Compendium
of
Cropping Systems Research
In
Three Decades

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Foreword

Department of Agronomy, Narendra Dev University of Agriculture & Technology, Kumarganj, Faizabad is publishing salient achievements of cropping system research which they have developed in these three decades.

The focus on producing more during the Green Revolution ensured food security to the millions but it also led to degradation of natural resources. Rice and wheat are considered as major constituent of National Food Security by contributing about 76% of total food grains production to the national basket. Continuous cropping of rice-wheat system during last 3 decades, however, created many fold problems such as deteriorated soil structure, build up of pests including weeds, declining factor productivity, development of nutrients deficiency and decrease in profitability etc. To deal all these issues, a comprehensive and collaborative efforts was needed to bring all the key resources together for enhancing the productivity.

Soil degradation is a global issue that lowers the soil quality and threatens agricultural sustainability. The soil resources are finite and shrinking day by day because of its degradation, urbanization and industrialization, the only alternative is to increase the system's productivity with practically no scope of area expansion. There is need of diversification of existing agriculture production system as well as development of efficient resource management strategies for sustaining higher profitability and soil health under intensive agricultural production systems.

The scientists and researchers of Narendra Dev University of Agriculture & Technology, Kumarganj, Faizabad has worked hard over the years in developing most cost effective, efficient and remunerative cropping patterns under various climatic, irrigated and soil conditions. The conclusion is rice-wheat + mustard - green gram, rice - potato + mustard - blackgram and rice – potato + garlic - maize + cowpea (green fodder) wee found more remunerative and productive than conventional rice - wheat system. But there are other better practices also depending upon the various climatic and soil conditions. The university has not only conducted live examples on its own farms, but it has also tested/evaluated the effects of various inputs on farmers' fields and has come out with some useful information which will help in increasing the income of the farmers. All this has been done under All India Coordinated Research Project on Cropping Systems. Various models/options of existing rice/wheat system for sustainable profitability, nutrient management were done and the results have been shown in this bulletin. This is the result of hard-work done by the scientists and researchers of Narendra Dev University of Agriculture & Technology, Kumarganj, Faizabad. I congratulate all of them.

I hope that this bulletin will prove worthy to agricultural researchers, students and farmers.

(Rajiv Kumar)

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Faizabad

Preface

India witnessed a remarkable growth on agricultural front, particularly, during green revolution era i.e. introduction of fertilizer responsive high yielding varieties (HYVs) of rice and wheat in mid-sixties. The productivity of major crops increased 3 to 4 fold in the forty years since 1965, enabling the country to become self-sufficient in food grain production. Rice-wheat cropping system occupies about 10.3 million hectare area in the Indo-Gangetic Plains, which is food basket and livelihoods for many millions. The stagnation in production and productivity of food grains for the past few years has become a matter of great concern and is posing a serious threat to our national food security. In an urge for short-term gains at the cost of long-term losses, over exploitation and mismanagement of limited soil resource much beyond its carrying capacity is resulting in fast degradation with consequent low productivity. The factors which have been responsible to usher in green revolution are becoming subject of criticism for their second generation problems.

There is no greater threat to sustainable agricultural production system than the alarming rate at which Indian soils are being mined of their plant nutrient reserves. Against an annual depletion of 28-30 million tones of nutrients from soil, the replenishment through fertilizers is only 20 million tones, leaving a net annual deficit of 8-10 million tones which keeps gradual depletion in soil fertility. Sooner or later, availability of such nutrients falls below a critical level, which leads to incidence of deficiency symptoms in plants. The unattended deficiency of a nutrient does not only constrain productivity, but it diminishes efficiency of all other inputs also. To meet the demand of the growing population the growth rate of food production must be around 2.0 percent. For which it is necessary to develop various technologies and to enable the farmers to take advantage of these technologies with their own ingenuity and wisdom.

The salient research findings of the All India Coordinated Research project on Cropping Systems on various key aspects viz. diversification and intensification of existing rice-wheat system for sustainable profitability, nutrient management etc., related to systems perspectives in general and in rice-wheat system in particular achieved during 1977-2009 have been reviewed and summarized in the present bulletin. The documentation of salient finding and constraints will be helpful in planning and execution of future research strategies for sustainability in crop productivity and profitability.

The authors are grateful to Indian Council of Agricultural Research, New Delhi and Project Directorate for Cropping Systems Research, Modipuram, Meerut for providing financial assistance to carry over this investigation. The contributions made by all the scientists and field staffs worked in the Project are duly acknowledged.

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Scenario of Eastern Uttar Pradesh – Problems and Constraints

The eastern U.P.- having 25 districts, located between 24^0 to 27.34^0 N latitudes and 81.13^0 to 84.11^0 E longitudes, has been divided into three agro-climatic zones namely, North Eastern Plain Zone (NEPZ), Eastern Plain Zone (EPZ) and Vindhyan Zone (VZ). Majority of the soils are under the order of Inceptisol followed by Alfisol, Entisol, Vertisol and Mollisol. Although, the average annual rainfall in eastern U.P. is around 1100 mm, it is quite erratic and confined to July-September (85-90%). The water table varies from 1 to 14.5 m during pre monsoon and 0.5 to 7.5 m during post monsoon.

The population of eastern U.P. is about 35% of the total population of the state. Nearly 85% population live in rural areas. The zone wise rural population is 84%, 87% and 82% in EPZ, NEPZ and VZ, respectively. The people directly engaged in agriculture is about 54% in eastern U.P. The most of the families are illiterate (40%) because of their poor economic condition and very poor infrastructure for education. The size of land holding is also very small. Nearly 82% of the farmers possess holding size less than 1 ha (0.39ha) and 12% farmers hold in between 1-2 ha (1.41 ha) land. Irrigation status of agricultural land in eastern U.P. indicates that about 40% of net sown area is wholly rain dependent and remaining (60%) is irrigated out of which only 18% of area is fully irrigated . The major area of the region is occupied by rice-wheat cropping system having the cropping intensity of 150%. The eastern U.P. contributes about 30% of total food grain production of the state. The NPK fertilizer consumption data showed that the use of fertilizers is inadequate (130 kg NPK/ha) and imbalanced (6.8: 2.8: 1.0). The following major constraints of crop production in Eastern Uttar Pradesh have been noticed:

1. **Small and fragmented holdings:** The adoption of well proven technology is constrained due to small size of holdings and poor farm resources. The small and marginal farmers (94% farmers having less than 2 ha land) do not dare to invest in the costly inputs due to high risk. The purchase capacity of these farmers is also very low.
2. **Fertility Management:** Application of FYM is common in most of the crops. But the quality and quantity both are poor and its method of application is defective. Cow dung and animal bedding materials are not properly placed in a pit but heaped in an open area resulting in the loss of nutrients through volatilization and leaching through rainwater. Factors responsible for limited and imbalance use of fertilizers are (a) non availability of fertilizers in time, (b) poor purchasing power of the farmers.
3. **Weed management:** The non availability of labours has accentuated the serious weeds problem in the area. *Kharif* weeding is generally practiced only when weeds become taller and the damage is visible. Generally, no weeding is practiced in *rabi* due to scarcity of labours. Continuous

cropping of same crops viz. rice-wheat system also promotes the problem of weeds particularly *Phalaris minor* and maize-wheat system promotes problem of wild oats.

4. **Water management:** Inspite of the fact that most of the rivers run through the eastern U.P., 40% of net sown area is rainfed. Only 18% area is fully irrigated and remaining 42% area is partly irrigated. The lack of water at the proper time especially due to roaster in canals and non availability of power (electricity & diesel) constrains the crop production in the area. Farmers prefer to wait for rain rather than invest money in tube well irrigation due to their poor economic conditions.
5. **Crop rotation:** In general, cereal-cereal crop rotations, mostly rice-wheat, are being continuous practice in more than 65% the area. There is ample scope of introducing short duration crops like pulses, rapeseed, fodder etc, to diversify as well as to intensify the existing system for sustaining soil health and crop productivity.
6. **Seed:** Farmers mostly use their own seeds. This is due to (a) non-availability of improved seed of the crops like maize, linseed, gram, lentil, pigeonpea etc.(b) Non availability of quality seed of wheat and rice in time, (c) higher cost of quality seed (d) poor purchasing power of the farmers.
7. **Management of problematic soils**: The eastern U.P. has a sizeable area of problem soils such as *Bhat* (calcarious) soil and submergence (1-3 weeks) in North-Eastern plain zone, *Diara* and waterlogged and sodic soils in Eastern Plain zone, *Karail* (black) soils and red-lateritic soils in Vindhyan zone. These soils need reclamation/specific management.
8. **Lack of Marketing facilities:** Due to lack of proper marketing/industrial net work, cultivation of certain commercial crops like safflower, sunflower, soybean, malt barley and a large number of aromatic/medicinal plants which are suitable for diversification for the area has lagged behind.
9. **Lack of mechanization**: Due to small and fragmented land holdings and poor socio-economic status of the farmers, there is very limited use of improved farm machinery which adversely affect the productivity of the crops.

Introduction

The importance of highly intensive crop sequence is well recognized to meet out the growing demands of ever-increasing population. To fulfill the demand of food, oil and vegetable with increasing human population, intensification of cropping sequences is essential depending on the need of the area. Oilseeds and pulses including vegetables are receiving more attention owing to higher prices due to increased demand. Inclusion of these crops in sequence was found more beneficial than cereals alone. An intensive cropping system which is not only highly productive and profitable but also stable over time and maintains soil fertility, is of great importance in present conditions. It is well established that the basic requirement for stabilizing the crop productivity lies in the betterment of soil fertility.

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L) is the most important crop sequence in India, occupying 60-70% of the total cultivated area in eastern Uttar Pradesh. Wide adoption of this system is mainly due to stable production and less labour requirement (Kumar et al., 2001). But continuous adoption of the sequence has led to the problem of specific weeds, reduced soil fertility in specific root zone with special reference to micro-nutrients and infestation of similar kind of pests, which ultimately resulted in declining the efficiency and productivity of the system (Kumar and Yadav, 2005).

After the resounding success of green revolution, a decline in rate of growth of food production is seen during the recent past in respect of crop productivity and fertilizer input response. Current generalized recommendations with respect to NPK fertilizers alone are pointing to soil fatigue, proving their decreased efficiency and thus need upward refinement and proper balance among the required nutrients. The concept of balanced fertilization can not be confined to N, P and K alone. Balanced fertilization includes application of all plant nutrients essential for high agricultural productivity and health of the soil. Integrated use of organic manures and chemical fertilizers has been found to be promising in arresting the decline in productivity through the correction of marginal deficiencies of some secondary and micronutrient elements and its beneficial inf1uence on the physical and biological properties of the soil.

Keeping above facts in view the following mandates were undertaken to overcome the problems of the crop production in the area:

1- To develop resource efficient, economically viable and sustainable crop production technology for different farming situations
2- To undertake nutrient management research for efficient resource utilization and yield maximization and evaluate their long-term sustainability.
3- To undertake on-farm testing, verification and refinement of system based crop production technology

To achieve the above mandates the following areas of research were identified:

1- Development of need-based efficient and profitable cropping systems.

2- Optimum crop combinations and planting geometry for intercropping systems.

3- Tillage requirements and crop establishment practices under different cropping systems.

4- Effect of long term INM and chemical fertilizer use on crop yields and soil fertility.

5- Organic farming.

6- On-farm evaluation and refinement of cropping systems technologies.

The following on station experiments were conducted to fulfill the requirement of above mentioned areas of research at university research farms Kumarganj and Masodha, Faizabad.

1. Intensification / diversification of need based cropping systems for eastern U.P.
2. Tillage requirements and crop establishment practices in rice based cropping systems.
3. Long-term studies on integrated nutrients supply system in rice-wheat crop sequence.
4. Long range effect of continuous cropping and manuring on yield stability in rice-wheat system.
5. Development of organic farming package for high value food crops (maize-potato-onion).
6. Site specific nutrient management in rice-wheat cropping system.

The following on farm experiments were conducted under farmers participatory approach in all the three NARP zones scattered in 25 districts of eastern U.P., rotating after every 5 years.

1-On-farm evaluation of alternative cropping systems

2. On-farm evaluation of intercropping under irrigated and rain fed conditions

3. On-farm performance of crop varieties, nutrient requirement and agronomic practices

4. On-farm evaluation of nutrient management in rice- wheat cropping system

  a. Responses of NPK fertilizers in rice-wheat system.

  b. Effect of zinc application in rice-wheat system

  c. Integrated nutrient management in rice-wheat system

Salient Findings

(A)-On Station Experiments

Location, Climate and soil of experimental site

The main center of cropping system research under the jurisdiction of Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad, Uttar Pradesh, India is functioning since 1977-78. The University is situated in Kumarganj, district Faizabad, at 26.43^0 N latitude and 82.8^0 E longitude at an altitude of 113 m above mean sea level. On station experiments were being conducted at Crop Research Station, Masodha and Agronomy Research Farm, Kumarganj, Faizabad.

The climate of the experimental site is sub-humid sub-tropical with hot summers and fairly cool winters. The area enjoys monsoon type of rainfall with an average 1040 mm annually. Nearly 90% of the total rainfall is received from the south-west monsoon during the months of July to September (*kharif* season).The average potential evapo-transpiration (PET) of the area is 1235 mm annually, showing moisture deficit index (MDI) of (-) 195mm annually.

The soil of the experimental site is alluvial, having developed from the alluvium deposited by rivers. The soil belongs to the order Inceptisol with silt loam texture (52.9% silt 22.3% clay). Potassium-bearing minerals such as feldspar, micas and micaceous clays (illite) predominate in the soil. The feldspar and micas are present in the coarse fraction (sand and silt) and the illite in the clay fraction of alluvial soils. The soil of Crop Research Station, Masodha, Dist. Faizabad was neutral in reaction (pH 7.3-7.7), and normal in salts content (EC-0.11-0.15 dS m^{-1}) while the soil of Kumarganj was partially reclaimed sodic having higher pH (8.2-8.8) and EC (0.4-0.5 dS m^{-1}) than normal soil. The soils of both the sites were low in organic carbon (0.37-0.46%), available N (108-142 kg/ha), P (10-15.3 kg/ha) and K (92-136 kg/ha).

OS-1. Cropping System Diversification/ Intensification

1.1. Intensification and diversification of conventional rice-wheat cropping system (1985-88)

A field experiment was conducted at Faizabad during 1985-86 to 1987-88 to find out the most remunerative cropping system under the prevailing conditions in eastern Uttar Pradesh out of the 6 rice-based cropping systems (Table 1). Rice-wheat +Indian mustard-green gram proved the most remunerative system with a net profit of Rs 12,178/ha/year and 1.07 cost : benefit ratio, whereas rice-wheat-fallow sequence showed the highest cost : benefit ratio (Table 2). The highest cost of cultivation (Rs. 17,337/ha/year) was incurred in rice-potato + Indian mustard- black gram cropping system. This system also gave the highest employment opportunity and the highest rice-grain equivalent. The maximum removal of N, P and K was found in rice-maize - maize + cowpea (fodder) sequence.

1.2. Diversification of existing rice-wheat cropping system (1991-95)

Another field trial was conducted during 1991-92 to 1994-95 on a silt-loam soil at Crop Research Station, Masodha, Faizabad to find out the possibility of diversification in traditional rice-wheat system in the light of sustainability, potentiality and economic feasibility with the impact on soil fertility. Results revealed that among the six cropping systems tested, rice-potato - cowpea provided the highest net profit of Rs. 22,626/ha/year and rice grain/equivalent yield of 22.55 t/ha besides the fertility benefit of legume crop (Table 3&4). The second remunerative system was rice-potato-okra (seed), that showed the rice-equivalent yield potential of 20.02 t/ha and net profit of Rs. 17,612/ha/year due to vegetable cash crop.

Table-1. Economic yields (tones/ha/year) of different cropping systems (average of 3 years)

Cropping system	**Rainy (*Kharif*)**	**Winter (*Rabi*)**	**Summer (*Zaid*)**	**Rice grain equivalents**
Rice-wheat-fallow	5.6	5.1	-	12.4
Rice-maize-maize+cowpea (fodder)	5.0	4.5	42.2	13.7
Rice-toria-wheat-*Sesbania aculeata* (GM)	4.1	0.55 & 2.2	-	9.1
Rice-potato+Indian mustard-blackgram	5.3	12.7 + 0.52	0.49	18.8
Rice-wheat+Indian mustard-greengram	5.5	4.3 + 0.28	0.61	14.8
Rice-wheat+sugarcane-ratoon-wheat	1.7	2.6 + 37.5	-	11.2
CD (P=0.05)				0.54

Table-2. Economics and labour employment of different cropping systems (average of 3 years)

Cropping system	**Gross expenditure (Rs/ha)**	**Net returns (Rs/ha)**	**Cost : benefit ratio**	**Labour employment (mandays/ha/yr)**
Rice-wheat-fallow	9009	11490	1.27	368
Rice-maize-maize+cowpea (fodder)	11327	10697	0.94	464
Rice-toria-wheat-*Sesbania aculeata* (GM)	11301	3750	0.33	425
Rice-potato+Indian mustard-blackgram	17337	11167	0.64	726
Rice-wheat+Indian mustard-greengram	11386	12178	1.07	452
Rice-wheat+sugarcane-ratoon-wheat	8854	8443	0.95	443

It was concluded that progressive farmers, having the facility of resources and human labour, may adopt rice-potato-cowpea or rice-potato-okra system for higher productivity and net returns. The poor resource farmers may include oilseed, legume and fodder crops, viz. rice-mustard-greengram and rice-lentil-maize + cowpea (fodder) for higher returns.

Table-3. Yield of crops (tones/ha/year) obtained from different cropping systems (mean of 4 years)

Cropping system	**Rainy (*Kharif*)**	**Winter (*Rabi*)**	**Summer (*Zaid*)**	**Rice grain equivalents**
Rice-wheat-GM*	5.64	4.81	-	10.87
Rice-maize-GM	5.65	4.92	-	11.69
Rice-potato-okra (seed)	5.56	21.80	0.36	20.02
Rice- lentil - maize + cowpea (fodder)	5.48	0.99	47.29	12.16
Rice-potato-cowpea	5.63	22.05	0.88	22.55
Rice-mustard-greengram	5.62	1.42	0.42	12.61
CD (P=0.05)				0.81

* Green manuring of *Sesbania aculeata*

Table-4. Economics and labour employment of different cropping systems (mean of 4 years)

Cropping system	Gross expenditure (Rs/ha)	Net returns (Rs/ha)	Rs/Re-invested	Labour employment (man days/ha/yr)
Rice-wheat-GM*	23618	14408	0.61	324
Rice-maize-GM	24730	11004	0.44	456
Rice-potato-okra (seed)	41477	17612	0.42	645
Rice- lentil - maize + cowpea (fodder)	21173	14171	0.66	378
Rice-potato-cowpea	38750	22626	0.58	560
Rice-mustard-greengram	22225	11773	0.52	380

* Green manuring of *Sesbania aculeata*

1.3 Diversification and intensification of rice-wheat system (1995-2000)

A field experiment involving 6 rice-based crop sequences was carried out from 1995-96 to 1999-2000 at Crop Research Station, Masodha, Faizabad to find out the stability of intensive crop sequences and their relative effects on soil fertility. Results showed that highly intensive crop sequences, viz. rice-potato + Indian mustard – blackgram, rice-potato +wheat- green-manure(*Sesbania aculeata*) and rice-potato + garlic – cowpea + maize(green fodder), were found to be distinctly better in terms of rice-grain equivalent (15.34 to 17.78 t/ha) and productivity (51.6 to 53.1 kg grain/day/ha) compared to rice-wheat-*Sesbania* green-manure (GM) sequence which yielded rice-grain equivalent of 11.45 t/ha and productivity of 44 kg grain/day/ha (Table 5). However, in terms of stability, the rice-wheat-green manure sequence was more stable, with a stability index 0.95 and profitable (benefit: cost ratio 1.68) than these intensive cropping systems.

Table-5. Productivity and stability of rice-based cropping systems (mean of 5 years)

Cropping system	Yield (t/ha)			Rice-grain equivalent (t/ha)	Productivity (kg/day /ha)	Sustainabi-lity index
	Rainy (*Kharif*)	Winter (*Rabi*)	Summer (*Zaid*)			
Rice-wheat-GM*	5.99	4.57	-	11.45	44.0	0.95
Rice-maize-GM	5.91	4.61	-	10.14	35.0	0.87
Rice-potato+Indian mustard-blackgram	6.00	19.1 + 0.63	0.74	17.78	53.1	0.85
Rice-potato+garlic-maize+cowpea (green fodder)	5.60	19.46 + 1.00	46.37	17.55	51.6	0.74
Rice-toria-onion	5.79	0.92	9.64	11.60	40.0	0.77
Rice-potato+wheat-GM	5.94	19.92 + 1.06	-	15.34	52.9	0.87
CD (P=0.05)				0.73	2.54	

- Green manuring of *Sesbania aculeata*

Over all results revealed that highly intensive crop sequences, viz. rice-potato + Indian mustard – blackgram, rice-potato + garlic – maize + cowpea (green fodder) were found distinctly better in terms of productivity and net returns for resourceful farmers (Table 6). The rice-wheat-*Sesbania* green manure sequence being more stable with minimum input requirements and may be adopted by resource poor farmers.

Table-6. Economics of rice-based cropping systems (mean of 5 years)

Cropping system	Gross expenditure (Rs/ha)	Net returns (Rs/ha)	Benefit : cost ratio	Labour employment (man days/ha/year)
Rice-wheat-GM*	33284	22821	1.68	252
Rice-maize-GM	35053	14642	1.42	336
Rice-potato+Indian mustard-blackgram	66001	21114	1.32	546
Rice-potato+garlic-maize+cowpea (green fodder)	64553	21446	1.33	492
Rice-toria-onion	43012	13824	1.32	429
Rice-potato+wheat-GM	58814	17538	1.30	414

* Green manuring of *Sesbania aculeata*

1.4. Intensification and diversification of existing rice based cropping system (2000-05)

The field experiment was conducted at Faizabad during 2000-05 to find out the effect of major constraints of traditional rice - wheat cropping system. Rice -potato-greengram sequence was found the most efficient with respect to production (18.1 t rice yield equivalent/ha/year), monetary return (Rs 43,200/ha/year) and water use efficiency (20.1 kg/ha/mm) followed by the rice-onion (Table 7&8). Berseem may be taken as a break crop successfully for reducing weed problem (weed control efficiency – 88.7%) in continuous rice-wheat system without any monetary loss. Rice-berseem sequence was also found the most efficient in terms of nitrogen use efficiency (80.2 kg grain/kg N). Inclusion of potato or onion (vegetable crops) were found quite stable with stability index of 0.86 and 0.83, respectively.

Table-7. Yield of various rice - based crop sequences (mean of five years)

Treatment	Yield (t/ha)			Rice yield equivalent (t/ha/year)
	Kharif	***Rabi***	***Zaid***	
Rice (MD)-wheat (NS)	5.3	4.61	-	11.7
Rice (MD)-berseem	5.35	53.91 +0.15	-	11.2
Rice (MD)-oat (multi cut)	5.32	34.21 +0.83	-	8.7
Rice (MD)-potato-greengram	5.47	24.71	0.91	18.1
Rice (LD)-wheat (late sown)	4.99	3.24	-	9.8
Rice (LD)-wheat (Trans)	4.84	4.00	-	10.9
Rice (LD)-wheat (zero till)	4.81	3.63	-	10.4
Rice (LD)-onion	4.89	13.65	-	13.4
C.D. (P=0.05)	-	-	-	1.02

Sale price: (Rs./kg)- Rice grain-5.60, Rice straw-0.25, Wheat grain-6.40, Wheat straw-1.00, Berseem green fodder-0.50 Berseem seed-80.00, Oat grain 5.00, Oat straw-1.00, Oat green fodder-0.50, Potato-2.50, Green gram-15.00, Onion-3.50
LD – Long duration, SD – Short duration, NS – Normal sown, LS – Late sown, Trans-Transplanted

Table-8. Economics of various rice - based crop sequences (mean of five years)

Treatment	Cost of cultivation (x 10^3 Rs/ha/ year)	Net returns (x 10^3 Rs/ha/ year)	B : C ratio	Sustainability index
Rice (MD)-wheat (NS)	30.6	33.4	1.10	0.96
Rice (MD)-berseem	28.7	33.1	1.15	0.82
Rice (MD)-oat (multi cut)	24.0	23.9	0.99	0.89
Rice (MD)-potato-greengram	56.3	43.2	0.77	0.86
Rice (LD)-wheat (late sown)	30.2	23.8	0.79	0.96
Rice (LD)-wheat (Trans)	36.4	23.4	0.64	0.94
Rice (LD)-wheat (zero till)	29.1	27.9	0.96	0.91
Rice (LD)-onion	37.4	36.4	0.97	0.83

Sale price: (Rs./kg)- Rice grain-5.60, Rice straw-0.25, Wheat grain-6.40, Wheat straw-1.00, Berseem green fodder-0.50 Berseem seed-80.00, Oat grain 5.00, Oat straw-1.00, Oat green fodder-0.50, Potato-2.50, Green gram-15.00, Onion-3.50
LD – Long duration, SD – Short duration, NS – Normal sown, LS – Late sown, Trans-Transplanted

Rice-potato-greengram and rice-onion sequences also gave the higher production efficiency of 57.4 and 55.9 kg/ha/ day against 45.1 kg/ ha/ day in rice-wheat sequence. The land use efficiency (86.3%) and employment generation efficiency (1.18 man days/ha/day) was found highest in rice-potato-greengram sequence due to intensification of this system. The increase in employment generation in rice-potato-greengram and rice-onion system enhanced the profitability but in rice-wheat (transplanted) system, it did not give monetary advantage over existing rice-wheat system (Table 9&10). The highest monetary return use efficiency (152 Rs/ha/day) and water use efficiency (20.3 kg/ha/mm) were obtained in rice-onion system (Table). Rice - berseem sequence was found most efficient in terms of nitrogen use efficiency (80.21 kg grain/ha/kg N) and third in production efficiency and land use efficiency. Late sowing wheat after long duration rice showed lower values of nitrogen and water use efficiencies, which were very close to respective minimum values obtained in rice-oat system.

Table-9. Efficiency of various rice-based crop sequences (mean of 5 years)

Treatment	Production efficiency (kg/ha/day)	Land use efficiency (%)	Nitrogen use efficiency (kg grain/ ha/kg N)	Water use efficiency (kg/ha/mm)
Rice (MD)-wheat (NS)	45.1	71.2	48.9	19.5
Rice (MD)-berseem	51.0	76.7	80.2	17.0
Rice (MD)-oat (multi cut)	33.5	71.2	39.6	14.5
Rice (MD)-potato-greengram	57.4	86.3	63.5	20.1
Rice (LD)-wheat (late sown)	38.9	71.8	40.9	14.9
Rice (LD)-wheat (Trans)	38.1	78.1	45.3	16.5
Rice (LD)-wheat (zero till)	37.7	75.3	43.2	15.7
Rice (LD)-onion	55.9	65.7	49.7	20.3

LD – Long duration, SD – Short duration, NS – Normal sown, LS – Late sown., Trans- Transplanted

Table-10. Efficiency of various rice-based crop sequences (mean of 5 years)

Treatment	Monetary return use efficiency (Rs/ha/day)	Employment generation efficiency (man days /ha /day)	Weed dry weight (g/m^2)	Weed control efficiency %
Rice (MD)-wheat (NS)	131	0.54	115	-
Rice (MD)-berseem	118	0.61	13	88.7
Rice (MD)-oat (multi cut)	92	0.47	13	88.7
Rice (MD)-potato-greengram	137	1.18	85	26.1
Rice (LD)-wheat (late sown)	91	0.54	75	34.8
Rice (LD)-wheat (Trans)	82	0.85	87	24.3
Rice (LD)-wheat (zero till)	101	0.53	108	6.1
Rice (LD)-onion	152	0.85	70	39.1

LD – Long duration, SD – Short duration, NS – Normal sown, LS – Late sown, Trans- Transplanted

Changes in the organic carbon and availability of major nutrients over five years (Table 11) showed that rice-oat (multi-cut) was more exhaustive cropping system probably due to higher dry matter production by multi-cut oat (fodder) crop. Inclusion of leguminous crop (green gram, berseem) in the sequences increased the organic carbon and availability of nitrogen, phosphorus and potassium in soil appreciably and improved the soil fertility.

Table-11.Changes in soil fertility parameters after 5th cycle (2005) as influenced by different rice - based crop sequences

Treatment	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Rice (MD)-wheat (NS)	0.56	154	21.5	148
Rice (MD)-berseem	0.62	168	24.2	146
Rice (MD)-oat (multi cut)	0.52	147	20.2	143
Rice (MD)-potato-greengram	0.59	160	23.4	159
Rice (LD)-wheat (late sown)	0.53	152	21.0	151
Rice (LD)-wheat (Trans)	0.53	148	20.7	153
Rice (LD)-wheat (zero till)	0.55	150	20.3	148
Rice (LD)-onion	0.57	159	22.8	163
Initial soil test values (2000)	0.54	142	18.6	136

LD – Long duration, SD – Short duration, NS – Normal sown, LS – Late sown, Trans- Transplanted

From the above results, it may be concluded that rice-potato-greengram sequence was most efficient for production, monetary return, employment generation and water-use efficiency followed by rice-onion. Berseem may be taken as a break crop successfully for reducing the weed problem effectively in continuous rice-wheat system without any monetary loss. The inclusion of leguminous crops improved the soil fertility.

1.5. Diversification of rice based cropping system (2005-09)

On the basis of 4 years (2005-09) experimentation at CRS, Masodha, it was revealed that medium duration hybrid rice (PHB-71) followed by potato- green gram crop sequence proved to be most remunerative with the net profit Rs. 1,25,645 / ha / annum (Table 12&13) followed by scented rice Pusa basmati-lentil-maize + cowpea (green fodder) which provided Rs. 97,575 /ha /annum as net return. The next best sequence was rice (PHB-71)-mustard-black gram followed by rice (Pusa basmati)-wheat-green manuring which recorded net return of Rs.93,530 and Rs. 70,660/ha/year, respectively. The lowest net return of Rs.51,550 / ha / annum was recorded from rice (Sarjoo-52)-wheat, the existing cropping sequence.

Table 12. Productivity of different crop sequences at CRS Masodha, Faizabad during 2005-09

Crop sequences / Variety/Duration/ NPK (kg/ha)			Yield (q/ha)			Rice yield equivalent (q/ha)*
Kharif	***Rabi***	***Summer***	***Kharif***	***Rabi***	***Summer***	
Rice (S-52),125 120:60:60	Wheat (PBW-343),145 120:60:40	Fallow	52.8	44.0	-	108.7
Rice (S-52),125 120:60:60	Wheat (PBW-343),145 120:60:40	GM (*Sesbania)* (Local),45	58.0	46.6	-	117.2
Rice HYB (PHB-71),125 150:60:60	Wheat (PBW-343),145 120:60:40	GM (*Sesbania)* (Local),45	75.9	45.2	-	133.3
Rice HYB (PHB-71),125 150:60:60	Potato (K Ashoka),110 150:60:90	Green gram (NDM-1),85 20:40:0	76.2	256.0	10.6	240.3
Rice HYB (PHB-71),125 150:60:60	Mustard (NDR-8501),120 100:40:40	Black gram (NDU-1),70 20:40:0	74.5	17.4	9.9	166.4
Rice (Pusa Basmati),137 120:60:60	Wheat (PBW-343),145 120:60:40	GM (*Sesbani*a)	44.4	46.0	-	136.8
Rice (Pusa Basmati),137 120:60:60	Berseem (GF) (Vardan),175 20:40:0	Berseem seed	43.5	520.8	1.70	125.4
Rice (Pusa Basmati),137 120:60:60	Lentil (NDL-1),128 20:40:0	Green fodder (Maize + cowpea),65 100:50:0	42.5	18.8	392.0	164.4

The highest benefit:cost ratio of 2.31 was recorded with rice (Pusa basmati)-lentil-maize + cowpea (green fodder) followed by rice (PHB-71)–mustard–black gram (1.95) against B:C ratio of 1.60 available with rice (PHB 71)–potato-green gram which gave highest net return (Table 13). The lowest B:C ratio of 1.26 was noted with existing cropping system i.e. rice (Sarjoo-52)-wheat.

The various efficiency indices of different cropping systems were calculated and are presented in (Table 14). The highest system productivity of 65.83 kg/ha/day was recorded by hybrid rice-potato-green gram followed by hybrid rice-mustard-blackgram (45.59) and least values of 29.78 kg/ha/day with rice-wheat cropping system. The highest values of land use efficiency (90.41%) was recorded with basmati rice-lentil-maize + cowpea (green fodder) closely followed by hybrid rice-potato-green gram (87.67%) and basmati rice-berseem (85.20%) while least land use efficiency was noted with rice-wheat system (73.97%).

Table 13. Economics of different crop sequences at CRS Masodha, Faizabad during 2005-09

Crop sequences / Variety/Duration/ NPK (kg/ha)			Cost of cultivation (Rs./ha/ year)	Net return (Rs./ha/ year)	B:C ratio
Kharif	***Rabi***	***Summer***			
Rice (Sarjoo-52),125 120:60:60	Wheat (PBW-343),145 120:60:40	Fallow	40850	51550	1.26
Rice (Sarjoo-52),125 120:60:60	Wheat (PBW-343),145 120:60:40	GM (*Sesbania)* (Local),45	45120	54508	1.21
Rice HYB (PHB-71),125 150:60:60	Wheat (PBW-343),145 120:60:40	GM (*Sesbania)* (Local),45	47620	65711	1.38
Rice HYB (PHB-71),125 150:60:60	Potato (K Ashoka),110 150:60:90	Green gram (NDM-1),85 20:40:0	78625	125645	1.60
Rice HYB (PHB-71),125 150:60:60	Mustard (NDR-8501),120 100:40:40	Black gram (NDU-1),70 20:40:0	47945	93530	1.95
Rice (Pusa Basmati),137 120:60:60	Wheat (PBW-343),145 120:60:40	GM (*Sesbani*a)	45620	70660	1.55
Rice (Pusa Basmati),137 120:60:60	Berseem (GF) (Vardan),175 20:40:0	Berseem seed	35910	70680	1.97
Rice (Pusa Basmati),137 120:60:60	Lentil (NDL-1),128 20:40:0	Green fodder (Maize + cowpea),65 100:50:0	42175	97575	2.31

Sale price (Rs./kg)- Coarse rice-8.50, Basmati rice 15.00, Rice straw-0.50, Wheat grain-10.80, Wheat straw-1.50, Green gram- 35.00, Black gram- 35.00, Lentil -30.00, Mustard 25.00, Potato 4.00, Berseem/maize + cowpea green fodder 0.50 and Berseem seed-90.00.

The apparent nutrient use productivity of 41.80 kg/ha/kg was noted with basmati rice-berseem (fodder & seed) followed by 38.10 kg/ha/kg noted by rice-potato-green gram against lowest value of 23.63 kg/ha/kg noted with traditional rice-wheat system. The highest energy production of 54738 Kx 1000 cal was recorded with hybrid rice-potato-green gram closely followed by hybrid rice-wheat-green manuring (41900 K x 1000 cal) against lowest values of 15051 K x 1000 cal noted with basmati rice-berseem (fodder & seed). Synonymous to system productivity and energy production, the highest system profitability of Rs. 392.64/ha/day was noted with hybrid rice-potato-green gram followed by 296.92 noted with hybrid rice- mustard-blackgram against lowest values of Rs. 173.04/ha/day noted with rice (Sarjoo 52) – wheat - green manuring.

Table 14. Various indices for efficiency of different cropping systems at Faizabad during 2008-09

Crop sequences / Variety/Duration/ NPK (kg/ha)			System productivity (kg/day)	LUE (%)	Apparent nutrient use productivity (kg/ha/kg)	Energy production (K x 1000 cal.)	System profitability (Rs/ha/day)
Kharif	***Rabi***	***Summer***					
Rice (Sarjoo-52),125 120:60:60	Wheat (PBW-343),145 120:60:40	Fallow	29.78	73.97	23.63	33493	190.90
Rice (Sarjoo-52),125 120:60:60	Wheat (PBW-343), 145 120:60:40	GM (*Sesbania)* (Local),45	32.11	73.97	25.48	36192	173.04
Rice HYB (PHB-71), 125 150:60:60	Wheat (PBW-343), 145 120:60:40	GM (*Sesbania)* (Local),45	36.52	73.97	27.20	41900	208.60
Rice HYB (PHB-71), 125 150:60:60	Potato (K. ashoka), 110 150:60:90	Green gram (NDM-1), 85 20:40:0	65.83	87.67	38.10	54738	392.64
Rice HYB (PHB-71), 125 150:60:60	Mustard (NDR-8501), 120 100:40:40	Black gram (NDU-1),70 20:40:0	45.59	86.30	32.63	38626	296.92
Rice (Pusa Basmati),137 120:60:60	Wheat (PBW-343), 145 120:60:40	GM (*Sesbani*a)	37.48	77.26	29.74	31278	216.08
Rice (Pusa Basmati),137 120:60:60	Berseem (GF) (Vardan),175 20:40:0	Berseem seed	34.36	85.20	41.80	15051	227.27
Rice (Pusa Basmati),137 120:60:60	Lentil (NDL-1),128 20:40:0	Green fodder (Maize + cowpea),65 100:50:0	45.04	90.41	36.53	21153	295.68

Sale price (Rs./kg)- Coarse rice-8.50, Basmati rice 15.00, Rice straw-0.50, Wheat grain-10.80, Wheat straw-1.50, Green gram- 35.00, Black gram- 35.00, Lentil -30.00, Mustard 25.00, Potato 4.00, Berseem/maize + cowpea green fodder 0.50 and Berseem seed-90.00.
K cal. (per 100 gm) rice-3.46, wheat-346, potato 97, green gram 334, blackgram 347, lentil 343, mustard 541.

The soil nutrients data (Table 15) revealed that there was increase in organic carbon and availability of nutrients viz. NPK in soil after competition of 4th cycle. The increase was more pronounced in rice potato-green gram followed by rice-mustard-black gram. The minimum increase was noticed in existing cropping system of rice-wheat. The systems, having leguminous crops or green manuring, showed more build up in organic carbon and nutrients availability.

Table 15. Effect of cropping systems on nutrients availability in soil after 4 cycles (June, 2009)

Crop sequences/ variety/ NPK (kg/ha)			O.C. (%)	Av. N	Av. P	Av. K
Kharif	***Rabi***	***Summer***		(kg ha^{-1})		
Rice	Wheat	Fallow	0.52	150	20.1	152
Rice	Wheat	GM (*Sesbania)*	0.58	160	21.4	156
Rice	Wheat	GM (*Sesbania)*	0.59	158	21.8	158
Rice	Potato	Green gram	0.62	162	23.7	162
Rice	Mustard	Black gram	0.60	164	22.4	155
Rice	Wheat	GM (*Sesbani*a)	0.57	160	21.6	154
Rice	Berseem (GF)	Berseem seed	0.62	166	22.0	158
Rice	Lentil	Green fodder	0.56	158	20.8	150
Initial value (June 2005)			0.51	142	18.0	136

OS-2. Tillage and Crop Establishment

2.1. Tillage and planting management in rice-wheat system

The experiment was conducted during 1990-91 to 1994-95 at CRS Masodha to study the effects of different tillage levels and planting management techniques on rice-wheat system. The average yield of five years (Table 16) revealed that there was adverse effects of reduction in the puddling for rice field on the grain yields of rice and wheat. The normal puddling with summer green manuring provided maximum rice yield (54.3 q/ha) followed by normal puddling (51.3 q/ha). The lowest yield was obtained with 50% reduced puddling before rice transplanting. Summer green manuring with normal puddling also showed its positive residual effects on succeeding wheat crops. The maximum wheat yield (48.3 q/ha) was recorded with conventional tillage and minimum with zero tillage (26.8 q/ha). The reduction in tillage operations to wheat crop resulted lower grain yield because of more weeds (Table 16) than conventional tillage operations. The results proved that long term reduction in tillage operations for wheat or puddling levels for rice caused increase in weed population tremendously which affected the productivity of rice and wheat adversely.

2.2 Tillage and planting management in rice-oilseed system

The experiment was conducted during 1995-96 to 1997-98 to study the effects of different tillage levels and planting management techniques on rice-mustard system. The average yield of three years data (Table 17) revealed that there was adverse effects of reduction in the puddling for rice field on the grain yields of rice and oilseed. The normal puddling with summer green manuring of *Sesbania aculeata* provided maximum rice yield (56.5 q/ha) followed by normal puddling. The lowest yield (44.2 q/ha) was obtained with 50% reduced puddling for rice transplanting. Summer green manuring with normal puddling also showed its positive residual effects on succeeding oilseed (mustard) crop. The maximum mustard yield (14.3 q/ha) was recorded with conventional tillage and minimum (4.7 q/ha) with broadcasting of mustard seed in standing rice crop before 7-10 days of its harvest (*Utera* cultivation). The 50% reduction in tillage operations to mustard crop resulted lower grain yield because of more weeds population than conventional tillage operations. The *utera* cultivation of linseed was found successful. The results proved that any reduction in tillage operations for mustard or puddling levels for rice from their conventional levels caused increase of weeds tremendously which affect the productivity of rice and mustard adversely.

Table -16: Effect of puddling/tillage levels on the grain yields (q/ha) of rice and wheat in a sequence and weed density (mean of five years)

Treatment	**Grain yield (q/ha)**		**Dry weight of weeds after 30 days of sowing (q/ha)**			
	Rice	**Wheat**	**Rice**		**Wheat**	
			1990	**1994**	**1990**	**1994**
For rice main plot						
50% reduced puddling	43.3	36.1	5.9	10.8	4.7	9.4
Normal puddling	51.3	38.2	3.6	7.0	3.5	7.9
Normal puddling + summer green manuring of *Sesbania aculeata*	54.3	39.6	3.2	6.0	3.4	7.9
For wheat (sub plot)						
Conventional tillage	50.8	48.3	3.7	6.9	3.1	3.5
50% reduced tillage	49.4	42.9	4.4	7.7	3.8	5.9
Zero tillage	48.9	26.8	4.8	11.5	5.1	16.8
One harrowing followed by planking	49.7	34.6	4.0	7.4	3.3	7.4

Table-17. Effect of puddling/tillage levels on the grain yields (q/ha) of rice and oilseed in a sequence (mean of three years)

Puddling/tillage treatments	**Grain yield (q/ha)**	
	Rice	Oilseed
For rice (Main plot)		
50% reduced puddling	44.2	8.8
Normal puddling	53.0	10.0
Normal puddling + summer green manuring of *Sesbania aculeata*	56.5	11.0
For oilseed (sub plot)		
Broadcasting of mustard seed in standing rice crop before 7-10 days of harvest	51.6	4.7
Reduced tillage for mustard	51.2	9.2
Conventional tillage for mustard	51.7	14.3
Broadcasting of linseed in standing rice crop before one week of harvest	51.1	11.7

The reduction in the normal puddling level for rice crop and tillage operations for mustard decreased the net returns in the system (Table 18). Green manuring along with conventional puddling showed positive response in the net returns. The *utera* cultivation for mustard crop reduced the net profit to a great extent. On the other hand, the *utera* cultivation for linseed crop was highly successful and provided good returns after conventional puddling for rice crop.

Table-18. Effect of puddling levels and planting management on the net returns (Rs/ha) in rice-oilseed system (mean of three years)

Main plot treatment for rice (puddling levels)	**Sub plot treatments for oilseed (planting management)**			
	Conventional tillage	**Reduced tillage**	***Utera** for mustard**	***Utera** for linseed**
50% reduced puddling	13441	8645	3326	8660
Conventional puddling	16374	11094	6327	11266
Green manuring + conventional puddling	18128	12580	6982	12660

Note: In *Utera* cultivation the seed of mustard/linseed is broadcasted in standing rice crop before 7-10days of its harvest.

2.3. Tillage and nutrient management in rice-wheat system

The experiment was conducted during 1992-97 with the objective to enhance the yield and profit of rice-wheat system by optimum combination of inputs and management practices. The yield data (Table 19) showed that there was no response of deep tillage over normal tillage in both wheat (*rabi*) and rice (*Kharif*) crops. However, levels of NPK influenced the grain yields of rice and wheat to a great extent. The increase of input levels from 100% recommended NPK dose to 150% recommended levels increased the grain yields of both rice and wheat about 4-5 q/ha. Further increase in NPK doses from 150 % to 200% of recommended levels showed adverse effects on the yields, of the system because of severe lodging in both the crops, with more extent in wheat.

Table-19: Effect of tillage and nutrient (NPK) levels on the grain yield (q/ha) of rice - wheat sequence (mean of 1992-97)

Treatments	**Rice**	**Wheat**
Tillage (Main plot)		
Normal tillage for both crops	53.9	44.6
Normal tillage for rice and deep tillage for wheat	55.4	45.3
Inputs levels (sub plot)		
100% recommended* doses of NPK	52.8	44.9
150% recommended doses of NPK	57.7	49.3
200% recommended doses of NPK	53.7	41.0

***** Recommended doses of NPK is 120:60:60

OS-3. Varietals adjustment in rice- wheat system

Sowing of wheat is generally delayed due to cultivation of high yielding long duration rice varieties which are harvested very late in the season. The problem is further aggravated by longer time required for land preparation to bring the soil at proper tilth for wheat sowing. However, studies have indicated that varietals adjustment for rice as well as wheat can play a vital role in sustaining the productivity of the system.

Rice varieties NDR 118 (95 days), NDR 80 (115days), Sarjoo 52 (125 days) and Mahsuri (140 days) were succeeded by wheat varieties suitable for early planting (HUW 12), normal planting (HUW 55) and late planting (HP 1209). The mean yield for three years (Table 20) show that yields were the highest for the system as a whole when medium early (NDR 80) to medium (Sarjoo 52) duration rice variety preceded to any wheat variety.

Table-20. Grain yield of rice and wheat as influenced by different varietals combinations (Average for 3 years)

Cultivars		Yield (t/ha)		
Rice	**Wheat**	**Rice**	**Wheat**	**Total**
NDR 118	HUW 12	3.28	5.53	8.82
	HUW 55	3.50	4.32	7.73
	HP 1209	3.45	4.51	7.96
NDR 80	HUW 12	4.68	4.88	9.56
	HUW 55	4.80	4.58	9.38
	HP 1209	4.52	4.67	9.18
Sarjoo 52	HUW 12	5.02	4.46	9.48
	HUW 55	5.28	4.32	9.60
	HP 1209	5.08	4.42	9.50
Mahsuri	HUW 12	4.00	4.36	8.36
	HUW 55	4.02	4.21	8.23
	HP 1209	3.68	3.88	7.56

OS-4. Water management for establishment of wheat after rice

The experiment was conducted during 1992-93 to 1994-95 to study water management practices to facilitate land preparation for advancing wheat sowing and its establishment after rice in rice- wheat sequence. Results showed that timings of pre-sown irrigation (*Palewa)* for wheat and first irrigation (near CRI stage) in wheat influenced the wheat yields significantly. Maximum wheat yield was recorded in the treatment receiving pre sowing irrigation in the standing rice crop before 10 days of its (rice) harvesting. This irrigation did not show any adverse effect on the yield of rice (Table 21). The first irrigation to wheat may be extended up to 30 days after sowing (DAS) as the grain yields were at par between the treatments receiving first irrigation at 21 and 30 days after sowing. But any delay in first irrigation beyond 30 days after sowing caused appreciable reduction (5-6 q/ha) in the grain yield of wheat.

Table-21: Effect of different irrigation treatments on the grain yield (q/ha) of wheat after rice (mean of three years)

Treatments	Wheat
Pre-sown irrigation (Palewa) for wheat sowing (main plot)	
10 days before harvesting of rice	48.16
After harvesting of rice (normal)	46.22
Dry seedling of wheat followed by irrigation	37.00
Time of first irrigation to wheat (sub plot)	
21 days after sowing	46.45
30 days after sowing	45.19
40 days after sowing	39.75

Note: The average yield of rice was 56.6 qha^{-1}

OS-5. Nutrient Management

5.1. Long range effect of continuous cropping and manuring on rice-wheat system

Results of a long- term manurial experiment which is in progress at Crop Research Station, Masodha, Faizabad since 1977-78, revealed that the yields of rice and wheat have fallen steeply in treatments without P fertilizers. Wheat yields declined more rapidly than rice. The application of 120 kg N/ha alone decreased wheat yields by 187 kg/ha/year and rice yields by 108 kg/ha/year. In contrast, when the crops received 120 kg N along with 80 kg P_2O_5/ha, the rate of decline was reduced to 105 for wheat and 51 kg/ha/year for rice. Application of 40 kg K_2O with 120 kg N/ha without P did not help in minimizing yield reduction. However, the reduction in yield was further minimized to 91 for wheat and 39 kg/ha/year for rice by the application of 120 kg N, 80 kg P_2O_5 and 40 kg K_2O/ha (Table 22).

Table -22. Rate of decline (kg/ha/year) in grain yields of rice and wheat in continuous rice-wheat system from 1977-2007 under different levels of NPK fertilizers

Fertilizer (kg/ha)			Yield decline rate over 30 years (kg/ha/year)	
N	**P_2O_5**	**K_2O**	**Rice**	**Wheat**
0	0	0	28	22
40	80	40	33	49
80	80	40	37	83
120	80	40	39	91
120	0	0	108	187
120	80	0	51	105
120	0	40	89	181
CD at 5%			18	21

Grain yields of both rice and wheat started declining after 10 years of cropping at different levels of NPK fertilizers. Omission of phosphatic fertilizers (SSP) accelerated the decline in yield of both the crops and exhibited clear deficiency symptoms of P and S in wheat and rice after 14 and 17 years of cropping, respectively. The yield response of rice and wheat crop to fertilizer N declined over the years, with a higher rate of decline in wheat (Table 23). The response to applied P increased with time in both crops, with a higher response rate in wheat. The rice and wheat crops did not respond much (<0.12 t ha^{-1}) to applied K during initial 20 years. Thereafter, the responses to fertilizer K increased in both crops with a higher response rate in wheat. In absence of phosphatic fertilizer over 30 years, nitrogen completely failed to produce any effect on grain yield of both the crops in rice-wheat system.

Table-23. Mean yield responses to nitrogen and phosphorus in twenty eight years of rice-wheat cropping

Period	Mean grain yield (q/ha) at		Response to applied N at		Mean grain yield at P_0	Response to applied P at	
	$N_0P_0K_0$	N_{40}	80 kg N over 40 kg N/ha	120 kg N over 80 kg N/ha		40 kg P_2O_5/ha	80 kg P_2O_5/ha
			(kg grain/kg N)			(kg grain/kg P)	
Rice							
Mean of I four years	11.5	29.2	24.2	19.2	33.6	26.3	21.1
Mean of II four years	11.0	28.8	20.5	20.5	32.2	31.4	25.7
Mean of III four years	8.3	24.9	19.2	19.0	27.7	29.7	26.0
Mean of IV four years	7.8	26.4	20.0	19.7	28.6	37.1	30.6
Mean of V four years	6.1	21.4	20.4	18.0	20.9	53.2	41.6
Mean of VI four years	6.7	16.8	20.7	16.5	15.8	56.3	45.2
Mean of VII four years	8.4	16.5	22.0	15.1	13.8	61.7	50.6
Wheat							
Mean of I four years	11.7	25.5	26.2	22.9	31.2	25.1	23.1
Mean of II four years	9.3	24.2	24.2	24.4	29.5	26.8	25.1
Mean of III four years	6.7	20.8	18.7	19.9	23.9	27.4	26.
Mean of IV four years	5.7	17.6	16.0	17.1	19.1	33.1	28.0
Mean of V four years	6.6	14.7	12.7	11.2	9.5	71.3	48.7
Mean of VI four years	5.3	11.8	12.8	11.4	5.3	86.0	58.2
Mean of VII four years	5.1	15.1	4.5	6.8	4.2	104.6	60.9

Note: Year of commencement 1977-78

Soil analysis data showing a decrease in the available soil N with time. Even the continuous application of 120 kg N ha^{-1} in each crop failed to maintain the initial level of mineralized soil N. The available P content of the soil increased about 3 fold by regular application of single super phosphate @ 80 kg P_2O_5 $ha^{-1}crop^{-1}$ over 30 years (Table 24). Omission of phosphatic fertilizer reduced available P near to half of its initial value (10 kg P ha^{-1}). As single super phosphate (P fertilizer) is also an indirect source of sulphur (12%S), the level of available S increased about 2 fold in 30 years from its initial level (11.4mg kg^{-1} soil) by applying P fertilizer (SSP) regularly. The omitting of P fertilizer declined available S near to half of its initial value. The available soil K increased by 20-30% through its regular application @ 40 kg K_2O ha^{-1} $crop^{-1}$ for 30 years. The neglecting of potassic fertilizers regularly for 30 years potassium availability reduced by 30-35%.

Table-24. Soil organic C, available N, P, K and S status after 30 years of continuous rice-wheat cropping system as influenced by different levels of fertilizer NPK

Fertilizer treatment (kgha^{-1})			**Org. C (g kg^{-1})**	**Av. N kg ha^{-1}**	**Av. P kg ha^{-1}**	**Av. K kg ha^{-1}**	**Av. S mg kg^{-1}**
N	**P_2O_5**	**K_2O**					
0	0	0	2.6	70	6.0	96	7.0
40	80	40	4.9	86	33.3	138	26.9
80	80	40	5.2	103	31.8	144	25.0
120	80	40	5.9	114	29.6	135	24.0
120	0	0	3.1	124	4.1	78	5.2
120	80	0	5.6	119	30.9	72	24.7
120	0	40	3.4	126	3.8	148	5.8
C.D. 5%			0.4	11.2	3.9	9.9	3.2
Initial value in 1977			4.5	130	10	113	11.4

In general, drastic reduction was found in the contents of DTPA extractable-Zn, Cu and Mn at all the nutrient levels of N, P and K (Table 25), whereas the regular application of single super phosphate @ 80 kg P_2O_5 ha^{-1} $crop^{-1}$ for 23 years tended to raise the status of available Fe from 16.1 to 44.1 mg kg^{-1} soil . However, it decreased to 11.0 mg kg^{-1} by omitting single super phosphate (P fertilizer). The DTPA-Zn level decreased from 2.72 to 0.78-0.92 mg kg^{-1} soil, DTPA-Mn content decreased from 11.4 to 3.5-4.4 mg kg^{-1} soil and DTPA-Cu from 2.24 to 0.86-0.96 mg kg^{-1} soil during the 23 years of rice-wheat cropping.

Table-25. Effect of NPK fertilizer levels on DTPA extractable Zn, Fe, Mn and Cu status in soil after 23 cycles of rice-wheat cropping

Fertilizer treatment(kgha^{-1})			DTPA-extractable			
N	P_2O_5	K_2O	Zn	Fe	Mn	Cu
			mg kg^{-1} soil			
0	0	0	0.92	12.0	4.2	0.88
40	80	40	0.78	44.1	3.8	0.96
80	80	40	0.80	42.4	3.5	0.94
120	80	40	0.83	40.8	3.7	0.93
120	0	0	0.90	11.0	4.4	0.86
120	80	0	0.81	41.3	3.9	0.95
120	0	40	0.91	11.4	4.1	0.90
C.D. 5%			0.06	3.6	0.4	0.07
Initial value in 1977			2.72	16.1	11.4	2.24

5.2. Response of NPK in rice-wheat cropping system

The four years results of another NPK response trial revealed that balanced doses of all the three major nutrients (N_{120} P_{60} K_{60}) was essential for higher grain yields (Table 26) of rice and wheat. Omitting of nitrogen reduced the grain yield of rice and wheat by 56.2 and 59.4%, respectively whereas neglecting P and K reduced the grain yield of rice by 25.4 and 6.0% and of wheat by 41.3 and 8.0%, respectively. Balanced fertilization of NPK showed maximum sustainability (0.90) of the system. The omission of N or K reduced the sustainability of the system. The response (kg grain/kg nutrients applied) to nitrogen was higher in rice than in wheat, whereas that to phosphorus and potassium was higher in wheat than in rice. Amongst the nutrients, maximum response was noted with phosphorus followed by nitrogen and potassium.

5.3. Site specific nutrient management in rice-wheat cropping system

A field experiment was conducted during five consecutive years (2003-08) at Crop Research Station, Masodha, Faizabad to evaluate site specific nutrient management approach in rice-wheat cropping system. On the basis of soil test values, S, Mn, Zn, and B were applied in rice hybrid (PHB-71) only, while NPK were applied to rice and wheat (PBW-343) both for observing the effect of macro and micro-nutrients in the system.

The five years results revealed that the mean grain yield of hybrid rice (PHB-71) and wheat (PBW-343) was significantly higher with combined application of macro and micro nutrients (N_{150} P_{60} K_{120} S_{40} B_5 Mn_{20} Zn_{25}), sowing 3.7 and 1.9 t ha^{-1} increase in hybrid rice and 2.0 and 0.9 t ha^{-1} in wheat over the farmers' practice (N_{90} P_{30}) and state recommendation (N_{120} P_{60} K_{60} Zn_{25}), respectively. Significant increase in grain yield was recorded with every increase in doses of P from 0 to 30 and 60 Kg P_2O_5 ha^{-1} and K from 0 to 40 and 80 Kg K_2O ha^{-1}, respectively (Table 27). Omitting of sulphur, zinc, manganese and boron in rice reduced the grain yield of rice by 0.8, 1.0, 0.4 and 0.6 t ha^{-1} and grain yield of wheat by 0.5, 0.4, 0.1 and 0.3 t ha^{-1}, respectively.

Table-26. Effect of NPK fertilization on grain yield and sustainability of rice-wheat system (mean of 4 years)

Treatment	Grain yield (t ha^{-1})		Whole system	
	Rice	Wheat	Rice yield equivalent (t ha^{-1})	SYI
Control	1.62	1.13	3.04	0.83
N	3.17	2.31	5.78	0.88
NP	4.36	3.79	8.63	0.87
NK	3.45	2.42	6.18	0.90
PK	2.03	1.67	3.91	0.87
NPK	4.63	4.12	9.27	0.90
C.D. 5%	0.15	0.21	0.39	-
Response of nutrients				
Kg grain/ kg N applied (N over control)	12.9	8.8	11.4	
Kg grain/ kg P_2O_5 applied (NP over N)	19.7	24.6	23.7	
Kg grain/ kg K_2O applied (NPK over NP)	4.7	8.2	8.1	

SYI : Sustainability yield index

Table -27. Effect of various SSNM treatments on grain yield (t ha^{-1}) and economics of rice-wheat cropping system (average of five years)

Treatment	Hy. rice grain yield (t ha^{-1})	Wheat grain yield (t ha^{-1})	Rice equivalent yield (t ha^{-1} yr^{-1})	Gross income (Rs. ha^{-1} $Year^{-1}$)	Cost of cultivation (Rs. ha^{-1} $Year^{-1}$)	Net return (Rs. ha^{-1} $Year^{-1}$)	Net return $Re.^{-1}$ invested
$N_{150}P_{60}K_{120}$ S_{40} B_5 Mn_{20} Zn_{25}	7.8	4.6	13.9	104250	42072	62178	1.48
$N_{150}P_{30}K_{120}$ S_{40} B_5 Mn_{20} Zn_{25}	6.6	3.8	11.7	87750	40874	46876	1.15
$N_{150}P_0K_{120}$ S_{40} B_5Mn_{20} Zn_{25}	5.7	2.7	9.3	69750	39676	30074	0.76
$N_{150}P_{60}K_{80}$ S_{40} B_5Mn_{20} Zn_{25}	7.6	4.5	13.6	102000	41145	60855	1.48
$N_{150}P_{60}K_{40}$ S_{40} B_5Mn_{20} Zn_{25}	7.4	4.4	13.3	99750	40218	59532	1.48
$N_{150}P_{60}K_0$ S_{40} B_5Mn_{20} Zn_{25}	6.9	3.7	11.8	88500	39291	49209	1.25
$N_{150}P_{60}K_{120}$ S_{40} B_5Mn_{20} Zn_0	6.8	4.2	12.4	93000	40872	52128	1.27
$N_{150}P_{60}K_{120}$ S_{40} B_5Mn_0 Zn_{25}	7.4	4.5	13.4	100500	40257	60243	1.50
$N_{150}P_{60}K_{120}$ S_{40} B_0Mn_{20} Zn_{25}	7.2	4.3	12.9	96750	41030	55720	1.36
$N_{150}P_{60}K_{120}$ S_0 B_5Mn_{20} Zn_{25}	7.0	4.1	12.5	93750	40780	52970	1.30
$N_{120}P_{60}K_{60}$ Zn_{25} (STR)	5.9	3.7	10.8	81000	37485	43515	1.16
$N_{90}P_{30}$ (FP)	4.1	2.6	7.6	57000	34130	22870	0.67
CD 5%	0.30	0.21	0.33	-	-	-	-

Sale price (Rs./kg): Rice- 7.50, Wheat- 10.00, FP= Farmers practice, STR= State recommended dose

The maximum net return (Rs.62,178 ha^{-1}) was noted by applying all the required nutrients including micro- and macro-nutrients (N_{150} P_{60} K_{120} S_{40} B_5 Mn_{20} Zn_{25}) on the basis of soil test values which was Rs. 18,663 and 39,308 ha^{-1} $year^{-1}$ more than that obtained with state recommendation and farmers practice, respectively (Table 27). Omitting of S, Zn, Mn, and B reduced the net return by Rs.9208, 10050, 1935 and 6458 ha^{-1} $year^{-1}$, respectively. Omission of P caused maximum reduction in net return (Rs. 32,104) while that of K caused a reduction of Rs. 12,969 ha^{-1} $year^{-1}$.

The soil analysis showed that application of nutrient directly or indirectly increased its availability appreciably in the soil (Table 28). The omitting of any required nutrient that is already below the optimum or critical level, resulted in further decline from its initial level. The omission of phosphatic and potassic fertilizers reduced their availability from 15.3 to 10.6 kg P ha^{-1} and 92 to 80 kg K ha^{-1}, respectively during five years, whereas the regular application increased their availability in the soil.

Table 28. Effect of SSNM treatments on availability of nutrients in soil after 3 cycles of rice-wheat cropping system (April, 2006)

Treatment	Available				DTPA- extractable			
	N	P	K	S	Fe	Zn	Mn	Cu
	Kg/ha			mg/kg soil				
$N_{150}P_{60}K_{120}$ S_{40} B_5 Mn_{20} Zn_{25}	125	19.2	108	16.4	14.4	0.84	6.8	0.94
$N_{150}P_{30}K_{120}$ S_{40} B_5 Mn_{20} Zn_{25}	123	13.7	105	17.2	14.8	0.86	6.3	0.97
$N_{150}P_0K_{120}$ S_{40} B_5Mn_{20} Zn_{25}	127	11.8	109	17.6	13.4	0.88	6.6	0.98
$N_{150}P_{60}K_{80}$ S_{40} B_5Mn_{20} Zn_{25}	129	18.6	111	16.3	15.1	0.88	6.8	0.92
$N_{150}P_{60}K_{40}$ S_{40} B_5Mn_{20} Zn_{25}	126	20.1	99	16.4	15.6	0.85	6.4	0.92
$N_{150}P_{60}K_0$ S_{40} B_5Mn_{20} Zn_{25}	128	19.5	84	17.5	14.7	0.81	6.7	0.96
$N_{150}P_{60}K_{120}$ S_{40} B_5Mn_{20} Zn_0	124	18.9	109	15.8	13.9	0.61	5.9	0.94
$N_{150}P_{60}K_{120}$ S_{40} B_5Mn_0 Zn_{25}	127	19.2	112	16.2	14.3	0.80	4.3	0.93
$N_{150}P_{60}K_{120}$ S_{40} B_0Mn_{20} Zn_{25}	126	18.3	106	16.6	13.4	0.87	6.2	0.90
$N_{150}P_{60}K_{120}$ S_0 B_5Mn_{20} Zn_{25}	122	20.4	107	9.3	12.9	0.83	6.6	0.96
$N_{120}P_{60}K_{60}$ Zn_{25} (STR)	117	19.8	109	12.0	14.7	0.85	4.4	0.96
$N_{90}P_{30}$ (FP)	109	14.4	83	9.8	15.8	0.64	4.2	0.98
Initial soil test values (2003)	108	15.3	92	11.	12.6	0.69	4.8	1.05

5.4. Nitrogen management in rice-wheat system

To enhance the efficiency of fertilizer nitrogen applied in rice crop, use of slow release fertilizers has been found quite effective. The experiment was conducted at CRS Masodha, Faizabad to study the direct effects of different modified urea materials on rice and residual effects on wheat. Average grain yields for two years (Table 29) indicate that use of urea super granules (USG) being at par with prilled urea (PU) in rice was superior than other sources registering an increase of 5 to 6 q/ha. Wheat yields due to residual effect of urea super granules were not affected.

Table 29. Effect of different nitrogen sources applied to rice crop on productivity (t/ha) of rice -wheat system (mean of two years)

N source	Rice	Wheat
Prilled urea	5.64	3.04
Sulphur coated urea	5.23	3.00
Mussorie phos coated urea	5.17	3.13
Gypsum coated urea	5.21	3.01
Urea super granules	5.77	3.05
Neem cake coated urea	5.21	3.01
C.D. 5%	0.20	NS

5. 5. Development of organic farming for high value crops (maize-potato-onion)

An experiment, conducted at Agronomy Farm, Kumarganj, Faizabad during 2003-08 on a partially reclaimed sodic soil to evaluate the long-term effect of various organic sources (farm yard manure, vermi-compost and neem cake, one third each), were tested against chemical fertilizers only (conventional) and integrated nutrient sources (chemicals + organics) in maize- potato- onion system.

During first year, the highest economical yield of maize (4.58 t ha^{-1}), potato (30.2 t ha^{-1}) and onion (20.0 t ha^{-1}) was obtained with recommended dose of chemical fertilizers followed by integrated nutrient management i.e. 50% through fertilizers + 50% N through FYM. The organic treated plots showed respective lower yields (Table 30). However, the yield gaps among the plots treated with chemical fertilizers and organic manures began to decrease from the second year onwards in all the crops. During third year, organic manured plots gave equal or more yield of potato and onion (under ground crops) to that of chemical fertilized treatment, but maize yield was higher in the fertilized plot. But organic manure plots gave higher economic yields of all the crops including maize, followed by integrated treatment (chemical + organics) and lowest in chemical-fertilized plot. The economics based on fifth-year data (Table 31) revealed that the organic manured and integrated (fertilizer + organics) treatments provided higher net returns (Rs.1,37,146 to 1,45,762 ha^{-1} $year^{-1}$) as compared to fertilizers alone (Rs. 1,31,600 ha^{-1} $year^{-1}$). However, the lowest net return (Rs. 1,29,749 ha^{-1} $year^{-1}$) was obtained in the treatment having intercrops, because the intercropping of *ageti rai* showed adverse effect on the growth and yield of potato.

Table 30. Economical yield (t ha^{-1}) of maize (grain) potato (tuber) onion (bulb) as influenced by various treatments

Treatment	Economical yield (t ha^{-1})								
	Maize			Potato			Onion		
	03-04	05-06	07-08	03-04	05-06	07-08	03-04	05-06	07-08
T_1- FYM + Vermi compost + Neem cake (each 1/3 of recommended N)	3.84	3.85	4.14	19.8	29.5	31.7	15.0	17.2	17.6
T_2-T_1+ intercropping (Black gram in maize, Ageti rai in potato and chillie in onion)	3.67 + 0.52	3.53 + 0.48	3.81 + 0.43	16.6 + 0.51	21.9 + 0.31	25.5 + 0.63	15.7 + 0.52	16.0 + 0.59	16.2 + 0.48
T_3-T_1+ hand weeding + (bio-pesticides and bio-herbicides as per need)	3.99	3.89	4.26	21.4	26.8	33.9	15.8	16.6	18.4
T_4- T_1 + Azotobacter + PSB	3.84	3.76	4.08	20.8	27.3	32.6	16.0	17.0	18.6
T_5- 50% recommended NPK + 50% N as FYM + 5 kg Zn	4.55	4.26	3.96	26.3	30.9	29.8	18.5	20.0	15.8
T_6- 100% recommended NPKS and Zn	4.58	4.18	3.72	30.2	28.4	26.3	20.0	14.8	15.2

Table-31.Economics of system based high value crops as influenced by various nutrient management practices

Treatment	**Maize equivalent yield (t ha^{-1} $year^{-1}$)**	**Gross income (Rs/ha /yr)**	**Total cost of cultivation (Rs/ha /yr)**	**Net return (Rs/ha/ year)**	**B:C ratio**
T_1- FYM + Vermi compost + Neem cake (each 1/3 of recommended N)	30.43	228225	91079	137146	1.50
T_2-T_1 + intercropping (blackgram in maize, Ageti rai in potato and chillie in onion)	29.80	223500	93751	129749	1.38
T_3-T_1+ hand weeding + (bio-pesticides and bio-herbicides as per need)	32.15	241125	95363	145762	1.53
T_4- T_1 + Azotobacter + PSB	31.39	235425	94161	141264	1.50
T_5- 50% recommended NPK + 50% N as FYM + 5 kg Zn	28.28	212100	68450	143650	2.10
T_6- 100% recommended NPKS and Zn	25.85	193875	62275	131600	2.11

Sale price (Rs./kg) : Maize – 7.50, Potato – 4.00, Onion – 4.00, Blackgram – 25.00, Ageti rai – 20.00 and Chillie – 10.00

The soil-analysis data after completion of fifth cycle (June, 2008) showed that there was appreciable increase in organic carbon, available N,P,K and decrease in soil pH in all the treatments compared with their initial values. The availability of N, P and K increased in organic-manured plots and reached almost equal or higher values compared with the fertilizer treated plots in 4 to 5 years. The increase in organic carbon and decrease in pH and electrical conductivity (EC) was more in organic-manured plots than in chemical ones due to its direct effects on these properties (Table 32).

The organic inputs took time to be apparently responsive in terms of productivity and soil health. The conjunctive use of various organic manures (farm yard manure, neem cake, vermi compost) proved conducive for sustaining soil fertility and productivity in long run.

Table -32. Soil nutrient status after completion of five cycles (June, 2008)

Treatment	pH (1:2.5)	EC (1:2.5) ds m^{-1}	Org. C (g kg^{-1})	Nutrient status (kg ha^{-1})		
				N	P	K
T_1- FYM + Vermi compost + Neem cake (each 1/3 of recommended N)	7.86	0.27	0.67	163	23.0	266
T_2-T_1 + intercropping (urd in maize, Ageti rai in potato and chillie in onion)	7.84	0.29	0.70	160	21.9	264
T_3-T_1+ hand weeding + (bio-pesticides and bio-herbicides as per need)	7.82	0.26	0.68	158	22.3	270
T_4- T_1 + Azotobacter + PSB	7.82	0.31	0.72	166	23.6	269
T_5- 50% recommended NPK + 50% N as FYM + 5 kg Zn	7.96	0.32	0.61	153	21.4	260
T_6- 100% recommended NPKS and Zn	8.05	0.36	0.48	144	20.7	258
Initial soil test (June,2003)	8.25	0.40	4.6	127	17.4	247

5.6. Long-term studies on integrated nutrient supply system in rice-wheat crop sequence

A long-term field experiment on integrated nutrient management in rice-wheat system is in progress since 1984-85 on a partially reclaimed sodic soil [pH 8.8, exchangeable sodium percentage (ESP) 27] at Kumarganj in Faizabad district to find out suitable combinations of organic manures and mineral fertilizers.

The yield data of rice and wheat (averaged for each 3 years) showed that during the initial years, 100% NPK through chemical fertilizers alone gave 3-9 q ha^{-1} higher rice yield than various combinations of chemical fertilizers and organic manures. During the following years (1987-2008), the substitution of 50 per cent N through farm yard manure and *Sesbania* green-manuring to rice gave equal or more yields than 100 per cent NPK fertilizers alone. The application of 50 per cent N to rice through wheat cut straw along with 50% NPK by fertilizers produced higher rice yields than that of the 75% NPK but considerably lower than that of 100% NPK through chemical fertilizers alone (Table 33). Among the different organic N sources, *Sesbania* green manuring and FYM proved significantly superior to wheat cut straw. A positive residual response to farm yard manure and *Sesbania* green-manuring was observed continuously on wheat yield.

Table -33. Effect of integrated nutrient management on the grain yield of rice and wheat grown in a sequence (average of 3 consecutive years) on partially reclaimed sodic soil

Promising treatment-Rice	**Rice-grain yield (t ha^{-1})**			
	1984-87	**1990-93**	**1996-99**	**2000-03**
Control	2.00	1.54	1.20	1.25
R_{100} W_{100}	3.94	4.37	3.96	3.43
$R_{50+50FYM}$ W_{100}	2.99	4.47	4.27	3.53
$R_{50+50WCS}$ W_{100}	3.41	4.19	3.47	3.04
$R_{50+50GM}$ W_{100}	3.23	4.34	3.89	3.25
Promising treatment-Wheat	**Wheat-grain yield (t ha^{-1})**			
Control	1.30	0.74	0.64	0.71
R_{100} W_{100}	3.42	3.25	3.53	3.64
$R_{50+50FYM}$ W_{100}	3.41	3.45	3.88	3.71
$R_{50+50WCS}$ W_{100}	3.04	2.99	3.26	3.21
$R_{50+50GM}$ W_{100}	3.16	3.03	3.47	3.50

100 % NPK-120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha.
FYM-Farm yard manure, WCS-Wheat cut straw, GM- Green manuring by *Sesbania aculeata*

The pH, electrical conductivity and exchangeable sodium percentage (ESP) of the soil decreased considerably from their initial values by regular application of chemical fertilizer alone as well as in combination with organic N sources (Table 34). They showed greater decrease when organic manures (FYM, *Sesbania* GM, WCS) were used along with chemical fertilizers as compared to 100% chemical fertilizers alone. The organic carbon increased from 0.37 to 0.49 per cent on application of 100 per cent recommended NPK doses through chemical fertilizers. The combined use of mineral fertilizers and organic N sources (50:50) further increased the organic carbon levels to 0.62, 0.57 and 0.59 per cent in FYM, WCS and *Sesbania* GM, respectively. The application of 100% NPK through chemical fertilizers or their combined use with organic N sources showed 10-27 kg ha^{-1} increase in available N and 10.4-14.4 kg ha^{-1} in available P status of the soil, but 67-139 kg ha^{-1} decrease in available K over the respective initial values in 20 years of continuous rice-wheat cropping. Further, among the different organic sources of N applied to rice, FYM and *Sesbania* green manuring registered more increase in available N and P content of the soil than 100 per cent NPK through fertilizers alone.

Table -34. Effect of integrated nutrient management on soil fertility changes after completion of 20 cycles of rice-wheat system

Treatment	pH (1:2.5)	EC (1:2.5) ds m^{-1}	ESP	Org. C (g kg^{-1})	Available nutrients (kg ha^{-1})		
					N	P	K
Control	8.4	0.36	17	2.8	70	5.4	245
R_{75} W_{75}	8.2	0.33	21	4.4	93	18.3	228
R_{100} W_{100}	8.0	0.32	18	4.9	112	24.2	216
$R_{50+50FYM}$ W_{100}	7.7	0.25	12	6.2	129	28.2	238
$R_{50+50WCS}$ W_{100}	7.8	0.28	16	5.7	118	21.3	288
$R_{50+50GM}$ W_{100}	7.6	0.22	9	5.9	126	26.7	254
Initial values(1984)	8.8	0.50	27	3.7	102	13.8	355

100 % NPK-120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha.
FYM-Farm yard manure, WCS-Wheat cut straw, GM- Green manuring by *Sesbania aculeata*

The DTPA-extractable Zn, Cu, Mn and Fe contents decreased appreciably in almost all the treatments from their respective initial values (Table 35), except the plots treated with *Sesbania* green-manure in which DTPA-Fe raised from its initial level. The rate of depletion was more in plots treated with 100% chemical fertilizers than under combined use with organic sources.

Table -35. Effect of integrated nutrient management on micronutrients after completion of 18 cycles of rice-wheat system

Treatment	DTPA extracted micronutrients (mg kg^{-1})			
	Zn	Cu	Mn	Fe
Control	0.80	0.99	6.9	10.4
R_{75} W_{75}	0.67	0.89	6.0	9.7
R_{100} W_{100}	0.64	0.84	5.7	9.3
$R_{50+50FYM}$ W_{100}	0.98	0.97	8.3	15.8
$R_{50+50WCS}$ W_{100}	0.86	0.93	7.6	13.6
$R_{50+50GM}$ W_{100}	0.93	1.03	9.2	23.4
Initial status in 1984	2.02	2.40	12.6	17.0

100 % NPK-120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha.
FYM-Farm yard manure, WCS-Wheat cut straw, GM- Green manuring by *Sesbania aculeata*

The study also showed that regular incorporation of organic materials (farmyard manure, *Sesbania* green-manure, wheat-cut straw) along with chemical fertilizers before puddling of rice improved the soil aggregation and thereby decreased bulk density which in turn increased the saturated hydraulic conductivity and infiltration rate of the soil (Table 36). The combined use of organics and fertilizers improves the physical condition of soil more effectively than continuous addition of chemical fertilizers (NPK) alone.

Table -36. Effect of integrated nutrient management on physical properties of soil after completion of 20 cycles of rice-wheat system

Treatment	MWD (mm)	B.D. Mgm^{-3}	H.C. mm h^{-1}	IR mm h^{-1}	Org. C mg kg^{-1}	CEC c. mol (p+) kg^{-1}
Control	0.40	1.51	2.9	2.5	2.9	15.9
R_{75} W_{75}	0.49	1.46	3.7	3.0	4.2	16.5
R_{100} W_{100}	0.51	1.43	4.1	3.0	4.6	17.4
$R_{50+50FYM}$ W_{100}	0.78	1.35	5.7	4.5	5.7	18.9
$R_{50+50WCS}$ W_{100}	0.72	1.36	5.1	4.0	5.4	18.3
$R_{50+50GM}$ W_{100}	0.78	1.33	5.9	5.5	5.8	19.5
Initial value (July, 1984)	0.36	1.38	2.6	2.1	3.7	17.1

MWD – Mean weight diameter, BD – Bulk density, HC – Hydraulic conductivity, IR- Infiltration rate, CEC – Cation exchange capacity, 100 % NPK-120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha., FYM-Farm yard manure, WCS-Wheat cut straw, GM- Green manuring by *Sesbania aculeata*

5.7. Effect of FYM in rice-wheat system

In an experiment, conducted at CRS Masodha, Faizabad, during 1978-1986 to study the effect of farm yard manure (FYM), revealed that application of FYM was quite beneficial. The grain yields of rice as well as wheat were significantly influenced by FYM application (Table 37). In general, direct effects were more pronounced than cumulative and residual effects. The responses to FYM were greater in wheat as compared to rice.

Table-37. Grain yield (t/ha) of rice and wheat as affected by FYM application (mean of 8 years)

FYM level (t/ha)	Direct effect		Residual effect		Cumulative effect	
	Rice	Wheat	Rice	Wheat	Rice	Wheat
0	3.94	2.98	3.63	2.87	4.01	3.12
15	4.34	3.58	3.97	3.26	4.46	3.75

5.8. Direct and residual effect of FYM in rice-wheat system

In another experiment on farm yard manure, it was found that supplying nutrients through fertilizer alone in rice crop resulted in higher yield as compared to that through FYM or through FYM + fertilizers in different combinations (Table 38). However, residual effect of FYM application on wheat was substantial. By applying 100% of recommended NPK through FYM (25%) + chemical fertilizers (75%) to the rice crop, about 25% saving of fertilizers was achieved in wheat without any appreciable loss in yield of the system as a whole. As FYM has some other long term advantages in supplying the organic matter, micronutrients and improving the physical conditions of the soil, it has been suggested that 25% of the total recommended NPK should be applied through FYM in rice crop for sustained production of rice-wheat crop.

Table-38. Residual effect of different fertilizer and farm yard manure levels applied in rice on succeeding wheat grain yield (t/ha) at two fertility levels

Treatment	Fertility levels to rice (% of recommended)						Fertilizer to wheat (% of recommended)		
	0	25	50	75	100	Mean	100	75	Mean
Control	0.85 (1.21)	- (-)	- (-)	- (-)	- (-)	- (-)	--	-	-
Fertilizer alone	- (-)	4.12 (2.28)	4.16 (3.17)	4.09 (3.85)	4.12 (4.37)	4.12 (3.47)	4.24	3.99	4.12
Fertilizer (75%) +FYM (25%)	- (-)	4.24 (2.30)	4.24 (2.97)	4.23 (3.60)	4.32 (4.20)	4.26 (3.27)	4.40	4.13	4.27
Fertilizer (50%) +FYM (50%)	- (-)	4.26 (2.17)	4.38 (2.67)	4.32 (3.38)	4.57 (3.91)	4.48 (3.02)	4.49	4.29	4.38
FYM alone	- (-)	4.27 (1.90)	4.44 (2.35)	4.46 (2.94)	4.69 (3.87)	4.46 (2.67)	4.57	4.36	4.67
Mean	-	4.23 (2.21)	4.30 (2.78)	4.28 (3.44)	4.42 (3.98)	-	4.43	4.20	

(Rice yield was given in parentheses)

5.9. Nutrient management for sustainable crop production in rice-wheat system

A field experiment was conducted during seven consecutive years (2000-06) at Crop Research Station Masodha, Faizabad, to find out suitable remedial measures to overcome the effect of two major non sustainable parameters (soil health and plant protection) in rice-wheat cropping system.

Average data of seven years (2000-2006), presented in Table39, show that application of 10 t FYM/ha in rice over recommended fertilizer doses increased the grain yields of rice and wheat by 5.2 and 4.6 q/ha, respectively. The application of NPK and Zn fertilizer on soil test basis provided 1.3 and 2.8 q/ha higher yield of rice and wheat, respectively, over recommended dose of NPK fertilizers. Maximum grain yields of rice and wheat of 53.4 and 44.9 q/ha were obtained when care of both the factors of sustainability i.e. plant protection and soil health measures were taken.

The data of economics, show that the highest net returns of Rs. 23564/ha/year was recorded by fertilization on recommended basis and by taking the care of soil health and plant protection measures (RDF + 10 t FYM + plant protection measures) followed by T_2 (Rs. 20409/ha) in which 10 t FYM was applied in addition to recommended dose of fertilizers (RDF) for soil health and T_4 (19181/ha/year) where fertilization was done on soil test basis. The application of fertilizer doses on soil test basis were found economical which provided an additional return of Rs. 3008/ha over recommended dose of fertilizers.

Table -39: Effect of different sustainable treatments of grain yield (q/ha) and economics of rice-wheat system (means of seven years - 2000-06)

Treatment	Grain yield		Rice equivalent yield (q/ha)	Gross income (Rs/ha/ year)	Cost of cultivation (Rs/ha/ year)	Net return (Rs/ha/ year)
	Rice (q/ha)	Wheat (q/ha)				
T_1- RFD	43.98	37.40	89.90	51248	35075	16173
T_2- RFD + FYM (10 t/ha)	49.24	42.03	100.85	57484	37075	20409
T_3- RFD + PP	46.64	40.16	95.95	54691	36275	18416
T_4- FST	45.26	40.23	94.66	53956	34775	19181
T_5- RFD + 10 t FYM + PP	53.40	44.86	108.49	61839	38275	23564

RFD – Recommended dose of fertilizer (120kg N : 60kg P_2O_5 : 60kg K_2O kg/ha to both the crops)
FST – Fertilizer on soil test basis (120kg N; 40kg P_2O_5; 55kg K_2O in both crops and 25 kg $ZnSO_4$/ha in rice only)
PP – Plant protection measures as per need.

(B)-On Farm Experiments

The technology generated at University Research Farms was tested/evaluated on farmers' fields under farmers' participatory approach. For this, 2-3 blocks were selected in each district and in each block 3-4 villages were taken. In each village, 2-3 farmers were selected for field experiments. The villages and farmers were changed every year with in the block. The district was changed after every five years.

OF-1. On Farm evaluation of alternative cropping systems

1.1.Crop intensification/diversification under irrigated/ rain fed conditions (1990-95)

The experiments conducted under upland irrigated conditions in Gonda, Basti and Bahraich districts of NARP Zone 7, during five consecutive years (1990-95) revealed that three crop sequences viz. til-gram-green gram, blackgram-mustard-green gram and maize-gram-greengram were more profitable than traditional maize-wheat system (Table 40). In normal irrigated situations rice-mustard-blackgram, rice-lentil-greengram and rice-gram-maize (green fodder) were found more remunerative than traditional rice-wheat system. Under lowlying unirrigated conditions, rice-gram, rice-lentil and rice-linseed were more remunerative than rice-barley system.

Similarly, the experiments conducted under upland-irrigated situations in Ghazipur, Mau, Jaunpur and Varanasi districts of the NARP Zone 8 revealed that maize-gram, blackgram-wheat and blackgram-mustard were more remunerative than traditional maize-wheat system. On the other hand in normal land irrigated conditions rice-lentil and rice-gram were found more remunerative than existing rice-wheat system.

Table 40: Grain yield and economic evaluation of various cropping system in NARP Zone 7 and 8 (mean of five years 1990-91 to 1994-95)

Crop sequences	Average grain yield (q/ha)			Gross return (Rs/ha/year)
	Kharif	***Rabi***	***Zaid***	
NARP Zone -7 (Gonda, Basti, Baharaich)				
Upland irrigated				
Maize-wheat	20.4	38.1	-	22380
Maize-gram-green gram	20.7	15.4	7.4	36825
Blackgram –mustard-green gram	8.0	12.5	7.4	38100
Til- gram- green gram	4.3	14.9	6.9	38550
Pegionpea –wheat	9.4	30.6	-	29160
Normal irrigated				
Rice-wheat	48.9	41.8	-	33835
Rice- gram-green fodder (maize)	47.5	16.2	160.5	42485
Rice-mustard-blackgram	47.7	15.6	5.7	43965
Rice-lentil-greengram	47.4	14.4	6.3	43320
Rice-linseed	48.1	13.3	-	30135
Lowlying unirrigated				
Rice-fallow	27.8	-	-	9730
Rice-lentil	29.2	15.0	-	28220
Rice-linseed	28.6	10.8	-	20810
Rice-gram	30.1	18.0	-	32135
Rice-barley	29.6	25.2	-	19180
NARP Zone -8 (Ghazipur, Mau, Varanasi, Jaunpur)				
Upland irrigated				
Maize-wheat	26.9	41.5	-	26015
Maize-gram	26.5	20.1	-	33395
Maize-mustard	26.8	12.3	-	24140
Blackgram-wheat	9.9	43.2	-	32130
Blackgram-mustard	10.0	13.6	-	31320
Normal land irrigated1				
Rice-wheat	43.8	43.2	-	32610
Rice-gram	44.0	20.4	-	39880
Rice-mustard	45.6	14.2	-	33000
Rice-lentil	43.5	21.1	-	40545
Rice-linseed	44.7	17.4	-	33045

Note: sale price (Rs/q) Rice-350, wheat-400, maize-350, barley-350, gram-1200, greengram-1500, blackgram-1500, pegionpea-1800, lentil-1200, mustard-1200, linseed-1000, til- 2400, maize fodder-40.

1.2. Crop intensification/diversification under irrigated/ rain fed conditions (1995-99)

The experiments conducted under irrigated conditions in Deoria, Gorakhpur and Padrauna ditricts of NARP zone 7 during four consecutive years (1995-99) revealed that pegionpea-wheat, rice-wheat and rice-gram crop sequences were more profitable than blackgram-mustard or maize-gram sequences (Table 41).

Similarly, the experiments conducted on farmers fields under upland unirrigated situations In the Ghazipur, Ballia, Mau and Jaunpur districts of the NARP zone 8, showed that maize-wheat and blackgram-wheat were found more remunerative followed by blackgram-mustard and maize-gram sequences (Table 41).

Table 41: Grain yield and economic evaluation of various cropping system in NARP Zone 7 and 8 (mean of four years 1995-96 to 1998-99)

Crop sequences	Average grain yield (q/ha)		Returns (Rs/ha/year)
	Kharif	***Rabi***	
NARP Zone -7 (Gorakhpur, Padrauna, Deoria)			
Upland irrigated			
Rice-wheat	42.0	44.0	45300
Rice-gram	42.9	15.1	43465
Blackgram –mustard	9.5	13.6	39400
Maize- gram	29.9	15.8	40230
Pegionpea –wheat	10.9	40.9	46340
Maize-barley	29.3	36.0	32650
NARP Zone -8 (Ghazipur, Mau, Ballia, Jaunpur)			
Upland unirrigated			
Maize-wheat	18.5	33.5	29350
Maize-gram	18.4	11.6	27760
Maize-mustard	18.3	8.3	21600
Blackgram-wheat	6.1	35.4	33440
Blackgram-mustard	6.3	10.1	27750

Note: sale price (Rs/q) Rice-450, wheat-600, maize-500, barley-500, gram-1600, blackgram-2000, pegionpea-2000, mustard-1500.

1.3. Crop intensification/diversification of rice-based cropping system in calcarious soils (1995-98)

Six rice-based cropping systems viz. rice-wheat, rice-potato-black gram, rice-toria-maize (fodder), rice-mustard-green gram, rice-lentil- green gram and rice-coriander were tested on cultivators' fields at 12 locations in calcarious soils of Gorakhpur, Deoria and Padrauna districts of North Eastern Plain Zone of Uttar Pradesh during 1995-98 to find out the most productive, remunerative and sustainable cropping system for the area.

The highest rice yield-equivalent of 12.73 t ha^{-1} $year^{-1}$ was recorded by rice-potato- black gram which was much higher than all other cropping system, showing an increase of 4.15 t ha^{-1} $year^{-1}$ over conventional rice-wheat system (Table 42). The highest net return of Rs. 24,045 ha^{-1} $year^{-1}$ was noted with rice-lentil- green gram followed by rice-potato- black gram (Rs. 20,670 ha^{-1} $year^{-1}$), rice-mustard-green gram (Rs. 18,175 ha^{-1} $year^{-1}$) and these systems gave higher returns than conventional rice-wheat system (Rs. 16,200 ha^{-1} $year^{-1}$). The benefit : cost ratio of 1.02 was higher with rice-lentil- green gram and lowest (0.52) with rice-toria-maize against 0.72 of rice-wheat. The diversified/ intensified cropping systems which were remunerative have also been found quite sustainable (SI = 0.94 & 0.85) and may be advocated to adopt by the farmers of the area.

Table 42. Comparative performance of various cropping systems in calcarious soils of North-Eastern Plain Zone of Uttar Pradesh (mean of three years, 1995-98)

Cropping system	Grain yield (t/ha)			Rice yield equivalent (t/ha/yr)	Cost of cultivation (Rs/ha/yr)	Net returns (Rs/ha/yr)	B : C ratio	Sequence stability index
	Kharif	*Rabi*	*zaid*					
Rice- wheat	4.08	3.96	-	8.58	22410	16200	0.72	0.96
Rice- potato – black gram	4.06	14.82	0.67	12.73	36615	20670	0.56	0.85
Rice- toria-maize (fodder)	4.11	0.61	17.33	6.70	19818	10332	0.52	0.90
Rice- mustard - green gram	4.14	1.04	0.70	9.09	22730	18175	0.80	0.92
Rice- lentil-green gram	4.17	1.51	0.67	10.58	23565	24045	1.02	0.92
Rice- coriander	4.17	0.72	-	7.37	19040	14125	0.74	0.94

1.4. Intensification/diversification of rice-based cropping system (2001-03)

To fulfill the demand of food, oil and vegetable with increasing human population, intensification of cropping sequences is essential depending on the need of the area. Oilseeds and pulses including vegetables are receiving more attention owing to higher prices due to increased demand. Keeping this in view, the fields of eight marginal farmers (85% of total house holds) in the village Anjrauli, Tehsil Milkipur, Dist. Faizabad were selected for conducting the experiment under farmers’ participating approach. Three cropping system viz., rice-wheat (conventional), rice-mustard and rice-vegetable pea + parwal- parwal continued (PC) + bhindi were tested during two consecutive years (2001-03). The crops were raised with recommended packages of practices.

The highest productivity in terms of rice-grain equivalent (28 t/ha) was obtained in the sequence of vegetables (pea, parwal, bhindi) while minimum rice grain equivalent (8.2 t/ha) was in conventional rice wheat system. The economics of different systems (Table 43) indicated that maximum cost of cultivation (Rs. 60, 743/ha/year) was incurred in vegetables based sequence as these crops required more inputs as protective measures. The maximum net returns per rupee invested (1.08) and employment generation (750man days/ha/year) were also obtained from vegetables based sequence. The replacement of wheat by mustard controlled the problem of *Phalaris minor* and supplied oil without any economic loss. Inclusion of vegetables in the system provided more income and employment regularly to the family member of marginal farmers, besides fulfilling their day to day needs.

Table 43. Productivity and economics of various rice-based cropping system (mean of 8 farmers during 2001-03)

Cropping system	Yield (t/ha)							
	Rice	**Wheat/ mustard /green pea pods**	**Parwal& bhindi**	**Rice – grain equivalent**	**Cost of cultivation (Rs/ha)**	**Net returns (Rs/ha)**	**Net returns per Re invested**	**Labour (man days/ ha/ year)**
Rice-wheat	4.44	3.04	-	8.2	25,148	11,552	0.46	280
Rice-mustard	4.44	1.28	-	8.4	23,351	14,549	0.62	240
Rice- pea + parwal-PC + bhindi	4.44	3.36	6.91 & 3.08	28.0	60,743	65,367	1.08	750

Sale price (Rs/kg) : rice- 4.50, wheat 5.50, mustard 14.0, green pea pods 8.0, parwal 12.0, bhindi 4.0
PC- Parwal continued

1.5. Intensification and diversification of existing rice-wheat cropping system (2000-06)

Under irrigated conditions of medium heavy textured soil, four rice-based cropping systems viz. rice-wheat (conventional) rice-gram, rice-mustard and rice-pea were tested at 60 locations on farmers' fields situated in Jaunpur, Sultanpur and Barabanki districts of NARP Zone 8 during six consecutive years (2000-06). Medium duration high yielding rice variety NDR-359 was sown in all the sequences.

On the average of six years data (Table 44) it was observed that diversification of cereal-cereal (rice-wheat) to cereal-pulse/mustard (rice-gram/mustard) was found more remunerative. The highest wheat-yield equivalent (9.78 t/ha) and net return of Rs. 35,929 ha^{-1} $year^{-1}$ was obtained by rice-gram followed by rice-mustard (Rs. 26968 ha^{-1} $year^{-1}$) and these systems showed an increase of Rs. 10642 and Rs. 1681 ha^{-1} $year^{-1}$ over net return of conventional rice-wheat system (Rs. 25287 $ha^{-1}year^{-1}$), respectively. The rice-pea sequence gave lesser return as compared to conventional system with a margin of Rs. 2222 ha^{-1} $year^{-1}$. B:C ratio was also higher in rice-gram and rice-mustard systems.

In light textured soil, under upland irrigated situations, another set of three cropping system viz. pigeonpea-wheat, pigeonpea + blackgram-wheat and blackgram-mustard were tested on 24 locations situated in Kurebhar and Sultanpur blocks of Sultanpur district during five consecutive years (2000-05). Results showed that pigeonpea intercropped with blackgram-wheat sequence gave maximum wheat yield-equivalent (7.81 t ha^{-1}) and highest net return of Rs. 26103 ha^{-1} $year^{-1}$ which showed an increase of Rs.

5613 and 6659 ha^{-1} year^{-1} over pigeonpea-wheat and blackgram –mustard cropping systems, respectively (Table 44).

Rice-wheat and pigeonpea-wheat systems were found most stable systems (SI=0.95 & 0.96) among all tested systems. The remunerative cropping systems rice-gram and pigeonpea +blackgram-wheat were also found quite stable (SI=0.90 &0.89) in terms of yield and may be advocated to adopt by the farmers' of the area under irrigated conditions and upland conditions, respectively.

Table 44.Productivity, profitability and sustainability of various cropping systems in NARP zone 8 (mean of six years -2000-06)

Cropping system	Grain yield (t/ha)		Wheat yield equivalent (t/ha/yr)	Cost of cultivation (Rs/ha/yr)	Net return (Rs/ha/yr)	B:C ratio	Sustainability index
	Kharif	***Rabi***					
A- Medium irrigated soils							
Rice-wheat	4.63	4.86	8.55	28569	25287	0.88	0.95
Rice-gram	4.70	2.26	9.78	25701	25929	1.40	0.90
Rice- mustard	4.75	1.69	8.21	24760	26968	1.09	0.94
Rice-pea	3.86	2.08	7.76	25811	23065	0.89	0.88
CD 5%	-	0.32	-	-	-		
B- Light textured soils							
Pigeonpea – wheat	1.30	3.31	6.70	21954	20490	0.93	0.96
Pigeonpea + blackgram-wheat	1.05 + 0.43	3.61	7.81	23114	26103	1.13	0.89
Blackgram-mustard	1.04	1.40	5.88	17622	19444	1.10	0.84

OF-2. On Farm evaluation of intercropping

2.1.Intercropping under irrigated/rainfed conditions (1990-95)

The experiments were carried out to find out the feasibility of intercropping for increasing the yield and income potential under irrigated/rainfed conditions. In Gonda, Basti and Baharaich districts of NARP zone 7, the sole cropping of pegionpea in *kharif* and wheat in *rabi* seasons were found more profitable than inter cropping of pegionpea with maize in *kharif* and wheat with mustard in *rabi* (Table 45). The use of additional doses of NPK fertilizers for intercrops did not show any appreciable influence on the grain yields of *rabi* and *kharif* crops.

In Ghazipur, Mau, Varanasi and Jaunpur districts of NARP zone 8, intercropping of maize with blackgram in *kharif* season and wheat with mustard in *rabi* season were found more remunerative than their sole crops (Table 45). In this zone the yields of intercrops (blackgram and mustard) increased (1.5 – 2.5 q/ha) by applying extra fertilizer doses of NPK for intercrops.

Table 45: Comparison of different intercropping system with varying levels of fertilizers (mean of five years-1990-91 to 1994-95)

Treatment	Mean grain yield (q/ha)				
	Kharif		*Rabi*		Maize yield equivalent
	Main crop	Inter crop	Main crop	Inter crop	
NARP Zone-7 (Gonda, Basti, Bahraich)					
Upland irrigated	**Pigeonpea**	**Maize**	**Wheat**	**Mustard**	
T_1 –Farmers' practices	17.4	13.4	25.3	1.4	136.6
T_2 -Sole main crop	24.0	-	40.9	-	170.2
T_3 – T_2 + intercrop with no fertilizers	17.5	14.1	34.8	1.4	148.7
T_4 – T_2 + intercrop with 50% fertilizers	17.3	13.5	34.7	1.9	146.9
T_5 – T_2 + intercrop with 100% fertilizers	18.4	14.2	35.5	2.2	156.9
Upland unirrigated	**Pigeonpea**	**Maize**	**Gram**	**Mustard**	
T_1 –Farmers' practices	7.7	6.9	10.4	1.5	87.3
T_2 -Sole main crop	14.3	-	20.1	-	142.5
T_3 – T_2 + intercrop with no fertilizers	10.8	7.6	15.2	2.2	122.8
T_4 – T_2 + intercrop with 50% fertilizers	11.4	8.7	14.5	2.5	125.6
T_5 – T_2 + intercrop with 100% fertilizers	10.6	9.8	14.2	3.2	124.0
NARP Zone 8 (Ghazipur, Mau, Jaunpur and Varanasi)					
Upland irrigated	**Maize**	**Blackgram**	**Wheat**	**Mustard**	
T_1 –Farmers' practices	15.6	4.5	21.7	3.2	70.7
T_2 -Sole main crop	25.9	-	46.4	-	78.9
T_3 – T_2 + intercrop with no fertilizers	23.7	5.9	42.6	4.7	113.8
T_4 – T_2 + intercrop with 50% fertilizers	24.1	7.3	42.1	6.1	124.4
T_5 – T_2 + intercrop with 100% fertilizers	24.5	7.8	43.5	7.3	132.7

Note: sale price (Rs/q) Wheat-400, maize-350, gram-1200, blackgram-1500, pegionpea-1800, mustard-1200.

2.2.Intercropping under irrigated/rain fed conditions (1995-2000)

The experiment was also carried out during 1995-96 to 1999-2000 to find out the feasibility of intercropping for increasing the yields and income potential under irrigated/rainfed conditions in other districts. The results showed that in Gorakhpur, Padrauna and Deoria districts of NARP zone 7, either intercropping of pigeonpea + maize or sole cropping of pegionpea both in *kharif* and intercropping of gram + mustard in *rabi* were found profitable (Table 46). The use of extra fertilizers for intercrops did not show any appreciable influence on the yields of *kharif* crops.

The intercropping of maize with blackgram in *kharif* and wheat with mustard in *rabi* was found more remunerated than their sole cropping. The application of full dose of fertilizers recommended to intercrops was more remunerative than 50% of RDF or no fertilization by Rs. 4010 and Rs. 9990/ha, respectively.

Table 46. Comparison of different intercropping systems with varying levels of fertilizers (mean of four years -1995-96 to 1998-99)

Treatment	Mean grain yield (q/ha)				
	Kharif		*Rabi*		Gross return (Rs/ha)
	Main crop	Inter crop	Main crop	Inter crop	
NARP Zone-7 (Gorakhpur, Deoria, Padrauna)					
Upland irrigated	**Pigeonpea**	**Maize**	**Gram**	**Mustard**	
T_1 –Farmer's practices	14.6	14.8	8.9	6.7	60890
T_2 –Sole main crop	19.9	-	14.9	-	63640
$T_3 - T_2$ + intercrop with no fertilizers	16.6	14.2	11.3	6.2	67680
$T_4 - T_2$ + intercrop with 50% fertilizers	15.7	18.6	12.9	5.7	69890
$T_5 - T_2$ + intercrop with 100% fertilizers	16.0	21.4	14.1	4.4	71860
T_6- Sole intercrop	-	23.7	-	14.8	34050
NARP Zone 8 (Ghazipur, Mau, Ballia and Jaunpur)					
Upland irrigated	**Maize**	**blackgram**	**Wheat**	**Mustard**	
T_1 -Farmer's practices	13.8	3.1	22.9	2.8	31040
T_2 -Sole main crop	23.9	-	45.8	-	39430
$T_3 - T_2$ + intercrop with no fertilizers	19.0	3.9	39.4	4.6	47840
$T_4 - T_2$ + intercrop with 50% fertilizers	19.4	5.2	41.7	5.8	53820
$T_5 - T_2$ + intercrop with 100% fertilizers	20.1	5.8	42.3	7.2	57830

Note: sale price (Rs/q) wheat-600, maize-500, barley-500, gram-1600, blackgram-2000, pegionpea-2000, mustard-1500.

OF-3. On Farm evaluation of crop varieties, nutrient requirement and management practices

3.1. Performance of crop varieties and their nutrient requirement under irrigated/rainfed conditions (1990-95)

The experiments were conducted in Gonda, Basti and Bahraich districts of NARP Zone 7 and Ghazipur, Mau, Jaunpur and Varanasi districts of the NARP Zone 8 during five consecutive years (1990-95) to study the impact of improved varieties, fertilizers application and improved management practices on the crop productivity. Results revealed that improved varieties of rice and wheat alongwith recommended fertilizer (NPK) doses increased the grain yields by 15-18 q/ha under irrigated conditions, while under unirrigated conditions increase was only 6-8 q/ha (Table 47). The improved varieties of rice and wheat did not show their full potential without recommended fertilizers doses. In case of maize and gram, the increase of 1.5 to 3.5 q/ha in grain yields were noticed due to improved varieties and recommended doses of fertilizers.

Table 47: Effect of recommended varieties, fertilizers doses and practices over farmers local practices on the grain yield (mean of five years-1990-91 to 1994-95)

Treatments	**Average yield (q/ha)**	
	Kharif	***Rabi***
NARP Zone 7(Gonda, Basti, Bahraich)		
Upland irrigated	**Maize**	**Gram**
T_1 Farmers local practices	13.8	13.0
T_2 Improved variety + T_1	15.4	14.3
T_3 Recommended fertilizers dose + T_2	17.5	16.8
T_4 Recommended practices + T_3	18.6	17.4
Lowlying irrigated	**Rice**	**Wheat**
T_1 Farmers local practices	24.8	20.8
T_2 Improved variety + T_1	27.3	22.6
T_3 Recommended fertilizers dose + T_2	42.8	40.5
T_4 Recommended practices + T_3	43.6	41.8
Lowlying unirrigated	**Rice**	**Wheat**
T_1 Farmers local practices	20.1	18.8
T_2 Improved variety + T_1	22.3	19.4
T_3 Recommended fertilizers dose + T_2	28.7	25.6
T_4 Recommended practices + T_3	31.0	27.6
NARP Zone 8(Ghazipur, Mau, Jaunpur and Varanasi)		
Low-lying irrigated	**Rice**	**Wheat**
T_1 Farmers local practices	28.2	25.9
T_2 Improved variety + T_1	33.3	31.8
T_3 Recommended fertilizers dose + T_2	42.6	39.3
T_4 Recommended practices + T_3	45.2	42.3

3.2. Performance of crop varieties and their nutrient requirement under irrigated/rainfed conditions (1995-2000)

The experiments were conducted on farmers fields during 1995-96 to1999-2000 in the Gorakhpur, Deoria and Padrauna districts of NARP zone 7 and Ghazipur, Mau, Jaunpur and Ballia districts of the NARP Zone 8 to study the impact of improved varieties, fertilizer doses and management practices. The yield data (Table 48) revealed that improved varieties of rice and wheat alongwith recommended fertilizer (NPK) doses increased the grain yields appreciably over farmers practices (local variety and lower fertilizer doses).

Table 48: Effect of recommended varieties, fertilizers doses and practices over farmers local practices on the grain yield (mean of five years 1995-96 to 1999-2000)

Treatments	**Average yield (q/ha)**	
	Kharif	***Rabi***
NARP Zone 7 (Gorakhpur, Padrauna, Deoria)		
Upland rainfed	**Maize**	**Gram**
T_1 Farmers local practices	20.3	13.8
T_2 Improved variety + T_1	22.6	16.5
T_3 Recommended fertilizers dose + T_2	26.0	17.9
T_4 Recommended practices + T_3	28.0	19.2
Normal irrigated	**Rice**	**Wheat**
T_1 Farmers local practices	26.0	26.3
T_2 Improved variety + T_1	33.0	29.7
T_3 Recommended fertilizers dose + T_2	47.3	36.1
T_4 Recommended practices + T_3	48.4	38.7
Calcarious irrigated	**Rice**	**Wheat**
T_1 Farmers local practices	25.6	27.4
T_2 Improved variety + T_1	28.2	30.6
T_3 Recommended fertilizers dose + T_2	32.3	36.0
T_4 Recommended practices + T_3	35.7	39.1
NARP Zone 8 (Ghazipur, Mau, Jaunpur and Ballia)		
Normal irrigated	**Rice**	**Wheat**
T_1 Farmers local practices	29.1	28.6
T_2 Improved variety + T_1	35.6	33.8
T_3 Recommended fertilizers dose + T_2	45.0	38.8
T_4 Recommended practices + T_3	49.2	41.3

Under irrigated conditions in normal soils, the grain yield of rice and wheat increased by about 15.0 and 7.0 q/ha, respectively by applying recommended fertilizer doses with improved varieties. In calcarious soil, the increase in grain yields was about 4-6 q/ha. Under rainfed conditions, 6 q/ha increase in maize yield and 3 q/ha in the yield of gram were noticed due to improved varieties and application of recommended doses of NPK fertilizers over farmers practices.

3. 3. Agronomical management practices for sustainable production in rice-wheat cropping system (2000-05)

The field experiments were conducted during five consecutives years of 2000-2005 on 2 to 3 farmers fields in Mahrajganj, Siddhartha Nagar and Basti districts of North Eastern Plain Zone (NARP Zone-7) and Sultabnpur, Jaunpur and Barabanki districts of Eastern Plain Zone (NARP Zone 8).

On the basis of five years results it was noted that application of recommended dose of NPK fertilizers increased the grain yield of rice and wheat significantly with margin of 0.80 and 0.69 t ha^{-1} under NEPZ and 1.35 and 0.98 t ha^{-1} under EPZ, respectively (Table 49). The adoption of improved package of practices over farmers practices further enhanced the grain yields of both rice & wheat significantly showing an increase of 0.37 and 0.32 t ha^{-1} in NEPZ and 0.65 and 0.45 t ha^{-1} in EPZ conditions of eastern Uttar Pradesh. The response of both factor of sustainability i.e. balanced fertilization and cultural plant protection measures shown better response in eastern plain zone as compared to north eastern plain zone of U.P. On an average, application of recommended dose of fertilizers and other management practices gave Rs. 11165 and Rs. 16390/ha/year additional income over farmers practices with a benefit ratio of 3.49 and 3.80, respectively.

Table -49: Effect of agronomic management practices on productivity (t ha^{-1}) of rice-wheat cropping system (mean of five years 2000-2005)

Treatment	North Eastern Plain Zone		Eastern Plain Zone		Mean		Rice yield equivalent (t/ha /yr)	Addit. cost over FP (t/ha /yr)	Addit. income over FP (t/ha /yr)	B:C ratio
	Rice	Wheat	Rice	Wheat	Rice	Wheat				
FP	3.34	3.03	2.79	2.65	3.07	2.84	6.32	-	-	-
FP + RFD	4.14	3.72	4.14	3.63	4.14	3.68	8.35	3200	11165	3.49
RFD + IP	4.51	4.04	4.79	4.08	4.65	4.06	9.30	4750	16390	3.80
C.D. at 5%	0.29	0.21	0.25	0.16	0.20	0.14	-	-	-	-

Price of produce - Rice @Rs. 5500/- and Wheat @ Rs. 6300/t^{-1}
F.P. - Farmers practice (Farmers own variety with $N_{90}P_{30}K_0$ kg/ha^{-1} fertilization
RFD - $N_{120}P_{60}K_{60}$ in both the crops and 25 kg Zinc sulphate ha^{-1} in rice only
IP (Improved practices) - Improved variety and need based plant protection measures

OF-4.On Farm evaluation of nutrient management in various cropping systems

4.1. Integrated nutrient management in rice-wheat system

The experiments were carried out at 120 cultivators fields in Gonda, Basti and Bahraich districts of NARP Zone 7 and Ghazipur, Mau, Jaunpur and Varanasi districts of the NARP Zone 8 during five consecutive years (1990-95) to workout suitable integrated nutrient supply system in rice-wheat sequence for efficient use of chemical fertilizers in conjunction with combination of organic manures.

The data of rice and wheat (Table 50) clearly showed that 50% of recommended chemical fertilizers (NPK) may be substituted by organic sources (FYM or green manure) in rice without any adverse effects on grain yields and net returns in rice-wheat sequence under irrigated conditions of NARP Zones 7 and 8. The residual effects of green manure or farm yard manure on succeeding wheat crop were positive as compared to 100% chemical fertilizers alone.

Table 50: Effects of farm yard manure, green manure and chemical fertilizers on the yield of rice and wheat under irrigated conditions (mean of five years-1990-91 to 1994-95)

Treatment	**Average yield (q/ha)**	
	Rice	**Wheat**
NARP Zone 7 (Gonda, Basti, Bahraich)		
100% NPK	48.4	37.8
50% NPK + 50% FYM	45.9	39.6
50 NPK + 50% GM	46.0	40.0
Farmers dose of fertilizer (60 N : 30 P_2O_5)	31.1	31.9
NARP Zone 8 (Ghazipur, Mau, Jaunpur and Varanasi)		
100% NPK	41.6	39.7
50% NPK + 50% FYM	39.0	40.2
50 NPK + 50% GM	40.1	39.3
Farmers dose of fertilizer (60 N : 30 P_2O_5)	28.4	27.3

Note: 100% NPK = 120 kg N, 60 kg P_2O_5 and 40 kg K_2O through fertilizers
50% FYM/GM = 50% N through farm yard manure or green manure (i.e. *Sesbania aculeata*)

Similar experiments were carried out at 60 locations in Ghazipur, Mau, Ballia districts of NARP zone 8 during 1995-96 to 1999-2000 to workout suitable integrated nutrient supply system in rice-wheat sequence. The yield data of rice and wheat (Table 51) clearly showed that 50% of recommended chemical fertilizers (NPK) may be substituted by organic sources(FYM or *Sesbania* green manure) in rice without any adverse effects on grain yields in rice-wheat sequence under irrigated conditions of NARP zone 8. The residual effects of green manure or farm yard manure on succeeding wheat crop were found positive over 100% chemical fertilizers alone.

Table 51: Effects of farm yard manure, green manure and chemical fertilizers on the yield of rice and wheat under irrigated conditions (mean of five years 1995-96 to 1999-2000)

Treatment	Average yield (q/ha)	
	Rice	Wheat
NARP Zone 8(Ghazipur, Mau, Jaunpur and Ballia)		
100% NPK	51.4	39.7
50% NPK + 50% FYM	50.0	42.6
50 NPK + 50% GM	48.4	40.3
Farmers dose of fertilizer (60 N : 30 P_2O_5)	35.0	31.8

Note: 100% NPK = 120 kg N, 60 kg P_2O_5 and 40 kg K_2O through fertilizers
50% FYM/GM = 50% N through farm yard manure or green manure (i.e. *Sesbania aculeata*)

Response of nitrogen sources in rice

A number of experiments were conducted to study the influence of various sources of nitrogen fertilizer in rice crop on cultivators fields in the districts of Pratapgarh and Ghazipur. Results revealed that application of 56 kg N under lowland rainfed condition in rice through musoriephos coated urea and gypsum coated urea gave higher yield of rice as compared to 84 kg N/ha applied through prilled urea indicating a saving of 28 kg N/ha (Table 52).

Table 52: Grain yield of rice (q/ha) as influenced by various sources of N fertilizer

Treatment	Rice grain yield (q/ha)	
	Pratapgarh	Ghazipur
Control	36.7	25.0
56kg N/ha through prilled urea in three splits	41.2	30.4
56kg N/ha through large size urea	45.3	36.6
56kg N/ha through mussoorie phos coated urea	49.2	37.0
56kg N/ha through gypsum coated urea	48.8	37.5
84kg N/ha through prilled urea in three splits	46.8	36.4

4.3. Responses of NPK fertilizers in rice-wheat system

Field experiments to assess the nutrient responses in rice-wheat system were conducted on 136 cultivators' fields in Mahrajganj, Siddharth Nagar and Basti districts of North Eastern Plain Zone (NARP Zone 7); and Sultanpur, Jaunpur and Barabanki districts of Eastern Plain Zone (NARP Zone 8) during five consecutive years (1999-2004). Results revealed that maximum yields of rice (4.37 t ha^{-1}) and wheat (4.07 t ha^{-1}) in North Eastern Plain Zone and of rice (4.79 t ha^{-1}) and of wheat (3.99 t ha^{-1}) in Eastern Plain Zone were obtained with balanced fertilization (N_{120} P_{60} K_{60}) to both the crops (Table 53). The response of nutrients was higher in rice than in wheat. The response of phosphorus was maximum, followed by that of potassium, whereas that of nitrogen was minimum in both the crops in both the zones.

Table 53. Grain yield and nutrient response in rice-wheat cropping system on cultivators field in Eastern U.P. (mean of five years-1999-2004)

Treatments	NARP Zone -7		NARP Zone -8	
	Rice	Wheat	Rice	Wheat
N0 P0 K0	1.72	1.78	2.03	1.88
N120 P0 K0	3.11	2.87	3.53	3.00
N120 P60 K0	3.78	3.52	4.21	3.59
N120 P0 K40	3.44	3.15	3.81	3.31
N120P60 K40	4.37	4.07	4.79	3.99
C.D. at 5%	0.20	0.22	0.24	0.19
Response of nutrient (kg grain/kg nutrient applied)				
N	11.64	8.98	12.49	9.27
P_2O_5	15.40	15.20	16.25	11.35
K_2O	14.75	13.52	14.42	9.85

4.4. Response of potassium on various crops

The results of a large number of experiments conducted on farmers' fields in various districts of Uttar Pradesh under E.C.F. programme indicated that there was positive response to K (3-8 kg grain kg^{-1} K_2O) upto 60 kg K_2O ha^{-1} for rice and wheat under irrigated condition. Pulses like gram, lentil, black gram and pigeon pea responded to K (4-8 kg grain kg^{-1} K_2O) up to 20-30 kg K_2O ha^{-1}, whereas the oilseeds like mustard and linseed responded (1.5-3.5 kg grain kg^{-1} K_2O) to 40-60 kg K_2O application. Potato crop also showed good response up to 100 kg K_2O ha^{-1}. In general, 8-12 per cent of the total increase in grain yield could be attributed to the K application only. The remunerative doses of K for pulses, cereals, potato and oilseeds were 20, 40, 50 and 60 kg K_2O ha^{-1}, respectively.

4.5. Response of sulphur in rice-mustard and rice-wheat system

The field experiments on cultivators' fields to study the response to sulphur fertilization in rice-Indian mustard and rice-wheat cropping systems were conducted at Faizabad and Gorakhpur districts of Uttar Pradesh during 1997-98 and 1998-99. Analyzed soil data of Faizabad and Gorakhpur districts of Uttar Pradesh revealed that 65% soil samples are deficient in available sulphur (< 10 ppm). Results showed that sulphur application to rice improved the grain yield, sulphur-use efficiency and S-uptake appreciably. The application of 30 kg S ha^{-1} to rice crop was found profitable for both the rice-wheat and rice-Indian mustard cropping systems in terms of returns and soil fertility.

4.6. Response of zinc in rice-wheat system

Four treatments (control i.e. NPK alone, 25 kg zinc sulphate/ha in rice alone, in wheat alone and in rice and wheat both along with 120 kg N + 60 kg P_2O_5 + 60 kg K_2O/ha in each treatment) were tested on 72 farmers fields in Mahrajganj, Siddhartha Nagar and Basti districts of North Eastern Plain Zone (NARP Zone 7) during 2000-05 and on 85 farmers fields in Jaunpur, Sultanpur and Barabanki districts of Eastern Plain Zone (NARP Zone -8) during 1999-2005. The soils of the experimental area (fields) were silty loam to silty clay loam in texture having pH in the range of 7.5 to 7.9 and organic carbon 0.4 to 0.6%.

The maximum grain yields of rice and wheat (Table 54) both were obtained with application of 25 kg zinc sulphate/ha to both the crops against lowest yields of control (NPK alone) registering an increase of 2.5 to 3.0 q/ha in NARP Zone 7 and 5 to 6 q/ha in NARP Zone 8. The differences in grain yields of both the crops due to zinc application either in any single crop or to both the crops were not significant indicating zinc may be applied in any crop.

On the basis of economics, averaged of all the 157 trials conducted in both the zones of eastern U.P., it was noted that application of zinc to both the crops gave higher additional income (Rs.5048/ha/year) as compared to additional income incurred with its application either in rice (3285/ha/year) or in wheat (2890/ha/year) alone.

Table 54. Response of zinc application on grain yield (kg/ha) in rice equivalent yield and additional income in Rice-wheat cropping system in NEPZ and EPZ (mean of five years 2000-05)

Treatment	NEPZ Mahrajganj		EPZ Sultanpur		Rice equivalent yield (kg/ha/yr)	Additional rice yield (kg/ha/yr)	Additional cost (Rs/ha/yr)	Additional income (Rs/ha/yr)
	Rice	Wheat	Rice	Wheat				
Control (No zinc)	4014	3742	4418	3695	9235	-	-	-
25 kg $ZnSO_4$ in rice alone	4222	3836	4867	3870	9836	601	500	3285
25 kg $NnSO_4$ in wheat alone	4062	3987	4514	4140	9773	538	500	2890
25 kg $ZnSO_4$ in both the crops	4264	4039	493	4255	10195	960	1000	5048
CD at 5%	126	214	320	128	-	-	-	-

* An uniform dose of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha to both the crops were applied.
Price – Rice Rs 630/q, wheat Rs. 850/q, $ZnSO_4$ Rs. 20/kg

On the basis of 72 trials conducted at cultivators fields in Bahraich, Balrampur and Shrawasti districts of NEPZ (NARP Zone-7) during 2004-08 and at 54 locations in Varanasi, Mirzapur and Sant Ravidas Nagar districts of EPZ and VZ (NARP Zone 8 & 9) during 2005-08 to test the response of zinc in rice-wheat system, showed that application of 25 kg zinc sulphate /ha to rice and wheat produced their significantly higher grain yields of both the crops. In NARP zone 8, higher response of zinc (direct and residual) was observed in rice, wheat and both as compared with that in NARP zone 7 (Table 55). Application of zinc to both the crops was found more beneficial than its application to any single crop. The zinc application to rice was preferred to that of wheat, as it showed higher residual response on wheat.

Table 55. Response of zinc application on grain yield (t ha^{-1}) in rice–wheat cropping system in NARP zone 7 and 8 (mean of four years)

Treatments	NARP Zone -7		NARP Zone -8	
	Rice	Wheat	Rice	Wheat
Control (no zinc)	4.01	3.74	4.45	3.68
25 kg Zinc Sulphate / ha in rice	4.22	3.84	4.80	3.86
25 kg Zinc Sulphate / ha in wheat	4.06	3.99	4.56	4.08
25 kg Zinc Sulphate / ha in both the crops	4.26	4.04	4.94	4.22
CD at 5%	0.13	0.10	0.17	0.19
Response over control (kg grain/kg zinc sulphate applied)				
In rice alone	8.3	3.8	17.6	7.4
In wheat alone	2.0	9.8	4.2	16.2
In both the crops	10.0	11.9	19.8	21.9

4.7. Effect of site specific nutrient management on rice-wheat system

The site specific nutrient management (SSNM) experiment, conducted at 12 locations on farmers' fields in Haidargarh block of Barabanki district of Uttar Pradesh during 2005-06, revealed that there was significant increase in grain yields of both the crops of rice and wheat with addition of K as well as sulphur and zinc over farmers' fertilizer practice ($N_{120}P_{60}$) at all the locations (Table 56). On an average, addition of K alone and in combination with S and Zn showed an increase of 847 and 1,701 kg/ha in rice grain-yield equivalent/ha/year, showing an extra net return of Rs. 3,838 and Rs. 7,566/ha/yr, respectively.

Table 56. Response of balanced fertilization (SSNM) in rice-wheat cropping system on farmers fields (mean of 12 locations)

Treatment	Rice grain yield	Wheat grain yield	Rice yield equivalent	Extra cost	Extra net return
	(q/ha)			(Rs/ha/year)	
NP (FFP)	51.0	35.9	92.7	-	-
NPK	55.6	39.2	101.2	900	3,838
NPSZn	58.0	39.0	103.3	1,060	8,253
NPKSZn	61.0	42.0	109.7	1,960	7,566
CD (P=0.05)	1.44	0.52	-	-	-

FFP- Farmers fertilizer practice (N_{120} P_{60})

SUMMARY

On Station :

- Rice-wheat + mustard-green gram, rice-potato+mustard-blackgram and rice-potato + garlic-maize + cowpea (green fodder) were found more remunerative and productive than conventional rice-wheat system.
- Progressive farmers having full resources may adopt rice-potato-okra (*Bhindi*), rice- potato-greengram, rice-onion and rice-potato-cowpea. While poor resource farmers may adopt rice-mustard-greengram or rice-lentil-maize + cowpea (green fodder) for higher productivity and profitability.
- Berseem may be taken as a break crop for better weed control and soil health in continuous rice-wheat system.
- For achieving maximum productivity and net return per unit area per unit time as well as employment generation, intensive cropping system viz. hybrid rice-potato-green gram or basmati rice-lentil-maize + cowpea (green fodder) or hybrid rice-mustard-blackgram may be adopted in place of existing rice-wheat cropping system.
- Reduction in puddling in rice and reduced tillage in wheat cultivation showed adverse effect on the yield of both the crops as compared to conventional tillage and puddling.
- Utera cultivation of linseed succeeding rice crop may be adopted successfully.
- For achieving higher production from rice-wheat system mid duration rice variety (Sarjoo-52) may be taken as compared to long duration (Mahsuri) before wheat.
- Grain yields of both rice and wheat started declining after 10 years of cropping at different levels of NPK fertilizers. Omission of phosphatic fertilizers (SSP) accelerated the decline in yield of both the crops and exhibited clear deficiency symptoms of P and S both in wheat and rice after 14 and 17 years of cropping, respectively. Yields of rice and wheat declined steeply by omitting P fertilizers showing more decline in wheat than rice. After 20 years of cropping, rice and wheat, both crops responded significantly to application of K and positively interacted with higher doses of P.
- Continuous cropping of rice-wheat resulted in declining the crop productivity in long-run even after applying recommended doses of NPK fertilizers. The responses to phosphorus and potassium emerged after 8-10 and 20-22 years, respectively, when their availability in soil reached below the critical limits.
- Soils initially well supplied with P, K or S become deficient when continuously cropped using N alone or sulphur free fertilizers.

- Response of N declined with the passage of time because other nutrient deficiencies (P, K) did not allow N to contribute fully. The responses to P and K increased over the years because of depletion of soil P and K.
- Balanced doses of all the three major nutrients (NPK) exhibited maximum sustainability (0.90) of rice- wheat system. The response (kg grain per kg nutrients applied) to nitrogen was higher in rice than wheat, while that to phosphorus and potassium was higher in wheat than in rice. Amongst the nutrients maximum response was noted with phosphorus followed by nitrogen and potassium.
- For achieving maximum grain and economic yields, application of all required nutrients is essential as per soil test values.
- Continuous use of chemical fertilizers (Urea, DAP, MOP) without organic manures resulted depletion of micro nutrients' reserve rapidly as compared to their combined use with organic manures.
- Substitution of 25-50 per cent N through FYM and *Sesbania* green manuring to rice resulted equal or more yields as compared to 100 per cent NPK fertilizers alone. Among the different organic N sources, green manuring of *Sesbania* and FYM proved significantly superior to wheat cut straw (WCS). A positive residual response to FYM was observed continuously on wheat yield. *Sesbania* green manure also showed positive response but with lower magnitude.
- Application of farm yard manure (6-12 t/ha) or *Sesbania* green manure (9-18 t/ha) holds great promise for 25-50% substitution of nitrogen fertilizer (30-60 kg N/ha) for rice in rice-wheat system. The use of organic manures along with chemical fertilizers sustained the yield through increased nutrients availability and nutrient-use efficiency.
- The integrated use of organic manures and chemical fertilizers improves the physical conditions of soil more effectively than continuous application of chemical fertilizers alone. Organic inputs took time (3-4 years) to be apparently responsive in terms of productivity and soil health.
- In general, the direct effects of farm yard manure were more pronounced than its cumulative and residual effects. The response to FYM was more in wheat as compared to rice.
- Yield of rice-wheat system can be sustained by managing sustainability factors i.e. soil health and plant protection measures well in time. Maximum yield was obtained by applying 10 t FYM/ha along with chemical fertilizers and plant protection measures.

On Farm:

- Under upland irrigated conditions in Gonda, Basti and Bahraich districts of North Eastern Plain zone (NARP Zone 7), blackgram-mustard-green gram, til-gram-greengram and maize-gram-greengram were found more remunerative than traditional maize-wheat system. Under normal (flat) irrigated conditions rice-mustard-blackgram, rice-lentil, grengram and rice-gram-maize (green fodder) were more remunerative than traditional rice-wheat system. Under low-lying unirrigated situations rice-lentil and rice-gram were found more profitable.
- Under upland irrigated situations of Ghazipur, Mau, Jaunpur and Varanasi districts of NARP Zone-8 (Eastern Plain Zone) maize-gram, blackgram-wheat and blackgram-mustard were more remunerative than maize-wheat system. In normal irrigated situations, rice-gram and rice-lentil were found more remunerative than conventional rice-wheat system.
- In calcarious soils of Gorakhpur, Deoria and Padrauna districts of North Eastern Plain Zone (NARP zone 7) rice-potato-blackgram, rice-lentil-greengram and rice-mustard-greengram cropping systems were found more productive and remunerative than conventional rice-wheat.
- In Jaunpur, Sultanpur and Barabanki districts of NARP Zone 8 (Eastern Plain Zone) under irrigated conditions of medium heavy texture soils, rice-gram and rice-mustard were found more remunerative than traditional rice-wheat system. In light textured soils pegionpea + blackgram-wheat system was found more profitable.
- Inclusion of vegetable crops viz. parwal, bhindi, green pea in rice-based system provided more income and employment regularly to the family members of marginal farmers.
- Intercropping of blackgram in maize crop during *kharif* season mustard in wheat during *rabi* season were found more remunerative than their sole cropping under upland irrigated situations in Ghazipur, Mau, Varanasi and Jaunpur districts of NARP Zone 8.
- Improved varieties of rice and wheat along with recommended fertilizer doses and management practices increased the grain yield by 70-90% and 35-45% under irrigated and unirrigated conditions, respectively. The improved varieties of rice and wheat did not show their full potential without recommended fertilizer doses even under irrigated condition.
- On farm experiments showed that 50% recommended doses of chemical fertilizers (N_{60} P_{30} K_{30}) may be substituted through farm yard manure or *Sesbania* green manuring in rice without any adverse effects on grain yields and net returns in rice-wheat system under irrigated conditions of NARP Zone 7 and 8.

- The responses of nutrients (NPK) was found higher in rice than wheat. Amongst the nutrients, the response of phosphorus was maximum, followed by potassium and nitrogen in both the crops (rice and wheat) and in both the zones (NARP zone 7 and 8).
- In general, 8-12% of the total increase in grain yield of cereals, pulses and oilseeds could be attributed to the K application only.
- In Gorakhpur and Faizabad districts, 65% soil samples were found deficient in available sulphur. Sulphur application to rice improved the grain yield, sulphur use efficiency and S-uptake appreciably in rice-wheat and rice-mustard cropping system.
- The application of zinc to rice and wheat both was found more beneficial than its application to any single crop. The zinc application to rice was more preferred to that of wheat, as it showed higher residual response on wheat.

Future Thrust

- The model of need based farming system should be developed for marginal and small farmers for their livelihood security.
- The need based and resource efficient cropping system should be developed for higher profitability and sustainability.
- The entire package of crop production of various components of the system should be developed for sustainable profitability.
- There is need to establish secondary and micro nutrient fertilization schedule for various crops and cropping systems based on soil test. Models of integrated nutrient management for different agro-ecological zones and cropping systems should be developed to provide guidance for rational and efficient fertilizer use.
- Biological soil quality should be improved through integrated farming system approach involving microbial inoculation, crop residue incorporation and integrated nutrient management.
- The strategy should be to prepare and distribute bulky sources of nutrients after enriching them with chemical fertilizers and biotic populations (N_2-fixing organisms, P-solubilizers, mycorrhizae) and using modern technology for reducing bulk.
- Organic farming may be promoted selectively (on area/crop basis), rather than blanket promotion.
- Farmers should be educated about the need of balanced fertilization including micro or secondary nutrients deficient in their region.

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1. Yadav, D.S., Kumar, Alok, Singh, R.M. and Achal, Ram (1991). Yield, economics and nutrient balance in cropping systems based on rice (*Oryza sativa*). *Indian J. Agric. Sci*. **61 (12):** 872-876.
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List of the Scientists and field staffs worked in the project during 1976-2010

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2. Dr. H.P. Tripathi

Soil Scientist

1. Dr. D.P.Sharma
2. Dr. L.P.Verma
3. Dr. Alok Kumar

Jr. Agronomist

1. Dr. R.M.Singh
2. Dr. R.A. Yadav

On Farm

Agronomist

1. Dr. Tar Jeet Singh
2. Dr. Awadhesh Singh
3. Dr. B.B.Singh
4. Dr. O.P.Singh
5. Dr. S.P.Singh
6. Dr. R.A. Singh

Field Staffs

1. Sri K.P.Tripathi
2. Sri M.L.Maurya
3. Sri Bakridi Khan
4. Sri R.A. Pandey
5. Sri A.N.Pandey
6. Sri R.R.Singh
7. Sri Tilak Ram
8. Sri R.L. Yadav
9. Sri J. B. Singh
10. Sri R.A. Yadav
11. Sri Amar Yadav
12. Sri P.C.Tripathi
13. Sri A.P.Singh
14. Sri B.P.Chaurasia
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List of M.Sc.(Ag.) and Ph.D. thesis produced

S.N	Name and ID No	Year	Degree	Major advisor	Title
1	Sri Shashi Kant Tripathi, A-2011/99	2001	M.Sc. Ag. (Soil Science)	Dr. Alok Kumar	Long-term effect of fertilizers on soil fertility and crop productivity in rice-wheat system
2	Sri Rakesh Kumar Singh, A-2600/02	2004	M.Sc. Ag. (Soil Science)	Dr. Alok Kumar	Effect of Long-term integrated nutrient management on soil properties under rice-wheat cropping system
3	Sri Ajay Kumar Maurya, A-554/97/98/03	2005	M.Sc. Ag. (Agronomy)	Dr. H.P.Tripathi	Effect of integrated nutrient supply in rice (*Oryza sativa* L) on succeeding wheat (*Triticum aestivum)*
4	Sri Kunwar Pal Singh, A-3066/04	2005	M.Sc. Ag. (Agronomy)	Dr. S.P. Singh	Residual effect of site specific nutrient management in rice (*Oryza sativa L*) on succeeding wheat (*Triticum aestivum* L)
5	Sri Manoj Kumar Upadhyay, A-2567/02/05	2009	Ph.D. Agronomy	Dr. H.P.Tripathi	Integrated nutrient management in rice (*Oryza sativa* L) – wheat (*Triticum aestivum* L) cropping system
6	Sri Ajay Kumar Maurya, A-554/97/98/03/05	2009	Ph.D. Agronomy	Dr. S.P.Singh	Site specific nutrient management in rice-wheat cropping system

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