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Review

Integrated Plant Nutrition System for Sustainable Rice-Wheat Cropping Sequence

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ABSTRACT

Present rice and wheat yield levels in Pakistan are low compared to developed and even many developing countries of the world. In view of increasing population trends, there is dire need to increase the crop yield per unit area. Sound soil fertility management strategies can play a pivotal role to increase and sustain the productivity of the system. For this purpose, an integrated plant nutrient management strategy involving the use of inorganic fertilizers on soil test basis at the proper time, by appropriate method of application, in balanced form and using all the possible sources of organic manure (FYM, green manures, composts, crop straw and bio fertilizer etc), has to be adopted. This will definitely enhance the productivity of rice and wheat crops by improving soil fertility and ameliorating adverse soil physical conditions. This paper reviews the effect of integrated plant nutrition system (IPNS) practices on sustaining the productivity of Rice-wheat cropping sequence.

Key Words: Rice-wheat; IPNS; Organic manure; Productivity; Cropping sequence

INTRODUCTION

In Pakistan, rice-based cropping system is practiced as Rice-wheat (R-W), rice-berseem, rice-pulses and rice-fallow. R-W cropping system in which rice and wheat are grown in a sequence is the major cropping system. R-W cropping system is practiced on 1.5 mha in Punjab and 0.3 mha in Sindh. Initially, the use of mineral fertilizers, improvement in crop cultivar, plant protection practices and increased irrigation coverage had led to green revolution. Despite the prime position of rice and wheat in food security and economy of country, productivity of system is poor with average rice and wheat yields of 2.0 and 2.25 Mg ha^{-1}, respectively (MINFAL, 1999). The crop yields in the system are stagnant and there are signs of declining factor productivity.

R-W system is a nutrient exhaustive system and is mining the soil nutrients at a rapid pace. A system yielding 3 Mg ha^{-1} each of rice and wheat may remove 148 kg N ha^{-1}, 45.4 kg P_2O_5 and 207 kg K_2O ha^{-1} (Zia, *et al*., 1999) apart from significant amount of different secondary and micronutrients. Fertilizer addition in the system is 135 kg N, 65.1 kg P_2O_5 and 2.1 kg K_2O ha^{-1} (NFDC, 1993). Thus, there is net negative balance of 13 kg N ha^{-1} and 205 kg K_2O ha^{-1}. In addition, fertilizers combined with low nutrient resources of soil, increased cropping intensity and irrigation have induced deficiencies of zinc (Zn) and boron (B) in particular and iron (Fe) on calcareous alkaline soils. Under these conditions, unless the system is provided with adequate amount of required nutrients, there will be much drain on the natural soil fertility. Thus soil will not be able to improve crop yield in the system and sustain even the present productivity level in future.

Besides the main reasons for poor wheat yields, it is attributed to deteriorated soil structure due to sodicity and puddling for rice. After the harvest of rice, when the land is prepared for sowing of wheat, big clods are formed, which affect the germination of wheat seed due to poor soil to seed contact and rapid loss of moisture. In addition, after the germination of wheat, when irrigation water is applied to the crop, it stands in the field for few days causing temporary water logging. This affects the wheat growth by creating O_2 stress, which leads to tremendous losses of N due to denitrification. Salinity/sodicity, calcareous nature of soil and high soil pH lead to tremendous NH_3 volatilization and thus greatly reducing N use efficiency. These characteristics also affect the availability of P and micronutrients to the crop.

In view of all above, soil fertility management is, therefore, extremely important for increasing the productivity of R-W cropping system. At the stage when the soil fertility is being depleted at a rapid pace and soil physical conditions deteriorated due to low organic matter in soil, IPNS is the most effective approach to rejuvenate the soil health improves soil productivity and increase crop yields at the farm level. This paper, therefore, presents a review on the impact of some of IPNS practices for increasing and sustaining the productivity of R-W system.

Soil fertility issues and nutrient deficiencies in R-W cropping system. The most important fertility related issues in the R-W system are low soil organic matter, conditions contrasting agro-ecosystem for growing of rice and wheat crops, nutrient depletion, low fertilizer use, poor fertilizer use efficiency, imbalanced use of fertilizers and negligible use of micronutrients especially the Zn.

In agricultural soils of Pakistan, organic matter content is low. It ranges from 0.8 to 1.2%, 0.5 to 0.8, 0.3 to 0.6% and 0.3 to 0.5% in rice zone 1, 2, 3 and 4, respectively (Zia, 1990). As a result inherent fertility status, especially of N is poor. Thus both the crops in the system require N fertilization on all paddy soils.

Both the rice and wheat crops in the system are grown under contrasting agro-ecosystem. Under flooded and irrigated condition, rice is mostly grown under anaerobic soil conditions. Under these conditions redox potential falls to -300 mV and native nitrate-N is lost by denitrification and ammonical N that becomes the dominant N species. Also the availability of P, K, Mn and Fe increases and that of S, Cu, and Zn decreases (Ponnamperuma, 1985). On the other hand, under aerobic condition, as under wheat crop, soils are in the oxidized state with high Eh and have both ammoniacal and nitrate N species. Under these conditions availability of S, Zn, Cu increases, whereas that of P, K, Mn and Fe decreases.

R-W happens to be a nutrient exhaustive production system. Nutrient removal by both crops exceeds that of nutrient addition. Thus there is a negative nutrient balance. Therefore, there are wide spread deficiencies of nutrients. Due to calcareous alkaline nature of these soils, P content was low to medium in majority of the rice soils (Zia, 1990). Because of dominance presence of illitic mica in these soils, K deficiency was comparative less. As regards micronutrients, Zn was a major problem and its deficiency was registered on 93% soils. Boron deficiency was recorded on 15-20% soils. However, Cu, Fe and Mn were found in adequate amount for normal crop production (Zia, 1990).

Comparing other developed and developing countries fertilizer use in Pakistan is only 116 kg ha^{-1} (Fathy, 1999), which is quite low. Overall fertilizer use in the country has increased substantially. During the period from 1990-91 to 1999-2000, it has increased by 19.2%. However, fertilizer use is highly imbalanced in favour of N (NFDC, 2000). Out of total fertilizer use 78.5% is N fertilizer, 20.7% P fertilizer and use of potash has been negligible (< 1%). Out of total fertilizer used in the country, 48% is consumed by wheat and 12% by Rice (NFDC, 1998).

Nutrient use efficiency in R-W system. Despite substantial increases in consumption of fertilizer in the country, crop yields have not increased proportionately indicating that fertilizers are not utilized efficiently. Efficiency of N under flooded lowland rice ecosystem ranges 30-45%, compared to 40 to 60% under upland crop conditions (Zia *et al.*, 1988 a, b). Recovery of added P by wheat varies from 10-23% and generally goes down with the increase in rate of application, but in absolute terms it increases (Tandon, 1980). Under wetland rice, its efficiency is slightly better (20-25%). Efficiency of potash is about 80% in wetland rice and 60% in upland wheat. Efficiency of Zn in wetland rice hardly exceeds 10% and in upland wheat, it varies from 15-20% (Zia *et al.,* 1999).

IPNS Concept. The basic concept underlying IPNS is the maintenance or adjustment of soil fertility to an optimum level for sustaining the desired crop productivity through optimizing the benefits from all possible sources of plant nutrients in an integrated manner. IPNS is aimed at maintenance of soil fertility, sustaining increased crop productivity, improving and rejuvenating soil health through improvement of soil physical conditions and improving farmer's profitability through judicious and efficient use of chemical fertilizers, organic manures, crop residues, compost and bio-fertilizers. IPNS involves a low to medium external input approach, taking into account a holistic view of soil fertility and plant nutrition management for a targeted yield based not only on cropping and farming systems but also on distinct geographical areas or villages a dynamic system. The IPNS approach can be modulated; a factor of targeted yield in any area according to land, water and climatic potential.

The cropping system rather than an individual crop and the farming system rather than individual fields are the focus of attention in this approach for developing IPNS practices for major agro-ecological zones. The best associations of various types of plant nutrients in different fields are identified for a balanced plant nutrition and high yield at the same time sustaining soil fertility and controlling nutrient losses. It is envisaged that locally available materials of plant and animal origin as by products of agricultural activities be used or where such materials are not available *in situ* production of organic be attempted. Introduction of green manuring of living or dead cover in the cropping system can also contribute to nutrient supplies. Status of IPNS in a selected village near Pindi Bhattian

Table I. Major cropping systems in village Thatta Karimabad near Pindi Bhattian

Cropping System	No. of farmers	Per cent farmers
Rice Wheat	25	46
Wheat Legume	29	54

Source: NFDC (1987)

Table II. Survey status of IPNS in village Thatta Karimabad

Category season	No. of farmers	Per cent
Fertilizer		
Rabi	70	100
Kharif	69	99
Farm yard manure	58	83
Own source	51	72.9
Purchased	1	1.8
Both	6	8.57
Green Manure	3	4.3
Compost	0	0

Source: NFDC (2000)

A survey was carried out by NFDC during 2001 to assess the status of IPNS in a village where mostly R-W cropping system is in practice. For this purpose, village Thatta Karimabad near Pindi Bhattian was selected. In this village, 46% of the farmers are following R-W cropping system. However, wheat legume system is the major cropping system, adopted by 54% farmers (Table I). In this village, almost all the farmers use chemical fertilizers during Rabi and Kharif. A large number of the farmers (83%) also use farm yard manure (FYM), about 73% from their own source and 1.4% by purchasing. Only 3% of the farmer used green manures but the farmers using it are quite convinced due to its positive effect on crop yield and soil productivity. No body uses compost in the area (Table II).

Effect of IPNS practices on crop yield and nutrient use efficiency. Both rice and wheat crops grown in a sequence are exhaustive feeders of soil nutrients. Unless adequate amounts of nutrients are supplied, it will be difficult to sustain the full yield potential of R-W system on a long-term basis. Since the soils are continuously in the process of nutrient depletion, therefore, along with macronutrients, deficiencies of micronutrients are likely to occur. Under such conditions, even if all the nutrients are applied in right amount, productivity of R-W will be constrained by single deficient nutrient not taken care off. In view of low organic matter in the soil, all the possible sources of nutrients both inorganic and organic are needed to replenish the nutrient removed and to improve organic mater levels for improving and sustaining productivity of the system.

The concept of IPNS is being used successfully in China and Vietnam and to some extent in Nepal. Its benefits can also be harvested in Pakistan especially in R-W system. Results of research studies carried out on IPNS practices are discussed as under.

Soil test based fertilizer recommendations. Site-specific fertilizer recommendations for crops, based upon soil test, are one of the most effective techniques to replenish the deficient nutrient in soil, improve crop yields and fertilizer use efficiency. It helps to avoid the application where responses to fertilizers are not expected. Fertilizer thus saved can be applied where substantial responses are expected (Crasswell & De Datta, 1980). Nitrogen requirements of rice have been reported to vary depending upon the native N status. Soils low in total N (<0.1%) need basal and top dressing application. Soils moderate in N (0.1-0.2%) need only a top dressing and mineral soils high in N (>0.2%) may need no fertilizer for a yield of 5 Mg ha^{-1} (Ponnampenuma, 1985). Similar is the case with other nutritionist. In a study on wheat, N fertilizer requirement in relatively rich fertile soil with mineral N of 91 kg ha^{-1} was only 25 kg ha^{-1} compared to 125 kg ha^{-1} on relatively poor fertile soil containing 19 kg mineral N ha^{-1} (Tahir *et al.,* 1997).

Balanced crop nutrition. Most paddy soils need N and P application. Good crop yield cannot be ensured with adequate supply of these nutrients if some micronutrients like zinc or boron are deficient in soil. In one study balanced application of NPK Zn and B increased rice yield by 104% (Zia, 1995a). It also helped to increase N use efficiency significantly. In the balanced nutrition of rice, ratios between fertilizer nutrients are also very important. In Pakistan with recommended doses of nutrient for various crops, ratio is 1.5:1 between N and Phosphate (P_2O_5). Present N: P ratio is 4:1 (NFDC, 2000), which has gradually deteriorated from 3.2:1 in 1984-85 (NFDC, 1985). This indicates that P_2O_5 use has declined. This could be one of the major factors for stagnant crop yield in Pakistan. Therefore, phosphate use needs to be promoted both by public and private sectors. Similarly use of potash and zinc need to be encouraged for enhancing crop yields and improving fertilizer use efficiency.

Proper fertilizer sources, method, time of application and effect of amendments. Nitrogen is the major input being used for rice production. Nitrogen fertilizers are not used effectively by the rice and losses upto 60% of the N applied have been reported. Ammonia volatilization is recognized as major mechanisms of loss (De Data *et al.*, 1990; Buresh & De Datta, 1991). Strategies to reduce the losses and improve fertilizer use efficiency have been discussed by Zia (1995b) and Zia *et al.* (1998), which are basal incorporation of urea without standing water, deep placement of urea and modification of urea with algaecides and urea inhibitors or coatings. Loss of N by nitrification/denitrification may be a serious problem, particularly when soil is dried after rice crops, left fallow and then flooded for subsequent rice crops. N use efficiency for rice was improved significantly with application of N fertilizers with gypsum or KCI or Aluminum sulfate alone or with their combinations (Zia *et al.*, 1997). Good crop management practices can improve crop yield and fertilizer use efficiency. Improved crop management practices such as good land proportion, proper seedling age, right time of transplanting, crop variety, adequate supply of irrigation water, control of weeds and insect pests can significantly improve the rice yields and fertilizer use efficiency (FAO, 1980).

For rice, generally ammonium-containing fertilizers, such as ammonium sulfate and urea, have been found to be comparatively more efficient than nitrate containing fertilizers (Zia *et al.*, 1988b; 1992b). For wheat, calcium ammonium nitrate (CAN) proved to be more efficient than ammonium sulphate and urea, which followed the order (Arshad *et al.*, 1999). In another study, the combined use of urea or CAN with different levels of organic matter was tested for rice production. Urea caused a significant increase in yield of paddy and N uptake compared to CAN, at three organic-matter levels tested (Mian *et al.*, 1988).

Table III. Effect of P sources for rice (average of three years)

Treatment	Paddy yield (kg ha^{-1})	Agronomic efficiency
T1 Control	3423	-
T2Nitrophos,NP+ Urea	4992	11.62
T3 TSP + Urea	5998	19.07
T4 MAP + Urea	5862	18.80
T5 DAP + Urea	5773	17.41

NP (135-67 kg ha^{-1}); Source: Bhutto *et al.* (1987)

Regarding phosphorus (P) management for rice, when agronomic efficiency of different P sources was tested, nitrophos (NP) plus urea gave the lowest efficiency i.e. 11.62 and triple super phosphate (TSP) + urea gave the highest efficiency i.e. 19.07 kg paddy kg^{-1} P_2O_5 (Table III).

While the agronomic efficiencies with mono-ammonium phosphate (MAP) + urea and di-ammonium phosphate (DAP) plus urea were, 18.80 and 17.41 kg paddy kg^{-1} P_2O_5, respectively (Bhutto *et al*., 1987). However, for wheat, a combination of SSP plus ammonium sulfate gave significantly higher yield than TSP plus urea but was at par with nitrophos plus urea (Malik, 1990). In another greenhouse study, the direct effect of graded rates of P (0 to 36 mg kg^{-1}) on wheat and its residual effect on rice were investigated under pot-culture conditions. Results revealed that wheat grain yield increased with increasing level of P. Maximum increase in wheat-grain yield over control was recorded with 36 mg P kg^{-1} soil. Rice yields in the sequence also increased, due to residual P applied to wheat, and maximum paddy was recorded with the application of 48 mg P kg^{-1} soil (Zia, 1988b).

Zinc deficiency in rice can be controlled by applying 5 to 15 kg ha^{-1} $ZnSO_4$ at 10 days after transplanting, dipping the nursery roots before transplanting in 1% $ZnSO_4$ or 2% ZnO suspension (Zia *et al*., 1988 a, b). In pot study, the direct effect and residual effect of applied Zn was investigated. Results revealed that direct effect of Zn applied to wheat was less as compared to its residual effect on paddy yield. Wheat grain-yield increased only by 4.5% with the application of 12 mg Zn kg^{-1} soil. Paddy-yield increased with increasing levels of Zn and a maximum increase of 15.2% in paddy-yield was observed with the application of 18 mg Zn kg^{-1} soil to wheat (Zia, 1988 a).

Contribution of green manures in increasing productivity of R-W system. Green manuring with N fixing legume is possible in R-W system. In Indian subcontinent, wheat is fielded off in mid April to early May with a lag period of 40-70 days for rice planting. A suitable green manuring species can be established in this fallow period and incorporated into the field, 45 to 100 days after seeding just before transplanting. Green manure crops improve the soil physical conditions (SFI, 1980), improve soil fertility (Rao & Gill, 2000; Buresh, 1993) and enhance availability of other nutrients (Hundal *et al*., 1988; Nagarajah *et al*., 1989). Improvement in soil fertility and physical conditions will surely improve the productivity of system. Practices, which affect the growth of green manuring crops, will also affect the N accumulation by that crop. For example P plays a key role in the symbiotic N fixation process. It is observed that use of 60 kg P_2O_5 ha^{-1} to green manure crops produced higher dry biomass and N harvest than the crops, which did not receive P in all the years. *Sesbania aculeata*, however proved a fast growing green manure legume and its productivity (5.5 Mg ha^{-1} dry weight and 109 kg N ha^{-1}) was almost three times higher than *Crotelaria juncea* in 1997 (Mann *et al*., 1999; Table IV).

Green manuring is an excellent source of N for the first rice crop following its incorporation but becomes a poorer source for the subsequent wheat crop. In most cases green manure N exceeds 120 kg ha^{-1}, which is more than sufficient for rice and occasionally leaves residual effect on soil fertility. In a field study, even after the harvest of rice sown after green manuring, soil organic matter and total N content improved (Zia *et al*., 1992). This improvement in residual organic matter and N fertility is likely to improve the crop yield after rice. From Pakistan, significant residual effect of green manuring on wheat yield after rice has been reported (Mian *et al*., 1988). Another study showed 9% improvement of wheat yield after green manuring (RRI, 1988).

Table IV. Effect of continuous Pre-rice green manure (three years) on wheat crop in rice-wheat cropping system, K.S.K, 1997

Treatments	Grain Yield (Mg ha^{-1})	
	1st. year	3rd. year
Control	1.60	1.41
90-60 kg N P/ha (as inorganic fertilizer)	3.91	3.86
Sesbania aculeate	2.34	3.64
Sesbania rostrata	2.24	3.78

Source: Mann (1997)

Similarly in Pakistan, effect of different green manures, FYM and inorganic fertilizers was studied in R-W system. Sunhump and sesbania green manure produced the higher rice yields than the other green manures and FYM. These green manures had also significant residual effect on the yield of following wheat crop. In a field study contribution of sesbania green manure, rice straw and FYM was studied along with urea-N. Both FYM and sesbania had similar effect on rice yield and were more effective to

Table V. Effect of inorganic and organic fertilizers on rice yield and residual fertility

Treatments	Straw yield	Grain yield		Residual fertility		
	(Mg ha^{-1})	(Mg ha^{-1})	O.M (%)	Total N (%)	AB-DTPA P (mg kg^{-1})	Ext. K (mg kg^{-1})
Control	4.2	3.7	0.52 c	0.055 c	6.45 c	145 b
Urea N	6.4	5.5	0.52 c	0.058 b	6.41 c	142 b
Urea N + GM	7.4	6.2	0.58 b	0.064 a	6.42 c	140 b
Urea N + FYM	7.5	6.5	0.61 a	0.062 a	6.90 a	152 a
Urea N + Straw	6.7	6.0	0.63 ab	0.061 a	6.63 b	154 a

Source: Zia *et al*. (1992)

increase rice yield compared to rice straw (Table V). Additional uptake of N due to green manure, FYM and rice straw amounted to 15, 13 and 2.85 kg ha^{-1}. Residual N fertility was the highest with sesbania green manure followed by FYM and rice straw (Zia, 1992). Residual P fertility was higher in case of FYM than other treatments. Whereas the residual effect of K fertilizer was the highest where rice straw was incorporated.

Other several studies on the integrated use of green manuring and the inorganic fertilizers have been carried out in Pakistan (RRI, 1988; Mian *et al*., 1988; Bhatti *et al*., 1988). One thing in these studies is quite clear that efficiency of green manuring crop to improve crop yield was quite high at no or low level of N fertilizer application and it dropped with increasing fertilizer dose. In one study, maximum rice yield of 3.24 Mg ha^{-1} was realized with 202 kg N ha^{-1} without green manuring. But with green manuring even the higher yield (3.68 Mg ha^{-1}) was obtained with 135 kg N ha^{-1}. Actually for maximum yield, the N release pattern should coincide with the N requirement or uptake of rice. If the release pattern does not coincide with N requirement of rice, supplemental application of chemical N would be needed. Therefore, adding inorganic N at 40-50 days after transplanting can be beneficial (Meelu & Morris, 1988).

Table VI. Effect of Azolla and N on paddy and wheat yield in rice-wheat cropping system

Treatments	Paddy Yield (Mg ha^{-1})	Per cent increase over control	Wheat yield (Mg ha^{-1})	Percent increase over control
Control	3.91	-	1.74	-
30 kg N ha^{-1}	6.13	56	2.75	58
30 kg N ha^{-1}+Azolla incorporated	6.68	71	3.36	93

Source: Sikander *et al*. (1998)

Benefits of Azolla green manure in R-W can also be harvested in comparatively cooler climatic regions especially in Swat valley and in lower Sindh. In a field study, Azolla green manuring increased rice yield by 15% and of following wheat yield by 35% (Table VI). In a green house study the effect of N and P application was investigated on N contribution of Azolla in R-W system. Rice grain yield was significantly increased due to N application (0, 50, 100 mg kg^{-1} soil) in the absence of Azolla. Phosphorus application upto 24 mg kg^{-1} increased the rice yield significantly. Further increase in P dose upto 36 mg kg^{-1} had no further effect on the yield. Maximum contribution of Azolla green manuring in N uptake occurred at the lowest N (50 kg N kg^{-1}) and medium P level of 24 kg kg^{-1}. Higher dose of both N and P was not favourable for growth of Azolla. Azolla green manuring increased organic matter and N content of soil after rice crop harvest that increased the yield of following wheat crop (Zia *et al*., 1998b).

Integrated use of farm yard manure and chemical fertilizers. Farm yard manure is the most important of organic manures. It is decomposed mixture of dung and urine of animals with straw and litter used for bedding and residues from fodder. Animal dung is the major component of FYM. In Pakistan there is tremendous potential for producing FYM. The use of FYM is extremely important from the point of view of improving soil fertility. Results of the studies have revealed that 5 Mg ha^{-1} of FYM can replace 60 kg N, 40 kg P_2O_5 and 30 kg K_2O if well managed and well rotten FYM is incorporated in the soil (Zia, 1989). Mian *et al.* (1988) reported the effect of FYM in combination with N sources on the yield of rice and wheat crop. Results revealed that application of FYM to rice not only increased the rice yield but it also improved the yield of following wheat crop (Table VII).

Premixing of P with FYM can improve its efficiency. Studies have revealed that if the P fertilizer is applied after mixing with double the quantity of well rotten FYM, its fixation in soil is reduced (Sharif *et al*., 1985). Further the affect of premixing of FYM with SSP was investigated in a field study and reported significant increase in wheat yield. Wheat yield due to 40 kg P_2O_5 as SSP premixed with FYM was almost at par with 60 kg P_2O_5 as SSP when used alone, indicating about 50% saving of P fertilizers (Table VIII).

Effect of crop straw on crop yield. If the farmers can afford to incorporate the rice and wheat straw into the soil, they can very well improve the soil productivity. Ponnamperuma (1984) has reported the positive effect of

Table VII. Effect of FYM on rice and wheat yields at different rates of N application

N Rates (kg ha^{-1})	Crops yield (Mg ha^{-1})			
	Without FYM		With FYM	
	Rice	Wheat	Rice	Wheat
0	1.64	1.78	1.76	2.13
75	2.53	2.16	2.87	2.56
150	3.56	2.62	3.62	3.31

Source: Mian *et al*. (1988)

Table VIII. Effect of premixing of FYM with SSP on wheat grain yield

Treatments	Wheat Grain Yield (Mg ha^{-1})	
	1974-75	1975-76
Control	4.48	4.05
FYM only	-	4.18
SSP-40*	4.97	4.78
SSP-40 + FYM (Unmixed)	4.97	4.81
SSP-40 + FYM (Premixed)	5.28	5.20
SSP-60* alone	5.26	5.25
LSD (P=0.05)	1.80	3.64

P_2O_5 kg ha-1; Source: Sharif *et al.* (1985)

Table IX. Rice dry matter yield (root + shoots + grain) and nitrogen uptake from soil amended with wheat straw and/or N fertilization

Wheat Straw amendment (%)	Fertilizer N (mg/pot)	Rice yield (g/pot)	N uptake (mg/pot)
0	0	42.5	224.9
0	120	60.8	311.0
0	360	81.6	469.1
0.1	0	39.3	214.5
0.1	120	47.3	264.7
0.1	360	67.8	429.2
0.3	0	25.6	151.2
0.3	120	38.0	209.1
0.3	360	62.8	407.6
LSD (P=0.05)	-	3.7	22.4

Source: Farooq (1990)

rice straw incorporation on soil fertility. In short-term studies, there can be negative effect of straw incorporation. Farooq (1990) reported reduction in rice yield and N uptake when straw was used @ 0.1%. Crop yield and N uptake was further decreased when the rate of straw incorporations was increased to 0.3% (Table IX). He further reported that when the period of incubation after straw incorporation was two weeks, differences in yield and N recovery due to lower rate (0.25%) and higher rate (0.50%) were greater. The yield and N recovery were also higher at lower rate of straw incorporation. But these differences diminish when the period of straw incubation after its incorporation was increased to 4 week (Table X). In one study effect of wheat straw management was investigated on N use efficiency for rice. Results revealed that burning of wheat straw significantly improved the rice yield and N recovery than the treatment where straw was retained. Recovery was the highest with sulphur coated urea whereas N application in 3 splits produced similar results (Zia, 1992).

Table X. Wheat dry matter yield (root + shoots + grain) and nitrogen recovery from soil amended with rice straw residues and fertilized with ^{15}N ammonium sulphate

Rice straw incubation conditions		Yield (g/pot)	N recovered plant + soil (%)	Unaccounted (%)
Incubation duration (Weeks)	Application rate (%)			
-	-	32.3	58.9	41.1
2	0.25	26.3	50.5	49.5
	0.50	25.6	54.6	45.4
4	0.25	28.3	57.2	42.8
	0.50	23.2	56.6	43.4
LSD (P=0.05)	-	2.15	-	-

Source: Farooq, 1990

Effect of compost on crop yield. Compost, prepared from crop residue, stubbles, Kallar grass, weeds, fallen leaves, remnants of fodder and green manure etc, can also be used for improving productivity of R-W system. In one study the effect of 2.5, 5 and 10 tones compost per hectare was investigated in rice wheat system with and without the use of urea-N. Without the application of urea N increasing rates of composts lowered the rice and wheat yields. Reduction was higher at the higher rate (10 Mg ha^{-1}) of compost application. With the use of urea @ 100 kg ha^{-1} to each crop, the yield of both the crops was significantly enhanced at lower (2.5 Mg ha^{-1}) and medium rate (5.0 Mg ha^{-1}) but the higher rate of compost (10 Mg ha^{-1}) application was not beneficial (Farooq, 1990, Table XI).

Table XI. Direct and residual effect of urea, compost and compost + urea on rice and wheat yield

Treatments	First Crop	Second Crop
	Rice grain yield (kg ha^{-1})	Wheat grain yield (kg ha^{-1})
Control	2725	4088
Urea-N	4613	6238
Compost 2.5 (Mg ha^{-1})	3212	6012
Compost 5.0 (Mg ha^{-1})	3175	5988
Compost 10 (Mg ha^{-1})	2963	6025
Compost 2.5 (Mg ha^{-1}) + Urea	4950	6063
Compost 5.0 (Mg ha^{-1}) + Urea	5662	6450
Compost 10.0 (Mg ha^{-1}) + Urea	3750	5825
LSD (P=0.05)	213	425

To rice Urea was applied @ 100 kg N/ha; To wheat 100 kg N and 50 kg P_2O_5 ha^{-1} were applied; Source: Farooq (1990)

Use of bio-fertilizer. Nitrogen fixing bacteria as *Azotobacter chrococcum* have lesser potential compared to that of legume inoculants. The beneficial effect of Azotobactor is attributed to production of growth promoting substances like IAA, gibberellins which enhance root biomass thereby enabling large quantity of nutrient absorption. In a field study, effect of L-Tryptophan and *Azotobactor* was investigated on wheat yield fertilized with 125-100-60 kg NPK ha^{-1}. Results (Table XII) revealed that application of L-Tryptophan *(LTRP)* or *Azobactor* inoculation alone significantly increased the wheat yield. However, their combined application produced more pronounced effect as compared with their separate application. Combined application of 10^{-3} M *LTRP* and *Azobactor* significantly increased the grain yield (21.3%) and total N uptake in grain and straw (56.3%) compared with untreated and uninoculated control (Khalid *et al.*, 1999).

Some soil microorganisms including fungi and bacteria can solubilize native as well as added insoluble phosphates. The increase in crop yield and P uptake has been reported to increase on treatment of seed or soil with these microorganisms. In a green house study, effect of different bacterial strains of phosphorus solubilizing microorganism (PSM) and rock phosphate was investigated

Table XII. Effect of Azotobacter inoculation and L. tryptophan application on wheat grain & straw yield and N uptake

Treatments	Grain Yield ($Mg\ ha^{-1}$)	Straw Yield ($Mg\ ha^{-1}$)	N. Uptake ($kg\ ha^{-1}$)
Control	3.04 d	6.22 d	69.0 d
Azotobactor (A)	3.19 d	7.16 c	83.2 c
10^{-3} ML-TRP	3.34 c	7.25 c	90.0 b
10^{-4} ML-TRP	3.39 bc	7.36 b	95.2 b
A + 10^{-3} ML-TRP	3.69 a	7.51 a	107.9 a
A + 10^{-4} ML-TRP	3.52 b	7.50 a	101.4 a

Source: Khalid *et al*. (1999)

Table XIII. Effect of different Biophos strains on wheat yield and P availability

Treatment	Wheat Biomass ($g\ pot^{-1}$)	Increase over RP (%)
RP*	7.12	-
RP + PSM** (B1)	8.86	24.4
RP + PSM (B3)	9.32	30.9
RP + PSM (B6)	8.08	13.5
RP + PSM (B8)	9.60	34.8

*Rock Phosphate was applied @ 200 mg kg^{-1} soil; **Phosphorus solubilizing microorganisms; Source: Samina (1999)

Table XIV. Effect of rock phosphate and biophos on wheat yield and P availability

Treatment	Wheat yield ($Mg\ ha^{-1}$)			Available P ($mg\ kg^{-1}$ soil)
	Straw	Grain	% increase in grain	
Rock Phosphate	7.80 ab	2.22 b	-	4.43 b
Rock Phosphate + Biophos	8.10 a	3.20 a	44.1	7.03 a

Source: Samina (2000)

on the growth of wheat. Results revealed that different bacterial strains of PSM increased wheat yield from 13.5 to 34.8% (Table XIII). Bacterial strain B8 was found to be most efficient strain followed by B1 (Samina, 1999). In other study, use of Biophos (PSM) along with rock phosphate significantly increased the wheat grain yield (Table XIV). Also after wheat harvest available P in soil was significantly higher in the treatment where rock phosphate along with PSM was used (Samina, 2000).

Future research needs in R-W cropping system. Despite the prime position of wheat and rice in food security and economy of the country, productivity of R-W system is almost stagnant. Both rice and wheat are nutrient exhaustive crops. Therefore, without judicious management of soil and applied nutrient it is not possible to sustain even the present level of crop productivity. Whereas the population in the country is increasing at a alarming rate demanding substantial improvement in the productivity of the system. Since fertilizers are an integral component of crop production system, therefore, future soil fertility management research should focus on the following.

- Nutrient indexing and dynamic in soil and plant system for delineating nutrient deficiencies and changes over period of time.
- In view of very high N losses through various N loss mechanisms in the system, N fertility management research need to be continued for reducing the losses and improving fertilizer use efficiency.
- Soil fertility research for investigating direct, residual and cumulative effects of P, K and micronutrients on productivity of R-W system also needs to be carried.
- Research investigation on integrated nutrient management strategies for developing site-specific nutrient recommendation is also the need of the time.
- The impact of inclusion of grain legumes in rice based cropping also need to be monitored on the crop system productivity.
- In view of enhancing and sustaining productivity of R-W system, research on IPNS should get top priority.

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