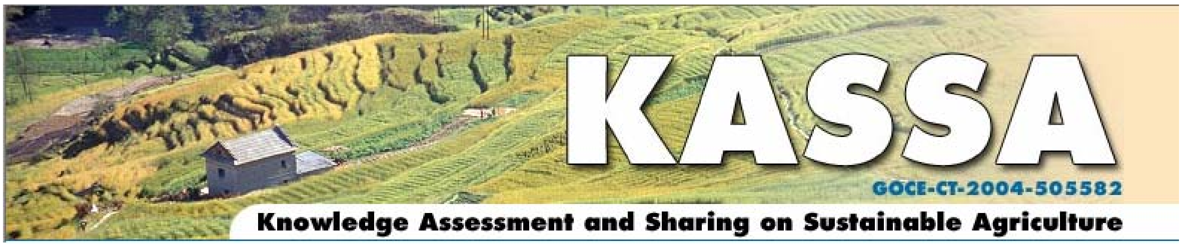

Deliverable 1.3 - Appendix A1

Conservation agriculture research in Indo-Gangetic Plains

R.K. Gupta[1*], S.C. Tripathi[2] and I. Hussain[3]

[1]Rice and Wheat Consortium – Centro Internacional de Mejoramiento de Maíz y Trigo (RWC-CIMMYT), Complex DP Shastri Marg Pusa, New Delhi 110012, India
[2]Indian Council of Agricultural Research - Directorate of Wheat Research (ICAR -DWR), Agrasain Marg, PO Box 158, Karnal 132001, India
[3]Pakistan Agricultural Research Council- National Agricultural Research Center (PARC-NARC), Park Road, Islamabad 45500, Pakistan
[*]Asian Platform Coordinator

Centre de coopération internationale en recherche agronomique pour le développement
Avenue Agropolis, 34398 Montpellier, France

www.cirad.fr

ACKNOWLEDGMENTS

The research reported here has been carried out in the context of KASSA project (Knowledge Assessment and Sharing on Sustainable Agriculture) a European Commission – funded project (DG-Research - Contract no. GOCE-CT-2004-505582) under the FP6 programme: "*Integrating and strengthening the European Research Area*"; Thematic priority "Sustainable Development, Global Change and Ecosystems", Sub-priority "Global Change and ecosystems".

Disclaimer

KASSA has been coordinated by CIRAD.
It worked between 1 September 2004 and 28 February 2006.
The KASSA Consortium assembled 28 contractors from 18 countries.
KASSA has been implemented through four regional "platforms": Europe, the Mediterranean, Asia and Latin America.
http://kassa.cirad.fr

Partners of the Asian platform:

24- RWC-CIMMYT, India;
27- CASA, India;
28- VASI, Vietnam.

Scientific advice has been provided by:

Michel Griffon (CIRAD, France);
Ren Wang (IRRI, Philippines);
Jaromir Kubat (VURV, Czech Republic);
Roberto Peiretti (AAPRESID, Argentina).

This document is the workpackage 1.1 report of the RWC, India

I. Concepts and Practices

In the beginning of green revolution the key research priority was on accelerating the production of food grains through the evolution and introduction of high yielding input responsive varieties, expansion of irrigation system and amplified use of agronomic inputs like inorganic fertilizers and pesticides. Investments from the public sector were crucial for making these inputs available to the farmers. Evidence is now appearing that continuous adoption of rice-wheat system caused decline in soil and crop productivity (Nambiar and Abrol, 1989). Recently, analysis of several long-term experiments on rice-wheat (Dawe *et al*., 2000, Duxbury *et al*., 2000 and Yadav *et al*., 1998) indicated a negative average yield trend of rice (–0.02 t/ha/yr or 0.5 % per yr) under fixed set of inputs and agronomic practices. The growing realization that the agriculture of the post-Green Revolution era will be guided by the need to produce more quality food from the same land and water resources, besides sustaining environmental quality, only adds to the challenge. Thus, the major challenge for the researchers is to develop an alternative system that produce more at less cost and improve profitability and sustainability. This suggests that agriculture systems will need a mixture of new technologies that are able to knock new sources of productivity yield growth and are more sustainable. With these in view the main focus in the present study of CIMMYT-India/RWC has been on sustainability and resource conservation techniques in rice-wheat cropping system of the Indo-Gangetic Plains region of India, Pakistan, Nepal and Bangladesh. The studies included in the inventory are dealing with different aspects of sustainability and resource conservation aspects like tillage, integrated nutrient management, carbon sequestration, crop residue management, mulching, crop diversification, socio-economic drivers etc.

I.1- Description of the region and cropping system and its importance

Indo-Gangetic Plains (IGP) exist in the fertile and adequately irrigated hot semi-arid to hot sub-humid regions of the Indus and Gangetic alluvial plains ($21^0$32’24” to $33^0$07’48” N latitude and $67^0$04’48” to $90^0$58’40” E longitude) of India, Bangladesh, Nepal and Pakistan. In India alone, IGP occupies 65 m ha covering the states of Punjab, Haryana, Uttar Pradesh, *Tarai* of Uttaranchal, Bihar and West Bengal which is about 20 per cent of the geographical area of the country (21^o31’ to 32^o20’ N latitude and 73^o16’ to 89^o52’ E longitude).

The climate of the IGP favours the rice and wheat to be grown in a double cropping pattern in one calendar year, rice in the summer and wheat in the winter. The annual rainfall ranges from less than 400 mm in the northwest to more than 1800 mm in the lower Gangetic plains of West Bengal and Bangladesh. Nearly 85 % of the total precipitation is received during the monsoon season between June and September. During winter months a few showers are received between December and February due to western disturbances in northwest portion. Weather is cool and dry in early part of wheat growing season (November to February) whereas temperature rises during grain filling period (March-April), more pronounce in eastern part of IGP, resulting reduced length of wheat growing period. On the other hand, warm humid monsoon season prevails during rice growing period (June to September). In the eastern part of IGP (Bihar, West Bengal and Bangladesh), rice can be grown in three seasons viz. Aus (April to July) Aman (July to November) and Boro (November to April). Temperatures are higher in the eastern IGP reducing the length of growing period of wheat.

Soils are mainly alluvial in nature and ranges in texture from loamy sands to silty clay loams and are probably one of the most fertile and productive agricultural areas of the world. Though some problematic soils (alkaline/acidic in pH) are also present in the region. The IGP are gifted with extensive canal irrigation systems using water storage reservoirs in the Himalayan mid-hills. Canal irrigation is supplemented with tubewell water and most rice-wheat areas are irrigated or partially irrigated. The other factors that enhance the rice-wheat cropping system in IGP includes the suitability of different resource conserving technologies (zero/reduce tillage, direct seeding, bed planting, laser levelling, green manuring, crop residue management etc.) to this system.

Rice and wheat are the world's two most important cereal crops, contributing 45% of the palatable energy and 30% of total protein in the human diet, as well as a substantial contribution to feeding livestock (Evans, 1993). Rice and wheat are the major crops of the Inod-Gangetic Plains region that contributes a foremost part in the total food grains production as rice-wheat cropping system is one of the most important cropping patterns for food safety in the region. It has been estimated that contribution of only these two cereals resulted a quantum gains in foodgrain production. During last four decades the growth rates of rice and wheat production in South Asia (2.5% and 5.2% per year, respectively) exceeded the population growth rate (2.22% per year), indicating an increase in the per capita availability of these two cereals that strengthen the food security, reduced rural poverty, and increased affordability of food at cheaper prices in the region. Rice-Wheat system in IGP has been favoured by a number of biophysical and socio-economic driving forces that includes climatic suitability, soil types, and water availability. Under these circumstances rice-wheat system has been practiced on nearly 13.5 million ha (10.0 m ha in India, which was less than 4.0 m ha in 1960; 2.2 m ha in Pakistan; 0.8 m ha in Bangladesh, and 0.5 m ha in Nepal) in the Indo-Gangetic plains (Ladha *et al.* 2000, Gupta *et al.* 2003; Woodhead *et al.* 1993; 1994; Zheng, 2000; Timsina, and Connor. 2001 and Razzaque, *et al.* 1995). This system covers about 32% of the total rice area and 42 % of the total wheat area in these four countries, and they account for one fourth to one third of the total rice and wheat production. Demand for rice and wheat is expected to grow at 2.5 % per year over the next two decades but it will become increasingly more difficult as the per capita rice–wheat growing area has already shrunk from 1200 m^2 in 1961 to less than 700 m^2 in 2001. The higher productivity potential of the region has been favored by fertile soils, optimal climate, assured irrigation systems, better socio-economic conditions and adaptation of improved agro-technologies. The climate of the IGP ranges from semi-arid in the west to sub-humid in the east, with a distinct wet monsoon summer season and a dry, cool winter season. This allows rice and wheat to be grown in a double cropping pattern within one calendar year, rice in the summer and wheat in the winter.

The rice–wheat cropping system does not grow only rice and wheat. The cropping patterns are many and varied, with at least two and sometimes three or more crops grown in any one calendar year. The triple and more intensive cropping patterns are found in middle and lower IGP, where average temperatures are relatively more than in the Trans IGP-2. There are many fields where farmers grow continuous rice–wheat, but in many cases, rotations break this continuous cereal system. Sugarcane, for example, is used in rotation with rice and wheat in parts of the IGP where it occupies the land for two or more years before returning to rice and wheat. Inevitably, this encouraged large-scale sequential cropping of rice and wheat in millions of ha even in non-traditional areas for both crops. The most of quality rice (Basmati) produced in the IGP for export and generate the foreign exchange and enhancing the farmer's economic standard. The cropping system of any region has been governed by the major food habit of the peoples, profit margins and minimum risk. Rice and wheat are the first choice of the farmers in IGP because the major cereals in the northwest (Transect 1 & 2) and eastern (region 3-5) IGP are wheat and rice, respectively which boost the cultivation of rice and wheat in the IGP. Rice- wheat cropping system is the most economic system also in terms of net return to the farmer's of IGP as compared to any other cropping system practiced in the region that makes this system most popular.

I.2- Driving forces and constraints to dissemination of alternatives to conventional agriculture (e.g., Conservation Agriculture and Organic Farming)

The research done in past had been focused mainly on enhancing the water and nutrient use efficiencies in the major food grain crops, primarily, rice and wheat. For this a number of experimental results have been reported for short as well as long term management of plant nutrients (mainly N & P) and irrigation water scheduling. After achieving the goal of self sufficiency in food grains production a gradual sprouting of public concerns about food safety, environmental quality, groundwater contamination, and soil and water conservation have led many growers and researchers to consider alternative means of agricultural production for future sustainability and natural resource conservation. This appeared mainly because of self sufficiency in the food grains production quantitatively but not qualitatively, spread of weeds and development of resistance against herbicides (e. g. resistance in *Phalaris minor* against isoproturon) . Soil productivity turn down because of decline in soil organic matter and a gradual drop in the supply of soil nutrients resulting nutrient (macro and micro) imbalances because of inappropriate fertilizer applications. Some regions of IGP especially northwest reflect depletion in ground water and contamination of surface and ground water both. Emerging awareness of global warming due to green house gasses (CH_4, NO_2, and CO_2 etc.) emission from agricultural systems causing. Availability of improved agro-technologies like zero till drill, bed planter, laser leveler, combine harvester etc. Socio-economic constraints at farmer's level and inappropriate government policies to promote the agriculture and conserve the natural resources under the global scenarios.

Above facts reviled that the future technologies needed to increase productive efficiency must lead to more efficient use of natural resources and have minimal environmental degradation effects, particularly in those areas where resources are currently used excessively, whilst also meeting the livelihoods needs of those in less productive and poorer areas. This is a major challenge for the agricultural researchers to promote the resource conserving or conservation agriculture (CA) technologies being promoted in the rice-wheat areas of the Indo-Gangetic Plains. To achieve the new set of goals of sustaining agricultural productivity and conserving the natural resources a number of options have been suggested by the researchers on the basis of results of research experiments done across the locations over the years. The important studies carried out to advocate the appropriate resource conservation technologies aimed at sustainable agriculture or with alternatives to conventional agriculture in focused area has been incorporated in the present inventory that are related to :

- Mounting conservation/reduced/zero tillage and crop residue management options,
- Diversification of cropping systems through the interventions of legumes or green manure crops, mulching for sustainable productivity ,
- Evolution of agricultural mechanization
- Reducing the GHGs emissions that are suppose to cause global warming,
- Conjunctive use of agricultural inputs like water and organic (biofertilizers, farmyard manure etc.) and inorganic sources of plant nutrients,
- Organic farming (although serious scientific efforts have been lacking).
- Evaluating land-use-cover changes, and
- Impacts of bio-physical and socio-economic drivers.

Traditionally people started crops cultivation without using any external power (animal/tractor) and followed a reduced or zero-tillage system. With the introduction of various techniques and mechanization it was realized that he need to till the soil for greater release of nutrients and control the weeds and diseases and for higher yield under continuous cropping. Constantly tilling the soil established a belief among the farmers that repeated tillage operations will provide the higher yield but in the during the 20th century, it became evident that unnecessary tillage was harmful to soil conservation and resulted in wasteful use of resources and that something had to be done to reverse these problems. Scientists and farmers started to question the adage of “more tillage, more yield” and started experimenting with reduced tillage, residue retention and management and even zero-tillage. The work on resource conservation technologies (RCTs), which is a first step towards conservation agriculture, was primarily started in the Indo-Gangetic Plains (IGP) under rice-wheat cropping system.

Several resource conserving technologies is being developed and made available to farmers for testing and adoption. Some are based on reduced tillage for wheat including zero-tillage. Bed planting systems are being promoted to increase water productivity and when combined with reduced tillage in a permanent bed system provide even more savings. Laser leveling combined with these tillage systems provides additional benefits. Many of the benefits of the tillage options for wheat are lost when rice soils are traditionally puddled (plowed while wet). System based technologies are now being promoted that do away with puddling so that total system productivity is raised. Use of groundwater to obtain early rice planting and efficient use of rainwater is another technology.

Zero-till and bed-planting techniques could answer the problem of late planting of wheat, pre-sowing irrigation and weeds in rice-wheat system of IGP. Results of farmer’s participatory approach used to speed up the acceptance of Zero-till to the farmers reviled a significant adapted this technology by farmers primarily for lowering cost of cultivation and better yields (RWC Highlights, 2003). Zero-till also helps reduce carbon emissions (reduced diesel use) and improves input use efficiency while raising system productivity and farm level profits. The greater adoption rate of zero tillage in different part of Trans-Gangetic plains was basically a result of a strong farmers' participatory approach (Gill *et al.*, 2000) that not only helps to get timely planting but also solves second-generation problems such as herbicide resistance.

In lower IGP, (region 4 and 5), where the main problem are excess/deficit soil moisture, farmers have the ability to increase wheat productivity by adopting no-till/direct seeding to get timely planting.

Direct seeding of rice saves energy and water for rice establishment and eliminates drudgery in transplanting. It can result in earlier maturity of rice, which helps improve wheat productivity through timelier establishment. Zero tillage drastically reduces the consumption of fossil fuels, which significantly reduce carbon emissions into the atmosphere and the risk of global warming, and the wear and tear of tractor parts and accessories (Hobbs *et al.*, 2002). Bed planting, especially permanent beds, is gaining acceptance, as more farmers receive equipment to experiment and see the benefits for themselves.

Data from India collected at RWC, suggest that use of permanent beds saves even more water (average 31%) than zero-tillage. The practice also improves yields (24%) across an array of crops, increases input-use efficiency, and cuts costs of production (RWC Highlights, 2003). It was observed that zero-till wheat under dry seeded rice field gave 14.3 % higher grain yield as compared to those under transplanted rice field (Tripathi *et al*., 1999 and Tripathi and Chauhan, 2001).

Zero-tillage technology has several advantages over conventional tillage that includes saving of 92 % diesel, which comes to 61 liters/ha compared to conventional system. Thus, it reduces the cost of cultivation (Rs 2500/ha), saves forex, advances time of wheat sowing (4-5 days), requires less water for first irrigation and less infestation of *Phalaris minor*, which is a burning problem in northwest IGP. Besides this, it provides eco-friendly wheat cultivation by reducing 135 kg CO_2/ha (assuming 2.6 kg CO_2 production/ litre of diesel burnt), which is one of the major fossils for global warming (Chauhan *et al.*, 2001).

Crop residues are primary substrate for replenishment of soil organic matter and hence it is a fundamental natural resource for conserving and sustaining soil productivity. Mineralization of crop residue supplies essential plant nutrients thus the residue incorporation can improve physical and biological conditions of the soil and prevent soil degradation. In the IGP, large amounts of crop residue are burned or removed after harvest. These results in loss of organic matter and nutrients and causes atmospheric pollution due to emissions of toxic and greenhouse gases such as CO, CO_2, and CH_4, which create a threat to human and ecosystem health. Demand for crop residue used for cooking fuel and animal feed is high in this region (Bronson *et al.*, 1998). Removal or burning of residue ensures farmers' quick seedbed preparation and avoids the risk of reduced crop yields associated with incorporating wide C/N ratio residue that immobilizes N during decomposition (Beri *et al.*, 1995). The benefits of sequestering soil organic carbon to sustaining crop productivity by applying organic amendments and crop residue and including legumes in crop rotations is well known.

As there have been increase in the area under high yielding varieties with widespread adoption of green revolution technologies it also lead to increase in both crop as well as straw yield in rice-wheat system in IGP. Advancement in the technological implements in the form of combined harvesting technologies, have become common and leave behind large quantities of straw. A total of about 78 and 85 million tons dry rice and wheat straw are generated in India alone in the year 2000. In case of combine harvesting almost all portion of the residue generated is left in the field as loose straw that finally end up in burning as there is very small time available between harvesting of rice and planting of wheat and moreover performance of the wheat crop is highly susceptible to any delay in planting.

Application Rotary Disc Drill that works on the principle of rotary mechanism followed by attached disc to facilitate a cutting edge resulting into a conservation agriculture practice by keeping the crop residue undamaged with the soil. The beauty of this machine is to sow the wheat seed in loose paddy residue and vice versa, which was a long standing problem of farmers of IGP particularly northwest transect. This will reduce the burning of crop residues of rice and wheat both, leading to eco friendly cultivation (Sharma *et al*., 2005). The irrigation water saving, however, varies with soil type, climatic conditions and cropping system. If we consider the rice residue incorporation followed by heavy irrigation to decompose, then there is possibility of water saving up to 20-25 per cent (Sharma *et al*., 2005).

Mulches are used for various purposes that includes soil moisture conservation, weed suppression, soil erosion mitigations and to create the favorable microclimate. Rice straw mulching has a significant effect on moisture conservation and weed growth suppression in zero-till wheat fields. Straw mulching for a short period of 20 DAS or straw mulch retained on the soil surface had similar effects in conserving soil moisture and suppressing weed growth at the early growth stages of the plant. Straw mulch enhanced root growth as indicated by higher values of root length/weight densities under mulching as compared to non-mulched plots. N-uptake and apparent N-recovery of applied nitrogen and yield of wheat ware significantly higher under mulching as compared to non-mulch conditions (Rahman *et al.*, 2005).

Considering the recycling of organic carbon (OC) and long-term effects on soil properties the rice straw mulch should be incorporated in the soil. However, from the point of the competitive and multiple use of rice straw, farmers might choose the alternative option of using straw mulch for a short period and thereafter for fuel. It was observed that wheat yield increased up to some extent when rice straw was left to cover the relay-planted wheat for different lengths of time on the germinating up to nine days. The results suggest that where soil moisture is sufficient for surface seeding before harvest of rice crop, it is better for farmers to relay plant and use the harvested rice straw as mulch. Keeping the rice straw mulch not only protects the seed from birds but maintains better soil moisture for germination. Many farmers in fact used this method during their experimentation with surface seeding.

Appropriate nutrients management is the prerequisite for high yields. Nutrients can come from the soil or fertilizer, either organic or inorganic. The important concept is to increase the efficiency of the applied nutrients that could be achieved through the balanced use of nutrients. If any one nutrient becomes limiting, it will limit the efficiency of others (Abrol, *et al,* 2000). Farmers will probably need to rely on a combination of organic and inorganic sources of nutrients, because there is not sufficient organic manure to provide the needed yield growth, and the cost of hauling organic manures is high. Proper timing of nutrients can help increase efficiency (Hobbs and Adhikary, 1998).

In the northwest IGP sodic or alkali soils characterize by excess of exchangeable sodium, high pH, and adverse soil physical properties occur widely and contains high amounts of extractable P but low absorption capacity. Hence, farmers undertaking reclamation of alkali soils and practicing rice-wheat crop rotation can economize on fertilizer P by skipping its application in the initial 3 to 5 years without any loss in yield. Because of application of amendments and growing of wetland rice, there is decrease in extractable P in the surface soil (Chhabra and Thakur, 2000).

The analysis of yield trends of LTE in Bangladesh, India and Nepal suggest that although significant yield decline is not widespread, yields of both rice and wheat are stagnant. In the rice-wheat system, particularly in IGP, rice yield are declining more rapidly than wheat. The causes of yield decline are mostly location specific but depletion of soil K seems to be most common (Ladha *et al,* 2003). Long-term study suggests that 120 kg N/ha should be applied to both rice and wheat to get optimum yields in reclaimed sodic soils. Phosphorus at the rate of 22 kg P/ha should be given to rice only when available P in top 15 cm soil depth has come down to 12.7 kg P/ha. There is no need to apply K in reclaimed sodic soils since they contain high available K and there occurs large contribution of non-exchangeable K towards total K uptake by crops (Singh and Swarup, 2000).

It was found that current recommendation fertilizer-N scheduling should be revised for better agronomic efficiency (Singh *et al.* 2002).The chlorophyll meter–based N management in rice can save 12.5 to 25% of the existing fertilizer N recommendation with no yield loss. Decrease in crop productivity over the years with intensive cropping could be largely traced in the deficiency of N and Zn, probable toxicity of Fe and Mn, and nutrient imbalance due to antagonism. Corrective measures such as curtailing P application where the build-up is noticeably high and raising the quantities of FYM and Zn are needed. The analysis of LTE with manure or straw treatments indicate that regular use of organic amendments (OA) did not improve grain yield in rice-rice and rice-wheat cropping systems but it could be profitable, provided the organic materials are used as a complement to a recommended doses of inorganic NPK (Dawe *et al,* 2003).

In the IGP, water availability for irrigation is decreasing due to more area is coming under rice thus reducing the availability per unit area (Sinha *et al.*, 1998), reduced water supply through canal irrigation, which is linked to less water reserving capacity of the reservoirs due to increasing siltation, and increasing competition for water for domestic and industrial use (Hobbs *et al.*, 1999). Water will become a major constraint to agriculture in the future, as the demand from domestic and industrial use increases and new irrigation facilities are not created. Water shortage is a major constraint to sustaining and increasing the productivity of rice-wheat systems. Reducing seepage, percolation and runoff losses from fields does not essentially save water if it can be recaptured at some other temporal or spatial scale, for example by groundwater pumping, cycling of runoff/seepage water in slopping land at lower elevation.

Many technologies like laser leveling, direct drilling, raised beds, non-ponded rice culture and irrigation scheduling appear to save substantial amounts of water through reducing irrigation water requirement, but whether these are true water savings is uncertain as components of the water balance have not been quantified. Reducing non-beneficial evaporation losses is true water saving, and optimal planting time of rice to avoid the period of highest evaporative demand and changing to non-ponded rice culture can save significant amounts of water. Puddling saves water is questionable, however, moving away from puddled, ponded to more aerobic rice culture sometimes brings new production problems. Farmers faced with unreliable water supplies need to store water on their fields as insurance, and puddling assists retention of water during the rice crop.

In the context of conservation agriculture, where soil is essentially biologically tilled, zero-till and bed-planting has significant role in enhancing the eco friendly cultivation with higher productivity and profitability of various cropping systems. The important crop rotations, which virtually can directly go for permanent bed planting, are Soybean-wheat, Maize-wheat, Pigeon pea-wheat, Maize-vegetable-wheat, Maize- toria / mustard-wheat, Pigeonpea + Mungbean / urdbean-wheat etc. Even direct seeding of rice in some cases produces similar grain yield with earlier maturity. This provides a chance to grow short duration vegetable pea/potato followed by wheat to enhance the crop and soil productivity as well as cropping intensity. The intercropping of sugarcane and wheat in autumn would enhance the wheat area and production and simultaneously sugarcane productivity.

II. Significance and impact of the results

The initial goal that was set at the beginning of green revolution and which was concentrated on self sufficiency in food grain production to feed our generations has been modified now as some negative impacts has appeared. These have been more highlighted after 1980s as imbalances in plant nutrients in soil, reduced soil organic contents, depletion in ground water levels, contaminations of surface and ground water resources, global warming issues etc. which resulted in stagnation or even reductions in crops productivities and sustainability.

As a result the research priorities have changed towards sustainable crop production through conservation agriculture or some alter natives to conventional agriculture. This approach boosts the inclusion of soil conditioning crops like legumes, green manure crops, some cash crops like potato, sugarcane, maize, medicinal and aromatic, floriculture, vegetable etc. to the existing cropping systems diversification. Simultaneously, the adoption of various tillage options (zero/ reduced / bed planting / laser leveler) have also been introduced. These technologies not only suppress the weeds population but also permit the timely sowing of the next crop, save labour, and reduce cost of cultivation (zero /reduced tillage in rice-wheat system) and resulted in better farm economy.

Irrigation water is the most expensive input in the rice-wheat cropping system and there are number of evidences that indicate a significant depletion in the ground water table at different locations of the IGP where continuous rice-wheat system has been followed for a long time. Bed planting and mulching techniques could answer this problem as evident from a number of experiments conducted by Rice Wheat Consortium and other researchers at experimental sites as well farmer’s fields in IGP. These technologies also facilitate residue incorporation in soil which not only enhances the soil organic carbon stock but also restricts the residue burning and green house gas emissions from agricultural systems and avoids global warming.

Balanced plant nutrients are key inputs that decide not only crop productivity but also soil health. A number of long term studies on potential management of plant nutrients have been included in the inventory to describe the consequences of different levels, sources and scheduling of organic manure and inorganic fertilizers for their economic use without demeaning soil health for sustaining productivity crops.

Above all the socio-economic circumstances of the end users, i.e. farmers, are important as these factors play a vital role in deciding the adoption of all developed technologies. The socio-economic conditions of the farmers are directly or indirectly regulated by the existing situations like their literacy levels, farm size, government policies, crop insurance, support price and transportation of farm produce, availability of the markets etc. A number of studies had been incorporated in the present inventory that deals with all these aspects.

III. Conclusions and proposals

The studies compiled under the present inventory conclude that the use of conservation agriculture is probably one of the best ways to increase production, food security, improve farmer livelihood and create environmental benefit while undertaking efficient natural resource use. It has been also concluded that prioritized research had been shrunken to the site specific which most of the times became less effective at farmer’s field. It necessitates the major research in future that could be more valuable also be supposed to be at farmer’s field under natural conditions and as per the farmer’s needs. It has been further manifest from the studies that most of the agricultural research in past had been focused on crop productivity and sustainability issues. It is the right time when agricultural scientist put more attention towards the multipurpose role of agriculture that could lead the socio-economic and policy issues of the region under the globalization context.

References

Abrol, I.P., Bronson, K.F., Duxbury, J.M., and Gupta, R.K. (eds.) 2000.Long-term soil fertility experiments in rice-wheat cropping systems. Consortium Paper Series 6.Rice-Wheat Consortium for the Indo-Gangetic Plains, New-Delhi, India. pp 171

Bronson, K.F., Cassman, K.G., Wassmann, R., Olk, D.C., Noordwijk, M., Garrity, D.P., 1998. Soil carbon dynamics in different cropping systems in principal eco-regions of Asia. In: Lal, R., Follet, R.F., Stewart, B.A. (Eds.), Management of Carbon Sequestration in Soil. CRC Press, Boca Raton, FL, pp. 35-57.

Chauhan DS, RK Sharma, SC Tripathi, AS Kharub and RS Chhokar. 2001. New paradigms in tillage technologies for wheat production. Directorate of Wheat Research, Karnal- 132 001. *Research Bulletin No. 8: 16pp* .

Chhabra, R., Thakur, N.P., 2000. Long-term study on phosphorus fertilization for rice-wheat cropping systems in alkali soils in the Indo-Gangetic Plains. In: Abrol, I.P., Bronson, K.F., Duxbury, J.M., Gupta, R.K. (Eds.), Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems. Rice-Wheat Consortium Paper Series 6. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, pp. 31-39.

Dawe, D.; Dobermann, A.; Ladha, J.K.; Yadav, R.L.; Bao, L..; Gupta, R.K.; Lal, P.; Panaullah, G.; Sariam, O.; Singh Y.; Singh, Y; Singh, P.; Kundu, A.L.; Sakal, R.; Ram, N.; Regmi, A.P., Gami, S.K.; Bhandari, Swarup, A and Zhen, Q.-X. (2003). Do organic amendments improve yield trends and profitability in intensive rice systems? *Field Crop Research*, 83:191-180.

Duxbury JM, Abrol IP, Gupta RK and Bronson KF 2000. Analysis of long-term soil fertility experiments with rice-wheat rotations in South Asia. P.vii-xxii. In I.P. Abrol et al. (ed.) Long-term soil fertility experiments with rice-wheat rotations in South Asia. Rice-Wheat Consortium Paper Series No 6. Rice-Wheat Consortium for Indo Gangetic Plains, New Delhi, India.

Evans, L.T., 1993. Crop Evolution, Adaptation and Yield. Cambridge University Press, Cambridge, 500 pp.

Gill, M.A., Kahlown, M., Choudhary, M.A, Hobbs, P.R. 2000. Evaluation of Resource Conservation Technologies in Rice–Wheat System of Pakistan. Water and Power Development Authority Report. Lahore. Pakistan.

Gupta, R.K., R. K. Naresh, P. R. Hobbs, Jheng Jiaguo and J. K. Ladha. 2003. Sustainability of Post-Green Revolution Agriculture: The Rice-Wheat Cropping Systems of the Indo-Gangetic Plains and China. *In* J.K. Ladha, J. Hill, R.K. Gupta, J. Duxbury and R.J. Buresh. (eds) Improving the productivity and sustainability of rice-wheat systems: issues and impact. ASA, Spec. Publ. 65. Chapter 1:1-25. ASA Madison, WI. USA.

Hobbs, P.R. and Adhikary, B.R. (1998). The Importance of Rice–Wheat Systems for Food Security in Nepal. p 1-5. In Hobbs, P.R., and N.P. Rajbhandari (eds), *Proceedings of the Rice–Wheat Research End-of-Project Workshop, October 1997, Hotel Shangri-La, Kathmandu, Nepal.* Mexico, D.F.: Nepal Agricultural Research Council (NARC), International Maize and Wheat Improvement Center (CIMMYT), and Rice-Wheat System Research Consortium.

Hobbs, P.R., Singh,Y., Giri, G.S., Lauren, J. and Duxbury, J. 1999. Direct seeding and reduced tillage options in the rice-wheat systems of the Indo-Gangetic plains of South Asia. Paper presented at IRRI workshop entitled “Direct Seeding in Asian Rice systems to be held in Bangkok, Thailand from 25-28 January 2000.

Hobbs, P.R., Y. Singh, G.S. Giri, J.G. Lauren, and J.M. Duxbury. 2002. Direct seeding and reduced tillage options in the rice-wheat systems of the Indo-Gangetic Plains of South Asia. *In* S. Pandey, M. Mortimer, L. Wade, T.P Tuong, K. Lopez and B. Hardy. Direct seeding: Research strategies and Opportunities. Proceedings of the international workshop on direct seeding in Asian rice systems: research issues and opportunities. 25-28 January, 2000, Bangkok. Thailand. International Rice Research Institute, Los Banos, Philippines. pp. 201-215

Ladha, J.K., J. Hill, R.K. Gupta, J. Duxbury and R.J. Buresh. (eds). 2003. Improving the productivity and sustainability of rice-wheat systems: issues and impact. ASA, Spec. Publ. 65. ASA Madison, WI. USA.

Ladha, J.K., K.S. Fischer, M. Hossain, P.R. Hobbs, and B. Hardy (Ed). 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic Plains: A synthesis of NARS-IRRI partnership research. IRRI Disc. Pap. Ser. No. 40. IRRI, Los Banos, Philippines.

Nambiar K K M and Abrol I P .1989. Long term fertilizer experiments in India. *An overview*. Fertilizer News.*34: 11-20*

Rahmana, M. A.; Jiro Chikushia, Saifizzamanb, M. and G. L. , Julie (2005). Rice straw mulching and nitrogen response of Zero-till wheat following rice in Bangladesh. *Field Crops Research,* 91:71–81

Razzaque, M.A., M. Badaruddin, and C.A. Meisner. (*ed*). 1995. Sustainability of rice-wheat systems in Bangladesh. Proc. of the National Workshop, Dhaka, Bangladesh, 14-15 Nov. 1994. Bangladesh and Australia Wheat Research Centre, Dhaka, Bangladesh.

Sharma, RK, SC Tripathi AS Kharub, RS Chhokar, AD Mongia, Jag Shoran, Ds Chauhan and S Nagarajan. 2005. A decade of research on zero tillage and crop establishment. *Research Bulletin No.18. : 36pp*. (ISSN 0972-6098). Directorate of Wheat Research, Karnal- 132 001.

Singh, K.N. and Swarup, Anand. 2000. Effect of Long-term Rice-Wheat Cropping Sequence on Yield and Soil Properties in a Reclaimed Sodic Soils. Page 40.49 in Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems (Abrol, I.P., Bronson, K. F., Duxbury, J. M. and Gupta, R. K. eds.). Rice-Wheat Consortium Paper Series 6. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Singh, B.; Gajri P.R.; Timsina J., Singh Y. and Dhillon S.S. (2002) Some issues on water and nitrogen dynamics in rice-wheat sequences on flats and beds in the Indo-Gangetic plains. *In*: *Modeling irrigated cropping systems*, with special attention to rice-wheat sequences and raised bed planting. Humphreys, E., and Timsina, J. (Eds.) Proceedings of a Workshop, CSIRO Land and Water, Griffith, NSW, Australia, 25-28 February 2002. CSIRO Land and Water Technical Report 25/02.

Sinha, S.K., Singh, G.B., Rai, M., 1998. Decline in Crop Productivity in Haryana and Punjab: Myth or Reality? Indian Council of Agricultural Research, New Delhi, India.

Timsina, J., and D.J. Connor. 2001. The productivity and sustainability of rice-wheat cropping systems: Issues and challenges. Field Crops Res. J. 69: 93-132.

Tripathi S.C and D.S Chauhan. 2001.Effect of tillage and fertilizer on productivity of wheat (*Triticum aestivum*) under dry seeded and transplanted rice conditions. *Indian Journal of Agronomy*. 46 (1): 107-111.

Tripathi SC; S Nagarajan and DS Chauhan. 1999. Evaluation of zero tillage in wheat (*Triticum aestivum*) under different methods of rice (*Oryza sativa*) transplanting. *Indian Journal of Agronomy*. 44 (2): 219-222.

Woodhead, T.; Huke, R. and Huke, E. 1993. Rice-wheat atlas of Pakistan. IRRI, CIMMYT and PARC publication. IRRI, Manila, Philippines. pp32.

Woodhead, T., R.Huke, E. Huke and L. Balababa. 1994. Rice-wheat atlas of India. IRRI, CIMMYT and ICAR publication. IRRI, Manila, Philippines. pp.146 .

Yadav, R.L., Dwivedi, B.S., Gangwar, K.S., and Prasad, Kamata. 1998. Overview and prospects for enhancing residual benefits of legumes in rice and wheat cropping system in India. Pages 207-225 *in* Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic

Zheng, XH; Wang, MX; Wang, YS; Shen, RX; Li, J; Heyer, J; Kogge, M; Papen, H; Jin, JS; Li, LT.: 2000, Mitigation options for methane, nitrous oxide and nitric oxide emissions from agricultural ecosystems, *Advances in Atmospheric Sciences* 17, 83-92.

PARC-Pakistan

INTRODUCTION

In Pakistan, rice – wheat cropping system is being practiced on an area of 2.2 million hectares. Major portion of the area is concentrated in Punjab. This zone is located within 31 - 32 North latitude and 72 - 74 East longitude. This mainly includes districts of Gujranwala, Sheikhupura and Sialkot which have mainly operated under largest rice-wheat sequence of the province. Wheat yields in the rice–wheat system are significantly lower than in any other irrigated areas of the Punjab and are also more variable (Hamid et al., 1987). Environment, crop management and socioeconomic conditions play a major role on rice and wheat production.

i. Major Soils of the Area

The soil categories commonly found in this zone are (Soil Survey of Pakistan. 1986);

- Well-drained loams, silt loams, silty clay loams, and sandy loams constitute the main group.
- Moderately well drained, seasonally imperfectly drained clays and silty clays. These soils are highly suitable for rice cultivation but may be less suitable for wheat and other crops grown in puddled soil after rice.
- The third soil group consists of substantial areas of saline unsuitable for cultivation.

ii. Farm size and Tenancy in the Area

This zone is characterized by small to medium size farms. Less than 5% of farmers are pure tenants and they operate on a lease tenancy as well as a share tenancy basis. Average farm size of the farmers is about 8 ha with over three-quarters of farmers operating between 1.5 ha and 20 ha. The number of very small farmers (<1.5 ha) and very large farmers (>20 ha) is relatively small, although several farmers operate over 100 ha, especially in Gujranwala district. A majority of the farmers in the area use their own or rented tractors for farm operations.

iii. Climatic Conditions and Irrigation Management

The area has well developed irrigated system; however, almost all farmers also use tube wells to supplement canal water. Farmers, especially in Sialkot District, rely exclusively on tube well water. Rainfall is an important supplement to irrigation water. Annual rainfall varies from 800 mm in Sialkot to 425 mm in Sheikhupura, of which one-third is received during the rabi season with considerable variation between years.

iv. Major Cropping Patterns of the area

Wheat is by far the dominant crop in the winter (rabi) growing seasons, accounting for 77 % of the sown area. The only other crop to occupy a significant area is fodder, sown on 17 % of the rabi and 10% of the kharif-cropped area. The remaining area is sown to a variety of crops, of which maize, sugarcane, and vegetables are the most important.

Cropping intensity has increased over the past two decades and during rabi almost 72 % of wheat in the area is sown after rice. There is relatively little variation in cropping patters by farm size. In areas with good soils, the average index of cropping intensity is 170 to 180, which is high relative to other areas of the Punjab. However, cropping intensity is lower in waterlogged and saline areas. Currently, the major cropping system prevailing is Rice-Wheat and almost 94 percent of the farmers are practicing this cropping system.

Factors behind low productivity

A survey conducted in 1984 in rice – wheat area, average wheat yields were as low as 1.8 Mg ha^{-1} with a high variability among fields. The information revealed the factors behind the low productivity of the system as under:

Continuous rice – wheat crop rotation

More than one half of the fields have been planted continuously to rice-wheat for five or more years. Continuous rice-wheat reduced yields by 23% relative to other rotations.

Late planting of wheat

Late planting of wheat reduces 1 % of its yield every day when planted late after 20^{th} November, since the delay causes wheat flowering and early grain filling to occur during the hot weather of March or April (Hobbs et al., 1987). Overall, 60% of the wheat was planted after 1 December and 30% after 15 December (Byerlee et al., 1984).

Rainfall pattern

The rainfall during wheat sowing time is very critical. There occurs a lot of variation in rainfall (Table 1) during the sowing time of wheat crop (Majid and Aslam 1998). The area planted to wheat crop is affected by rainfall patterns. The magnitude of the effect varied between soil types, rice variety used and topography. This unusual pattern of rainfall resulted in the delay of rice crop harvesting considerably. Ultimately, wheat planting could not be possible in time as well as its area under cultivation was reduced.

Land preparation

Land preparation is especially important for stand establishment of wheat following rice, since the field must be converted from the hard puddle condition necessary for rice to a form suitable for wheat. Rice stubble, especially of the tall basmati rice, is difficult to incorporate and increases the cost of land preparation. Land preparation is generally performed by tractor equipped with a cultivator and followed by a plank. The number of tillage operations performed varies from 2 to 10 with an average of six operations. Farmers perform more tillage operations on lighter soils and if they own a tractor. After rice, fewer tillage operations are performed because of the time shortage. Hence poor land preparation is most evident in wheat following rice on heavier soils. However, in case of light soils the land preparation is better than the heavy soils.

Late maturing Basmati rice

One of the major problems of the system is the late planting of wheat due to cultivation of wheat after late maturing Basmati rice. In 1985, a new earlier maturing Basmati rice variety was introduced which allowed rice to be harvested 2 weeks earlier. Farmers used this extra time by allocating one extra week to land preparation and by planting one week earlier.

Weed infestation: Serious infestation of wheat fields with the weed *Phalaris minor*.

Non-availability of skilled labor: At the time of rice planting, non availability of skilled labor delay rice transplanting and results in poor rice yields.

Insufficient irrigation water availability: The rice – wheat system has higher water demand mostly due to rice crop. The rising demand of water for other crops is resulting in lower water availability for the rice and wheat crops.

Emerging concepts and elements of conservation agriculture

Zero tillage wheat:

To avoid late planting and poor land preparation the research intervention of zero tillage is being introduced in the rice-wheat regions of Pakistan as well. It ensures timely planting and better wheat stand establishment of wheat and gives grain yield better than conventional method. It also saves 30 % on irrigation and land preparation costs (Aslam et al. 1999). Locally manufactured zero tillage drill is available and promotion of zero tillage technology is under progress. The farmers are on the way to adopt this technology. Crops can be planted under a wider range of soil moisture conditions with zero-tillage than with conventional tillage. Zero-tillage saves one irrigation and has better distribution and placement of seed and fertilizer.

Advantages of No-Till

- Fuel and time are saved since fewer field operations are required.
- Plant residues, which remain on the surface, protect the soil against water and wind erosion.
- More area can be planted per unit of time.
- Soil dries less than with conventional tillage, therefore moisture is conserved in the root zone.
- Populations of some weed species may decline since weed seeds are not incorporated into the soil and stimulated to germinate by aeration and tillage.
- Reduced capital investment in tillage equipment.
- Retention of soil organic matter levels.

Social benefits

No single tillage system can be used for all soils and agro-ecological environment. All tillage systems have to be locale specific, and should be developed for all conditions to solve specific problems of soil and water management, cropping systems and energy needs of the region. In 1993, the FAO[*] identified the following priorities for the development of No-Till:

- to develop cheap alternative methods of weed control.
- to develop effective and specific herbicides without harming the subsequent crop.
- to develop suitable crop rotations including cover crops, and improved cropping sequences that may result in more effective storage of rainfall and efficient utilization of available soil water.
- Provision of appropriate equipment for planting and fertilizer application.

The major constraints to the adoption of No-Till in Pakistan include the socio-economic sphere of the farmers that usually makes them reluctant to change from present practices, and the shortage of suitable equipment (special No-Till drill). Scarcity of foreign currency which discourages the import of new machinery or purchase of spare-parts for No-Till drills and the lack of funds for research and development are associated constraints to the dissemination of No-Till technology in Pakistan.

Surface Seeding

In addition to zero-till drill, wheat can be sown without land preparation through surface seeding. Surface seeding is appropriate where the soils are fine textured, drain poorly, and land preparation is difficult and causes poor tilth.

Chinese Seeder

Chinese scientists developed a seeder that prepares soil and places seed in one operation. Planting into standing rice stubble on heavy soils is also possible with this machine. This seeder consists of a shallow rotavator, followed by a six-row seeding system and a roller for compaction of the soil. Soil moisture is critical in this system.

Bed-planting of Wheat and Rice:

Rice and wheat (and also other Rabi crops) can be planted on raised beds. Wheat sowing on bed is more suitable in low lying and poor drained fields to avoid injury due to excessive moisture. Main advantages of the technology are: (a) management of irrigation water is easy and water-use efficiency is more than 30 to 40%, (b) fertilizer efficiency increases because of better seed placement, (c) it requires less seed rate and plant stand is better.

Technologies for Rice Planting

Mechanical Transplanting of Rice

Mechanical rice transplanting is feasible compared to conventional transplanting method as it ensures optimum plant population and a uniform crop stand. PARC has identified, acquired and modified a Chinese Rice Transplanter.

Parachute Method of Planting Rice

The experiments on parachute method of planting rice were initiated in the year 2000. This technique requires plastic bubble sheets to raise seedlings. Specially raised seedlings can be broadcast manually or with the help of a blower. The technique is labour saving. The technique is being tested and demonstrated jointly by NARC, Islamabad; Rice Research Institute, Dokri; On-Farm Water Management, Punjab and Guard

Agricultural Research and services Pvt. Limited, Lahore. Optimum plant population and high paddy yield can be obtained with this technology.

Production practices of CA

Straw-residue management

In hot and humid situations, such as in Pakistan, cultivation results in the loss of moisture and needs irrigation to provide sufficient moisture for germination. In No-Till, the straw residue keeps the moisture reserved, which can save up to one irrigation. However, problem arises when wheat is drilled directly into the rice stubble. Spring tines attached with No-Till drill need to be of high standard so that they can penetrate into the straw residue, and drop the seed at an appropriate depth. With the efforts of local research in Pakistan, such a drill is now available and it is anticipated that if the price of No-Till drill remained within the buying or hiring power of the farmer, No-Till in the rice-wheat areas of Pakistan would flourish.

Weed management

Herbicides and pesticides are both generally expensive and have to be used selectively in conjunction with proper rotations and with efficient use of crop residues for controlling weeds and pests. Weeds are also a major yield limiting factor in the rice-wheat cropping system of the subcontinents. In Pakistan, for example, the winter grassy weeds germinate when temperatures drop to critical levels and this becomes a major constraint to higher wheat production. However, there is plenty of data available concerning suitable herbicides for controlling the weed in this cropping rotation.

Rice stem borer (*Scirpophaga incetulas*) is also a potential constraint to the adoption of No-Till for wheat. There is no problem to recommend wheat planting under No-Till in a stem borer free area. However, within stem borer area too, wheat can still be planted under No-Till, after proper stem borer control measures are undertaken.

On the other hand it is also observed that in the conventionally tilled soil seed is buried too deep and its emergence gets difficult. Therefore, in No-Till, seed emergence percentage is better than conventionally tilled crop. Moreover, it has also been observed that due to more disturbance of soil in the case of conventionally tillage, weed seeds get onto the surface and germinate. Therefore, 43% fewer weeds were counted under No-Till wheat planting in the rice-wheat area in Pakistan.

Crop rotations

In Pakistan, the rice crop is rotated with various winter crops mainly wheat. However, to lesser extent oilseeds, chickpeas, lentil, and clovers as fodder crops also followed after rice or cotton. Other crops such as maize, sugarcane and miscellaneous vegetables are also cultivated after these crops. According to land use 1992 statistics, cotton and wheat crops were sown on an area of 2.28 and 5.66 million hectares respectively in the cotton-wheat area in Pakistan. According to another survey nearly 70% of wheat following cotton is planted after 15th. December while its appropriate sowing time in the cotton area falls in the last three weeks of November. It is also a fact that about 50% of the cotton fields are sown to wheat and accordingly this amounts to an area of 1.14 million hectares i.e. 20% of the total wheat area. The delay in wheat planting after cotton in this area tends to reduce wheat production. Thus, No-Till is seen as an alternative mean of sowing wheat sunder such conditions.

The farmers face a similar situation in the Rice-Wheat rotation. Two major rice varieties are cultivated. Basmati variety (mostly Basmati-385) covers 80% of the area while coarse variety such as IR-6 and other local varieties cover the rest of the area. Basmati-385 is a comparatively late maturing variety than IR-6 or any other coarse varieties. The average turn-around time for wheat after Basmati rice is about 18 days compared to 29 days after IR-6 and other varieties. A lot of acreage of wheat sown after rice is planted late due to long duration of Basmati rice varieties result in decrease of wheat production under this cropping pattern. To overcome the delay in planting of wheat after rice, poor land preparation; and poor establishment/stand, No-Till method of wheat planting is encouraged.

Machinery/seed drills

Availability of No-Till drill has always been the most important factor in adopting or rejecting No-Till. Research has confirmed that differences in emergence do exist between different coulter designs, with their success determined by their ability to retain and utilise the liquid and vapour moisture present in the micro-environment. It is for sure that the seeding tool design can influence emergence and that this can be used to develop precise guidelines for future designs of furrow openers and press wheels. Thus, good seed emergence can usually be achieved by sowing in the wetter soils and by using press wheels to get a good soil-seed contact.

No-Till drills often require more power to pull than their tillage counterparts. It is a general observation that farmers having tractors from 30 to 50 kW range generally have low land holdings, thus they need to adopt No-Till. On the other hand, farmers with bigger tractors may also have a wide range of agricultural equipment. Thus, depending upon other factors, No-Till or conventional method, either can be adopted.

Soil Moisture

Like in much of the rice-wheat cropped land of south and south-east Asia, in Pakistan too, only limited irrigation water is available. The issue of using this water becomes more important when, for example, only one irrigation is available. In the rice-wheat systems in Pakistan, the timing of first irrigation is critical as water-logging frequently occurs after an irrigation as there is normally the problem of restricted rooting zone caused by the hard soil underneath and slow percolation of water. It is a common observation that since young wheat seedlings are sensitive to water-logging, early irrigation often results in yellowing of plants and reduction in plant stands. Pre-irrigation before seeding has been suggested as a means to avoid water-logging during the establishment phase. It is estimated that pre-irrigation before broadcast seeding and mulching on No-Tilled soil can improve plant establishment by 42%.

Nutrition Management

Almost all farmers use fertilizer in wheat production, with a common dose of 2.5 bags/ha of diammonium phosphate (DAP) at planting time followed by 2.5 bags/ha of N in form urea. Fertilizer application is related to other cultural practices, such as land preparation and irrigation that may determine the response. Use of farmyard manure is negligible. The split application of urea as basal and at first irrigation is common in the area. However, farmer who did not apply urea at first irrigation applied it at second irrigation.

It is important to mention that some farmers feel that more use of DAP will also help in enhanced germination of wheat. However, the dose of DAP applied during wet year was close to the recommendations than applied dry year.

Irrigation Management

In wheat for seedbed preparation pre-irrigation (rauni sowing) is desirable. However, "wadwater" (irrigation in the preceding rice crop) is also in practice to reduce the turn-around time in sequential double cropping systems. Wheat crop particularly at seedling stage is very sensitive to standing water and shows chlorosis and is also killed by excessive standing water. Farmer's practices to irrigate wheat crop varies tremendously in the areas. It is observed that after planting wheat, 28 % farmers irrigate twice; 60 % irrigated three times; and 12% irrigated four times. Farmers with better access to canal water may be applying more than the economic optimum, compared to other farmers who depend entirely on tube well water. Farmers with main source of water from tube well face problem of high water prices and ultimately results in high costs to production of wheat. Application of water to wheat after mid March is responsible for the reduction of wheat yield. Due to poor drainage; low lying fields and expected rainfall, irrigation applied after this period causes damage to wheat crop (it is lodged) due to water logging.

Weeds and Weed control

The major weed found in wheat fields is *Phalaris minor*. Some fields are infested with wild oats (*Avena fatua*) and rye grass (*Lolium* spp.) however; broad leaf weeds are also common. Majority of the farmers express sever weed problem especially when wheat is planted after rice. However, weed problem is minimized when it follows vegetables and potato. Wheat planting by rauni method is helpful to control weeds. The other method reported by the farmers to control weeds is rotation with berseem. The continuous watering and cutting of fodder ensures germination but not seed setting of grassy weeds. Since *Phalaris minor* requires cool temperatures for germination, only a rotation with a rabi crop, such as berseem, can be an effective weed control strategy. Some large farmers have successfully controlled *Phalaris minor* using Dicuran and Arelan. However, these farmers expressed that use of chemicals to control weeds is very expensive. Manual weeding is common in fields close to the village, where the weeds are utilised as fodder.

Yield Management

The major conflict in the rice-wheat system is the widespread late planting of wheat, especially after basmati rice. There is also a trade-off between good land preparation for wheat planting and timely planting of wheat. The overall average yield for wheat in rice-wheat sequence is lower (1.8 t/ha) than the neighboring non rice-wheat sequence zone (2.1 t/ha). These low yields were characterized by heavy soils more often followed Basmati rice, and had been continuously sown of wheat for three or more year. Low yielding farmers also performed fewer tillage operations, planted older varieties, and applied less nitrogen and irrigation water. Finally, almost half of the low yielding fields were substantially or seriously infested with *Phalaris minor*. Almost all the farmers have expressed that wheat yield are reduced up to 10 monds per acre due to *Phalaris minor*. It was also commonly observed that farmer expected more wheat yield after ranui method compared to wadwatter method of sowing.

Implication for Research

Agro-climatic classification of rice-wheat zones is very important and climate oriented cropping technology needs to be developed. This is possible if areas are zoned on a crop basis and the best cropping time and duration are delineated for each crop. In rice-wheat zones long term climatic data are available. Locations with analogous climatic characters may be grouped as rice-wheat zone. Research may be guided to develop climate oriented cropping technology.

- Zone-wise climatic variables constraining rice and wheat yields.
- Identify and improved management practices suggested to Farmers.
- Proper understanding of agro-climatic information will assist Farmers in planning, crop production, productive farming system and technology transfer.
- Long term climatic data base may be used in studies in epidemiology, weather and crop modeling

Conclusions and follow ups

Wheat yields in the rice-wheat systems are significantly lower and are also more variable than in any other irrigated areas of the Punjab. Previous rice crop, environment (edaphic and ariel), crop management and socioeconomic conditions play a major role in this regard. There is a need to collect the scattered information on CA and to guide farmers on the crop management issues. Wheat Program at NARC, Islamabad in collaboration with national scientists and international collaborators especially CIMMYT had started systematic studies adopting farmer’s participatory approach during 1984. The studies included formal and informal surveys to diagnose farmer’s problems and circumstances in which the farmers make decisions about crop management. It was followed by extensive on-farm experimental work and technology demonstration from 1984 to date involving farmers and other provincial institutes. These studies showed that there is considerable variability in turnaround time to wheat after rice. If farmers are short of time, they can irrigate the standing rice crop to provide moisture for wheat planting (“wad water”). The alternative is to harvest the rice, irrigate the field, and then commence land preparation for the following wheat crop (“rauni method”). Although the rauni method results in a better seedbed and early weed control, the time at which the soil comes into appropriate moisture condition for wheat planting depends on temperature, rainfall, and soil type. In years of very cool temperatures or for rainfall at planting time, wheat planting can be delayed considerably. A further complication is that some farmers, whose fields are severely infested with grassy weeds, delay planting until temperatures are cool enough to stimulate germination of these temperature-sensitive weed species. Zero tillage that was introduced during 1984 in Pakistan ensures timely planting and better wheat stand establishment of wheat and gives grain yield better than conventional method. It also saves 30 % on irrigation and land preparation costs. Locally manufactured zero tillage drills are now available and promotion of zero tillage technology is under progress. The farmers are on the way to adopt this technology. Wheat Program is now looking for further funding so that it can emphasis to refine this technology as it has strong interaction with soil and wheat varieties. To promote this and other resource conservation technologies wheat Program in collaboration with other national and international institutes would like to involve itself in on-farm research activities.

References

Aslam, M., A. Majid and Mushtaq A. Gill. 1999. Zero tillage wheat productionTechnology: Prospects and threats. Science Technology & Development. An International Journal, Islamabad. Vol. 18, No.3, July-September 1999.

Aslam M, A. Majid and N.I. Hashmi. 1996. Water management issues and concerns in Rice-Wheat farming system of the Punjab: Evidence from farmer's field. Rice-Wheat Project. Wheat Programme, National Agricultural Research Centre (NARC) Islamabad. Report No.1-96 (wheat).

Amir, P. and H. C. Knipscheer. 1986. Resources use among rice farmers in Pakistan: A Production factor analysis. Applied Agricultural Research. 1(2):152-158.

Amir, P. and M. Aslam. 1992. The rice-wheat system of the Punjab: a conflict in crop management. In Farming systems of Pakistan. [Ed]. Derek Byerlee and Tariq Husain; Vanguard Books Pvt. Ltd. Lahore, Karachi, Islamabad Pakistan. ISBN: 969-402-063-8.

Byerlee, D., L. Harrington and P. Marko. 1980. Farmers practices, production problems and research opportunity in Barley production in the calpulalpan/Alpan valley, Mexico.CIMMYT Economics paper 80/3, Mexico D.F.

Flinn, J. C., and M. Ali. 1986. Technological Efficiency in Basmati Rice Production. Pakistan Journal of Applied Economics 5(1):63-79.

Majid A and M. Aslam. 1998. Effect of EL-NINO rains on wheat planting in the Rice-Wheat areas of the Punjab: Evidence from farmer's field. Wheat Programme, National Agricultural Research Centre (NARC), Islamabad. Report No.1-98 (wheat).

Soil Survey of Pakistan. 1986. Proceedings of XII International forum on soil taxonomy and agro-technology transfer. Pakistan, (Oct. 9-23, 1995). Soil survey of Pakistan, Lahore, Pakistan.