-wheat' together is the highest, contributing about 65% to the foodgrain production (Singh *et al.*, 2004), while rice-wheat system contributes 40% (Shukla *et al.*, 2004). Cropping systems of a region are decided by and large, soils and climatic parameters which determine overall agro-ecological setting for nourishment and appropriateness of a crop or set of crops for cultivation. Nevertheless, at farmers' level, potential productivity and monetary benefits act as guiding principles while opting for a particular cropping system. These decisions with respect to choice of crops and cropping systems are further narrowed down under influence of several other forces related to infrastructure facilities, socio-economic factors and technological developments, all operating interactively at micro-level.

[1]Project Director (directorpdfsr@yahoo.com)
[2]Principal Scientist (agrosankar2002@yahoo.co.in)
[2]Principal Scientist (kamta_pdcsr@rediffmail.com)

Resources for cropping systems

Estimates indicate that more than 56 per cent of total food grain comes from irrigated ecosystem while progress has been considerably sluggish in rainfed agriculture which still accounts for 92.8 million hectare or 65 per cent of net area sown and contributes only 44 per cent to national food grain production. If past trends are any indication, it may be visualized that in future also the major gain in production, at least 80 per cent of the incremental food needs required by 2025, has to come from irrigated ecosystem where new climate resilient crops/ cropping systems with improved genotypes and intensive nutrient use will continue to play dominant role in enhancing crop productivity. The principal crops having sizeable percentage of area under irrigation in the country are; sugarcane (87.9%), wheat (84.3%), barley (60.8%), rapeseed and mustard (57.5%), rice (46.8%), tobacco (41.2%), cotton (33.2%), chickpea (21.9%), maize (21.8%) and groundnut (19.2%). Among the states, Punjab ranks first with 94.6 per cent cropped area under irrigation followed by Haryana (76.4%) and Uttar Pradesh (62.3%). A large diversity of cropping systems exists under rainfed and dryland areas with an overriding practice of intercropping, due to greater risks involved in cultivating larger area under a particular crop. Due to prevailing socio-economic situations (such as; dependency of large population on agriculture, small and-holding size, very high population pressure on land resource etc.), improving household food security has been an issue of supreme importance to millions of farmers of India, who constitute 56.15 million marginal (<1.0 hectare), 17.92 million small (1.0-2.0 hectare) and 13.25 million semi-medium (2.0-4.0 hectare) farm holdings, making together 90 per cent of 97.15 million operational holdings. An important consequence of this has been that crop production in India has remained, by and large, a subsistence rather than commercial activity. One of the typical characteristics of subsistence farming is that most of the farmers resort to grow a number of crops on their farm holdings, primarily to fulfil their household needs and follow the practice of rotating a particular crop combination over a period of 3-4 years interchangeably on different farm fields.

Cropping systems research in India

All India Co-ordinated Agronomic Research Project (AICARP) established in 1968-69 pioneered the efforts of cropping system research in India by encompassing studies on appropriate cropping patterns and crop production potential for different agro-climatic zones of the country among its objectives. System based research was initiated during early seventies as a part of this programme but it was only during seventh five year plan that the AICARP was upgraded into full-fledged Project Directorate for Cropping System Research (PDCSR) to strengthen all aspects of research in cropping systems at the country level. Till 2009, the directorate took up research through country-wide cropping system network, which included 37 on-station centres (25 main centres and 12 sub-centres) and 32 on-farm centres working directly in the farmer's field with the participation of farmers in system/technology selection. Main centres were necessarily located at agricultural universities whereas sub-centres were located at various agricultural colleges as well as general universities so as to represent different National Agricultural Research Project (NARP) zones of the states. The on-farm research centres remained in operations for 3 to 4 years in different districts representing the NARP zones. As a result, more than 50 % districts and 110 NARP zones could be covered. The research programmes included development of economically viable and resources efficient cropping systems for varying agro-ecological conditions, development of agro-technologies for major cropping system, problem diagnosis and prioritization of researchable issues under various farming situations. Two long term experiments, one on integrated nutrient management and another on long range effect of chemical fertilizers, were continuing since 1983-84 and 1977-78, respectively, with rice-wheat, rice-rice, sorghum-wheat, pearlmillat-wheat, maize-wheat and rice-maize crop sequences on main as well as sub-centres of the network. In addition, several other commodity/resource based coordinated projects have started system based research in recent past.Voluminous data have been generated through agronomic research in cropping systems by AICRP on cropping systems and other relevant partners, suggesting alternative cropping system for diversified eco-edaphic conditions and resource base. Various milestones of cropping systems research are given below.

1947: Dr A.B.Stewart recommended Simple Fertilizer Trials

1953: Initiation of Simple Fertilizer Trials on Cultivator's fields + Model Agronomic Experiments

1956: Establishment of All India Coordinated Agronomic Experiments Scheme (AICAES)

1968:AICAES renamed as All India Coordinated Agronomic Research Project (AICARP)

1989:AICARP upgraded as Project Directorate for Cropping Systems Research, Modipuram and AICRP on Cropping systems also continued

2010:PDCSR renamed as Project Directorate for Farming Systems Research, Modipuram with AICRP on Integrated Farming Systems

Since 2010, the cropping systems research is being transformed in farming system research where in the cropping systems research will serve as a component of farming systems with major focus on small and marginal farmers.

Identification of efficient cropping systems

Widespread occurrence of second-generation problems, such as over-mining of soil nutrients, decline in factor productivity, reduction in profitability, lowering of groundwater tables and build up of pests including weeds, diseases andinsects has been reported during post-green revolution era in most of the intensively cultivated, high-productivity, cereal based production systems, which are threatening their sustainability (Gangwar and Kamta Prasad, 2005). Studies carried out under ACIRP on Cropping System have resulted in identification of appropriate duration of varieties for some popular crop sequences for different regions of the country.Considering the specific needs of different regions, concerted efforts have been made to design new alternative cropping system. These multiple cropping system included sequential as well as intercropping systems, including several variants such as mixed cropping, relay cropping, alley cropping, parallel multiple cropping, multi-storied cropping etc. An effort is made here to review the recent research work done in important cropping system, based on major food crops of the country.

Sequential cropping

Intensification in sequential multiple cropping through introduction of non-conventional crops/short duration crop cultivars and intensive input management, is a common way of increasing land use efficiency especially in irrigated ecosystems. Rice-wheat system is among the most productive cropping systems in the world. However, this system has shown signs of fatigue and evidences suggest that a decline in natural resources and micronutrient are two major reasons for reduction of productivity in this system (Prasad, 2005). Through innumerable studies undertaken in different regions and agro-ecological/farming situations of the country in recent years, several alternative cropping system with higher system productivity, net returns and B:C ratio have been identified for various locations by several workers. Comprehensive review of work done in different parts of country reveals that the system productivity ranges from 5.8 t ha^{-1} of wheat equivalent yield in wheat –lentil system (Narendrakumar *et al*., 2008) to as high as 508.9 t ha^{-1} in rice equivalent yield in rice-garlic-maize (Rathore and Bhatt, 2008). Scope for achieving net return of 2.17 lakhs (rice-garlic-maize in Nagaland) and B: C ratio of 5.34 (winter rice-*toria*-greengram system in Assam) also exists in the country through crop diversification and improved production practices. Comparative performance of various cropping systems evaluated for 6 years in western Himalayan region indicates rice-wheat-sorghum + cowpea for fodder was found to be more productive with rice equivalent yield of 11835 kg/ha (Gangwar *et al*., 2006). Efficient alternative systems identified for Maharashtra, (Gangwar *et al.,* 2003) and Haryana and Punjab (Katyal *et al.,* 2002) clearly indicates higher yield stability and input use efficiency. In coastal areas, diversified systems are found to produce 8 to 48 t/ha/year of economic yield (Gangwar *et al.,* 2004b).Recommended cropping systems for different agro-climatic regions based on the experimental results of AICRP on IFS from 2007 to 2012 reveals that the productivity can be enhanced to as high as 32 t/ha in Trans Gangetic Plains consisting of Haryana and Punjab states with maize-potato-onion and 35.2 t/ha in Upper Gangetic Plains with maize + blackgram-potato-onion. Gangwar and Singh (2011) have documented the efficient alternative cropping systems for various agro-climatic zones. The present mean productivity of 9.2 t/ha in various locations can be increased to 16.9 t/ha (Table 1) through demonstration of high productive systems identified at various locations.

Intercropping

Practice of raising two or more than two crops in mixed stands (sowing crop-mixtures without maintaining discrete rows for each crop), has been one of the typical characteristics of traditional agriculture in India. Component crops of the system were, in general dissimilar in nature in respect of rooting, growth cycle or nutrient and water use pattern. This not only provided an assurance against failure of one or the other crop, due to vagaries of weather or disease/pest epidemics in rainfed agriculture, but also enable the farmers to enhance productivity through more efficient use of land, water and solar energy in vertical dimension. However, with the ingress of modern methods into agriculture, i.e., crop management with high input responsive varieties, assured water supply, higher fertilizer use, chemical control of diseases/pests etc., culminated into declining popularity of this practice. But subsequently, it was widely recognized that intercropping system (sowing two or more than two crops in distinct but proximate rows), designed on scientific basis in crop production, hold a great promise in increasing the land productivity under India condition. Significant advantages in land-use-efficiency, crop productivity and monetary returns in intercropping, as compared with sole cropping of diverse agro ecological situations are observed. Intercropping results in more efficient use of solar energy and harnessing benefits of positives interactions in crop associations. These advantages are, in general more pronounced in wide spread crops and stress environments. The experimental results on prominent intercropping systems at various locations suggest, scope for promotion of the same by introducing appropriate incentive schemes. The system productivity of sugarcane can be enhanced to 200.6 t/ha of sugarcane equivalent yield with intercropping of maize (Table 2). Higher net returns of Rs 2.39 lakhs /ha/annum are reported in Maize + (tomato + gardenpea + frenchbean) relay intercropping system at Almora.

On-farm evaluation of cropping systems

The on-station evaluated alternate systems have been experimented in farmers' field for testing their efficiency under farmer's management conditions. The yield increase over existing systems with alternate efficient cropping systems was found to be 40 to more than 300 % in various

Table 1. Identified high productive systems for selected locations

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

Source: Gangwar and Singh, 2011

Table 2. Potential intercropping systems at various locations

Cropping systems	Location	System productivity* (t/ha)	Net returns (x10^3 Rs/ha)	B:C ratio	Reference
Wheat + mustard	Kangra	4.7	26.7	2.55	Anil Kumar and Thakur (2006)
Maize + tomato + gardenpea + French bean(RI)	Almora	71.3	239.6	3.05	Ved Prakash *et al.* (2007)
Maize + potato	Pusa	14.0	35.7	2.14	Bharati *et al.* (2007)
Pearlmillet** + custerbean (2:2)	Bikaner	72.8	47.3	3.27	Sharma (2008)
Chickpea + Indian mustard (8:2)	Kanpur	2.4	17.1	2.4	Tripathi *et al.* (2005)
Sunflower + French bean (2:2)	Jammu & Kashmir	12.3	13.1	1.95	Singh (2007)
Castor + greengram	Udaipur	4.9	50.2	4.29	Porwal *et al.* (2006)
Sugarcane + maize	Pantnagar	200.6	124.9	1.90	Rana *et al.* (2006)
Ratoon cane + berseem	Lucknow	90.8	56.2	2.64	Singh *et al.* (2007)
Greater yam (normal row planting) + maize	Bhubaneswar	18.7	-	-	Nedumchezhiyan (2007)

* in terms of equivalent yield of base crop, ** for fodder

agro-climatic zones (Table 3). In terms of equivalent yield, profitability and B:C ratio, rice-potato-onion was found be better alternative for rice-wheat in Western Himalayas where as 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 29158 x1000 kcal ha^{-1} compared to the existing system (Rs.60634 ha^{-1} and 24498 x1000 kcal ha^{-1}). On an average, it was found that, the net return and total calories can be increased by 93.2 and 19 % through diversification of existing cropping systems with location specific identified alternative systems. In rice-wheat system, on an average, application of recommended package to rice and wheat resulted in 35 and 33% increase in yield respectively across the locations. Among the different constraints addressed in rice-wheat system, introduction of improved variety of rice and wheat recorded higher yield increase of 74.5 and 44.5% respectively followed by nutrient management (32.4 and 28.2% respectively for rice and wheat).The yield increase with adoption of recommended scientific package was found to be 38.8% over farmer's method indicating the yield gap due to production constraints at farmer's field. 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 respectively in various existing pre dominant cropping systems.

New/emerging systems

Several, new cropping systems are coming up in selected regions due to the opening up of market for commodities in the light of General Agreement on Trade and Tariff (GATT).New concept of bio-intensive complementary cropping systems was introduced and evaluated as a part of strategic research. The results reveal that raising maize for cobs + vegetable cowpea in 1:1 ratio on broad beds (BB) and *Sesbania* in furrows during *kharif* and mustard in furrows and 3 rows of lentil on broad beds in *rabi* while 3 rows of green gram on beds in summer for grain and residue was remarkably better than other systems which produced highest yield of 18.32 t ha^{-1} as rice equivalent with productively of 50.2 kg grain $ha^{-1}day^{-1}$ and profitability of Rs.363 $ha^{-1}day^{-1}$. *Sesbania* was utilized for *in-situ* green manuring with 30 t ha^{-1} green foliage incorporated after 35 days of sowing and timely sown mustard crop in furrows resulted in a good harvest (1.94 t ha^{-1}) and a bonus yield of lentil (1.44 t ha^{-1}). In this system, about 40 % of irrigation water could be saved as applied only in

Table 3. On-farm evaluation of alternate systems at various locations

Agro climatic zone	Location	Existing system	Alternative systems	% increase over existing
WH	Dhansaur	Rice-wheat	Rice-potato-onion	230.7
		Maize-wheat	Maize-potato-onion	338.5
	Pantnagar	Rice-wheat	Rice-potato-vegetable cowpea	123.3
EH	Karimganj	Rice-potato	Rice-rajmah	42.5
LGP	Kakdwip	Rice-greengram	Rice –okra	106.9
MGP	Patna	Rice-wheat	Rice-wheat-moong	59.8
UGP	Saini	Rice-wheat	Sesame-pea	97.8
EPH	Kawardha	Soybean-gram	Soybean-tomato-cowpea	244
	Dhenkanal	Rice-moong	Rice-tomato	116.9
	Gondia	Rice-wheat	Rice-wheat-cowpea	76.3
CPH	Udaipur	Maize-wheat	Maize-wheat-okra	359.6
WPH	Aurangabad	Soybean + Pigeonpea	Soybean-gram-fodder maize	208.4
	Ahmednagar	Soybean-wheat	Soybean-onion	238.9
SPH	Warrangal	Rice-rice	Rice-maize	39.9
	Bangalore	Rice-finger miller	Rice-green brinjal	250.7
	Paiyur	Rice-rice	Rice-tomato	42.2
ECPH	Kendrapara	Rice-moong	Rice-bittergourd	88.9
WCPG	Thiruvalla	Rice-rice-fallow	Rice-rice-okra	243.5
	Roha	Rice-cowpea	Rice-maize	105.7
GPH	Thasara	Tobacco	Tobacco-Fodder Rajka Bajra	169.6
		Bajra-wheat	Bajra-Lucerne (seed)	129.5
	Deesa	Pearlmiller-mustard	Moong-fennel	55.5
		Castor	Fennel-fodder pearlmillet	41.1

Note: WH: Western Himalayas, EH: Eastern Himalayas, LGP, MGP, UGP: Lower, Middle, Upper Gangetic Plains, EPH, WPH, CPH, SPH: East, West, Central, Southern Plateau and Hills, ECPH: East coast plains and hills, WCPG: West coast plains and ghats, GPH: Gujarat plains and hills furrows. Ghosh (2011) observed that intercropping rice with tubers at 4:1 stand enhanced the total productivity and profitability of the rainfed lowland rice system. Several, aromatic and medicinal crop based intercropping systems have been studied in semi-arid tropical condition which are having the promise to fit in to the systems for enhancing profitability of the farmers (Prakasa Rao *et al*., 2000). In the emerging cropping system of rice-banana, the permanent conversion of rice field is not taking place in Kerala, thus the fields can easily be reconverted to rice crop with nutrient enrichment and carbon sequestration (Kuruvilla Varughese, 2006). Rice-banana is advantageous system to the coastal regions for food security and environmental safety.

Climate resilient cropping systems

Climate change is real and its effects are already being experienced in several parts of the world, as is evident from the increase in average maximum temperature all over the world. In India, the changes in temperature and rainfall are predicted to vary from 0.87°C to 6.31°C and –24.83% to +15.18% respectively, by 2080s (Jat *et al*., 2012). Though C3 crops like pulses and oilseeds might benefit from increased CO_2 levels, these benefits are likely to be offset by warmer climate and changed rainfall pattern. The simulation outputs indicate that climate change in the dryland regions characterized by existing high temperature, will reduce crop productivity by reducing length of growing period and crop duration (faster crop development, thereby using less natural resources), radiation interception, harvest index, biomass accumulation and increasing water stress in plants as a result of increased evapotranspiration demand due to high temperature (Dimes *et al*., 2008). There is need to identify climate resilient crops and cultivars for different regions to fit in to the cropping systems. Through simulation studies using APSIM, Dimes *et al* (2008) found that in the semi-arid regions of Zimbabwe, pigeon pea and sorghum were more resilient to the climate change shocks compared to maize and groundnut, mainly due to improved harvest index and water-use efficiency respectively. The simulation studies for groundnut done at ICRISAT showed that in the warmer regions of India (northern, western and some parts of southern India), where in spite of increase in CO_2 and rainfall, the detrimental effects of increase in temperature are large, there is a need for cultivars that are temperature-tolerant, and fit well according to length of growing period (ICRISAT, unpublished results). Under the climate change scenarios, many of the conventional cultivation practices and strategies may no longer be relevant. Therefore, there is a need to recommend technologies to the farmers which respond well to climate change effects and give greater resilience against such shocks. Growing early maturing, photo-insensitive, high tillering cultivars with optimal root traits and tolerant to abiotic and biotic stresses; mulching with crop residues; planting more seedling per hill for heat stress; better soil nutrient and water management, moisture conservation for late onset of monsoon and life-saving irrigation with stored rainwater for mid-season drought to harvest positive effects of the increased CO_2 level are a few strategies which can be thought of in cropping systems mode. Crop intensification and diversification with high-value crops helped households achieve production of basic staples and surplus for modest incomes in model watersheds adopted by ICRISAT (Wani *et al*., 2011). The balanced application of NPK either through inorganic fertilization or through inorganic NPK with 50 % of nitrogen substituted by FYM / crop residue / green manure to rice and NPK to wheat improved soil / particulate organic and microbial biomass carbon concentrations, and sequestering organic C (0.4-0.6 Mg C ha^{-1} yr^{-1}) in long term experiments in Indo-Gangetic plains.

Cropping systems management

Tillage and residue management

The advent of intensive agriculture has led to dramatic losses of organic matter and hence organic carbon from cultivated soils. The carbon in soil organic matter supports soil microbes by providing energy for their activities and thus keeps the soil live, hence, organic carbon sequestration, a management strategy which ensures the storage of carbon in soil (sinks) assumes much significance in the present day agriculture. Conventional practices of crop cultivation accelerates the oxidative losses of soil organic carbon. However, cropping systems with more residue addition and minimum tillage can reverse the losses of organic carbon from soil. The experimental evidences reveal that the new emerging problems can be mitigated or minimized to a considerable extent through effective management of resources in an integrated manner (Gangwar *et al.,* 2004a). Sudha and George (2011) found that coconut with pineapple as intercrop and minimum disturbance of soil could enhance soil organic carbon besides giving the better returns to the farmers. An experiment conducted at Dehradun indicated that strip cropping reduces the soil and water loss which in turn increase the maize and wheat yield at 3:1 and 2:1 proportion compared to cultivated fallow and contour farming (Bharadwaj, 1994). The water and soil loss was 51.8% and 54.08 t ha^{-1} in cultivated fallow as against contour sowing and strip cropping. Soybean-wheat, a predominant crop sequence in irrigated areas of Madhya Pradesh could be made more remunerative by adopting conservation tillage and effective weed control without affecting the system productivity. Rotational tillage system has been found more effective in reducing soil weed seed bank (Mishra and Singh, 2009). Rajeev Singh and Yadav (2006) found that incorporation of rice residue recorded higher organic carbon content by (17.5 and 7%) over rice-residue removed and rice-residue retained treatment respectively in rice-wheat system. Dileep Kachroo and Dixit (2005) reported that incorporation of residues like rice straw in wheat and wheat straw in rice before transplanting of rice and sowing of wheat in rice-wheat system though at par with FYM, after harvest of second year wheat crop, the organic matter content and microbial population increased significantly compared with initial values, no residue and flay ash treatments. In general, incorporation of residues or conservation tillage in many cropping systems was found to be beneficial.

Weed management

The crops that quickly form a shade canopy and are allelopathic in nature have an adverse impact on weeds sensitive to shade and can be adopted as weed control measures. Raju and Gangwar (2004) reported that uncontrolled weeds reduces the system productivity of rice-rice by 31.5%. Berseem [*Citrifolium alexadnrinum (L) Tuslen*] may be taken as a break crop successfully for reducing weed problem (weed control efficiency: 88.7%) in continuous rice-wheat system without any monetary loss (Alok Kumar, *et al*., 2008). Intercropping of dhaincha + direct seeded rice recorded 62% less density of weeds than sole rice with a concomitant increase in weed smothering efficiency (Ravisankar *et al*., 2008). Both direct seeded rice and wheat may be grown in tillage getting higher weed control and productivity and profitability of the rice-wheat system under irrigated conditions (Mishra and Singh, 2007). Application of 10 t FYM ha^{-1} before solarisation for 45-60 days with irrigation up to field capacity was effective in reducing weed menace, release of nutrient and improving the productivity of sunflower-bell pepper sequence (Thimmegowda *et al*., 2007). Weed management through cover crops, intercrops, relay cropping are best strategies for cultural control of weeds.

Water management

Irrigation is a commonly used platform for intensification because it offers a point at which to concentrate inputs. Making this *sustainable* intensification, more crop and profit per drop of water approach should be followed which is possible only through carefully designed cropping systems. Water productivity can be considerably increased through relay intercropping systems (Bastia *et al*., 2008; Ved Prakash *et al*., 2007; Bharati *et al*., 2007; Gangwar *et al*., 2004a; Tetarwal and Rana, 2006; Singh and Rana, 2006; Rana *et al*., 2006; Kantwa *et al*., 2005; Rana *et al*., 2005). The concept of complementary intensive intercropping systems, which seek raising of morphologically and physiologically different crops in an agricultural year under the sequential intercropping systems which have complementarities among themselves and succeeding associations (Gangwar 1983). This concept has significance under declining water availability conditions and deserves to be tested further.

Nutrient management

It was in early seventies that systematic studies with intensive cropping system were initiated under All Indian Coordinated Project of the ICAR in order to rationalise the fertiliser use, exploit the positive nutrient interactions for enhanced nutrient use efficiency and to develop cropping system based fertiliser recommendations. Under the Coordinated Project on Long-Term Fertiliser Experiments (LTFEs) long-term experiments involving rice, maize, soybean and fingermillet based double and multiple cropping systems were started at 11 locations during 1971. Later on two multi-location permanent-plot experiments were started in 1977-78 and 1983-84 under the aegis of All Indian Coordinated Agronomic Research Project (now AICRP on Integrated Farming Systems) with the objective of studying the effect of continuous use of chemical fertilisers in combination with organic manures, respectively in cereal-cereal system. Besides, a large number of location specific short term studies have also been carried out in different parts of the country, which contributed valuable information on system based nutrient management. Integrated application of blue green algae @ 2 kg/ha /Azotobacter @ 0.5 kg/ha, vermicompost @ 5 t/ha and farm yard manure @ 5 t/ha could meet the nutrient requirement of organic basmati rice-wheat-greengram besides enhancing uptake of iron, zinc and Mn in grains and soil microbial population and enzymatic activity (Singh *et al*. 2011a). Site specific nutrient management strategy increased the crop yield, system productivity and profitability with in different rice-based systems compared to treatments based on existing recommendations or farm practice (Singh *et al.* 2011b). Nayak *et al.,* (2012) concluded that application of recommended dose of NPK either through inorganic fertilization or through inorganic fertilizer NPK with 50 % of N substituted by FYM, crop residues or green manure to rice and full NPK to wheat improved the soil organic carbon, microbial biomass carbon and their sequestration rate. High yields to the tune of 12-20 t/ha could be achieved in organically managed maize-onion at Rajendranagar, rice-onion in Bihar, baby corn - chinese *sarson*- onion in Himachal Pradesh, rice–potato–lady's finger system at Bhubaneswar and Chiplima (Odisha) and maize-potato-onion in Kanpur (Uttar

Pradesh).Continuous rice-wheat cropping without fertilizer or manure application resulted in yield reduction by 28% in rice. Fertilizer applied at recommended dose also could not prevent yield decline in rice, although the extent of reduction was smaller (-4.5%) than unfertilized plots. Balancing of fertilizer dose with S (45 kg/ha) accounted for higher yield improvement by 8.9% in rice. Among the organic sources used for substitution of 25% NPK, Sulphicated Pressmud (SPM) proved superior over others, and gave 19% extra rice yield over its initial yield. Application of SPM or FYM to rice in *Kharif* season crop had more pronounced effect than its application in winter crop. Growing of mungbean during fallow period of summer and its residue incorporation after picking of pods before rice transplanting +25% NPK substitution for rice crop gave 15% higher yield advantage over the years. Integrated nutrient management practices evaluated in the long term experiments at various locations suggests that 25 to 50 % RDF can be substituted through FYM, crop residues Green leaf manure (GLM) or Green manure (GM) in *kharif* and 100 % RDF to *Rabi* crops at most of the locations.

On-farm response of prevailing systems to nutrients

Response studies for various nutrients were conducted across the locations under on-farm conditions. Partial Factor Productivity (PFP) and Agronomic efficiency (AE) of N was higher when applied with P and K rather than N alone or with P or with K in the pre dominant cropping systems of all the zones indicating the importance of balanced nutrient application for enhancing nitrogen use efficiency. PFP of N can be increased by 54.6, 33.9, 35.7 and 55.6 % in rice-rice, rice-wheat, rice-greengram and maize-wheat systems, respectively, by applying N with P and K compared to N alone. Relative response to treatment over control was higher with application of recommended dose of NPK for all the systems.Marginal returns of N was 426, 254, 339 and 476 % for rice-rice, rice-wheat, rice-greengram 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. Among the zones, eastern, southern plateau and hills regions and East coast plains and hills region recorded higher yield. However, the PFP and AE of N in these zones were lower compared to Eastern himalayas, Lower Gangetic plains and West coast plains and ghat regions indicating need to enhance the use efficiency of N in the eastern and southern regions.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 were higher in the same zones where in yield levels were higher.

On-station and on-farm cropping systems research over the years has contributed immensely for enhancing the land and resource use efficiency besides increasing the profitability of cultivators. Major findings are summarized below.

- Alternate efficient cropping systems evolved at on-station and tested in participatory mode in farmers field to replace the existing systems which were facing the second generation problems at various locations covering 13 agro-climatic regions promises increase in net returns ranging from Rs 0.45 to as high as 257 thousand/ha/yr.
- Maize based relay intercropping systems involving tomato; garden pea and frenchbean as relay crops at Almora gave higher water productivity thus improving the water use efficiency of inter/relay cropping systems. This also promises to control weeds.
- Tillage and residue management techniques involving principles of conservation agriculture in rice-wheat system promises to increase the input use efficiency of water and nutrients besides considerable increase in soil organic carbon.
- In few select locations, trade oriented cropping systems involving medicinal and aromatic plants were evaluated which gives scope for external earnings.
- Small, marginal and semi-medium categories of operational holdings in India are often subjected to weather vagaries leading to failure of crops. Well planned complimentary sequential and intercropping systems can reduce the risk through differential performance of crops to moisture stress, intermittent unexpected water logging and terminal drought.
- Nutrient management practices evaluated in long term experiments concludes that yield and income of many cropping systems contributing for food basket can be sustained through application of 50 – 75 % recommended dose of fertilizers with 25-50 % N supplied through farm yard manure, crop residues, green and green leaf manures for *kharif* crops followed by 75 to 100% recommended dose of fertilizer during *rabi*.
- Combined application of NPK to major cereal based cropping systems (rice-rice, rice-wheat, rice-green gram and maize-wheat), increases the efficiency of applied N, P and K nutrients. The efficiency increase ranges from 110 to 230 % in various systems.

The contribution of agronomic research on cropping systems research especially at on-station from early 70's to 2000 was found to be more profit oriented with minimal consideration to the natural resource availability like water and nutrient. Thereafter, input use efficiency became an issue in cropping systems management. Ever increasing population contributes for more fragmented land holdings which warrant more production and profit from less resource such as land and water. Sustenance of small and marginal land holdings will depend on better integration and utilization of resources from unit piece of land. Thus farming systems management gives scope for enhancing the livelihood of small and marginal farmers. Considering the emerging needs of fragmented holdings, the focus of cropping systems research has been shifted to farming systems from 2010 onwards. Accordingly, Project Directorate for Cropping Systems Research (PDCSR) has been renamed as Project Directorate for Farming Systems Research (PDFSR) and the associated coordinated project also renamed as AICRP on Integrated Farming Systems. Cropping systems management will form as a major component in farming systems research. Few researchable and extension issues in cropping systems which needs to be addressed through farming systems perspective are:

- Participatory evaluation of crops in sequential and intercropping systems and their associated management practices for developing a zone wise climate resilient cropping systems package. This will facilitate for development of climate risk proof farming systems models.
- Development/evaluation of cropping systems involving agro-forestry for wastelands needs to be done on priority as feed and fuel requirements of ever increasing population can be met with effective utilization of under or unutilized lands.
- Demonstration of proven systems in cluster approach will pave the way for large scale adoption of recommended systems which will ensure enhanced profits to farmers who were reeling under lower returns from the lands.
- Evaluation of all the available extra short duration varieties of crops in cropping systems mode to develop intensive systems which can increase the cropping intensity to 400 to 500%.
- Identification of integrated index by developing composite score for evaluation of cropping systems is necessary. The integrated index should be able to identify the best systems in terms of water, nutrient, land use, profitability, energetic and sustainability.
- Human and animal energy available to agriculture to perform various operations are on the decline. Research needs to be carried out to identify the systems which involve less drudgery and human energy.
- Keeping in view of opening of markets for free trade in agricultural products, trade oriented sequential and intercropping systems involving flowers, orchids, spices, medicinal and aromatic plants needs to identified for specific regions based on the infrastructural capability of the location.
- Cropping system modules having the better input-output relationship in farming systems perspective needs to be developed for crop+ livestock and crop + fish farming systems.

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