Fertilizer Best management practices in important cropping system

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Fertiliser Best Management Practices in Important Cropping Systems

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Nutrient management is a major component of soil and crop management system. It becomes even more important in intensive high yielding cropping system because of the increasing energy cost and economic pressure. Fertiliser best management practices (FBMPs) which emphasise on better crops and soil management strategies are meaningful options to attain sustainable higher yields. FBMPs focus on site-specific nutrient recommendations, its intensive management, improved efficiency and effectiveness, and environmentally sound use of crop production inputs. Infect the concept of applying the right fertiliser at the right time, right rate and at right place is a guiding theme for FBMPs. The intent of this publication is to compile the information available on FBMPs for pre-dominant cropping systems of the country covering the various aspects like concern of multi-nutrient deficiencies, yield gaps and means to bridge these, site-specific nutrient management. In order to tailor the BMPs at small field holders managing spatial field variability using modern tools like remote sensing, GIS, sensor based nutrient management, and nutrient experts are also discussed.

Interactive effects of crops in a particular cropping system plays important role for nutrient management and it decides the overall system productivity. The basic principal of crop rotation governs the nutritional demands for each crop of the system and its supply through interaction with available resources for sustained soil health. Similarly, cropping system of a given environment also depends upon the crop pattern followed and its interaction with available resources and enterprises. In the view of locational significance and efficient resource management Project Directorate for Farming Systems Research, Modipuram has identified thirty important cropping systems for irrigated conditions based on the rationale of spread of crops in each district of the country. 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 (34). However, the systems those are considered to be the major contributors to national food basket are rice-wheat (10.5 mha), rice-rice (5.9 mha) and coarse grain based systems (10.8 mha). Out of all these systems, rice-wheat system contributes 40% to food basket (18). Fertiliser plays a critical role in enhancing the production of all the crops in the cropping systems. However, in most cases and across the regions, the fertiliser use is skewed in favour of N (wider NPK consumption ratio). Consequently multi-nutrient deficiency which includes secondary and micro nutrients especially sulphur and zinc are also observed in many systems (27). Stagnation in productivity and decline in crop response to fertiliser also adds to the complexity of fertiliser management strategies. In the current context of food insecurity, tight fertiliser markets and of increasing focus on environmental issues, there is an urgent need to take necessary measures to maximize the benefits of fertiliser use and to minimize the negative impacts associated with its misuse, over-use or under-use. In this context, development and promotion of Fertiliser Best Management Practices (FBMPs) adapted to local conditions in systems perspective will help to improve food supply and farmer's income, mitigate the environmental footprint of fertiliser use, and reduce, if not eliminate, negative reactions against fertiliser use.

Productivity of Predominant Cropping Systems and Yield Gaps

Results obtained under AICRP-IFS reveals that a vast untapped potential in respect of the yield for all the crops prevails in different agro-climatic zones of the country. Such production gaps between potential and realizable and between realizable and averaged realized yield in the country generally ranged around 50 to 100%, respectively. The agro-climatic zone wise yield potential computed in terms of Rice Equivalent Yield (REY) at Project Directorate for Farming Systems Research, Modipuram indicates that highest productivity ranging between 8.46-12.04 t/ha for rice-wheat system, 8.61-11.35 t/ha for maize-wheat system and 5.84-7.46 t/ha for pearl millet-wheat system in Trans-Gangetic Plains. On the other hand lowest productivity of rice-wheat system (4.72-8.73 t/ha) and maize-wheat system (4.35-9.34 t/ha) was noticed in Western Himalayan region. Assessing yield gap in terms of REY for various cropping systems varies from 0.88 to 7.54 t/ha in different agro-climatic zone (**Figure 1**). Further, yield gap between state average and on-station research average varied from cropping system to cropping system and from region to region within a system. The important viable options for vertical productivity improvement are efficient input management such as balanced nutrient application, use of quality seed, and efficient crop protection measures in conjunction with increasing the irrigation facilities/infrastructure. Among the different factors,

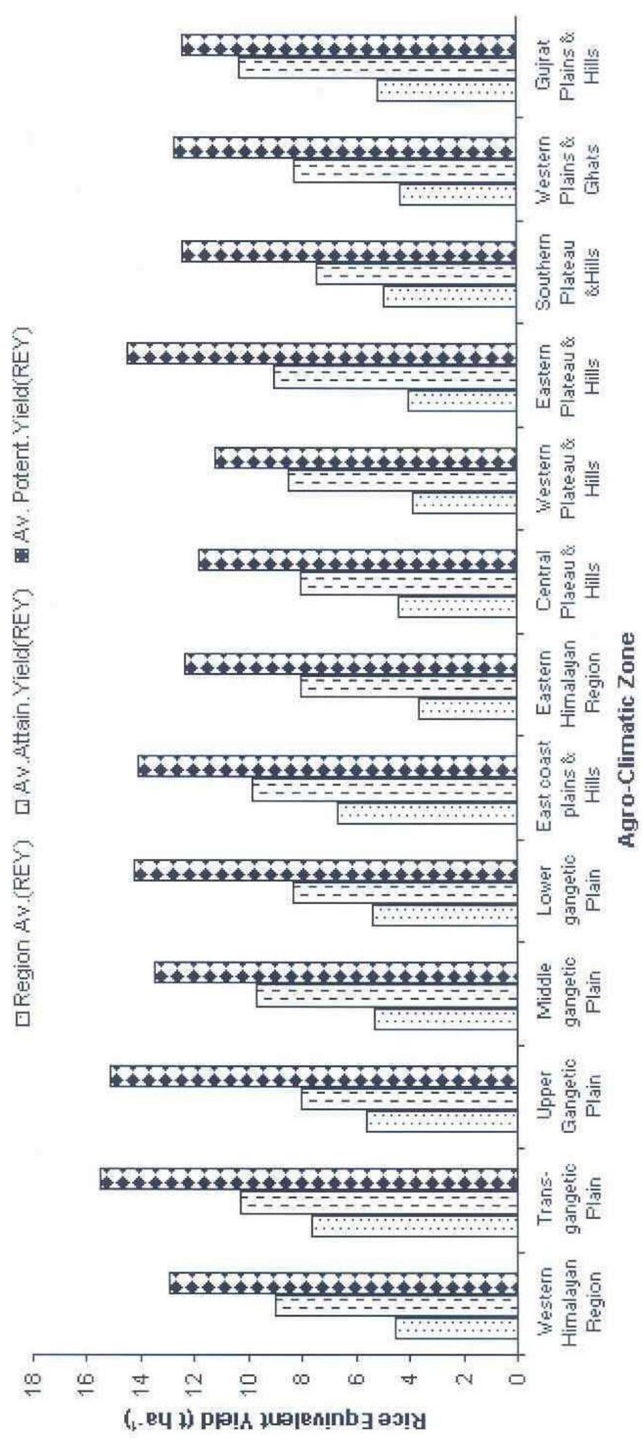

Figure 1 – Yield gap between attainable yield and potential yield under different cropping system

fertiliser of course plays a key note to bridge such gap as it alone can contribute 50% for achieving the production target. The apparent example like: average wheat productivity in Bihar and Uttar Pradesh are 43% and 61% to that of Punjab state. On the other hand, the average rate of fertiliser use in Bihar and U.P. as percentage of the Punjab is 46% and 66%, respectively (31). These facts highlight the significance of best fertiliser management practices for enhanced productivity and sustained soil health.

Major Concerns with Soil Fertility Management

Increasing Nutrient Deficiencies

Long-term studies conducted under AICRP-IFS revealed that the indiscriminate use of straight fertiliser; say N only had deletions effects on crop productivity and soil fertility (35), leads removal of other nutrients apart from N and as long as the soil has an adequate reserve of other nutrients (11). The further addition of N will fail to produce any increase in crop yield. To site a specific example, on an average, a crop of wheat removes from the soil 25, 9, 33, 5.3, 4.7 and 3.7 kg of N, P, K, Ca, Mg and S, respectively and 624, 70, 56, 24, 48 and 2 g of Fe, Mn, Zn, Cu, B and Mo, respectively per tonne of harvested grains. It is, thus, evident that balanced application of major and micronutrients is essential for getting more yields per unit area of land. During the initial years of introduction of the HYVs, only macronutrient deficiencies were discovered as an obstacle to their high yields. With passes of time the situation has worsened with increasing use of high analysis fertilisers free from secondary and micronutrients, decreasing use of organic manures and neglected recycling of crop residues. As a result, multi-nutrient deficiencies (macro+micro) are being observed in recent years (8). Soil exhaustion has spread to such an extent that N deficiency is now universal across the Indian soils, phosphorus deficiency affects is 65-70% of these soils, while potassium fertility is either low or medium in more than 50% of soils.

Intensive cropping during past decades brought a general depletion in the availability status of S and micronutrient (especially Zn, B and Fe) status of the soils, which led to increased incidence of their deficiencies in plants and also crop responses to their application (26). Since currently used high analysis fertilisers do not allow periodic addition and accretion of S in soils, the crops largely meet their S requirement through native S reserves (32). As a consequence, S deficiencies are no longer confined to coarse-textured soils and oilseed growing regions, but expanded to almost all soils and all major crops/cropping systems. Extensive field experimentation under recently concluded TSI/FAI/IFA collaborative project on 'Sulphur in Balanced Fertilisation' revealed an enhanced mining of soil S due to neglect of S application and also a build-up of soil S consequent to inclusion of S in fertiliser schedules (6, 21).

Among micronutrients, Zn deficiency is the most common soil disorder accounting for nearly 48% of the soil samples analyzed under ICAR's AICRP on Secondary and Micronutrients and Pollutant Elements (19). Next to Zn are B (38%) and Fe (12%) deficiencies. Since these estimates exclude any data on micronutrient status generated outside the AICRP, the actual magnitude of micronutrient deficiencies may be still greater. Further, the estimates on B deficiencies are based on a limited number of soil samples, because B determinations are not as frequent as those of DTPA extractable Zn, Fe, Cu and Mn. Recent studies, however, revealed occurrence of B deficiencies even in the soils of arid and semiarid regions, which are otherwise considered adequate in B supply.

Multi-nutrient Deficiencies

Emergence of multi-nutrient deficiencies in soils is repeatedly referred to in the literature, but no quantitative assessment of the nature and extent of this complex soil fertility problem exists. Databases generated under different projects and soil fertility maps developed so far deal with individual nutrients in isolation. It is not known if a soil assessed deficient in a nutrient X is simultaneously deficient in nutrient Y or Z also. Pilot-scale studies on evaluation of multi-nutrient deficiencies recently taken-up at IARI indicated widespread deficiencies of at least 6 nutrients *viz.* N, P, K, S, Zn and B in soils representing different agro-ecological regions, with NK, NPKB, PKZn, NKS and NPB as some of the prominent multi-nutrient deficiency combinations (7). The decadenal emerging multi-nutrient deficiency pattern is presented in **Figure 2**. In fact, inadequate uses of organic amendments have caused gradual depletion of soil organic carbon pool, thereby adversely affecting the physical, chemical and biological properties of the soils. Furthermore, this has led to a reducing overall soil indigenous nutrient supplying capacity. Therefore, it is of urgent need of optimum fertiliser prescription, along with integrated organic incorporation, to ensure the correction of all existing nutrient deficiencies as well as to fulfil the crop demand. Here it is pertinent to mention that full advantages of organic along with fertiliser only be harness when all deficient nutrients are fulfilled in right amount and right time.

Declining Soil Health

Total factor productivity and growth rate of productivity of crops are decreasing year after

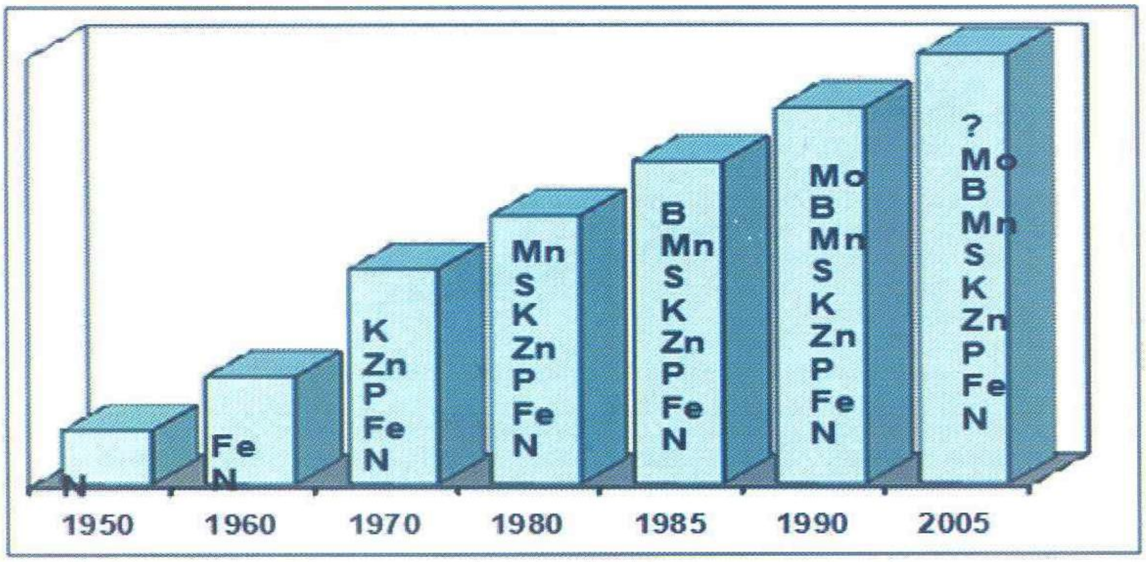

Figure 2 – Progressive expansion in the occurrence of nutrient deficiencies in India

year and deterioration of soil health is the major contributor for the same. Exhaustive cropping systems cause mining of soil nutrients far in excess of external supply. Nutrient uptake of major cropping systems (**Table 1**) indicates continuous mining of soil nutrient resource in the intensively cultivated areas. Rice-wheat-cowpea fodder system removes around 800 N+P+K kg/ha. Further, wider nutrient application gap between recommended and farmers practice also makes situation more alarming in various systems (**Table 2**). Further, study made across the major cropping systems under aegis of AICRP-IFS indicates that farmers are applying 33.3, 38.8, 57.1 and 93% lesser NPK and micro nutrients as compared to recommended doses of these nutrients. Continuous application of sub-optimal/imbalanced doses of nutrients to intensive systems like rice-rice, rice-wheat, and maize-wheat also leads to decline in soil health. Higher nutrient removal under intensive cropping systems along with smaller external fertiliser supplements emphasise the need of developing substantive nutrient management practices.

Table 1 – Nutrient uptake in high intensity cropping systems in India

Cropping systems	Yield (t/ha)	Nutrient uptake (kg/ha/year)		
		N	P	K
Rice-wheat	8.8	235	92	336
Pigeonpea-wheat	4.8	219	71	339
Maize-wheat-greengram	8.2	306	62	278
Rice-wheat-greengram	11.2	328	69	336
Maize-potato-wheat	8.6 +11.9 (t)	268	96	358
Rice-wheat-cowpea	9.6 +3.9 (f)	272	153	389

t, f represents tuber and fodder yield, Source: (30).

Table 2 – Nutrient application gap (%) between farmer's fertiliser management practice and recommended nutrient management practice in important cropping systems of India

Cropping system	No. of observations	Nitrogen	Phosphorus	Potassium	Micro-nutrients
Rice-rice	132	-1.1	-12.6	-36.4	-100.0
Rice-wheat	223	-38.9	-40.1	-79.0	-92.3
Rice-greengram	48	-53.6	-38.4	-50.4	144.6
Maize-wheat	56	-37.8	-46.7	-91.4	-28.1
Pearlmillet-wheat	36	-35.2	-56.1	-100.0	-100.0

Declining Crop Response and Widening Yield Gap

Temporal decline in response of nutrients has been observed in many cropping systems and across the systems. Decadenal study made over response to fertiliser NPK use reveals that the response of 13.4 kg yield/kg of NPK in 1960 has come down to 2.7 kg/kg (**Figure 3**). On- farm studies made in AICRP-IFS indicated that the yield gap due to application of recommended nutrient doses (Macro and micro) over farmers

Figure 3 – Temporal changes in crop response to applied nutrients

fertiliser management practice was to the tune of 2996 kg/ha under maize-wheat system followed by rice-wheat (2215 kg/ha) (**Figure 4**). Further partitioning of yield between major (NPK) and micro nutrients indicates that in case of cereal–cereal system contribution of NPK in bridging the yield gap was higher (72 to 86%) as against to micronutrients (14 to 28%). However, in rice-green gram system, the contribution was almost equal (52 and 48%, respectively). It indicates that nutrient requirement specificity varies with crops as well as with cropping systems.

Environmental Pollution

With continuous mono-cropping and indiscriminate use of fertiliser has led several environmental threats such as; methane emission from submerged rice field, ground water pollution through NO^-_3-N leaching and

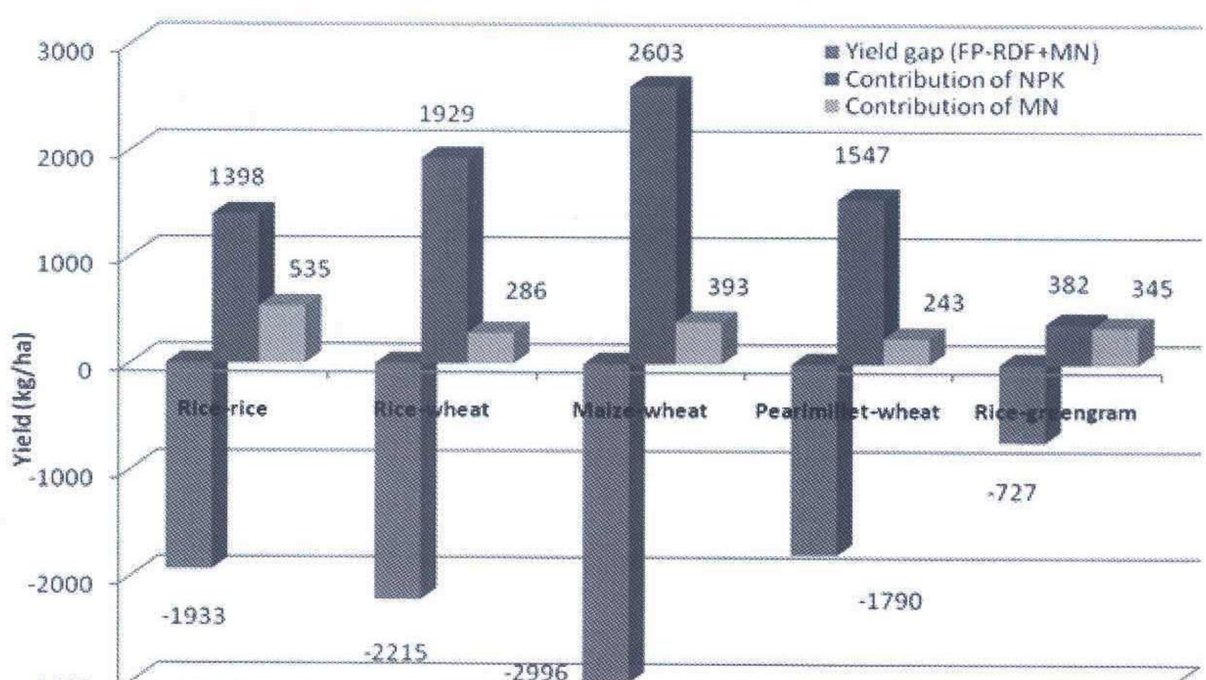

Figure 4 – Yield gap between farmer's fertiliser management practices and recommended nutrient package and contribution of major and micro-nutrients to bridging yield gap under pre-dominant cropping systems

increased concentration green house gasses through burning of rice straw. On station studies conducted in Upper Gangetic Plains reveals that imbalance nutrition to continuous rice-wheat cropping system led increased NO_3-N movement beyond the effective root zone (24).

Strategies for Fertiliser Best Management Practices (FBMPs) under Different Cropping Systems

FBMPs focus on site-specific recommendations, intensive management, improved efficiency and effectiveness, and environmentally sound use of crop production inputs. It is important to note that FBMPs are site-specific; they vary from one region to next depending on current and historic soil, climate, crop, and management expertise. Therefore, appropriate strategies for executing fertiliser management practices is of prime significance. There are three general management practices to foster the effective and responsible use of fertiliser nutrients. These are:

1) Matching nutrient supply with crop requirements,

2) Fertiliser application, and

3) Minimizing nutrient loss or transport from fields.

Within each of these general categories, these are specific practices that could be classified as FBMPs. Fertiliser best management practices (FBMPs) are agricultural production techniques and practices developed through scientific researches and verified in farmers fields to maximize economic, social and environmental benefits. Such management practices foster the effective and responsible use of fertiliser nutrients matching with nutrient supply and crop demands enhances the efficiency of applied nutrients by minimizing the losses. The specific objective behind FBMPs is to meet the targeted productivity without endangering soil health. All the crop management practices which support this philosophy fall under the umbrella of $FBMP_s$. Some of the important aspects which have direct bearing on efficient fertiliser management practices are being given here as under:

Crop Management Practices

Soil Management

Soil management practices like balanced fertilisation, application of amendments and integrated nutrient management, inclusion of legumes in crop rotation, mulching with crop residues and tillage influences the nutrient use efficiency. Studies made at Modipuram by (23) indicated in rice, optimum puddling in rice reduces leaching of nutrients and provides effective control of weeds. The partial factor productivity in rice was better when rice was transplanted with two pass of puddler (**Table 3**). On the other hand, decreasing puddling upto 01 pass of puddler had significant negative effect on rice productivity and N use efficiency.

It is pertinent to mention that optimum puddling in desirable for rice as well as to succeeding crops. But excessive puddling have ill effect on succeeding crop establishment, root proliferations, growth and development as well as on soil physical properties, therefore, an optimum puddling only to be recommended in a particular location (9).

Residue Management and Surface Mulching

There are several reports on residue management like incorporation and surface mulching for increasing nutrient and water use efficiency and building C stock to the soil. Surface mulching helps to check evaporation, improve soil water content and biological processes of nutrient transformation and chemical transformations like sorption, desorption, and fixation and diffusion of nutrients in soil through moderation of temperature and moisture in the soil. Acharya and Kapur (1) reported that application of pine needle mulch @ 10 t/ha at the time of sowing of potato in a shallow depth silty clay loam soil significantly improved tuber yield and water use efficiency (WUE), and resulted in saving of one irrigation equivalent to 40 mm. Application of mulch @ 10 t/ha with 60kg N/ha registered significantly higher tuber yield and WUE than 120 kg N/ha without mulching, indicating saving of 60 kg N/ha through the former treatment.

Nutrient Management for Modern Resource Conservation Technologies (RCTs)

The "precision land levelling with raised bed" planting can be used to improve crop yield, water and nutrient use efficiency over the

Table 3 – Effect of puddling in rice on the grain yield and partial factor productivity (PFP) of nitrogen in rice at Modipuram

Passes of puddling	90 kg N/ha		120 kg N/ha	
	Grain (kg/ha)	PFPn	Grain (kg/ha)	PFPn
One	3496	38.8	4165	34.7
Two	3747	41.6	5077	42.3
Four	3996	44.4	5452	45.4

existing "traditional land levelling with flat" planting practices. Field experiment conducted during 2002-2004 at Modipuram, India to quantify the benefits of alternate land levelling (precision land levelling) and crop establishment (furrow irrigated raised bed planting) techniques alone or in combination (layering precision-conservation) in terms of crop yield, water savings, and nutrient use efficiency of wheat production in IGP. The wheat yield was about 16.6% higher with nearly 50% less irrigation water with layering precision land levelling and raised bed planting compared to traditional practices (traditional land levelling with flat planting). The agronomic (AE) and uptake efficiency (UE) of N, P and K were significantly improved under precision land levelling with raised bed planting technique compared to other practices (10).

In order to conserving natural resources and harnessing the potential benefits of RCTs, field studies were conducted at Modipuram by (29) to evaluate permanent raised bed (PRB) vis-à-vis the conventional flat bed (FB) systems of planting at varying fertiliser NP rates in the pigeonpea-wheat system indicated that pigeonpea on PRB had greater N and P recycling (11-23% N and 8-14% P) through its residue comprising root, stubble and leaf litter. Although wheat yield following pigeonpea under PRB was lower ($p<0.05$) compared with that under FB, the system productivity in terms of wheat equivalent yield was 8.44% higher under PRB. The economic optimum doses of fertiliser N and P for wheat in the pigeonpea-wheat system were smaller (128 kg N and 28 kg P/ha) under PRB as compared to FB (152 kg N and 30 kg P/ha) owing to increased N and P supply, greater P use efficiency and a better crop growth environment under PRB planting. The P use efficiency was greater under PRB, particularly in treatments that received both N and P fertilisers. Also, in the treatments that received both N and P, post-harvest NO_3-N content below 20 cm soil depth was lower compared to those receiving N or P alone. After three crop cycles, soil OC and Olsen-P content in 0-20 cm depth were increased compared to the initial content under both planting techniques but the magnitude of increase was greater under PRB.

In another set of field experiment on rice- maize system with 75 kg K_2O/ha applied to each rice and maize conducted for 3 years on a Typic Ustochrept sandy loam with medium K_{ex} (113 mg/kg K) content at Modipuram, Meerut, mean rice K response was highest (610 kg/ha response) for transplanted puddle rice (TPR) practised on a TPR followed by conventional-tilled maize (TPR-CTM) system, followed by conventional-tilled direct seeded rice (CTDSR) (445 kg/ha response) practised on a CTDSR-CTM system and zero-till DSR (330 kg/ha response) followed by zero-till maize (ZTDSR-ZTM) system (**Table 4**). Such response for the succeeding maize was 735, 410 and 340 kg/ha, respectively, for the three systems. Further, mean K responses were comparatively higher for residue removed plots (620 to 637 kg/ha) than residue retention on surface (287 to 370 kg/ha) in both crops. Growing DSR also has pronounced effect on K response of succeeding CTM, and compared with TPR-CTM yield gain in maize after DSR due to K application was lowered by 43.6% and 44.6% in residue removed and residue retained plots, respectively. The least K responses in both rice (210 kg/ha) and maize (250 kg/ha) under ZTDSR-ZTM with maize residue retention indicate the significant K contribution through residue which was further attributed to undisturbed soil physico-chemical environment under zero-till system.

Conservation Agriculture is further helpful in enhancing nutrient use efficiency by the way of increasing soil moisture content. Acharya *et al.* (2) reported higher grain yield under conservation tillage might be due to greater root proliferation and utilization of higher amount of soil moisture

Table 4 – Response to K application (kg/ha) in rice and maize with different crop establishment practices and residue management options under rice-maize system at Modipuram, India

Crop establishment technique	Residue removed (-R)	Residue retained* (+R)	Mean K response
Rice			
TPR-CTM	830	390	610
DSR-CTM	630	260	445
ZTDSR-ZTM	450	210	330
Mean K response	637	287	462
Maize			
TPR-CTM	920	550	735
DSR-CTM	510	310	410
ZTDSR-ZTM	430	250	340
Mean K response	620	370	495

*In TPR-CTM maize residue was incorporated before rice transplanting
TPR= Transplanted puddle rice, DSR= Direct seeded rice, ZTDSR= No-till and direct seeded rice, CTM= Conventional till maize, ZTM= no-till maize.

Table 5 – Effect of tillage and N on grain yield of rainfed wheat

Tillage practices	Grain yield (Mg/ha)		
	Nitrogen	1989-90*	1990-91**
Lantana application to preceding maize and its incorporation at sowing of wheat	N_{60}, N_{120}	2813.27	3494.29
T_1 + conservation tillage in wheat	N_{60}, N_{120}	3103.83	4124.27
Repeated tillage in maize (farmers practice)	N_{60}, N_{120}	1631.83	2232.77
CD (P=0.05)	-	0.27	0.24

*5 rains of 69.5 mm in Nov., 5 rains of 114 mm in Dec.; **3.4 mm in Nov., 7 rains of 262 mm in Dec.

stored in 0-30 cm soil layer (**Table 5**). Superiority of conservation tillage with respect to yield of wheat was more pronounced at 60 kg N/ha than 120 kg N/ha thus saving of 60 kg of N/ha. This shows that moisture conserved under conservation tillage was just optimum for more efficient N utilization at 60 kg N/ha.

Efficient Irrigation Management

For higher nutrient recovery and crop productivity optimum amount of irrigation water and its scheduling is very important schedules. Studies conducted at Modipuram indicated that intermittent submergence i.e., irrigation after 02 days of disappearance of water was of greater magnitude in terms of rice productivity at a recommended fertiliser N rate (150 kg/ha) as compared to continuous submergence. Also the NO_3-N losses beyond effective root zone were lower under intermittent submergence (25). Normally, water use efficiency values are higher under water stress condition as compared to optimum and sub-optimum levels of irrigation. The total water use and water use efficiency of consumptive use increased in all the crop sequences with the increase in frequency of irrigation, whereas the water use efficiency was highest under irrigation at 0.75 IW/CPE ratio in case of high water requirement crops such as wheat and groundnut and at 0.40 IW/CPE in case of low water requirement crops viz safflower, sorghum and gram (4) (**Table 6**). Singandhupe *et al.* (20) observed that the application of nitrogen through the drip irrigation in ten equal splits at 8-days interval saved 20-40% nitrogen on a clay loam Inceptisol as compared to the furrow irrigation when nitrogen was applied in two equal splits (at planting and 1 month thereafter). Blending of urea-N and its application along with irrigation scheduling on /ha/CPE ratio had highest rice-wheat system productivity (14).

Fertiliser Application

The way fertilisers are managed can have a major impact on the efficiency of nutrient use by crops and potential impact on the surrounding environment. Four 'R' (Right time, Right amount, Right method and Right place) come in to play in the fertiliser application. Recent work done at Modipuram indicated that a major portion of the recommended N applied at rice transplanting or wheat sowing is lost and not utilized by the crop. Alternatively, skipping of basal N dressing, and application of entire recommended dose in three splits as top-dressing at 20, 45 and 70 days after transplanting/sowing appeared promising (**Table 7**).

Real-time N Supply in Rice-wheat System an Example

Improving the synchronization between crop N demand and the available N supply is an important key to improve N-use efficiency. Crop N requirements are closely

Table 6 – Input use efficiency of different crops under irrigated conditions in different agro-ecological situations of India

Crops	Locations	Soil types	Nitrogen rates (kg/ha)	IW/CPE schedule	No. & depth of irrigations	Yield (t/ha)	WUE (kg/ha cm)	NUE (kg grain/ kg of N)
Wheat	Belvatgi (Karnataka)	Clay	80	0.80	4 (6)	3.73	155	47
				0.90	5 (6)	3.83	128	48
				1.00	6 (6)	3.92	109	49
Maize	Rahuri (MS)	Clay loam	50	0.50	2(6)	3.00	250	60
				0.60	3(6)	3.50	194	70
				0.80	4 (6)	3.61	150	72

Source: (3)

Table 7 – Effect of N application schedule and doses of N application on wheat productivity

N schedules (03 splits)	N doses (kg/ha)				
	0	60	120	180	Mean
FP+CRI+PI	2154	2980	3930	4488	3388
Sowing+CRI+PI	2083	3175	4325	4650	3558
CRI+Tillering+PI	2042	3450	5038	5285	3954
Mean	2093	3202	4431	4808	-
CD at 5%N splits (S)=328; N dose (N)=422; S x N= 589					

FP= field preparation; CRI= crown root initiation; PI= panicle initiation.
Source: (25).

related to yield levels, which in turn are sensitive to climate, particularly solar radiation and the supply of nutrients and crop management practices.

A fertiliser N management strategy must, therefore, be responsive to variations in crop N requirements and soil N supply. The LCC strategy, which has been calibrated with SPAD, is a simple and efficient way of managing N in real time. However, this requires the determination of critical LCC values for a group of varieties exhibiting similar plant type and growth duration (e.g. traditional long duration, semi-dwarf short duration, hybrid etc.). Once the critical values for different varietal groups are determined, they are valid for similar groups of varieties grown elsewhere in the tropics. Therefore, the critical or threshold LCC values that optimize simultaneously the grain yield and N-use efficiency viz. Agronomic efficiency of N (AE_N) and recovery efficiency of N (RE_N) need to be defined. Studies made by (18), AE_N and RE_N exceeding 20 and 50, respectively with consistent high grain yield are regarded as efficient for rice germplasm. Likewise, AE_N of 20 and RE_N of 50 for late-shown wheat and AE_N of 25 and RE_N of 60 for early and timely-shown wheat with high grain yields are regarded efficient. Using these agronomic parameters, following LCC values were judged to be critical values: LCC ≤ 3 for Basmati, LCC ≤ 4 for Saket-4 and LCC ≤ 5 for Hybrid PHB71 for rice and LCC < 4 for all wheat cultivars (**Table 8**).

Table 8 – Grain Yield and N-Use Efficiencies (AE_N and RE_N) of three rice and wheat genotypes grown with different N management options at Modipuram

N management treatment	Total N applied kg ha^{-1}	Grain yield t ha^{-1}	AE_N kg grain kg^{-1} N	RE_N %	Total N applied kg^{-1} N	Grain yield t ha^{-1}	AE_N kg^{-1} grain	RE_N %
	Rice				Wheat			
	Genotype: Basmati 370				Cultivar: PBW-343 (Early sown)			
No N control	0	2.7	-	-	0	2.1	-	-
LCC ≤ 3, No basal N	20	3.2	26.7	69	60	4.2	**34.3**	71.6
LCC ≤ 4, No basal N	80	4.3	20.7	58	120	5.7	29.7	63.3
LCC ≤ 5, No basal N	100	4.1	15.2	52	160	6.1	24.0	55.6
Recommended N	80	3.7	14.5	49	120	5.2	25.0	52.5
	Genotype: Saket 4				Cultivar: HD 2087 (Timely sown)			
No N control	0	3.5	-	-	0	2.2	-	-
LCC ≤ 3, No basal	75	5.2	23.2	59	60	4.1	**31.6**	65.0
LCC ≤ 4, No basal	135	6.5	21.5	50	120	5.6	29.0	61.6
LCC ≤ 5, No basal	150	6.7	20.6	48	160	5.9	23.1	56.2
Recommended N	120	5.4	16.1	39	120	5.0	23.3	52.5
	Genotype: Hybrid PHB 71				Cultivar: PBW 226 (Late sown)			
No N control	0	3.8	-	-	0	1.8	-	-
LCC ≤ 3, No basal N	90	6.6	30.9	59	90	4.1	25.5	54.4
LCC ≤ 4, No basal N	135	7.6	28.1	57	120	4.5	22.7	52.5
LCC ≤ 5, No basal N	165	8.1	25.9	54	160	4.8	18.8	45.6
Recommended N	150	6.9	20.7	44	120	4.1	19.1	44.2

Source: (18)

Integrated Plant Nutrient Supply System (IPNS)

Integrated nutrient management (INM) plays a critical role in ensuring timely supply of nutrients which matches with cropping systems demand. The IPNS approach aims at efficient and judicious use of mineral, organic and biological sources in an integrated manner, so as to attain maximum economic yield without any deleterious effect on soil properties and ecological balance. With the onset of yield plateauing trends in rice-wheat system, the IPNS has gained considerable attention. Results from LTEs have established that the high productivity of rice-wheat system cannot be sustained with a single type of nutrient source, be it fertiliser or organics including bio-fertiliser (**Table 9**).

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

Table 9 – Best performing treatments under long-term experiment on INM (AICRP-IFS) for the pre-dominant cropping systems in different agro-climatic zones

Agro-climatic regions	Location	Cropping system	Treatments with source	System yield (t/ha)
Western Himalayas	Jammu (25)	Rice-wheat	50% NPK+50% N FYM (K) + 100% NPK (R)	8.0
	Palampur (5)	Rice-wheat	50% NPK+50% N FYM (K) + 100% NPK (R)	6.9
Eastern Himalayas	Jorhat (24)	Rice-wheat	75% NPK+25% N through rice straw (Winter) +75% NPK (R)	6.9
Lower Gangetic Plains	Kalyani (5)	Rice-wheat	50% NPK+50%N FYM (K) + Gobar gas slurry100% NPK (R)	7.2
Middle Gangetic Plains	Sabour (5)	Rice-wheat	50% NPK+50% N FYM (K) +100% NPK (R)	9.9
	Faizabad (5)	Rice-wheat	50% NPK+50% N FYM (K) + 100% NPK (R)	9.2
	Varanasi	Rice-wheat	50% NPK+50% N FYM (K) + 100% NPK (R)	7.5
Upper Gangetic Plains	Kanpur (5)	Rice-wheat	50% NPK+50% N FYM(K) + 100% NPK (R)	8.8
	Bichpuri (5)	Pearlmillet-wheat	50% NPK+50% N FYM(K) + 50%NPK+ 50%N GM Dhaincha (R)	8.0
Trans Gangetic Plains	Ludhiana (5)	Rice-wheat	50% NPK+50% N FYM(K) + 100% NPK (R)	11.3
	Hisar (5)	Pearlmillet-wheat	50% NPK+50%N FYM (K) + 100% NPK (R)	9.1
Western Plateau and Hills	Akola	Sorghum -wheat	100% NPK (K) + 50% NPK+50% GM (R)	6.4
	Karjat (5)	Rice-rice	100% NPK each (K+R)	11.2
	Parbhani(5)	Sorghum -wheat	100% NPK (K) + 50% NPK+50% FYM (R)	5.6
	Rahuri (5)	Sorghum -wheat	50% NPK+50%N FYM (K) + 100% NPK (R)	7.1
Central Plateau and Hills	Jabalpur (5)	Rice-wheat	50% NPK+50%N FYM(K) + 100% NPK (R)	7.6
Southern Plateau and Hills	Rajendranagar (5)	Rice-rice	75% RDF+50%N Glyricidia GLM (K) + 75% RDF (R)	8.4
	Reudrur (5)	Rice-mustard	75% RDF+25%N Glyricidia GLM (K) + 75% RDF (R)	8.2
	Kathalgere	Rice-maize	75% N+ 25%N through Rice straw (K) + 75% NPK (R)	11.5
Eastern Plateau and Hills	Raipur (5)	Rice-wheat	50% NPK+50%N through GM (K) + 100% NPK (R)	9.1
	Ranchi (5)	Maize -wheat	50% NPK+50%N FYM (K) + 100% NPK (R)	7.0
	Chiplima (5)	Rice-rice	50% NPK+50%N through GM Dhaincha (K) , 100% NPK (R)	11.7
East Coast Plains and Hills	Maruteru (5)	Rice-rice	50% NPK+50%N FYM (K) 100% NPK (R)	13.5
	Bhubaneswar (5)	Rice-rice	50% NPK+50%N through GM Azolla (K) + 100% NPK (R)	11.6
West Coast Plains and Ghat	Karmana (5)	Rice-rice	5% NPK+50%N FYM,(K) 50% NPK+ 50%N through GM (R)	9.5
Gujarat Plains and Hills	SK Nagar (5)	Pearlmillet-wheat	75% NPK+25% N through GM(K) + 100% NPK (R)	4.1
	Junagarh (5)	Pearlmillet-wheat	50% NPK+50% N FYM (K) + 100% NPK (R)	6.3
	Navsari (5)	Rice-wheat	75% NPK+25% FYM (K) + 75% RDF (R)	5.7

( ): Figures in parenthesis are number of years of experiments, *K: Kharif, R: Rabi*
Source: (16).

meet the nutrient requirement of organic basmati rice-wheat-greengram besides enhancing uptake of Fe, Zn and Mn in grains and soil microbial population and enzymatic activity (28). Nayak *et al.* (15) concluded that application of recommended dose of NPK either through fertiliser or through fertiliser 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). In a long term study being carried out since 1993 at Modipuram continuous rice-wheat cropping without fertiliser or manure application resulted in yield reduction by 28% in rice. Fertiliser applied at recommended dose also could not prevent yield decline in rice and wheat crops, although the extent of reduction was smaller (-4.5%) than unfertilised plots. Balancing of fertiliser dose with S (45 kg/ha) accounted for higher yield improvement by 8.9% in rice. Integration of sulphitation pressmud or FYM for 25% NPK substitution proved sustainable option for continuous rice-wheat cropping (22).

The results of field experiment conducted at Modipuram reveals that inclusion of cowpea as fodder in rice-wheat system during fallow period of summer (April-June) or replacement of rice with pigeon pea not only increased the total system productivity and nutrient use efficiency but also helped in trapping the NO_3-N losses occurring in rice-wheat system (**24**).

Improving the Nutrient Use Efficiency through Balanced Fertilisation

Response studies for various nutrients were conducted across the locations under on-farm experiments of AICRP-IFS. All the cereal based systems responds positively with the addition of recommended quantity of N, P and K. Among the various systems, rice-rice recorded higher rice equivalent yield (REY) of 11439 kg/ha with recommended quantity of NPK application followed by rice-wheat (8959 kg/ha), rice-greengram (8103 kg/ha) and maize-wheat (8069 kg/ha) systems (**Table 10**). Application of recommended quantity of nutrients to maize-wheat system recorded 161.8% increased yield over control followed by 95.3 and 94.8% in rice-wheat and rice-rice systems, respectively. The rice-greengram system recorded 72.4% yield increase with balanced fertilisation. Similarly, application of recommended quantity of P and K along with N registered increase in REY to the tune of 55.6, 51.9, 35.7 and 33.5% in maize-wheat, rice-rice, rice-greengram and rice-wheat systems, respectively compared to application of N alone to these systems. Among the combination of using P and K with N, it was found that application of P with N was more beneficial in rice-rice, rice-wheat and maize-wheat systems while K with N was found to be better for rice-greengram system as it registered marginal increase in yield (3.4%) with NK than NP. On an average, an additional yield (REY) of 2794 kg/ha can be obtained by application of recommended quantity of P and K with N instead of application of N alone to the cereal based systems, which is in practice under larger area of the country. The yield increase due to application P with N or K with N was found to be only 1274 and 1674 kg/ha, respectively. Maize-wheat system had maximum yield gain as it increased the yield by 161.8% with recommended quantity of nutrients over control and 55.36% over application of N alone. Higher yield obtained in balanced application of NPK to all the systems can be attributed to involvement of P in better root development and subsequent absorption of N while K is involved in N metabolism in cereals. The efficiency parameters measured in terms of productivity, agronomic efficiency (**Table 11**) and relative yield response were higher when balanced NPK fertilisation was made. Such improvement in efficiency parameters were attributed due to increased indigenous nutrient supplying capacity for N, P and K in soil under balanced NPK fertilised plots (33).

Soil Test Crop Response (STCR) based Fertiliser Application

Soil testing is one of the best

Table 10 – Rice equivalent yield (kg/ha) of cereal based cropping systems as influenced by nutrient application

Cropping system	Rice equivalent yield (kg/ha)				
	Control	N	NP	NK	NPK
Rice-rice	5871± 608	7529 ± 569	9470 ± 550	9234 ± 536	11439 ± 711
Rice-wheat	4585 ± 478	6712 ± 664	8080 ± 663	7464 ± 678	8959 ± 665
Rice-greengram	4699 ± 416	5970 ± 144	6895 ± 204	7136 ± 115	8103 ± 124
Maize-wheat	3082 ± 435	5186 ± 892	7038 ± 958	6040 ± 953	8069 ± 1032

Table 11 – Agronomic Efficiency (AE) of N, P and K (kg grain/kg of applied nutrient) of cereal based cropping systems as influenced by nutrient application

Cropping systems	AE_N		AE_P*		AE_K*	
	-PK	+ PK	-K	+K	-P	+P
Rice-rice	7.2 ± 1.2	24.4 ± 3.9 (238.9)	36.3 ± 6.1	56.5 ± 8.5 (55.6)	38.2 ± 4.9	63.1 ± 6.8 (65.1)
Rice-wheat	8.7 ± 1.4	18.5 ± 1.6 (112.6)	31.4 ± 4.0	39.4 ± 4.1 (25.5)	35.5 ± 4.2	55.9 ± 6.6 (57.5)
Rice-greengram	12.7 ± 2.7	34.0 ± 2.9 (167.7)	27.5 ± 2.6	42.5 ± 3.7 (54.5)	36.2 ± 9.5	50.2 ± 11.4 (38.7)
Maize-wheat	11.3 ± 2.5	27.2 ± 3.1 (140.7)	49.0 ± 9.5	61.7 ± 10.6 (25.9)	53.8 ± 10.3	91.5 ± 13.8 (70.1)

( ) Figures in parenthesis are per cent increase, * in the presence of nitrogen.

scientific means for quick and reliable determination of soil fertility status. Soil test crop response study in the field provides soil test calibration between the level of soil nutrients as determined in the laboratory and the crop response to fertiliser as observed in the field for predicting the fertiliser requirement of the crop.

The principle behind this concept is the existence of highly significant linear relationship between grain yield and uptake of nutrients (NPK) by crops, which mean that, for unit production of grain a definite amount of nutrient is obtained from the soil. In this methodology the information on parameters namely, (i) nutrient requirement (kg/q of grain produce), (ii) per cent contribution from soil available nutrient, and (iii) per cent contribution from fertiliser/manure nutrient are to be derived from the soil test crop response field experiment. This procedure provides a scientific basis for balanced available nutrients in soil and their actual requirement by crop. Once the actual requirement of nutrient for specific level of production is known, the needed fertiliser dose can be calculated after considering the percent efficiency of soil available and fertiliser of nutrient. Therefore, it provides the fertilisers dose in balanced and quantitative terms in relation to soil text values and crop requirement which is necessary to optimize the response to added fertilisers, maximize the profit and achieving the desired yield target with ± 10% deviation. Application of fertilisers according to the need of the situation also helps in maintenance of soil fertility and ensures sustainability of crop productivity. Field experiments conducted in Upper Gangetic Plain zone revealed that fertiliser use according to general state recommendation i.e., 120 kg N, 26 kg P and 33 kg K/ha out-yielded farmer's practice (FP) but application of fertilisers according to soil-test further increased the yield of both rice and wheat crop. Soil-test based IPNS, involving 5 t/ha SPM or 4 t/ha FYM, gave highest grain yields of rice and wheat crop under rice-wheat system (**Table 12**).

Site-Specific Integrated and Balanced Nutrition

The effective nutrient management is considered key factor to sustain the productivity of cropping systems. Location specific recommendations for balanced nutrition under different cropping system are very well documented by earlier reports, which depicts the availability of organic and fertiliser resources and their ratio to be used (AICRP-IFS, report). The on-farm studies on region specific constraints of nutrient management have pronounced effect on the increase of system productivity up to 56% over farmers practice (**Table 13**). Inclusion of legume crops (grain, fodder, and/or green manure) within cereal-based cropping systems, regularly or intermittently, is of great help due to their soil ameliorating benefits. Recycling of crop residues may be a potential organic source to sustain the soil health. Incorporation of crop residues of either rice or wheat increased the yield and yield components of rice and nutrient uptake and also improved the physico-chemical properties of the soil which provided better soil environment for crop growth. Studies carried

Table 12 – Effect of soil test based nutrient management strategies on the grain yield (t/ha) of rice and wheat under rice-wheat system on cultivator's fields in Upper Gangetic Plains

Treatments	Rice	Wheat	Total
Farmer's practice	4.80	4.37	9.17
State fertiliser recommendation for the area	5.27	4.61	9.88
Soil-test based NPK for targeted yield	5.39	4.88	10.27
Soil-test based IPNS for targeted yield	5.67	4.98	10.65

Source: (6).

out with cereal-based cropping systems under AICRP-IFS have established that 25-50% fertiliser-NPK dose of *Kharif* crops can be curtailed with the use of farm-yard manure (FYM), *Sesbania* green manure or green leaf manure or crop residues in rice-rice system under different situations. In long-term experiments on integrated nutrient management in rice-wheat system, application of 50% of recommended NPK + 50% N through crop residues in rice followed by 100% NPK in wheat through fertiliser could stabilize yields of rice-wheat system at Kanpur, whereas 50% N need of rice can be supplied by FYM, followed by 100 per cent NPK in wheat at Ludhiana. At Jabalpur, the 50% of recommended NPK + green manuring could stabilize yields of both the crops, whereas at Masodha, yields of rice and wheat were stabilized under application of 50% of recommended NPK + crop residues. At Kalyani, 75% recommended NPK + green manuring in rice followed by 75% of recommended NPK in wheat could stabilize yields of rice-wheat system and saved 25% N fertiliser in winter season. The result signifies the importance of location specific integrated nutrient management planning for sustained productivity and improved soil health.

Site- specific Nutrient Management for Breaking Yield Barrier

Site-specific nutrient management (SSNM), considering indigenous nutrient supply of the soil and productivity targets is a strategy that may provide sustained high yields on one hand, and assure restoration of soil fertility on the other. Site-specific nutrient management (SSNM) provides an approach for 'feeding' crop with nutrients as and when needed. SSNM strives to enable farmers to dynamically adjust fertiliser use to optimally fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources; which include the soil, organic amendments, crop residues, manures, and irrigation water. The SSNM approach does not specifically aim to either reduce or increase fertiliser use. Instead, it aims to apply nutrients at optimal rates and times in order to achieve high rice yield and high efficiency of nutrient use by the crops, leading to high cash value of the harvest per unit of fertiliser

Table 13 – Location specific major constraints and their management

Kharif	*Rabi*	Yield (kg/ha)			Increase (%)
I	II	I	II	Total	
Major Constraints: Micro-nutrient deficiency (zinc) under rice-rice system in Southern & High Rainfall zone (Tiruneveli), Tamil Nadu					
T_1 Farmer practice (62-25-25 NPK kg /ha)	Farmer practice (62-25-25 N-P-K kg/ha)	4046	3881	7927	-
T_1 + $ZnSO_4$ @ 25 kg/ha	T_1 + $ZnSO_4$ @ 25 kg/ha	4370	4123	8493	40.2
Full package (125-50-50 NPK kg/ha)	Full package (125-50-50 N-P-K kg/ha)	4917	4853	9770	46.5
CD (0.05)		122	172	-	-
Major Constraints: Nutrient management Prevailing system under rice-groundnut system in South Konkan Coastal zone (Ratnagiri, Maharashtra)					
$T_1$45-15-15NPK kg/ha	20-15-0 N-P-K kg/ha)	4724	2436	9596	-
T_2 100-50-50 NPK kg/ha	25-50-0 N-P-K kg/ha)	6382	3116	12614	31.45
Full package	Full package	7462	3774	15010	56.41
CD (0.05)		167	108	-	-
Major Constraint: Nutrient application in rice-rice system under Coastal Midland zone (Trissur, Karela)					
T_1 Farmer practice (40-30-18 NPK kg/ha)	Farmer practice 40-30-18 N-P-K kg /ha)	4125	4850	8975	-
T_2 T_1 + cow dung @ 5 t/ha	T_1 + cow dung @ 5 t/ha	4065	5500	9565	6.57
T_3 Recommended practice (90-45-45 NPK kg/ha)	Recommended practice (90-45-45 N-P-K kg /ha)	4595	5600	10195	13.59
T_4 T_3 (1/3 as basal + 30 kg LCC-3)	T_3 (1/3 as basal + 30 kg LCC-3)	4890	5750	10640	18.55
T_5 T_3 (1/3 as basal + 30 kg LCC-4)	T_3 (1/3 as basal + 30 kg LCC-4)	4840	6050	10890	21.33
CD (0.05)		485	367		

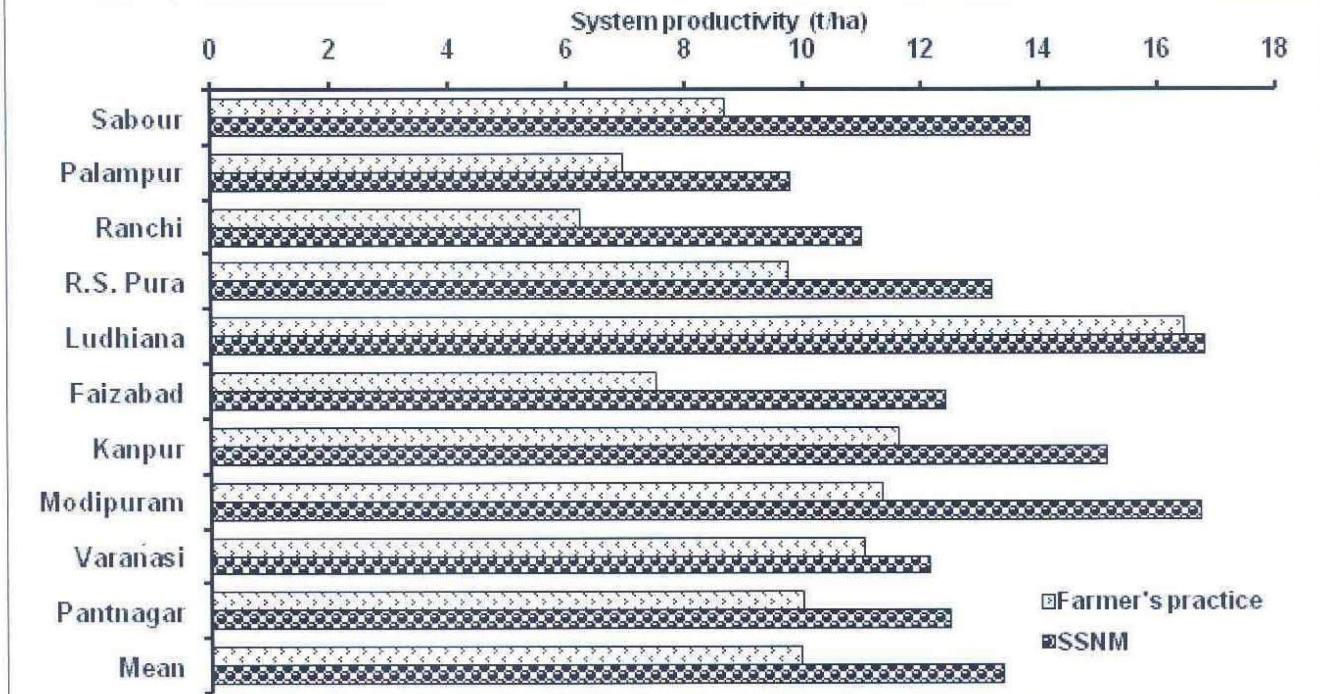

Figure 5 – Performance of site-specific nutrient management as compared to farmer's fertiliser practice under rice-wheat cropping system. (Source: 23)

invested. On-station experiment conducted in different cropping system at Modipuram as well as under AICRP-IFS indicates SSNM as a promising agro-technique to attain high productivity goals (**Figure 5**) along with additional profits (**Table 14**). SSNM not only showed the yield improvement over farmer fertiliser management practice but also over the state recommended fertiliser management practices for different crops and cropping system (**Tables 15 and 16**).

Precision Soil Nutrient Management Strategies using Sensor, GIS based Mapping and Nutrient Expert Models

Traditionally, farmers in the Indo-Gangetic Plains of South Asia and elsewhere apply nutrient uniformly as a blanket recommendation for large regions in different pre-dominant cropping systems. Many farmers often use uniform rates of fertilisers based on expected yields (yield goal) that could be inconsistent from field-to-field and year-to-year depending on factors that are difficult to predict prior to fertiliser application. Also, farmers often apply fertiliser nutrient in doses much higher than the blanket recommendations to ensure high crop yields. Large temporal and field-to-field variability of soil nutrient supply restricts efficient use of fertiliser nutrients when broad based blanket recommendations are used. Under such situations, site-specific nutrient management can effectively replace the blanket fertiliser nutrient recommendations for achieving high nutrient-use efficiency. Application of fertiliser that corresponds to the spatial variability of the nutrient need of crops should not only lead to increased nutrient-use efficiency but also to reduced possibility of fertiliser nutrient-related environmental pollution. With 86% or more operational land holdings in India having less than 2 ha (remaining 10-15% up to 10 ha), it seems that high fertiliser nutrient-use efficiency can be improved through field-specific fertiliser nutrient management because it takes care of both spatial and temporal variability in soil nutrient supply. Quantifying the spatial and temporal variability of soil properties and responding to such variability via carefully designed site- and time-specific input application are believed to enhance nutrient assimilation in crops. At present, development of sensors suited to quantify soil properties at the scale required for accurate mapping of within-field variability is a necessity. Ideally, sensor devices are fitted with a global positioning system (GPS) to allow for soil data to be captured on-the-go and instantaneously converted into distribution maps. This would facilitate real time monitoring and intervention of soil nutrient status, which can potentially offset limitations imposed by the inherent spatial and temporal variability in soil nutrient supply.

Table 14 – Changes in economic returns while shifting from farmers' nutrient management practice to SSNM in rice- wheat cropping system

Location	Crop	SSNM vs Farmers' practice			
		Extra cost of fertiliser (Rs/ha)	Value of extra produce (Rs/ha)	Net return (Rs/ha)	Net return (Rs/Re extra invested in nutrients)
Sabour	Rice	2755	21561	18806	6.8
	Wheat	1695	15198	13503	8.0
	System	4450	36759	23309	7.3
Palampur	Rice	3048	7556	4508	1.5
	Wheat	1418	9984	8566	6.0
	System	4465	17539	13074	2.9
Ranchi	Rice	3098	16914	13817	4.5
	Wheat	1665	11595	9930	6.0
	System	4763	28510	23747	5.0
R.S. Pura	Rice	5875	11271	5396	0.9
	Wheat	2955	10639	7684	2.6
	System	8830	21911	13081	1.5
Ludhiana	Rice	2940	8552	5612	1.9
	Wheat	810	3087	2277	2.8
	System	3750	11639	7889	2.1
Faizabad	Rice	4190	20313	16123	3.8
	Wheat	1860	13823	11963	6.4
	System	6050	34137	28087	4.6
Kanpur	Rice	3760	15449	11689	3.1
	Wheat	1635	9107	7472	4.6
	System	5395	24556	19161	3.6
Modipuram	Rice	1090	20822	19732	18.1
	Wheat	300	12259	11959	39.9
	System	1390	33080	31690	22.8
Varanasi	Rice	3490	6625	3135	0.9
	Wheat	600	6373	5773	9.6
	System	4090	12998	8908	2.2
Mean over location	Rice	3361	14340	10980	4.6
	Wheat	1438	10229	8792	9.5
	System	4798	24570	18772	5.8

Source: (23).

Table 15 – Increase in system productivity of different rice based cropping systems prevailing in Upper Gangetic Plains due to inclusion of secondary and micronutrients under SSNM schedule over NPK alone fertilisation at Modipuram

Cropping systems	System productivity (kg/ha) as rice equivalent yield		Gain in productivity due to S + Zn + B	
	NPK + S + Zn + B	NPK only	kg/ha	%
Rice-mustard	15218	13363	1855	12.2
Rice-chickpea	16671	15224	1448	8.7
Rice-garlic	32912	29256	3656	11.1
Rice-berseem	11796	11131	666	5.6
Rice-potato	28883	24989	3894	13.5

Source: (29).

The efficiency of site and time-specific crop-soil management and monitoring strategies can be improved by using low-cost sensors to estimate soil properties that impact crop yields. On-the-go soil sensor technologies that can serve as a rapid method for measuring soil mechanical, physical and chemical properties are steadily developing. Soil sensors can be used to generate real-time soil data, such as pH, electrical conductivity, salinity, dissolved oxygen and nutrient concentration, which are subsequently turned into geo-referenced maps to facilitate site-specific nutrient application. Numerous on-the-go sensors have been developed to measure mechanical, physical and chemical soil properties and most of them have been based on electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic and electrochemical measurement concepts.

Information on spatial variability of soil nutrients in fragmented land-holdings is quite limited in India. Initial studies by (17) revealed both spatial and temporal variation of pH during the cropping season and showed high variability in wheat and rice yields. Subsequent studies conducted at Modipuram also showed a consistent relationship of spatial variability in soil fertility with yields. Recently (12) and (13) developed village fertility maps based on spatial nutrient variability studies in the red and lateritic soils of West Bengal and Jharkhand, respectively. These maps, while highlighting the depleted nature of these soils, clearly demarcated management zones that will require different strategies of nutrient management for optimum productivity. Such studies highlighted the necessity to comprehensively understand the spatial variability of soil nutrients under the prevalent small-scale operations to develop guidelines for soil nutrient management and

Table 16 – Effect of SSNM on cane yield and economic gain over balanced NPK fertiliser schedule in different sugar mill jurisdictions of western UP (two years average)

Sites/Location of sugar mill territory	Cane yield (t/ha)				Economic gain (Rs/ha)			
	SSNM	SR	Increase due to SSNM over SR (Rs/ha)	%	SSNM	SR	Increase due to SSNM over SR (Rs/ha)	%
Mohiddinpur	72.4	65.2	7.2	11.0	86561	75805	10756	14.2
Sakoti	85.6	80.0	5.6	7.0	118929	89747	29182	32.5
Mawana	115.6	78.8	36.8	46.7	125589	103733	21856	21.1
Dourala	90.4	66.0	24.4	37.0	92622	85662	6960	8.1
Kinouni	78.0	69.2	8.8	12.7	110937	71099	39838	56.0

Source: (29).

fertilisation for optimum production, economics as well as environmental protection in the coming decades. The success of cropping system specific soil delineation for developing GIS based fertility maps in western plain zone by (22) are further advanced application of the technology for its application in wider domain with reduced expenses on soil sampling (**Figure 6**). In recent past efforts made by IPNI for developing nutrient expert for field/ crop specific nutrient recommendation which take cares of available farm resources and production level has shown pronounced significance on enhanced productivity and optimal fertiliser use under predominant crops like wheat and maize in western IGP.

FUTURE RESEARCH THRUST

To consider wide scale applicability of FBMPs and exploiting its maximum benefits following areas needs serious

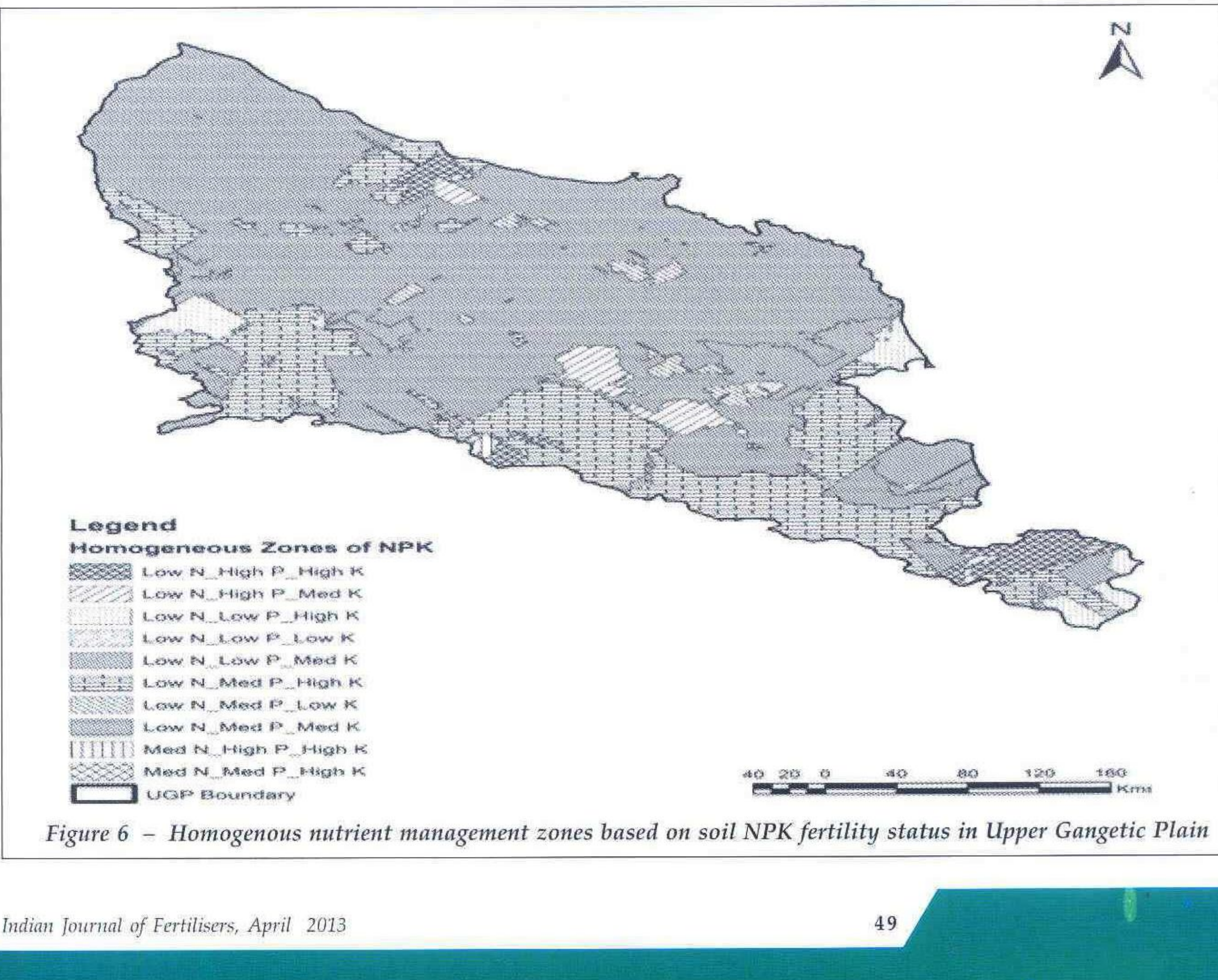

Figure 6 – Homogenous nutrient management zones based on soil NPK fertility status in Upper Gangetic Plain

attention

♦ There is paucity of information on nutrient depletion/build-up pattern in different soils owing to continuous intensive cropping and fertiliser/manure application. Benchmark sites in different productivity zones may, therefore, be identified and changes in major, secondary and micronutrient content monitored through periodical soil and plant analysis in long term basis.

♦ Integrated nutrient supply system based recommendations for different crops/cropping systems needs to be standardized quantifying precisely the nutrient efficiency and supply of all major secondary and micronutrient through organics applied in combination with fertilisers.

♦ Based on available information on LTEs on INM computer based models has to be developed for various IPNS options available under different cropping systems. Such approach may be helpful for advising the site-specific IPNS packages for varying farming systems, farm size, input availability and socio-economic situations.

♦ For harnessing maximum benefits of crop residue under FBMPs studies on in-situ decomposition of crop residues including stubbles in relations to soil properties and crop productivity are needs on short, medium and long term basis.

♦ Quantification of fertiliser equivalent of organic resources, flow and fluxes of nutrients under IPNS, in situ compositing of crop residues and nutrient input potential of dual-purpose legumes are the other important areas of BMPs demanding greater research thrust.

♦ Remote Sensing (RS) technology has the potential for the detection, characterizing, modelling of agricultural productivity based on soil nutrient variability, biophysical attributes of crops (e.g., LAI, biomass, yield etc.), biochemical properties of crops (e.g., Nitrogen content, chlorophyll, leaf water content etc.), species compositions (weeds management), detections of pests and diseases in crop and so on. Such technologies need to be studied in Indian conditions for its suitability in small scale holdings.

♦ GIS base fertility mapping for different cropping system in various agro-ecologies needs to be emphasised and these maps needs has be integrated with farmers crop management practices and socio- economic conditions for developing site-specific nutrient prescriptions. In this context, RS techniques coupled with GIS proved to be viable techniques for providing valuable information in a synoptic way.

♦ Resource conservation technology like Precision farming, variable rate fertiliser applications technologies etc. requires accurate field variability mapping from before sowing till the harvest of the crop. An interactive use of RS and GIS can play significant role for enhancing efficacy of these techniques.

♦ Monitoring long-term changes under different agro-ecological systems and building up models for prediction of changes in soil health for national planning and remedial measures has to be done.

♦ For accruing maximum potential benefit of FBMPs for different cropping systems have to be refined by collating and synthesising the existing information's.

♦ Mass awareness on location specific FBMPs need to be done and promotional literature should be prepared in local language and made available to the farmers and extension personnel in addition to some adaptive research, demonstration and specific training programmes.

REFERENCES

1. Acharya, C. L. and Kapur, O. C. *Indian. J. Agric. Sci.*, 71: 306-309 (2001).

2. Acharya, C. L., Kapur, O. C. and Dixit, S. P. *Soil and Till. Res.*, 46: 153-63 (1998).

3. Annual Reports. *AICRP on water management, Directorate of Water Management Research*, Bhubaneswar, Odisha (2004-06 & 2006-07).

4. Bharambe, P. R., Sondge, V. D., Oza, S. R., Jadhav, G. S. and Shelke, D. K *J. Indian Soc. Soil Sci.*, 51: 95-98 (2003).

5. Dwivedi, B. S., Shanker, A. R. and Singh, V. K. *Annual Report*, Project Directorate for Cropping System Research (PDCSR), Modipuram (2003).

6. Dwivedi, B. S., Shukla, A. K., Singh, V. K. and Yadav, R. L. Development of farmers' resource-based integrated plant nutrient supply systems: experience of a FAO-ICAR-IFFCO collaborative project and AICRP on soil test crop response correlation, *In*: Subba Rao, A., Srivastava, S. (Eds), Indian Institute of Soil Science, Bhopal, pp. 50-75 (2001).

7. Dwivedi, B.S. et al., IARI New Delhi and PPI/PPIC India Programme, pp 1-60, (2006).

8. Dwivedi, B.S. and Dwivedi, V. *Indian J. Fert.*, 3 (4): 11–23 (2007).

9. Dwivedi, B.S., Singh, V.K., Shukla, A.K. and Meena, M.C. *Europ. J. Agron.*, 43: 155– 165 (2012).

10. Jat, M. L., Raj-Gupta, Saharawat, Y. S. and Raj-Khosla. *Am. J. Plant Sci.*, 2: 578-588 (2011).

11. Ladha, J.K., Dawe, D., Pathak, H., Padre, A.T., Yadav, R.L., , Bijay-Singh, Yadvinder-Singh, Singh, Y., Singh, P., Kundu, A.L., Sakal, R., Ram, N., Regmi, A.P., Gami, S.K., Bhandari, A.L., Amin, R., Yadav, C.R., Bhattarai, E.M., Das, S., Aggarwal, H.P., Gupta, R.K., and Hobbs, P.R. *Field Crops Res.*, 81:159-

180 (2003).

12. Majumdar, K. and Chattopadhyay, G. N. (Unpublished), International Plant Nutrition Institute, *India Programme* (2007).

13. Majumdar, K. and Sarkar, A. K. (Unpublished), International Plant Nutrition Institute, *India Programme* (2007).

14. Mishra, R. P. and Singh, V. K. *PDFSR Annual Report*, Modipuram, Meerut, India (2011-12).

15. Nayak, A.K., Gangwar, B., Shukla Arvind, K., Sonali, P. Mazumdar, Anjani Kumar, Raja, R., Anil Kumar, Vinod Kumar, Rai, P.K. and Udit Mohan. *Field Crops Res.*, 127: 129-139 (2012).

16. QRT Reports. *Quiquinnial Review Team Report*, Project Directorate for Farming Systems Research, Modipuram, Meerut (2007-12).

17. Samra J. S., Singh, V. P. and Sharma, K. N. S. *Soil Sci.*, 145: 250-256 (1988).

18. Shukla, A. K., Sharma, S. K., Singh, V. K. and Upadhyay N. C. *In* Souvenir- of National Symposium on Second Generation Problems in Agriculture and its Remedies, Modipuram, Uttar Pradesh, India, pp 121-39 (2004).

19. Shukla, A.K. and Behra, S.K. *Indian J. Fert.*, 7(10): 14–33 (2011).

20. Singandhupe, R. B., Rao, G. G. S. N., Patil, N. G. and Brahmanand, P. S. *Europ. J. Agron.*, 19: 327-340 (2003).

21. Singh, V. K. and Gangwar, B. *PDFSR Bulletin No. 1*, Project Directorate for Farming Systems Research, Modipuram, Meerut, India, pp. 70 (2011).

22. Singh, V. K. and Mishra, R. P. PDFSR. *Annual Report*. Project Directorate for Farming Systems Research, Modipuram, Meerut, India (2011-12).

23. Singh, V. K., Tiwari, R., Gill, M. S., Sharma, S. K., Tiwari, K. N., Shukla, A. K. and Mishra, P. P. *Better Crops-India*, 2 (1): 16-19 (2008).

24. Singh, V.K., Dwivedi, B.S., Shukla Arvind, K., Chauhan, Y.S. and Yadav, R.L. *Field Crops Res.*, 92: 85–105 (2005).

25. Singh, V.K., Dwivedi, B.S., Shukla, Arvind K. and Yadav, R.L. *NATP Final report (PSR 7)*, Indian Council of Agricultural Research, New Delhi (2003).

26. Singh, V.K., Tiwari, R., Gill, M.S., Sharma, S.K., Tiwari, K.N., Dwivedi, B.S., Shukla, A.K. and Mishra, P.P. *Better Crops-India*, 2(1): 16–19 (2008).

27. Singh, Vinod K., Dwivedi, Brahma S., Roland J. Buresh, Jat, M. L., Kaushik Majumdar, Babooji Gangwar, Vidhi Govil, and Susheel K. Singh, *Agron. J.*, 105: 471–481 (2013).

28. Singh, Y.V., Dhan, D.W. and Agarwal, B. *Indian J. Agron.*, 56(3): 169-175 (2011a).

29. Singh,V. K., Dwivedi, B. S., Shukla, A. K. and Mishra, R. P. *Field Crops Res.*, 116: 127–139 (2010).

30. Tandon, H.L.S. and Sekhon, G.S. Potassium Research and Agricultural Production in India, FDCO, New Delhi, India pp. 104-115 (1988).

31.Tiwari, K. N. *Fert. News*, 47 (8): 23-49 (2002).

32.Tiwari, K. N. Proc. TSI-FAI Symposium on Sulphur in Indian Agriculture, pp SI/1/1-5, New Delhi, India (1997).

33. Yadav, R. L. *Expt. Agric.*, 37 (01): 99-113 (2001).

34.Yadav, R.L. and Subba Rao. *PDCSR Bulletin*. Project Directorate for Cropping Systems Research, Modipuram, pp. 96 (2001).

35.Yadav, R.L., Singh, S.R., Prasad, K., Dwivedi, B.S., Batta, R.K., Singh, A.K., Patil, N.G., Chaudhary, S.K. *In*: Yadav, J.S.P., Singh, G.B. (Eds.), Natural Resource Management for Agricultural Production in India, ICMNR, New Delhi, pp. 775–870 (2000). ■