# SUSTAINABLE INTENSIFICATION OF RICE-WHEAT CROPPING SYSTEMS IN INDIA

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## Introduction

The rice-wheat production system of South Asia are among the most productive cropping systems in the world. Despite expanding populations, production of rice and wheat has kept pace with demand in South Asian countries, and especially in India. However, the system is showing signs of fatigue and evidence suggests that natural resource degradation may be reducing productivity in South Asia's rice-wheat systems. This has serious implications for millions of farmers who depend on this system for their livelihoods, and for meeting the ever-increasing food demand due to population growth.

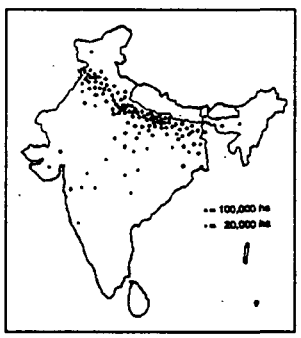
Rice and wheat dominate India's food supply, accounting for over 70 percent of the total food grain production. Although average rice and wheat yields increased at about 2 percent a year between 1960 and 1990, these impressive rates are no longer being maintained. With traditional sources of productivity growth being nearly exhausted, analysts believe that production increases will be hard pressed to cope with even a very modest growth in demand over the long run, associated with rising incomes of the people.

It is thus a formidable challenge for the researchers and the policy makers to find out ways to improve the food production scenario to keep pace with ever-increasing demand. This paper attempts to analyze the problems facing the rice-wheat cropping systems in India with a view to finding remedial actions to resume the productivity growth on a sustainable basis without affecting the natural resources base.

## Importance of Rice-Wheat systems in India

Rice - Wheat cropping systems in India extend across Indo Gangetic flood plains, up into the Himalayan foot-hills and in some irrigated zones further south (figure 1). It occupies an area of over 11m hectares (ha) mainly in six states, Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, and Bihar.

Figure 1. Distribution of Rice-Wheat Cropping Systems in India



Source: Adapted from Huke and Huke, 1994.

Technological changes introduced through the Green Revolution, marked by a rapid expansion of rice and wheat areas often associated with farmers' adoption of rice-wheat rotational systems, played a leading role in the agriculture development in the country. Prior to the Green Revolution in India (which got underway in mid sixties) agricultural growth was from an expansion of cultivated area. The area under food grains increased from 101 m ha in 1950-51 to 128 m ha in 1990-91; this was coupled with consistent increase in double cropped area, made possible, to a large extent, by the expansion of irrigated area from 20.9 m ha in 1950-51 to 50.2 m ha in 1995[1] and availability of short duration varieties.

The key features of the Green Revolution strategy included the expansion of irrigated area, the introduction of high yielding dwarf rice and wheat varieties, and the promotion of fertilizer usage. Other supporting elements included the expansion and strengthening of research, and extension services, and agriculture support policies. The combined effect of the increased use of these variables resulted in a substantial increase in food grain production from 55 m tons 1951 to 236 m tons in 1996[2].

Table 1. Production of Rice (paddy) and Wheat in India[2]

(m.tons)

| Crop | 1951 | 1961 | 1971 | 1981 | 1991 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|
| Rice | 31.6 | 53.5 | 64.6 | 79.8 | 112.0 | 121.5 | 125.4 |
| Wheat | 6.5 | 10.9 | 23.8 | 36.3 | 55.13 | 65.4 | 64.0 |

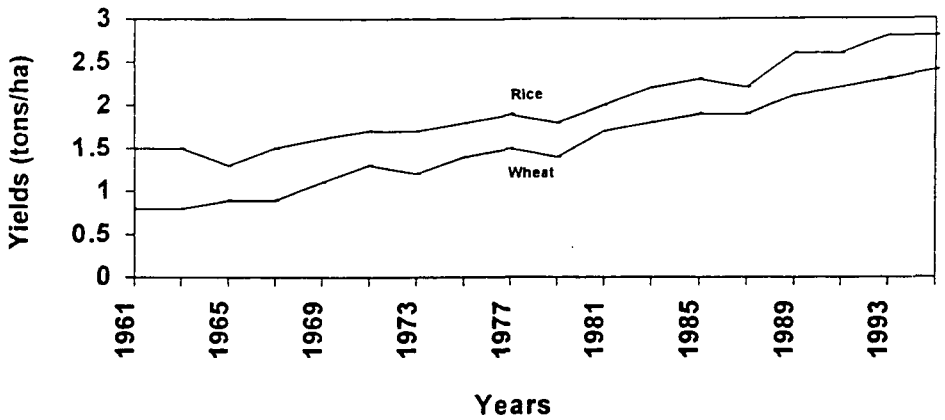
**Rice and Wheat Productivity Trends and Emergence of Two Rice-Wheat Production Scenario**

Rice yield rates in India rose steadily from 1.66 tons per hectare in 1960-71 to 2.6 tons per hectare in 1989 before slowing down. This stagnation in yield growth was partially attributed to the spread of low yielding superior quality rice varieties, although reduction in yield rates was found even in areas where no varietal substitution took place (figure 2).

[1] Indian Agriculture in Brief, Directorate of Economics and Statistics, Govt. of India.

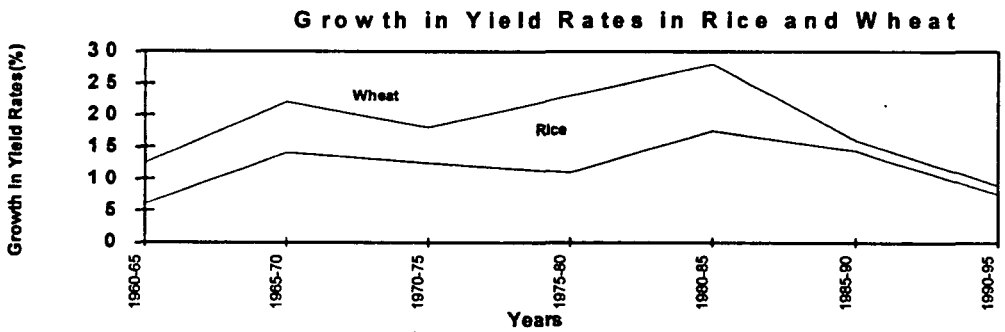
[2] FAO Online Production Data

Figure 2. Rice and Wheat Yields in India (1961-1995)




The growth rate in Asian rice yields and total rice production declined dramatically in the 1980s. Rice area expansion halted in Asia in the 1980s[3], and the yield growth reduced from 2.6 percent per year to 1.5 percent per year between 1972-81 and 1982-88. Although India's overall yield growth performance has been considerably better than Asian average, International Rice Research Institute (IRRI) notes that the northern and western regions of India showed a characteristic decline in yield growth after the mid 1980s.

Wheat yields in India showed a steady growth from 1.2 tons per hectare in 1969-71 to 2 tons per hectare in the mid 1980s before slowing down and barely remaining positive. An analysis of irrigated wheat production trends in Pakistan and Pakistan's Punjab[4] indicates that the yield growth has slowed down from 4.6 percent per anum during 1967-76 to 1.9 percent during 1977-86, well below the population growth rate. An analysis of Indian statistics during the same periods also projects a similar pattern ( Figure 3)



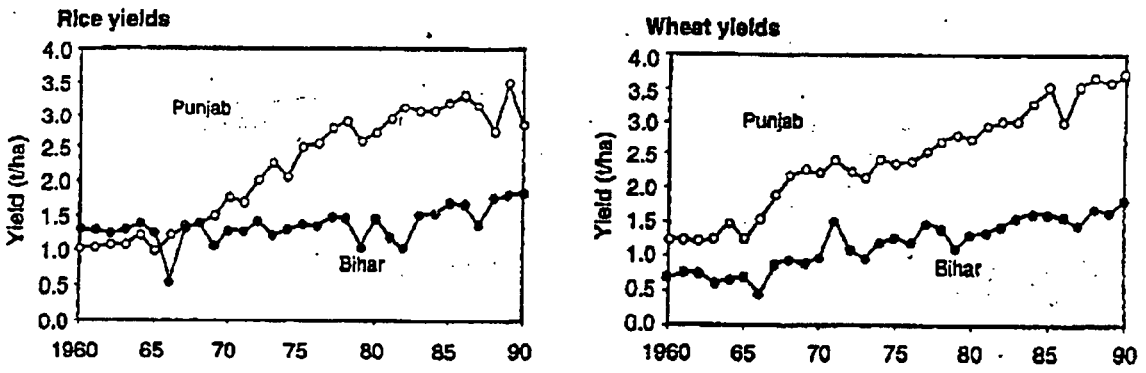

[3] Sustaining Rice Productivity Growth in Asia : A Policy Perspective, M Rosegrant and P.L. Pingali, IRRI, January, 1991.

[4] Sources of Growth in Wheat in Pakistan's Punjab, 1965-2000 : Is there a Sustainability Issue -D. Byerlee and A. Siddiq, CIMMYT 1992.

In the highly diverse rice-wheat cropping systems in India, two production scenarios have become evident since the sixties. In high yielding areas in north west India , farming is characterized by the intensive use of farm inputs , fertilizers, pesticides, good irrigation facilities, mechanization, good infrastructure and extension services. The gap between average field productivity levels and the yield potentials with the available germplasm and technology in this zone is nearly closing. In this situation the productivity growth of wheat and especially rice has been declining or leveling off since mid 1980s.

In contrast, low yielding areas in eastern India have less irrigation capacity or are rainfed, use more of animal power, have poor infrastructure and extension services and have greater socioeconomic constraints. As a result, the technologies that had worked so well in the North-west, transforming agriculture, could not be adopted to the same extent, resulting in slow and delayed growth in rice and wheat production. The productivity levels in the east remained one third of what was consistently achieved in the North-west. In this situation sustainability issues have not yet arisen and there is enough potential to enhance the present yield rates by exploiting the existing germplasm and available technology options (figure 4).

Figure 4. Rice and Wheat yields in the states of Punjab and Bihar




Source: Fertilizer Association of India.

Comparison of average farm productivity with maximum research and full input demonstration yields indicate that on-farm rice-wheat system yields in the northwest are leveling off at 25 percent below full input small plot demonstration yields and 45 percent below maximum research yields. Many better managed farms in suitable lands are already performing above full input demonstration yield levels. Further increasing average farmer production will be difficult.

A study made by the researchers in Cornell University[5] showed that the average grain yields in the high yielding areas are close to 10 tons /ha/year (4t/ha Wheat and 6t/ha Rice)

[5] Sustainability of post Green Revolution Agriculture: The Rice-Wheat Cropping System of South Asia - Cornell University in Collaboration with The Rice -Wheat Consortium for the Indo Gangetic Plains, International Institute of Rural reconstruction (IIRR), Bangladesh Rural Advancement Committee.

with a potential to raise this to 15 tons /ha/year, provided sustainability and resource degradation issues are effectively addressed. Low yielding areas average 5 tons /ha/ year ( 2t/ha Wheat and 3 t/ha Rice) with potential to double this output at the least. This means that both high yielding and low yielding areas have approximately the same potential for increasing yields and therefore both merit attention.

Evidence that productivity growth of rice-wheat systems is slowing down has been further substantiated by factor productivity studies, which analyze yield trends after adjusting for changes in levels of input use. In India, factor productivity continues to increase in some areas but in others it shows signs of leveling off or even declining. A study[6] on productivity changes for wheat in Punjab during 1970s and 1980s revealed that with consistent intensification of input use, productivity gains could approach 2 percent per year, and that there was no signs of increase in total factor productivity at rates equal to those achieved in the past.

Partial factor productivity studies[7] also revealed declining productivity growth trend in rice with annual increases smaller during post Green revolution period (1981-88) than during Green Revolution period. The productivity growth averaged 1.0 percent during the period of study (1971-72 to 1988-89), with market infrastructure, research investment, availability of canal irrigation, and balanced use of fertilizers representing the most important sources of productivity growth.

**Concerns about the Sustainability of Rice-Wheat Systems**

Decline in the yield on long term experimental plots, stagnating farmer yields, declining productivity growth rates, and factor productivity in both farm and research settings and degrading soil and water resources have raised questions about the sustainability of rice-wheat rotation systems. This is a serious concern especially at a time when the production of staple food in whole of South Asia must increase at a rate of 2.5 percent per year to meet the projected population growth. However, an analysis of statistics from Punjab and Haryana over the past 20 years shows that the north western Green Revolution miracle is over; with currently available germplasms, and crop/ soil management practices growth in rice-wheat system productivity seems unlikely to exceed the current levels of 2 percent per anum.

A major concern arising out of intensive rice and wheat cropping with a corresponding decline in pulses and coarse grains has been nutritional imbalance, especially micronutrient malnutrition among the people. This situation has developed because the production of micronutrient rich crops (coarse grains, pulses) has not matched the increasing output of wheat and rice.

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[6] Technical Change and Wheat Productivity in Post Green Revolution Punjab, D.S.Sidhu and D. Byrelee,1991, Economic and Political Weekly 26(52) : A159-A 166.

[7] Productivity and Sources of growth for Rice in India, P. Kumar and M.W. Rosegrant, 1994, Economic and Political Weekly 29(53): A183-A188.

Fears have been expressed that the continuing intensive practice of this system could seriously impair soil health, create problems of alkalinity/ salinity, deteriorate soil texture, excessively mine soil nutrients, lead to new pests, disease and weed problems, and ultimately affect agricultural production in the long run. The signs of deterioration in agricultural production systems are already evident in high productivity areas.

**Causes of Stagnation of Productivity Growth -Near Exhaustion of Past Resources**

*Expansion in area virtually halted*

In the past, an important element in the growth of rice and wheat production has been the expansion in crop and irrigated areas. In India , rice area grew steadily during 1960s and 1970s, with the total area planted to rice increased from about 34 million ha in 1960 to 40 million ha in 1980. Since 1980, growth in rice area has slowed, with the 1990s showing no growth at all. The wheat area which had been stagnant at 13 m hectares in the early 1960's expanded dramatically beginning 1967. This growth spurt continued for little over a decade and by 1979 the area under wheat in India reached 22 m hectares, with only a marginal increase in area after that.

*Irrigation capacity expanded to the maximum viable point*

Irrigation expansion, which played a pivotal role in the success of rice-wheat system has also been exploited to the extent that it is economically viable. The area under irrigation in India has increased from 31.4 m hectare to 50.2 m hectares between 1980 and 1995. However, the availability of irrigation water at subsidized rates has led to enormous misuse. In the high intensity zone in Punjab, rice-wheat systems are being over -irrigated by 15 percent; this is depleting the ground water table at an alarmingly high rate.

*Degradation of natural resources*

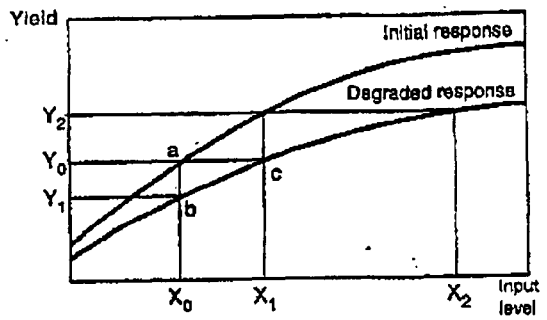
With the reduction in the rate of yield growth, there are indications that the natural resource base on which the systems depend is also weakening. Water induced land degradation, salinization, sodification, and ground water depletion have become a major problem. Slow loss of soil fertility due to the continuous extraction of nutrients that surpasses the input application and management of organic matter is causing concern. Continuous monocropping has also led to an increased incidence of pests, diseases, and weeds.

Experiments[8] at Pantnagar, India, have shown declining yields in intensive rice-wheat systems when input levels are kept constant. Experiments at Faizabad, India, provide clear evidence of the long term degradation of the natural resource base with intensive cropping. The results here show that the yield levels corresponding to fertilizer

[8] Yield Sustainability of Rice-Rice and Rice-Wheat Systems under Long Term Fertilizer use, K.K.M.Nambiar,1994, In *Resource Management for Sustained Crop Productivity*, New Delhi, India: Indian Society of Agronomy.

application rates have declined. Only by increasing fertilizer application rates the original yield levels can be maintained (figure 5).

Figure 5. Shift in fertilizer response function due to resource degradation.




Source: D. Byerlee. 1987.

*Decline in soil fertility*

Because most rice-wheat systems are heavy extractors of nutrients, chemical deficiencies are bound to occur after years of continuous cropping unless proper measures are taken to mitigate the problem. Organic matter levels are known to affect soil chemistry. The physical properties of the soil can also affect the productivity of rice-wheat systems. The puddling of rice soil breaks down soil aggregates, resulting in reduced pore sizes and the formation, in some soils, of a plow pan. This restricts water percolation and creates favorable conditions for rice.

Soil biological factors may also be contributing to the decline in productivity in rice-wheat systems. Solarization trials[9] in Nepal showed that the incidence of root nematode in rice and root necrosis in wheat are negatively correlated with yield, indicating that underground pathogens may be partly responsible for reduction in yields. It is hypothesized[10] that the main cause of declining rice yields has been reduction in the natural ability of the soil to provide nitrogen by interactions between organic matter and soil microbes.

*Problems related to water management*

The increased demand for irrigation water has surpassed the natural ability of the ecosystem to replenish the ground water. Concern about water availability has mounted, especially in North-western India. During the past decade, water tables have dropped at a

[9] Soilborne Diseases of Wheat in Warmer Areas in South Asia : an update, H.J. Dubin and H.P. Bimb, 1994, In D.A. Saunders and G. P. Hettel(eds.), Wheat in Heat Stressed Environments: Irrigated, Dry Areas, and Rice-Wheat Farming Systems. Mexico, D.F: UNDP/ ARC/ BARI/ CIMMYT.

[10] Extrapolating Trends from Long Term Experiments to Farmers' Fields: The Case of Irrigated Rice Systems in Asia, K.G. Cassman and P.L. Pingali, 1995, In V. Barnett, R. Payne, and R. Steiner(eds.), Agricultural Sustainability : Economic, environmental, and Statistical Considerations . London, UK. : John Wiley.

rate of 0.5- 0.8 m per year in the state of Haryana and at a rate of 0.2-1.0 m per year in the neighboring Punjab. Problems relating to the quality of irrigation water have also multiplied; many rice-wheat tracts in north west India are being affected by water borne compounds. Deficiencies in water management at the farm and system level, though not unique to rice-wheat system, are quite pronounced because of the contrasting management for the two crops. Salinity and sodity problems are sometimes aggravated by poor water management practices in the lower reaches of canal irrigation systems, where sufficient water may not be available to leach out salts[11].

*Pest and disease problems due to intensive monocropping*

Agricultural intensification in general and continuous monocropping of cereals in particular have increased the incidence of pests, diseases, and weed problems in some rice-wheat zones. Among the weeds that negatively affect productivity, the most damaging is *Phalaris minor*, a grassy weed which poses an especially serious problem for wheat in cooler areas.

Continuous rice-wheat cropping has been accompanied in some areas by an increase in insect pest problems. Growth in the area planted to rice and wheat has expanded the host environment for many insects, while the intensification of the cropping pattern has extended the period of an available host environment. This has resulted in build up of pests and appearance of overlapping generations of insects. Rice-wheat rotations on a continuous basis have also led to disease infestations by providing a host environment that is essential for the pathogen to complete the lifecycles. Intensity of soil-borne pathogens has also increased under this system.

Contrary to the conventional wisdom, most modern rice and wheat varieties carry high levels of resistance to major diseases, and in most cases they are more resistant than the traditional varieties they replace. Yet diseases remain a threat unless crop diversification is introduced.

*Crop management problems*

Productivity levels in rice-wheat cropping systems have been negatively affected by the intensification process itself. The management decisions taken to increase the productivity of one crop has often adversely affected the other crop in the rotation. Decision to increase rice productivity by introducing a high yielding long-duration variety can lead to the late planting of wheat in the rotation.

[11] Salinity in Punjab Watercourse Commands and Irrigation System Operations: The Imperative Case of Improving Irrigation Management in Pakistan, J.W. Kijne and E.J. Vander Velde,1990, International Irrigation Management Institute (IIMI)

Delayed planting of wheat significantly reduces the yields and decreases the efficiency of fertilizer uptake[12]. Adoption of reduced tillage practices can help to alleviate this problem, but introduction of reduced tillage technology in turn is likely to create new problems.

**An Analysis of Production Scenarios in the Two Zones**

Analysis of the rice-wheat systems in India reveals that the two productivity zones have different sets of problems that are affecting their yield performances, and that the two zones require different solutions and institutional back-up to provide relevant policies and technologies to sustain increased productivity.

The production scenario in the high intensity zone (Punjab, Haryana) is characterized by:

- a diminished gap between technological frontier and farm yields;
- declining productivity and profitability of rice-wheat rotation;
- increased pest build up due to changes in pest-predator balance and pest composition;
- increasing labor scarcity;
- chemical and water induced land degradation (salinization, sodification, ground water depletion);
- slow loss of soil fertility;
- poor irrigation and drainage management.

The problems in low intensity zone (Bihar, Orissa) are:

- weather related production variability;
- poor irrigation, soil physical condition, and drainage;
- low yielding and long duration cultivars;
- weaker extension network;
- peak season labor scarcity;
- poor roads, agricultural support services, and marketing facilities.

**Emerging Challenges --What needs to be done**

The problems associated with rice-wheat systems threaten the sustainability of this vital component of food security in the South Asian countries. The gains from the input intensive agriculture of the Green Revolution era, with high inputs, high yielding varieties, irrigation and other infrastructural facilities have been largely realized. Agriculture, at this point, has to move on from input intensive agriculture to knowledge intensive agriculture where knowledge is not only embodied in physical products but also

[12] Agronomic Practices and Problems of Wheat following Cotton and Rice, P.R. Hobbs,1985, In R.L. Villareal and A.R. Klatt (eds.), Wheats for More Tropical Environments : A Proceeding of the International Symposium. Mexico, . ; CIMMYT.

in more complex technical information for crop management[13]. It is the application of this knowledge, strengthened by suitable support policies, that will bring about changes in the rice-wheat situation in the region.

However, for future productivity growth to increase and to keep pace with the demand, it will be necessary to have points of intervention at the following three levels:

- Farm Level,
- Institution level,
- Policy Level.

At the **Farm Level**, priority should be given to the quantification of site specific problems. In most parts of India today, farmers are responding to the problems of rice-wheat systems themselves, by adopting precision farming techniques, by better soil and water management, by altering the time, placement, and amount of nutrient application. Using their own ingenuity, the farmers are beginning to diversify crops through rotation, use alley cropping techniques, and try for reduced tillage operations and increased water use efficiency. Wasteland development is also being considered as a possible option for increasing production in the rice-wheat area.

However, the broad areas where technological interventions will be needed can be broadly outlined as:

- Integrated nutrient management;
- Water management;
- Tillage and crop establishment;
- Land degradation, and changes in soil physical characters;
- Integrated pest management;
- Crop diversification.

A new agricultural research paradigm has to evolve that will emphasize the long term sustainability of the agricultural production systems, and have an *expanded focus*[14]. However, it will be important to continue with the problem focused 'down-stream' research designed to increase efficiency of farmers' resource use in the short run, which has to be complemented by more strategic 'up-stream' research designed to focus on factors affecting the long run productivity of major cropping systems. An important aspect of development is the *participation of farmers in research*, as the farmers can provide the most useful input, the on-farm practical hands on experience.

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[13] Knowledge-intensive Crop Management Technologies : Concepts, Impacts, and Prospects in Asian Agriculture, D. Byerlee, Dec.,1996.

[14] Meeting South Asia's Future Food Requirements from Rice-Wheat Cropping Systems: Priority Issues facing Researchers in the Post-Green revolution Era, P. Hobbs and M.Morris,1996. NRG Paper 96-01, Mexico,D.F.: CIMMYT.

Although it is often suggested that in terms of annual cropping alternatives no other system can compete with rice-wheat except when there is water stress. it is important to have *crop diversification* from the point of view of sustainability and restoration of soil fertility. It is also important for the balanced nutrition of the farming community to have different crops and vegetables under the production system.

Crop diversification of rice-wheat system by introducing 'alley cropping' with fodder crops has proven to be successful in India[15].Under the system, in western Uttar Pradesh, upland rice was raised in rainy season, followed by wheat in winter in between two hedge rows (5m apart) of *Leucaena leucocephala (subabul).* The system, tested on alkali soils for 3 years revealed that application of 90 kg N/ ha in combination with leucaena added 6 tons/ha /year of green manure to the soil before rice and wheat planting and saved input cost. In addition, the fodder crop helped in bringing down the soil pH and there was considerable improvement in the infiltration rate and available NPK in the soil. This system saved 25% of the inorganic fertilizer, besides producing green fodder and fuel wood. resulting in a net saving of about $100/ ha/ anum over only sequence cropping of rice and wheat.

The strategic areas where on-farm research is most needed to improve rice-wheat scenario can be outlined as :

*Soil Fertility*

- Nutrient dynamics and simulation modeling,
- Organic matter recycling and enrichment,
- Micronutrients,
- Integrated fertilizer recommendation.

*Water Management*

- Identification and measurement of indicators of productivity and sustainability in relation to progress and impact of existing irrigation schemes, water tables, salinity and sodity, water logging and water distribution,
- Improvement in water use efficiency at crop, farm, and system level,
- Improvement of drainage system to enhance productivity,
- Studies of the effects of policy issues on water management efficiency at selected sites.

*Integrated Pest Management*

- Spatial characterization of pest complexes,
- Assessment of pest and weed problems in long term trials,

[15] Alley Cropping of Rice -Wheat Sequence with Leucaena leucocephala, K.S. Gangwar, Spectrum, Apr-June,1996.

- Identification of pest carryover between crops,
- Recommendation of IPM components suitable for rice-wheat systems.
- Evaluation of pesticide policies.

*Resource Characterization*

- Soil resources,
- Crop area cropping system dynamics,
- Water management issues,
- Nutrient management issues,
- Tillage residue management,
- Socioeconomic policy issues.

*Improved Tillage Practices*

- New tillage and crop residue management practices as an alternate to residue burning,
- Alternate tillage and crop establishment practices in areas where water table is declining,
- Efficient complimentary practices for zero and reduced tillage systems for establishing wheat after rice,
- Development and validation of simulation models to predict the long term consequences of different tillage and residue management strategies.

*Diversification of Rice-Wheat Systems*

- Development of short duration cereal crops for rabi and kharif seasons,
- Introduction of grain, fodder, legumes, oilseeds as intercrops in rice-wheat systems,
- Inclusion of tree crops and agroforestry in cropping systems,
- Mixed crops / livestock systems.

*Raising the Crop Yield Ceilings*

- Development of new rice and wheat varieties suited to different nutrient and water availability situations,
- Development of quality hybrids of rice and durum wheat and management practices for seed and crop production.

At the **Institutional Level,** strengthening research and extension systems is of crucial importance for the development and dissemination of on-farm technologies. To achieve this, the Rice - Wheat Consortium (RWC), a partnership linking four public national agricultural systems (NARSs) and five IARCs has been formed which shares the goal of increasing the productivity in South Asia's rice-wheat cropping systems. NARSs in different countries in collaboration with IRRI, ICRISAT, and CIMMYT, are working on improving rice -wheat productivity and sustainability on an ecoregional basis. The collaboration addresses through multidisciplinary cross commodity teams, the

interactions between rice and wheat and among the physical, biological, and socioeconomic factors influencing the system.

As crop management practices become more complex, it will be necessary to improve the extension services, the links between the researchers and the extension agents, so that effective mechanisms exist to speed the flow of technology from researchers to extension specialists to farmers, as well as to communicate the feed back from the farmers. At present researchers and extension specialists often work in isolation from one another. Researchers must realize that their responsibility extends beyond the development of technologies; at the same time, extension agents must be encouraged to serve as a two way conduit capable of effectively conveying information in both directions between researchers and farmers. It is critical to encourage greater participation of private sector and NGOs in research, extension, and input supply activities.

Infrastructure development will also be an important part in bringing about changes in rice-wheat scenario. Farmers should have easy access to credit and input delivery system, good roads, markets, and electricity supply.

At the **Policy level,** a resurgent agriculture will need a coherent set of policies which begin with the premise that agriculture involves not only primary commodity production but all the intermediate processes between the producer and the consumer. Input subsidies, trade controls, and agricultural support services have been used in India to promote agricultural growth. It is important to improve the effectiveness of these policies in achieving the desired objectives.

There are concerns that existing policies do not take into account such factors as regional disparities, and the special benefits obtained by the better off consumers and farmers, There are questions as to whether the benefits from the existing subsidies have accrued to more advanced regions, and to large farmers within these regions. These regions have more irrigation infrastructure and higher levels of input use. They also have larger marketable surpluses.

In areas where the use of modern varieties and associated inputs is already intensive , input subsidies can actually be counter productive. With removal of these subsidies farmers would have major incentives to move toward more efficient use of inputs. At the same time, new type of support policies are needed to foster changes in the way technologies are created and delivered to farmers. A good example involves polices relating to the protection of intellectual property rights for agricultural technologies.

In a case study in Punjab[16] alternative policy options were analyzed against eighteen combinations of farm practices under rice wheat rotational systems. Financial and

[16] Rice- Wheat Production in North West India, R.P.S. Malik and Paul Faeth,1993, Agricultural Policy and Sustainability, WRI publication.

economic values for each farming practice were compared in the study; environmental costs were estimated under each policy option in a natural resource accounting framework. The analysis clearly indicated that agricultural policy can dramatically affect the relative profitability of production practices:

- Under the current policy, as represented by subsidized prices for fertilizers and electricity etc., after accounting for soil depreciation and groundwater depletion costs , the largest financial returns are obtained by farming systems that reduce water consumption to recommended levels, reduce tillage operations, and use inorganic fertilizer alone or in combination with farmyard manure.
- By removing all consumer commodity support, like shadow prices etc., the net financial values of every production practice will nearly double. The prices farmers currently receive on their produces are well below world market prices. However, systems using farmyard manure would be slightly more profitable.
- Leaving commodity price subsidies intact, but removing producer input subsidies would bring about significant financial shift towards most resource conserving production practices. For rice-wheat systems employing reduced tillage, the most profitable practice would use 20 percent less irrigation than recommended.
- Removing both commodity support and input subsidies would also encourage the conservation of natural resources. The most resource conserving rice-wheat system is 20 percent more profitable than the typical system using conventional practices. Due to higher crop prices, profitability for all systems is much greater than under current price policy. Because production costs are not subsidized, the full costs of natural resource degradation are reflected in the balance sheets.
- The free world trade scenario, intended to represent a completely undistorted economic environment, would be possible if the industrial countries eliminated producer price subsidies and stopped dumping surplus production on the world market.

Food production in India must increase by 2.5 percent each year to meet the demand of the growing population and to reduce malnutrition. A significant part of it has to come from rice-wheat crop based production systems. This assumes special challenge as the data on rice-wheat yield trends indicate plateauing or progressive productivity decline in Punjab, Haryana,, and Western Uttar Pradesh.

For future productivity growth to keep pace with the increasing demand, it is necessary to address the problem at various levels. It will be important to make investments in developing appropriate technologies, and enable the farmers to take advantage of these in combination with their own ingenuity and ageold wisdom. A coherent set of policies is also necessary to create an enabling environment to make crop intensification sustainable.