



Approaches for sustainability of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system in Indo-Gangetic plains of India – A review

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ABSTRACT

This paper describes the results of some innovative approaches for sustaining productivity of rice-wheat cropping system in the Indo-Gangetic plains. Integrated nutrient management with green manuring as a substitute saved 50% of the chemical fertilizers, with an average productivity of rice (4.8 t/ha) and wheat (3.3 t/ha). Site-specific nutrient management using judicious application of primary, secondary and micronutrients as per soil test and specific yield target was also found an economically-viable option with benefit : cost ratio of 4.9 under multi-location trials, with 15-17 t/ha of productivity of rice and wheat. Resource conservation technologies (RCT) like zero tillage, bed planting and laser land leveling saved substantial quantity of irrigation water. Zero tillage saved 20% irrigation water, along with saving of 300 million litres of diesel per annum. Likewise, bed planting saved 37.5 cm irrigation water. Laser land leveling led to 18.4% saving of water and higher water productivity (1.19 kg grain/m³ water) in wheat under on-farm trials. The average water productivity in wheat under on-farm trials in Punjab was 0.33 and 0.52 kg grain/m³ water under no levelling and laser leveling, respectively. Happy seeder gave 7-8% higher productivity and retained 5-7 t/ha rice crop residue for soil fertility improvement. Besides water-saving and direct productivity gain, RCT was a valuable option for reducing the cost of cultivation in terms of land preparation, timely sowing, decreased seed rate, improved water and nutrient-use efficiency, and left indirect effect on mitigating the adverse effect of climate change. Remote-sensing technology also proved valuable for decision-support system in N saving, based on management-zone approach.

Key words: Integrated nutrient management, Remote sensing, Resource conservation technology, Rice-wheat system, Sustainability, Site-specific nutrient management

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L. emend. Fiori & Paol.) are the staple food crops, which have become the integral part of human diet of 800 million people in South-East Asia. The system is fundamental to employment, income and livelihood for 700 million population in India. The rice-wheat cropping system fulfills 80% of the food requirement and 60% of the nutrition requirement of Indian population (Timsina and Connor, 2001). This system took shape during early 1970s and now occupies 12.3 million ha in north India, of which 10 million ha is in the Indo-Gangetic Plains (IGP), covering 75% of the total wheat area. Out of the total rice and wheat production in India, 42% comes from IGP comprising Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. The productivity data indicate an increasing trend for the period 1958-1998, but a decreasing and stagnating trend afterward (Gupta *et al.*, 2003). During the Green Revolution period (mid-1960s), a phenomenal yield increase was observed with a corresponding increase in net cultivable

area, realization of high yield with short-duration, nutrient and irrigation-responsive, high-yielding varieties. Later mechanization in this cropping system also improved the labour efficiency and increased the production and productivity of crops. The post-green revolution period, however, showed a decline in yield trend, mostly because of imbalanced use of fertilizers and pesticides, over-exploitation of the natural resources, particularly water, deterioration in physical conditions of the soil and emergence of new bio-types of pests and diseases. These led to yield stagnation, causing concern about the future potential for productivity growth and long-term sustainability in the irrigated rice-wheat system. Thus the major challenge before the researcher is to innovate appropriate technologies to produce more food from diminished land resources for the burgeoning population pressure and to improve as well as conserve the natural resources of small and marginal farmers who contribute the greatest in this important production system.

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Sustainability issues

Soil degradation

Rice-wheat cropping system requires contrasting edaphic environment in the sense that rice is grown predominantly under anaerobic soil condition, whereas wheat is grown under well-aerated soil having good tilth. Puddling reduces infiltration of water at the risk of destruction of structure (Sharma and De Datta, 1985). Excessive tillage (6-8 ploughings) in dry rice soil to have good tilth results in late planting of wheat and consequently reduces its yield (Hobbs and Gupta, 2003). In rice-wheat system high intensity deep ploughing has been found to reduce drainage losses of water and fertilizer nutrients, and favour rice growth in most of soils. However, destruction of soil aggregates due to puddling in rice results in poor tilth and increases soil strength in the surface and subsurface layers, decreases hydraulic conductivity and infiltration, and inadequate charging of the soil profile for the crop following rice (Prihar *et al.*, 1985). These unfavourable soil conditions reduce the wheat yield following rice (Meelu *et al.*, 1982). Wheat rooting is often restricted in soils after puddled rice due to reduced sub-soil layers and it continues to remain wet and anaerobic long after the harvest of submerged puddled rice (Kar, 1995). Soil degradation due to salinization is another problem in channel-command areas due to excessive irrigation and rise in water-table in Trans-Gangetic Plains region.

Decline in water table

The rice-wheat cropping system requires more than 170 cm water. Rice is a water-guzzling crop. To fulfill its additional water need, excessive pumping of underground water leads to decline in water table. The farmers are shifting from centrifugal pumps to submersible tube well, costing Rs 1 lakh and requiring extraction of water from the lower strata. Therefore, the water table is declining at a faster rate – another serious concern in agricultural sector.

Inadequate plant population

To harvest optimum yield of rice, 33 hills/m² are required but usually in farmers' fields it varies from 18 to 22 hills/m². To avail the maximum benefit of applied inputs and solar energy, it is essential to keep the plant population optimum. Besides, under delayed transplanting it is necessary to keep 44 hills/m². Likewise, wheat sowing by broadcast leads to non-uniform plant population, which reduces the productivity due to lodging through over-population.

Drop in soil organic matter

Long-term experiments conducted in IGPs revealed that the yields of rice and wheat were constantly greater in all the years when complete doses of NPK were applied

through fertilizers or 50% doses of NPK were applied through fertilizers along with organic materials compared with that of unfertilized control. At Ludhiana and Pantnagar, where yield levels during the initial years of the experiment were relatively high, a declining trend in yield was observed over years. At other locations, the trend in rice or wheat yield in the treatments receiving full dose of NPK was not significant, but in the treatments under conjunctive use of fertilizers and manure, positive and significant trend in rice was observed in sustaining the crop yield. Soil organic C decreased over time at the locations where organic C was greater than 6.5 g/kg at the beginning of long-term experiment but increased at the locations having its low initial value (<5.0 g/kg) (Yadav *et al.*, 2000).

Nitrate pollution in ground water

Pollution of ground water owing to leaching of nitrates appears to be a serious concern in rice-wheat cropping system, which requires more than 300 kg N/ha. The situation is worse in coarse-textured soils where use of N fertilizer is still higher with excessive irrigations. A high nitrate content in ground water in intensively cultivated rice-wheat system was noticed (Bajwa *et al.*, 1993). Long-term experiments conducted under All India Coordinated Research Project on Cropping Systems clearly demonstrated the need for application of 120 kg N/ha to each crop, as there was no scope for skipping or even reducing the dose of N fertilizers to either crop (Yadav, 1998). Therefore, the only option is to improve the N-use efficiency, which hardly exceeds 40% in Indian soils (Prasad, 1996).

Emergence of multiple nutrient deficiencies

Prior to Green Revolution, need for secondary and micronutrient application through fertilizers was not felt because of lower nutrient demand of low-yielding varieties. With the adoption of HYVs and high-grade fertilizers, widespread deficiencies of S and Zn and sporadic deficiencies of Fe, Mn and B were reported in rice-wheat system (Biswas and Tewatia, 1991). Various workers reported yield advantage due to S application in rice-wheat system (Tiwari, 1989; Dwivedi, 1996; Katyay *et al.*, 1997) but quantified recommendation on S application under location-specific conditions in this system is still to be worked out.

The results of All-India Coordinated Scheme on Secondary and Micronutrient and Pollutant elements revealed that rice responded more to applied Zn than wheat (Takkar *et al.*, 1989). In same places Zn was listed as the nutrient limiting rice yield next to N (Rattan and Singh, 1997). The yield losses were, however, mitigated by foliar spray of ZnSO₄ @ 5 kg/ha (Nambiar, 1994), indicating the signifi-

cance of Zn application in improving the efficiency of other nutrients.

In recent years, deficiencies of Mn in salt-affected soils of Punjab and B in calcareous soils of Bihar have become evident. In the highly permeable soils of Punjab, wheat grown after rice suffered from Mn deficiency. In rice-wheat system, the loss in yield of wheat due to B deficiency was found in soils of West Bengal (Chatterjee *et al.*, 1987). Soil application of borax corrected the deficiency and improved the wheat yield substantially (Sakal *et al.*, 1995). The experiments further suggested that the range between deficiency and toxicity of B was very narrow and that B fertilization should be made after careful appraisal of its deficiency. More field data are needed to formulate B management strategies in rice-wheat system.

Appearance of new weed bio-types and resistance to applied herbicides

Many new weed species have emerged in rice and wheat crop, which are not controlled by the commonly recommended herbicides. In rice, *ghrilla ghas*, wrinkle grass, and broad-leaved weeds, and in wheat *jangli palak* and *bhang* (*Cannabis sativa*) are very common. Besides, isoproturon herbicide is not able to control *Phalaris minor* in wheat due to development of resistance to it. Similarly, wrinkle grass is not controlled by butachlor application in rice.

Cultivation of rice on light-textured soil

Another problem encountered is the appearance of Fe deficiency in rice and S deficiency in wheat when grown in sandy soil. The crops remain stunted and produce fewer tillers, leading to low yield.

Inadequate and imbalanced use of fertilizer

The farmers in general are applying N and P but not K. Moreover, the appropriate N : P : K ratio of 4 : 2 : 1 is not being followed. The excessive use of N leads to lodging, and greater incidence of pests and diseases, and ultimately low yield.

Delay in wheat sowing

In heavy-textured rice soils of the middle and lower Gangetic plains, the continuous drop in soil hydrothermal regime after rice harvest poses problem for land preparation for timely sowing of wheat because the soil is not dried quickly. The delay in wheat sowing by one week from the recommended time (first fortnight of November) causes 150 kg/ha reduction in wheat yield.

Weather aberration

The erratic distribution of rainfall in time and space also affects the crop yield. Increase in minimum tempera-

ture resulted in the reduction in diurnal temperature affecting wheat productivity. Moreover, abrupt rise in temperature at reproductive phase of wheat caused yield reduction. An increase in 2 to 3°C caused 4-5% reduction in crop yield.

A close corollary of the discussions made in the previous section clearly indicated that the sustainability of rice-wheat system is a threat to IGP of India. In the subsequent sections, we have attempted to discuss several innovative approaches to sustain the productivity of this important cropping system.

Integrated nutrient management

Sustainable agriculture means differently to different agencies and researchers depending upon the objective. Sustainable agriculture involves successful management of resources for increased agricultural production to satisfy changing human needs while maintaining or improving the environmental quality and natural resources. Integrated plant nutrient system (IPNS), as conceptualized by FAO, is the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner (Roy, 1995). Frinck (1998) opined that the concept of fertilization should be widened into the more comprehensive concept of nutrient management, integrated with other production factors. Integrated nutrient management, developed on the principle of eco-friendly and efficient balanced fertilization and based on optimization of nutrient supply from all available sources (inorganic or organic) for pre-defined yield targets of the cropping sequence *vis-a-vis* efficient combination of soil, water, organic matter and nutrient management, constitute the IPNS. Thus IPNS is a prescription for sustainable agricultural development.

The rice-wheat cropping system is an exhaustive cropping system, requiring high quantum of macro-, secondary and micronutrients (Sharma and Prasad, 1980). Its continuous cultivation over a longer period leads to nutrient deficiency. The survey conducted by PDCSR clearly demonstrated that the farmers are using differential doses of nutrients in various sub-regions of IGP (Table 1).

The highest NPK use in rice-wheat system is in Trans-Gangetic Plains and the lowest in Lower Gangetic Plains. The economic, social and climatic factors as well as soils are largely responsible for spatial variation in major nutrient application. Integration of various sources of inorganic and organic nutrients is an age-old practice. Among various organic sources, FYM or compost and green manuring mostly by growing *Sesbania aculeata* after harvest of wheat are the common practices. It is realized that inclu-

Table 1. Major nutrients used in various sub-regions of IGP.

Sub-regions of IGP	Area (x 10 ³ ha)	Nutrient use (kg/ha)					
		N		P		K	
		Rice	Wheat	Rice	Wheat	Rice	Wheat
Trans-Gangetic Plains	3,809	166.1	154.2	51.3	49.6	0.8	12.3
Upper Gangetic Plains	3,160	115.0	109.8	40.7	37.6	5.2	11.4
Mid-Gangetic Plains	3,133	116.1	100	29.1	32.7	4.3	20.5
Lower Gangetic Plains	119	82.6	87.1	16.3	21.4	36.4	44.0

Source: Annual Report, PDCSR (2006-07)

sion of legume in rice-wheat cropping either as a substitute or in a sequence enriches the soil due to their capability to fix atmospheric N₂. The potential of N₂-fixation varies from 26 to 300 kg/ha, depending upon the species, duration and purpose (food, fodder, green manure etc.) (Table 2). The legumes have synergistic effect on the succeeding crop too.

Crop residues on the other hand constitute an important source of organic nutrients (Table 3). About 80.12 m t crop residues are available for recycling with a total nutrient potential of 1.61 m t, which can replace 0.80 m t chemical fertilizer.

Use of biofertilizers is an integral part of IPNS as these

Table 2. Potential N contributions of N₂-fixing legumes in Indian soils

Crop	Fertilizer N equivalent (kg N/ha)	
	N fixed (kg N/ha/year)	Residual effect on succeeding cereal crop
Alfalfa (<i>Medicago sativa</i>)	100-300	
Clover (<i>Trifolium</i> spp.)	100-150	83
Chickpea (<i>Cicer arietinum</i>)	26-63	60-70
Cowpea (<i>Vigna unguiculata</i>)	55-85	60
Greengram (<i>Vigna radiata</i>)	50-55	30
Groundnut (<i>Arachis hypogaea</i>)	112-152	60
Guar (<i>Cyamopsis tetragonoloba</i>)	37-196	
Lentil (<i>Lens culinaris</i>)	35-100	18-30
Pea (<i>Pisum sativum</i>)	46	20-32
Pigeonpea (<i>Cajanus cajan</i>)	68-200	20-49
Soybean (<i>Glycine max</i>)	49-130	

Source: Subba Rao (1988)

Table 3. Crop residues of rice and wheat, and its contribution

Crop	Grain production (m t)	Grain : straw ratio	Total residues (m t)	Crop residues available for recycling (m t)	Nutrient content (%)			Nutrient potential (m t)		
					N	P	K	Total	Available for recycling	Fertilizer replacement value
Rice	86.0	1 : 1.5	129.0	43.00	0.61	0.18	1.38	2.79	0.93	0.46
Wheat	74.2	1 : 1.5	111.3	37.12	0.48	0.16	1.18	2.02	0.67	0.33
Total	160.2		240.3	80.12				4.82	1.60	0.80

Source: Pal et al. (2002)

contain living cells of different types of microorganisms that have ability to mobilize the nutrients from unavailable to available form through biological process. It broadly includes N₂-fixers, both symbiotic and non-symbiotic bacteria, phosphate-solubilizing bacteria and fungi. The estimated potential of biological N₂ fixation in India is 20 m t for 1997-98 compared with 10.08 m t from fertilizers. The association of rhizobial legumes, *Cyanobacteria* and *Azospirillum* leads to gross N₂ fixation of 50-300, 15-25 and 10-30 kg/ha, respectively (Hamri, 1995). *Azolla*, depending on whether raised as a green manure crop or dual crop, typically provides N equivalent to 20-90 kg/ha fertilizer N (Hegde et al., 1999). With 12.0 m ha under rice-wheat cropping system and taking into consideration the biological N₂ fixation from legumes and blue-green algae, the net annual saving is 1 m t fertilizer N, valued at Rs 50 crores per year. In addition, the contribution of non-symbiotic N₂ fixers, *Azolla*, phosphate solubilizers, and *mycorrhizae* in effective saving on chemical fertilizers offers an alternative option.

A study on integrated nutrient supply system at 8 locations in IGP under AICRP on Cropping Systems during different years demonstrated that the highest mean yield of rice (4.80 t/ha) could be achieved by substituting 50% N with green manuring, followed by 100% chemical fertilizers and 50% N substitution with FYM during rainy (*khari*) season. The performance of farmer's practices, though varied in different locations, was the lowest. The mean performance of IPNS during winter (*rabi*) season was altogether different, giving the highest response under 50% N substitution with FYM. The impact of 100% chemical fertilizer and IPNS packages was statistically at

par. All the IPNS packages helped in attaining the highest sustainable yield index (SYI) within a range of 0.7 to 0.8 at Ludhiana, Sabour, Raipur and R.S. Pura. In other centres, viz. Varanasi, Jabalpur, Kalyani and Navsari, it was lower than 0.7 except at Varanasi, where it was attained under 50% N substitution with crop residue during *rabi*. The highest sustainable yield index of 0.7 was attained only at Varanasi and Kalyani, whereas at other centres, Ludhiana, Sabour, Raipur, Jabalpur, R.S. Pura and Navsari, the sustainable yield index ranged from 0.4 to 0.7 (Fig. 1).

Analyses of rice yield indicated positive trend under all the IPNS packages at Sabour, Varanasi, Raipur, R.S. Pura, Kalyani, Jabalpur and Navsari, but increased yield was observed at Ludhiana only through farmers' practice. A positive trend in wheat productivity was recorded under all the IPNS packages except at Ludhiana, Sabour, Varanasi, Raipur, Jabalpur, Kalyani and Navsari. At R.S. Pura, only the farmers' practice showed increasing trend in yield.

Compared with 100% chemical fertilizer, the IPNS package helped in attaining the highest level of organic C and available N at all the six centres (Ludhiana, Sabour, Jabalpur, R.S. Pura, Kalyani and Navsari), but the avail-

able P increased at all the centres, except Ludhiana where a decrease was noticed. The available K increased only at Sabour and Jabalpur, but declined at Ludhiana, Kalyani and Navsari. At Sabour, the available K under 50% N substitution with FYM, crop residues and green manuring remained constant over the years (Fig. 2).

In another long term-study conducted at PDCSR on an *Ustochrept* soil, the application of sulphitated pressmud and FYM with sub-optimal fertilizer NPK to rice increased annual productivity of rice-wheat system by 1.78 and 1.06 t/ha respectively compared with the recommended fertilizer NPK + Zn treatment. Use of greengram residue in rice and FYM in wheat along with 75% NPK had yield (8.46 t/ha) almost equal to that under 100% NPK. Incorporation of rice and wheat residue declined annual productivity by 1.46 t/ha. In all the integrated nutrient management treatments, rice yield declined and wheat yield increased over the years (Fig. 3-4). The study also demonstrated other beneficial effects on soil physico-chemical properties under IPNS packages compared with the recommended doses of fertilizers.

This approach ensures the sustainability of rice-wheat system. The long-term studies envisaged that combined

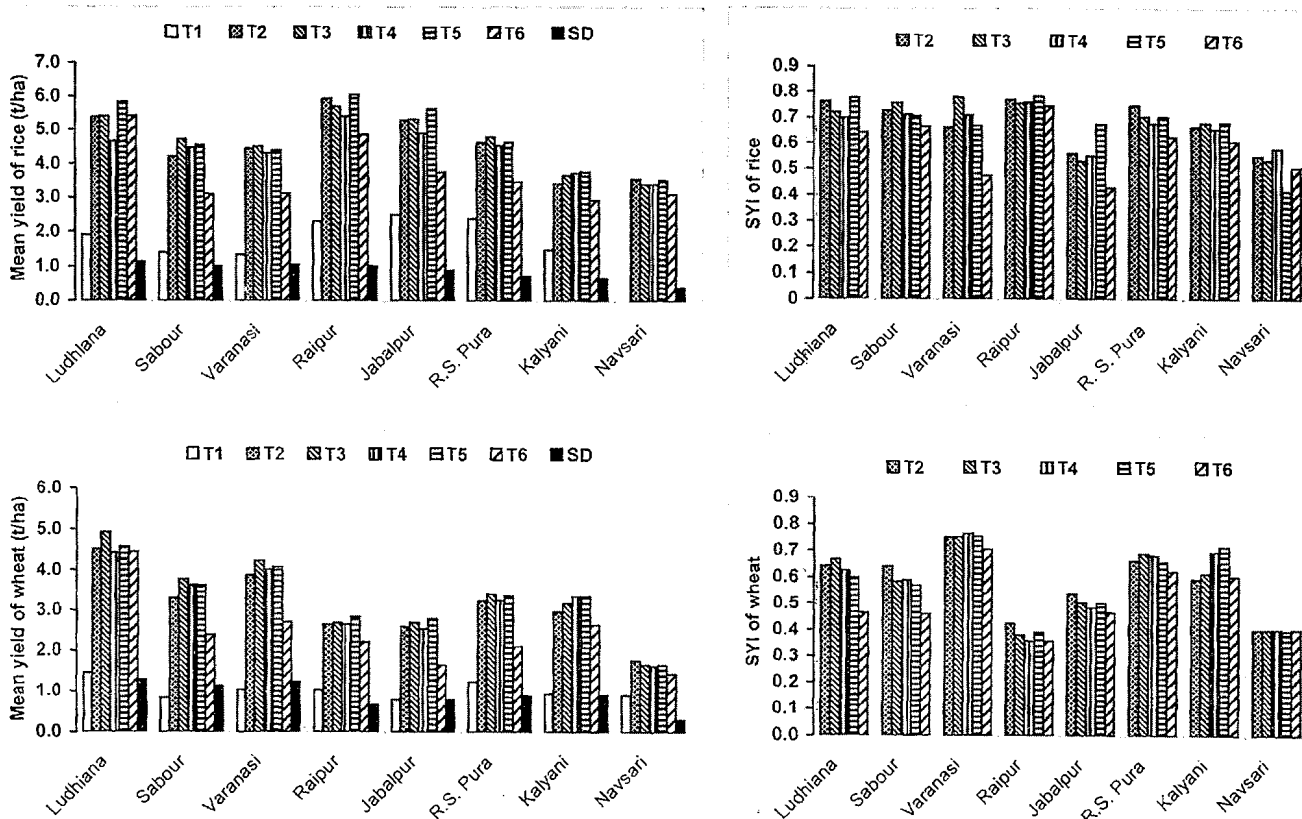


Fig. 1. Yield and sustainable yield index of crops under IPNS package in rice-wheat system over 16 years
 T1 - control, T2 - 100% recommended dose of fertilizer, T3 - 50% N through FYM, T4 - 50% N through crop residues,
 T5 - 50% N through green manure, T6- farmers' practice

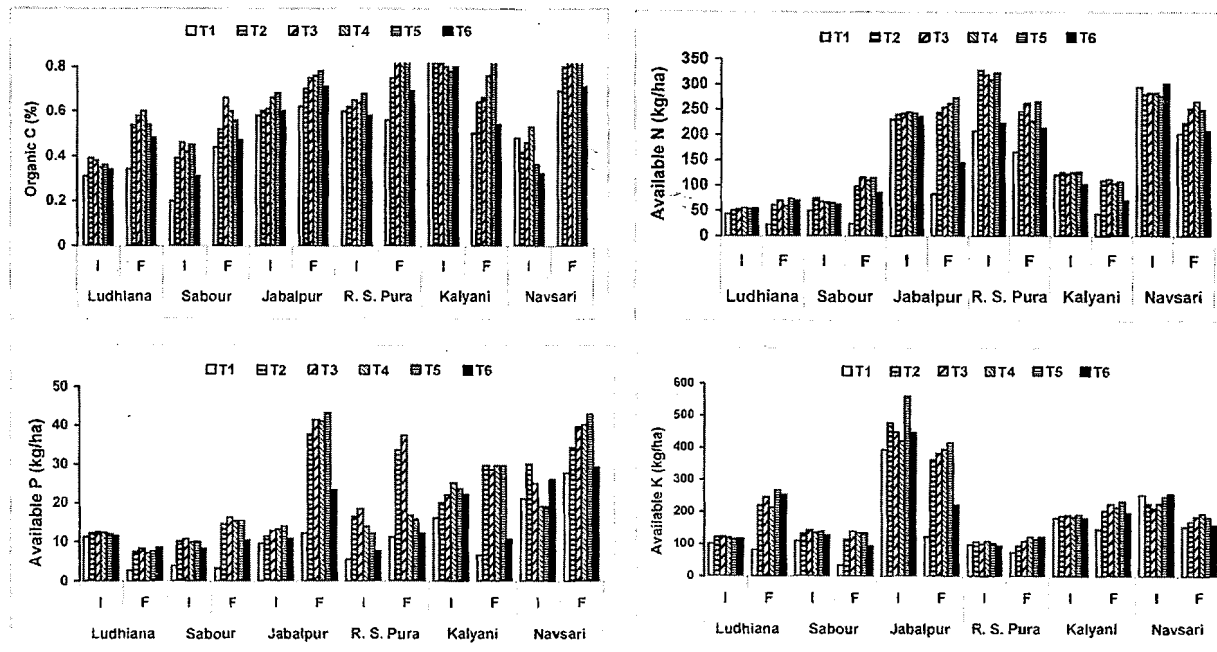


Fig. 2. Changes in soil fertility under IPNS packages in rice-wheat system over 16 years (I - initial, F - final)

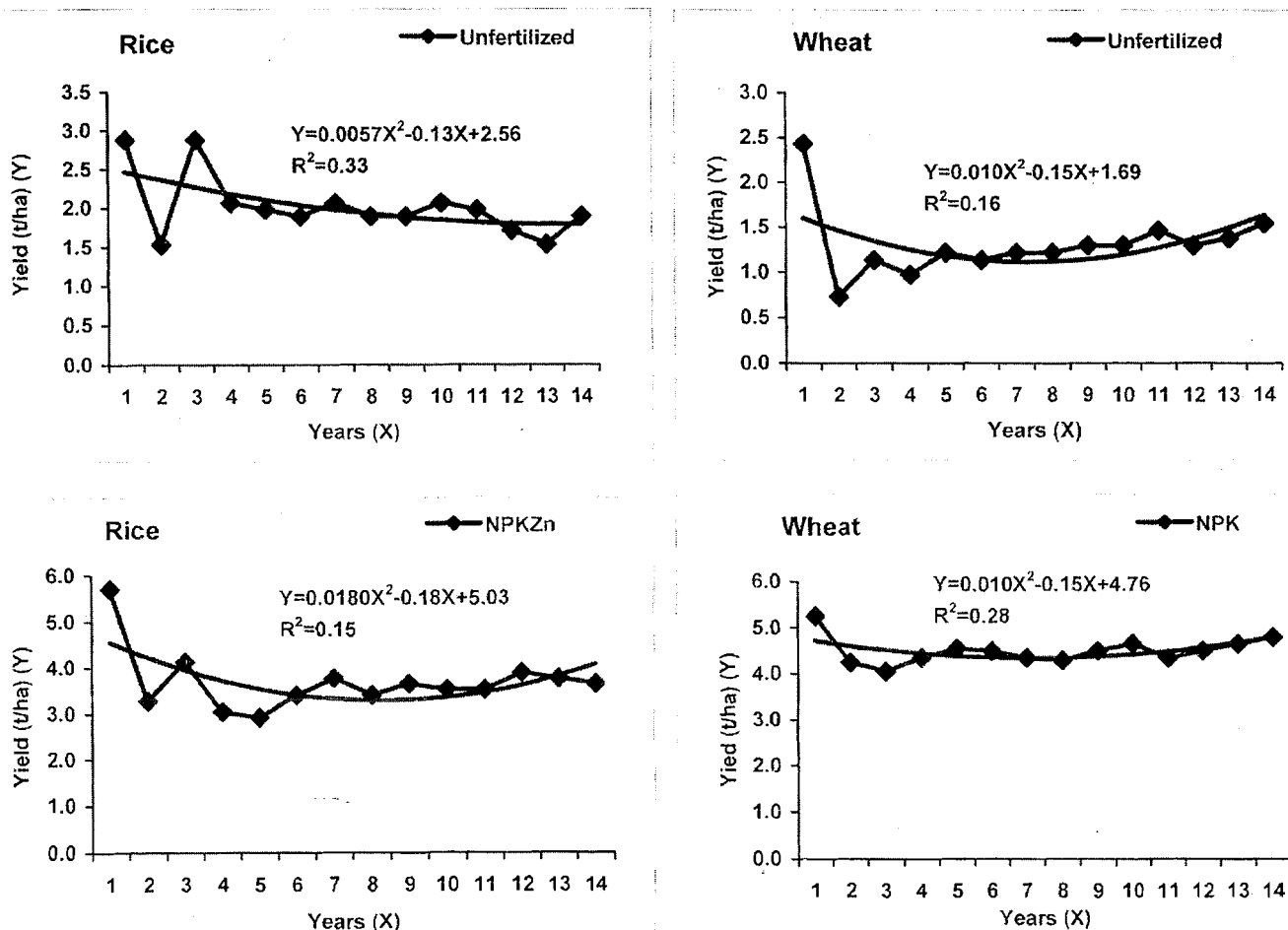


Fig. 3. Trends of yields of rice and wheat with balanced nutrition during 14 years

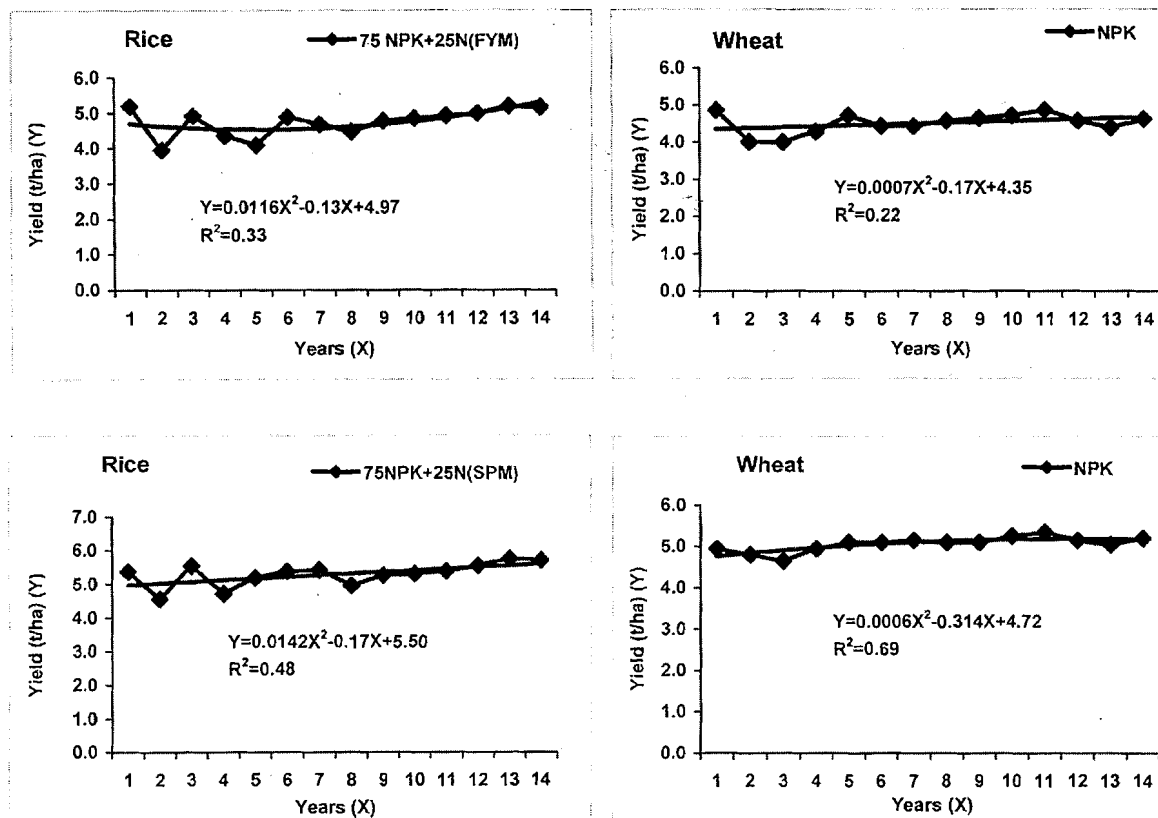


Fig. 4. Trends of yields of rice and wheat with fertilizers and manures over a period of 14 years

use of FYM or green manure @ 6 t/ha at the time of rice transplanting along with 50% recommended NPK not only gave as good yield as that obtained with 100% recommended NPK, but it saved 50% expenditure of chemical fertilizers. The soil organic C, N, P, K status of the soils also improved. Use of biofertilizers in IPNS system is, however, restricted because of non-availability of quality input in time. However, this can be mitigated to a great extent by use of effective microbial culture, which is prepared by fermenting various naturally-occurring substances of animal (cow) and plant origin to harness dual benefit of improving soil fertility and to have disease suppression.

Development of sustainable production model

One innovative approach for sustaining the productivity of rice-wheat system is to find out the non-sustainability indicators in the said cropping system. This is done by an extensive field survey under stratified random sampling to find out the most important factor for non-sustainability. Drop in soil organic matter, emergence of new pests and diseases and weed flora, multi-nutrient deficiencies, low plant population, imbalanced use of fertilizers etc. have been found to be the most important non-sustainability indicators. The dominant non-sustainability

indicator is addressed by imposing treatments with the help of existing research information. Under All India Coordinated Research Project on Cropping Systems, extensive research work has been carried out to tackle the most determinate non-sustainability indicator. In one such trial at Modipuram, soil test crop response (STCR)-based nutrient application had significant positive effect on rice productivity after nine crop cycles in contrast to state recommended nutrient application, which produced 33% lower grain yield. Linear function fitted for nine crop cycles indicated that nutrient management and STCR had consistently higher productivity of rice over recommended fertilizer use. Wheat yield under IPNS and SCTR remained constant over years. Recommended dose of NPK application alone could not sustain the productivity and yield declined over initial to the extent of 30-35% compared with IPNS and SCTR. However, under organic farming wheat yield increased by 31% over the initial level (Fig. 5).

In another on-station trial at Ludhiana, recommended package of practices (RPP) + green manure (GM) + 44 hills/m² gave the highest SYI during both *kharif* and *rabi* seasons. At Masodha, RDF + PP + plant protection gave the highest value of SYI (0.92) during *kharif*, whereas it was 0.82 under RDF+STCR during *rabi*. At Pantnagar,

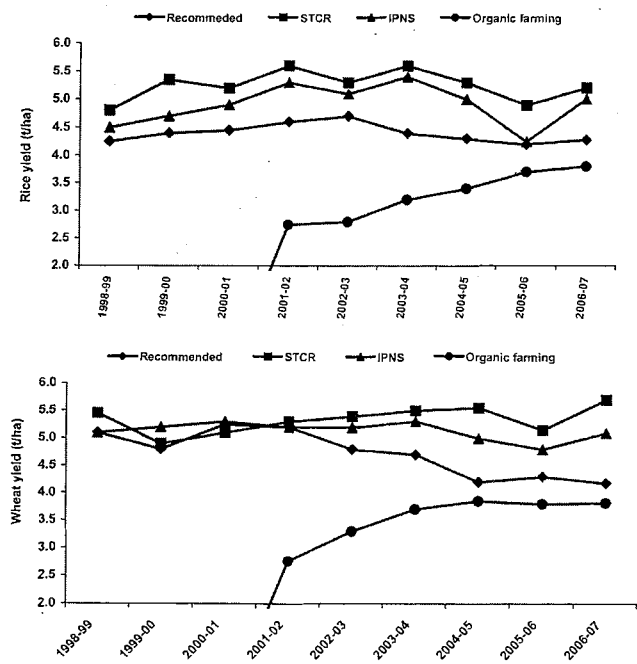


Fig. 5. Yield trends for sustaining rice–wheat productivity under IPNS

RDF for direct-seeded rice gave the highest SYI (0.77) and for zero-till wheat (0.98) (Table 4)

Resource conservation as an aid for sustainability

The economic sustainability of rice-wheat cropping system can not be attained without proper adoption of resource conservation technologies, such as zero till, bed planting, laser-land levelling and direct-seeded rice. A corollary of the resource bases in rice–wheat system shows that the natural resources are under severe threat of sustainability owing to the intensification of this cropping system with excessive mechanization for land preparation, over-irrigation, and use of poor-quality water, which lead to soil degradation. The increase in bulk density in the sub-soil due to excessive tillage is a common consequence followed by salinization, alkalization and waterlogging due to excessive irrigation. Excessive tillage without appropriate strategy to manage the crop residues and native soil organic matter also leads to degradation of soil qual-

ity and results in non-sustainability.

Tillage alone accounts for 7% energy in rice–wheat cropping system. This can substantially be reduced by adopting appropriate conservation technologies that combine tillage and crop establishment techniques and by maintaining at least 30% soil surface covered with residues after planting. Zero tillage is being practiced on almost 2 million ha in IGP. The beginning was made from Punjab and Haryana, and being extended to other parts of IGP. The zero tillage establishment of wheat after rice uses a modification of the opener for seed drill to allow planting of wheat into field following rice harvest without ploughing the field. The modification is based on an inverted T-opener used in a seed drill and was first introduced at Pantnagar during 1988. On-station as well as on-farm studies on zero tillage clearly demonstrated yield advantage over conventional tillage because of timeliness of planting and less weed population, higher organic matter content, greater retention of soil moisture and saving of 20% irrigation water. Since the yield of wheat is higher and the cost of production is lower, the farmers are enthusiastically adopting this technology. The adoption of this technology on 2.0 million ha area saved 300 million litres of diesel annually (Gupta *et al.*, 2003).

In bed planting of wheat, rice and other crops are sown on the top of bed and irrigation is applied in furrows. Since 1988 this system is being promoted mainly for the benefit that is accrued from water saving (25-30%). This practice is also recommended in areas where grassy weeds are a problem, since this system allows mechanical weeding and a reduction in costly herbicide application (Gill and Jat, 2007). This system also allows for fertilizer placement, both basal and top-dressed, and results in increased efficiency of these inputs. A saving of one irrigation in wheat and four irrigations in rice would save 3.75 million litres irrigation water. It is also possible to combine it with drip irrigation system for greater benefit of water and nutrient resources.

The rice–wheat cropping system requires both submerged and arable soil conditions, which affect the inherent soil physical conditions substantially. The physical

Table 4. Yield and sustainable yield index of crops in Trans-Gangetic Plains at Ludhiana

Treatment	Mean crop yield (t/ha)		SYI	
	Kharif	Rabi	Kharif	Rabi
T1: RPP (120-30-30, Zn 25, 33 hills/m ²)	6.09	4.95	0.94	0.85
T2: T1 + 15 t GM/ha	6.64	5.34	0.94	0.91
T3: T1 + 15 t GM/ha + 44 hills/m ²	6.68	5.29	0.89	0.90
T4: 150-0-30 (STCR) + 33 hills/m ²	6.28	5.06	0.90	0.84
T5: Farmers’ practice + 180 kg N/ha + 33 hills/m ²	5.74	4.72	0.89	0.88

Source: Annual Report, AICRP on C.S. (2006-07)

condition governs the oxidation and the reduced conditions determine the availability of plant nutrients. It is, therefore, pertinent to give due consideration to tillage management in this system. Often puddling is done before rice transplanting to create minimum percolation rate required for a specific soil condition. Japanese researchers suggested that for a rice yield of >6 t/ha, percolation rate should be 10 to 25 mm/day. Likewise, extensive research work on the effect of puddling to minimize percolation loss has been worked out under various soil and climatic conditions (Adams *et al.*, 1992). Puddling process is also affected by soil surface conditions like degree of tillage or green manuring or in fields where sufficient crop residue of the previous crop is maintained.

The plough pan is formed in puddled rice owing to repeated tillage in the ponded water. However, there is no definite time for its formation. Once the plough pan is formed, strategy should be made to break it by using chiseler. Before considering any resource conservation practice, the basic need of tillage for the component crops in rice-wheat system under location-specific conditions should be thoroughly understood and conservation technologies should be applied accordingly. Compaction is another option for light-textured soil to reduce the rate of percolation, which saves irrigation water up to 20-25 cm depth used during puddling. Tillage system for wheat following rice must tackle the physical problems of the soil created by puddling or compaction and submergence in rice. This may affect the succeeding crop in relation to delayed sowing due to excessive soil moisture, infiltration of water, porosity, inadequate water storage in the profile, restricted rooting behaviour and consequent low input-use efficiency and post-seeding aeration or water stress. In conservation agriculture, major research efforts were made for efficient utilization of crop residue with suitable tillage practices, which enabled the farmers to grow rice as unpuddled direct-seeded crop and transplanted rice, and no-till wheat in the presence of crop residues to save water, and improve soil health and sustain productivity. Field experiments showed that resource conservation technologies provide higher yield, reduce water consumption, exert a favourable impact on the environment and at the same time promote crop diversification. Late sowing of wheat is very common in the rice field located at low elevation or the field suffering from alkalinity. The wheat sown after 15 November gives 1.0-1.5% reduction in yield/day (Sarkar and Thapliyal, 1988). The sowing of wheat by zero-till drill helped save Rs 2,500 to 3,000/ha because no field preparation is required and the crop is raised on residual moisture. If moisture is insufficient in the seed zone, very light irrigation is applied on the hard surface, where half the irrigation water is required com-

pared with the tilled field. Thirdly, weeds do not emerge in the undisturbed hard soil surface.

At Modipuram, zero, strip and rotary-till drill helped in saving 70-80% time, 64-71% labour, 67-85% fuel, 65-80% cost and 67-85% energy compared with conventional sowing. Bed planter recorded effective field capacity of 0.39 ha/hour and needed slightly more time, labour and fuel, and lesser energy compared with zero, strip and rotary till drill but it was superior to conventional sowing (Sharma and Singh, 2004). In another long-term experiment for residue recycling under different tillage practices, rice yield was lower than conventional tillage and wheat yield was reduced under reduced tillage. Among residue management practices, residue incorporation with 20% extra N recorded the highest yield of rice (4.85 t/ha) and wheat (4.66 t/ha).

Rotary, strip and zero till drill and bed planting of rice and wheat provided higher yield (2-8%) and were more cost-effective (9-27%) and energy-efficient (21-32%) compared with conventional sowing. The strip and zero till drill further provided 1.5-2.8% higher wheat yield under crop residue cover compared with no residue cover. *In situ* recycling of wheat residue gave higher rice yield than residue retrieval and burning. The net returns for residue recycling under such condition were 5.7% higher but B : C and energy output : input ratios were 1.3 and 13% lower (Sharma and Singh, 2004).

The performance of happy seeder (which allows sowing of wheat in the standing crop residue after combine harvest) was evaluated at various sites in IGP. The efficiency of this instrument over conventional sowing was also very encouraging in terms of timeliness of sowing, increase in the efficiency of nutrients and water, reduction in the cost of cultivation and ultimately improvement in yield.

Raised bed planter is used for planting the crops on raised beds. Making of beds on tilled soils, sowing of seed, basal application of fertilizer, and covering and dressing of planted bed are done in one operation. For planting of seeds on permanent beds, the same machine is used for single operation which helps reduce the cost of planting compared with those on fresh bed or flat sowing. In a study conducted at Bhopal, planting of wheat on permanent beds was found to be 41.6% energy efficient and 44.3% cost-effective compared with the conventional three-tillage flat sowing (operational energy, 1,976 MJ/ha and cost operation Rs 1,903/ha). Similarly, planting on permanent beds gave 63.2, 55.7 and 57.2% advantage of time, energy and cost effectiveness respectively than that on fresh beds (Rautaray, 2004).

Laser levelling, which allows smoothening of the land surface within ± 2 mm from its average elevation using a

laser-equipped bucket, has a great potential as a precursor technology for adopting resource conservation techniques. The results of on-farm demonstrations in western Uttar Pradesh revealed that laser levelling led to 18.4% saving in irrigation water and 2.7% increase in wheat yield compared with the non-levelled land (Table 5).

Table 5. Effect of land levelling on irrigation water use and wheat productivity

Levelling practice	Total water use (m ³ /ha)	Saving in irrigation water (%)	Wheat yield (t/ha)
Laser levelling	3830	18.4	4.57
Traditional levelling	4650		4.45

Source: Annual Report, AP-Cess Fund (2005-06)

Likewise, on-farm studies conducted at Ludhiana clearly demonstrated the beneficial effect of laser land levelling in which the mean water productivity in wheat under laser land leveling was 0.52 kg grain/m³ water compared with 0.33 kg/m³ under unlevelled condition (Table 6).

Table 6. Effect of laser levelling on yield and water productivity of rice in Punjab

Field condition	Total water applied (m ³ /ha)	Water saved over unlevelled (m ³ /ha)	Grain yield (t/ha)	Water productivity (kg/m ³)
Unlevelled	23,530		7.76	0.33
Levelled once	16,957	6,572	8.22	0.48
Levelled twice	15,893	7,637	8.31	0.52

Source: Annual Report, AP-Cess Fund (2006-07)

The results of another study conducted at Modipuram revealed that at recommended level of NPK, the water productivity under laser land levelling was 0.91 kg/m³ which was 2.15 times more over the traditional levelling (Table 7). Likewise the agronomic efficiency of N, P and K improved with a substantial margin. The average increase of agronomic efficiency of N, P and K under laser land levelling was 118.2, 130.3 and 130.2% over the tra-

ditional levelling (Pal, 2005). Therefore, on account of such high agronomic efficiency, laser levelling is a precursor technology of precision farming (Gill, 2006).

The cultivation of rice following direct-seeding gives fairly good yield and saves 30% irrigation water. In addition, no puddling is required and the crop does not suffer from transplantation shock, besides it matures 10-15 days earlier and gets best fit in different cropping systems. In this practice, the physical, chemical and biological conditions of the soil remain productive or congenial for the growth of crop plants. The growing of legume like summer greengram after the harvest of wheat and incorporation of green vegetative parts after picking of pods not only gives 0.7-0.9 t/ha grain yield of greengram but also saves one-third N to rice and giving grain yield equal to that with balanced fertilizer despite improvement in soil fertility.

Site-specific weed management practice using herbicide at the appropriate time, with optimum dose following proper method of its application with right choice of weed-specific chemicals will encourage weed suppression and reduce resistance problem.

Site-specific nutrient management

Rice-wheat cropping system in IGP is practised in a myriad of soil conditions ranging from heavy-textured clay soils as in Lower Gangetic Plain to light-textured soils in Trans-Gangetic Plain. Nutrient reserves as well as nutrient-supplying capacity of the soils under these vastly different soil and climatic conditions and management strategies to achieve desirable yield are the major reasons for spatial variation in crop yield. Thus the site-specific nutrient-management strategies have a great potential to attain higher yield in this cropping system by addressing judicious application of deficient nutrient for fulfilling their full requirement for a specific yield target based on soil-supply capacity and nutrient removal by the crops in the cropping system.

General guidelines for formulating maximum economic yield (MEY) are appropriate fertilizer to maintain plant-nutrient level adequate to sustain productivity and profitability, albeit non-limiting nutrient supply and nutrient

Table 7. Effect of laser land levelling on grain yield and water productivity of rice

Treatment	Grain yield (t/ha)		Total water use (m ³ /ha)		Water productivity (kg/m ³)	
	2003	2004	2003	2004	2003	2004
LL + N ₁₂₀ -P ₂₆ -K ₄₀	6.33	6.20	6,950	6,880	0.91	0.90
TL + N ₁₂₀ -P ₂₆ -K ₄₀	5.00	4.90	9,150	9,110	0.55	0.54
TL + no fertilizer	4.08	3.80	9,110	9,130	0.45	0.42

LL – laser levelling, TL – traditional levelling

Source: Pal (2005)

accumulation not detrimental to agriculture and environmental system. The site-specific nutrient-management planning is designed on soil, crop and cultivars as well as landscape and crop management. As seasonal variation in crop yield is common, the site-specific management strategies are also designed to take care of the seasonal variation in nutrient-supplying capacity of the soils and crop design. The SSNM approach aims at achieving MEY of crops by assuring site-specific application of major, secondary and micronutrients on soil-test basis, which takes into account various sources of nutrients present in the soils. The selection of most economic combination of nutrients is taken into consideration under SSNM. Nevertheless, as several inputs and factors collectively improve the production level, application of nutrients alone cannot bridge that yield gap. Nutrient and irrigation water are the key elements that occupy an important place in our strategies to improve productivity.

It has been realized that 15-17 t/ha annual grain yield of rice–wheat system can be achieved by applying the knowledge of SSNM at several locations (Tiwari, 2006). The multi-location data for 13 centres of All India Coordinated Research Project on Cropping Systems revealed that site-specific systems are probably the best opportunity available to develop a truly sustainable crop–production system (Gill, 2006).

Four treatments including farmer's fertilizer practice (FFP), FFP + K, FFP + S + Zn and FFP + K + S + Zn were evaluated by following all other improved packages of practices (sowing time, seed rate, weed and irrigation management) for achieving higher number of targeted productive tillers required for pre-determined yield targets. The productivity of rice varied from 3.98-7.17 t/ha in accordance with the farmer's crop and nutrient-management practices at different locations. The average data of nutrient-management options under the existing farmer's crop-management practice (FCM) gave 4.32 to 6.95 t/ha rice yield, which improved by 3-25% with recommended crop-

management practice (RCM) at different locations. Inclusion of K, S and Zn along with farmers' fertilizer management gave 0.86, 1.78, 1.11, 0.98, 1.40 and 0.75 t/ha extra yield at Modipuram, Banda, Pantnagar, Varanasi, Sabour and Fatehgarh Sahib, respectively. These responses have direct relationship with farmer's crop-management practice and showed a significant gain under RCM over FCM (Table 8). Wheat productivity increased over FFP, which varied from 0.13 to 0.68 t/ha with an average of 0.6 t/ha at Modipuram, 0.18 t/ha at Fatehgarh Sahib, 0.6 t/ha at Pantnagar, 0.13 t/ha at Banda and 0.68 t/ha at Sabour. Application of 30 kg S along with K exhibited yield advantage while its omissions led to wheat yield loss ranging from 3-13% (Fig. 6, 7).

Resource conservation technology and crop adaptation to climatic stress

Climate change seems to be a threat to nation's food security. Long-term data suggested that wheat productivity has declined since 2000, mostly due to a rise in minimal temperature by 3-4°C at reproductive phase and some change in land configuration. The resource-conservation technology, such as sowing with zero-till or strip-till drill, which enables the sowing of wheat crop in the standing crop residue, creating a favourable micro-environment with higher moisture along with constant nutrient supply, buffering soil temperature due to mulching effect of above-surface standing as well as loose residue biomass, thus mitigating the adverse climatic impact. Likewise, the resource-use efficiency improves on account of planting wheat on beds, which saves 20-30% irrigation water, improves nutrient-use efficiency, reduces weed population and saves 10% seed. The new crop-establishment techniques by using second-generation machinery also help grow the rice crop without puddling, using 25 kg seed/ha. This saves 25% irrigation water, makes the condition aerobic in nature and thus reduces methane emission and enables the crop to mature 10-15 days earlier by avoiding the

Table 8. Grain yield response (t/ha) to K, S and Zn application over farmers' fertilizer-management practice

Nutrient applied	Modipuram	Fatehgarh Sahib	Sabour	Pantnagar	Varanasi	Banda
<i>Rice</i>						
K over NP	0.47	0.40	0.76	0.66	0.47	0.79
K S and Zn over NP	0.86	0.75	1.40	1.11	0.98	1.78
S and Zn over NP	0.30	0.47	0.57	0.26	0.30	1.01
S and Zn over NPK	0.40	0.35	0.63	0.45	0.50	0.99
<i>Wheat</i>						
K over NP	0.60	0.18	0.68	0.61		0.13
K and S over NP	0.85	0.34	1.20	0.92		0.50
S over NP	0.35	0.22	0.30	0.50		0.30
S and Zn over NPK	0.26	0.16	0.52	0.31		0.36

Source: Annual Report, PDCSR (2006-07)

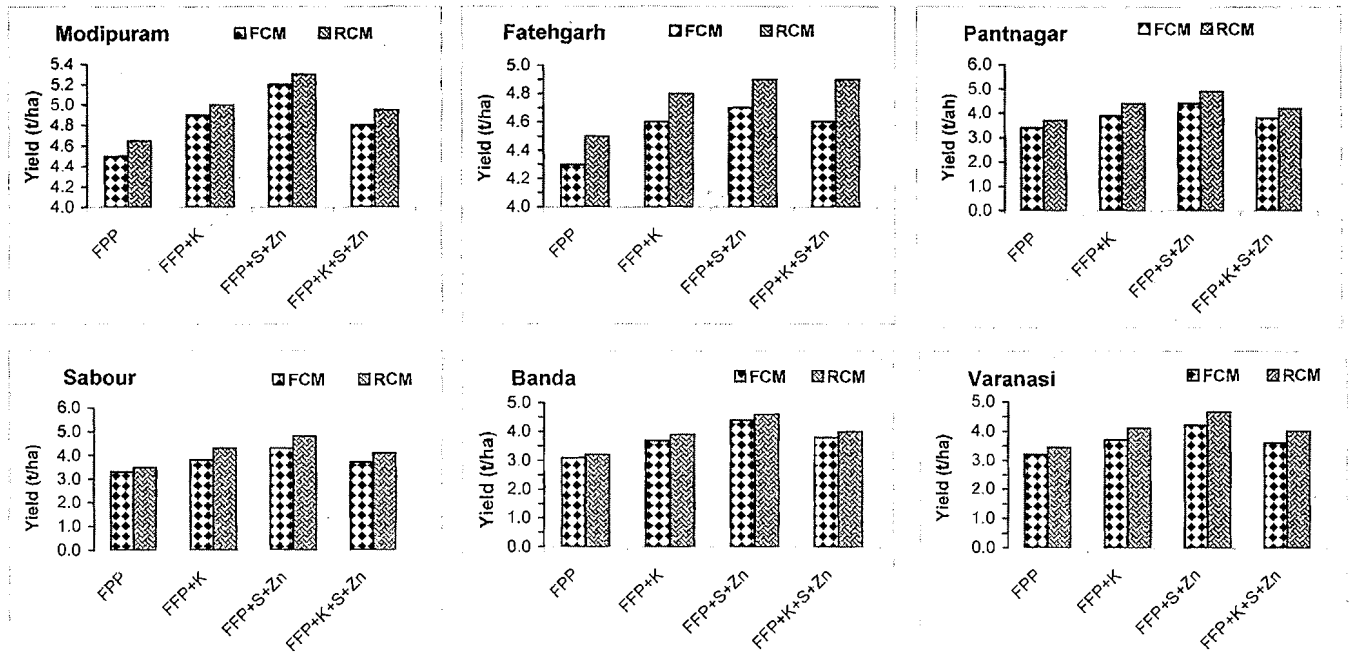


Fig. 6. On-farm rice productivity as influenced by site-specific nutrient management practices (FCM-Farmers' crop- management practice, RCM-recommended crop-management practice)
Source: Annual Report, PDCSR (2006-07)

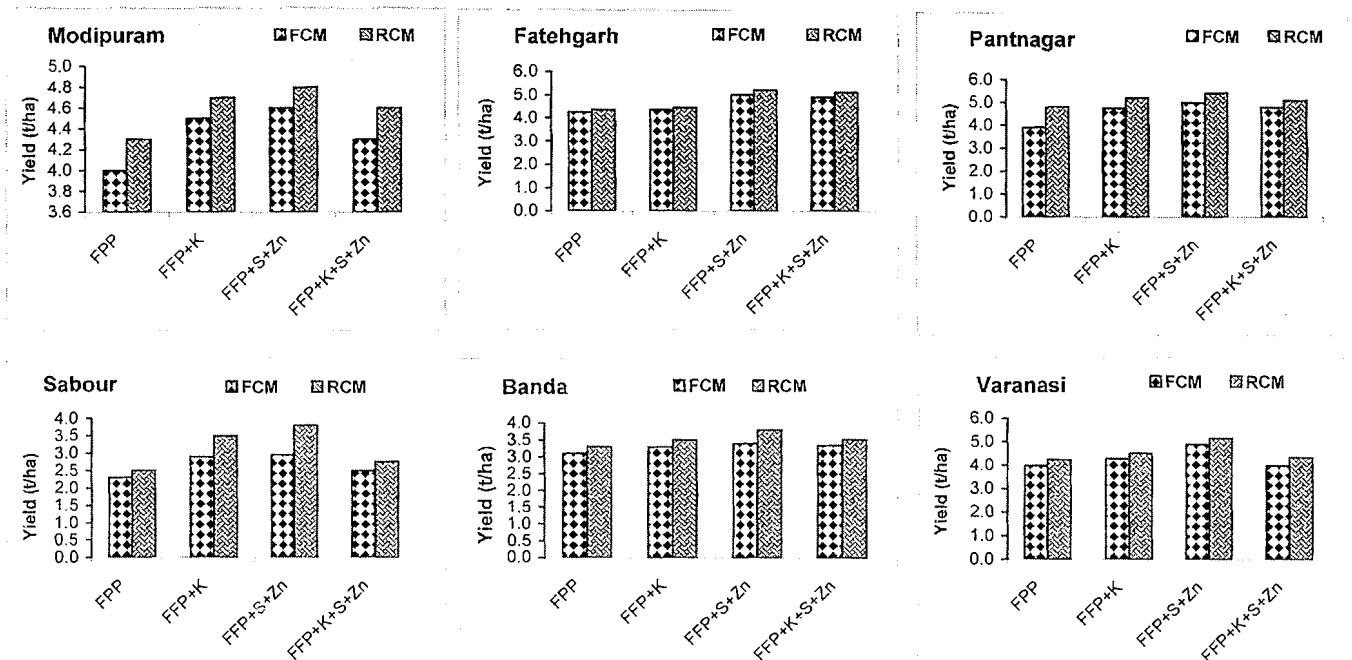


Fig. 7. On-farm wheat productivity as influenced by site-specific nutrient management practices (FCM-Farmers' crop- management practice, RCM-recommended crop-management practice)
Source : Annual Report, PDCSR (2006-07)

transplanting shock. This establishment technique improves suitability of rice to get the best fit under different cropping systems (Gill *et al.*, 2006).

Remote sensing and GIS

Improvement in resource-use efficiency through natu-

ral or external resources can be achieved by using modern tools like remote sensing and GIS. Remote sensing is a device of getting information about an object using electro-magnetic radiation of short-wave length from a distant object like satellite. The light emitted by the sensor from an observation satellite after hitting the target can

be used in assessing the quality and quantity of the object. GIS is a highly sophisticated computer technique that uses the digital data to produce map about an object. The energy reflected at red and infra-red wavelengths is sensitive to variation in both crop and soil characteristics. Red reflected energy, which is visible to the eye, is absorbed by chlorophyll in healthy green plants for use in photosynthesis. The reflected near infrared energy, which is not visible to the naked eye, is particularly sensitive to leaf cell structure and water content. Healthy dense crops are therefore characterized by strong absorption of red energy and strong reflectance of near-infrared energy. It is advantageous to combine these measurements into a single index that increases the sensitivity to variation in the crop. Such mathematical combinations of the digital data are known as vegetation indices. One such index is Normalized Difference Vegetation Index, defined as: $NDVI = (Infrared - Red) / (Infrared + Red)$

The sustainability of the rice-wheat system can be improved greatly by adopting precision farming or site-specific farming by providing the required amount of production input in proper time at proper place, at proper dose and using proper method. The spatial and temporal variabilities are major reasons for variation in crop yield and can very well be managed by dividing a heterogeneous field in supposedly uniform management zones. The management zones are created on the basis of information on crop yield; soil data or crop conditions adopting remote sensing techniques. The data obtained are superimposed on a base map to create management zones using GIS. These management-zone maps can be used for site-specific management inputs rather than applying a uniform dose. Extensive research work through on-farm trials in IGP clearly demonstrated that these modern tools are very effective for site-specific management inputs. The use of green seeker, which is also a hand-held instrument for measuring NDVI at various critical growth stages, generates data for crop conditions. This NDVI data from a reference plot, which has been sufficiently fertilized with N can be compared with a reference plot for which the N requirement is to be determined. The NDVI value from standard plot, which has been sufficiently fertilized with N, is correlated with crop yield (Fig. 8), this relation is used for estimating N requirement for crops during a season. The use of green seeker helps in applying adequate N at specific crop-growth stage in various management zones.

In a study conducted at PDCSR, the INSEY-GY relation used for calculating the N fertilizer dose in rice was: $y = 90.79 * INSEY - 0.602$ at the stage of 54-57 days and $Y = 315.35 * INSEY - 0.958$ at the sate of 41-43 days. The same relationship for calculating N fertilizer dose

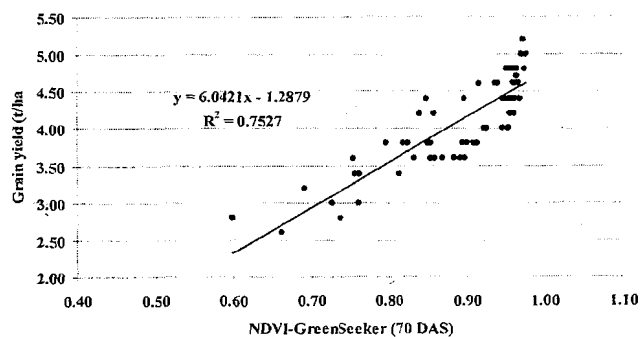


Fig. 8. Relationship between wheat-grain yield and green seeker NDVI

Sources: Annual Report, PDCSR (2005-06)

was: $y = 1978 * INSEY - 1.926$ for Freekes 5-6 and $y = 6192.7 * INSEY - 1.605$ for Freekes 7-8. By using such relationship, maximum yield of rice (9.06 t/ha) and wheat (5.60 t/ha) can be achieved in the schedule for N application in rice with 143 kg N/ha for rice applied at 7, 28 and 49 days after transplanting and wheat with 130 kg/ha applied at basal 60, CRI 60 and Freekes 7/8 days (10 kg/ha) (Tables 9, 10).

In another on-farm study conducted in eastern Uttar Pradesh in an *Ustochrept*, the grain yield of rice under green seeker-based N application helped in attaining yield of rice (6.04-6.99 t/ha) and wheat (5.93-6.71 t/ha).

Role of advance genotypes

The sustainability of rice-wheat system cannot be overlooked without the use of appropriate crop genotype. As the IGP in India varies in its physiography, land form, climate, natural resources and management practice depending on the socio-economic status of different categories of stakeholders, the resource conservation technologies like zero tillage, bed planting etc. are being popularized and the farmers are in need of appropriate crop genotypes that perform better in renewed land configuration and also in altered micro-environment. The development of suitable varieties for such specific conditions will certainly improve system productivity and sustainability.

Package of practice for improving sustainability

Based on climate, physiography, soil type etc., the IGP is divided into five broad transects, viz. Trans-Gangetic Plain (Punjab and Haryana), Upper and Middle Gangetic Plain in western-central and eastern Uttar Pradesh, Bihar and the *tarai* of Uttarakhand and Lower Gangetic Plain in West Bengal. As the production constraints among transects of IGP are different and wide in dimension, despite a few common production constrains, the future strategies for improving and sustaining the productivity of rice-wheat system should be different.

The soil of the Trans and Upper Gangetic Plains are

Table 9. Grain yield and fertilizer-N use with green seeker-based N-management options in transplanted rice

Basal	Fertilizer N (kg/ha)					Total	Grain yield (t/ha)
	7 DAT*	21 DAT	28 DAT	42 DAT	49 DAT		
0	0	0	0	0	0	0	4.90
40	0	40	0	40	0	120	8.85
20	0	40	0	25 (GS)**	0	85	8.23
20	0	60	0	30 (GS)	0	110	8.18
30	0	30	0	40 (GS)	0	100	7.92
40	0	40	0	36 (GS)	0	116	8.75
0	20	0	40	0	79 (GS)	139	8.23
0	20	0	60	0	54 (GS)	134	7.71
0	30	0	30	0	76 (GS)	136	8.94
0	40	0	40	0	63 (GS)	143	9.06
50	50	50	50	50	50	300	11.25
CD (P=0.05)	1.66						

*DAT=Days after transplanting, **Green seeker-based application

Table 10. Effect of green seeker-guided N fertilizer application on grain yield and N-use efficiency of wheat

Basal	CRI*	Fertilizer N (kg/ha)			Total	Grain yield (t/ha)	N-use efficiency (kg/kg N)
		Feekes 5/6	Feekes 7/8				
0	0	0	0	0	1.46		
60	60	0	0	120	5.26	0.72	
75	75	0	0	150	5.57	0.74	
60	0	19 (GS)**	0	79	3.74	0.61	
80	0	15(GS)	0	95	4.57	0.68	
100	0	11(GS)	0	111	4.96	0.71	
40	40	9(GS)	0	89	4.30	0.66	
50	50	7(GS)	0	107	5.27	0.72	
60	60	4(GS)	0	124	5.53	0.74	
60	0	0	24(GS)	84	3.68	0.60	
80	0	0	21(GS)	101	4.52	0.68	
100	0	0	18(GS)	118	4.73	0.69	
40	40	0	18(GS)	98	4.39	0.67	
50	50	0	14(GS)	114	5.42	0.73	
60	60	0	10(GS)	130	5.60	0.74	

*CRI=Crown root-initiation stage, **Green seeker-guided fertilizer application based on equation developed at Feekes 5/6 and 7/8
Source: Annual Report, PDCSR (2006-07)

calcareous and micaceous alluvium with sandy loam to loam in texture. The soils are deficient in N, P, Fe, Zn and also K. Excessive irrigation has caused soil salinity. Consequently, nutrient and water-use efficiencies are less. The future strategies for these zones to sustain and improve the productivity of rice-wheat system should focus on optimum use of critical inputs like seeds, fertilizers and water following judicious use of organic and inorganic nutrients.

Application of FYM @ 10 t/ha, green manuring of *Sesbania* or introduction of short-duration, double-purpose legumes after harvest of wheat have a great potential in improving the nutrient and water-use efficiency. The optimum time for nursery raising should be around 10-20 May in 400 m² land using 20 kg seed and 30 t/ha FYM for one ha of transplanted rice. The crop should be transplanted with 3-4 weeks old seeding @ 2 plants/hill at 20

x 15 cm spacing. The field should be well prepared in ponded water using 2 passes with cultivators followed by planting. The ponding of water in the field should be maintained at 8 cm during the first fortnight for crop establishment and higher herbicide-use efficiency, and the subsequent irrigations should be at hair-crack stage of soil till 15 days before harvesting. Fertilizer management should comprise one-third N and full doses of P and K at transplanting and the remaining N in two equal splits at 3 and 6 weeks after transplanting.

Rice is commonly established through manual transplanting. The self-propelled mechanical transplanter using mat-type nursery (though limited in use) can be advocated as a labour-saving device. Rice can also be established direct by seeding or by wet sowing. Direct-seeding of rice is an alternative to puddled transplanting for saving in

labour and water. Weeds, can be controlled by applying butachlor @ 1.5 kg/ha and anilophos @ 0.4 kg/ha within 2-3 days after transplanting or sowing. In aerobic rice, application of pendimethalin @ 1.5 kg /ha followed by hand-weeding 40 days after sowing is a viable option for weed control.

The sowing of wheat by drill not only ensures timely sowing but also saves diesel, labour and energy worth Rs 1,500/ha. Recommended varieties of wheat using 100 kg seed/ha by drilling at 15 cm row interval should be used during the first fortnight of November because the delay of one week in sowing reduces the grain yield by 0.38 t/ha. Half the N requirement and full doses of P and K should be applied at sowing and the remaining N at first irrigation. While controlling weeds, new formulations should be used for tackling resistance problem to control *Phalaris minor*. The new formulations such as fenoxaprop ethyl 0.1 kg/ha, sulfosulfuron @ 25 g/ha and metsulfuron @ 5 g/ha in 250 liters water are viable spray schedules. Four to five irrigations are sufficient for wheat. The first irrigation should be applied 28 days after sowing and the subsequent two irrigations at 4-5 weeks interval in timely sown as well as medium-textured soils. The last irrigation to timely-sown wheat should be applied during mid-March and to late-sown, wheat in the first week of April.

CONCLUSION

The concept and experimental results discussed above clearly highlight the possibility to sustain the productivity of rice-wheat system. System of Rice Intensification (SRI) needs to be interpreted with greater explanations. The use of integrated nutrient management helps curtail the fertilizer cost by 50% without any reduction in crop yield. The site-specific nutrient management in rice-wheat system gives the benefit : cost ratio of 4.9, which advocates the scope of this component research for its large-scale adoption. The use of second generation machinery not only ensures timely sowing, combines many operations into one, saves labour cost and keeps the crop residue as effective soil cover but ultimately leads to improvement in physical, chemical and biological properties of the soil. The use of advanced technological component such as laser land levelling, use of remote sensing and GIS technology helps to develop decision-support system at on-farm level on the basis of site-specific management zone for achieving uniform higher yield. A consortium of efforts made on the part of planners, researchers and stakeholders will help in sustaining rice-wheat productivity in Indo-Gangetic Plains.

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