African Journal of Agricultural Research Vol. 7(42), pp. 5611-5620, 2 November, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJARx11.027
ISSN 1991-637X ©2012 Academic Journals

Review

Scope for enhancing and sustaining rice productivity in Punjab (Food bowl of India)

G. Mahajan*, Kuldeep Singh and M. S. Gill

Punjab Agricultural University, Ludhiana-141004, India.

Accepted 23 November, 2011

Rice production in Punjab has increased 23 times in the past seven decades, mainly due to increased grain yield rather than increased planting area. This increase has come from the development of high-yielding varieties and improved crop management practices, such as optimum transplanting time, nitrogen fertilization, improved weed and irrigation management. However, sustainability of rice cultivation in Punjab is at risk due to receding water table and degradation of natural resource base. As the population of India rises, it will pose more pressure on Punjab to produce more rice (about 20%) by 2030 to meet the domestic needs, due to less arable area, less water, global climate change, labour shortage and increasing consumer demand for high quality rice (which often comes from low yielding varieties). The major problems confronting rice production in Punjab are excessive use of fertilizers and pesticides, receding water table, degradation of soil health, and oversimplified crop management. Despite these challenges, good research strategy can lead to increase in rice production in Punjab. These include the development of new varieties with high yield potential, resilience to climate change and tolerance to major abiotic stresses such as drought and heat, and the establishment of integrated crop management and new crop establishment method, namely direct seeded rice.

Key words: Rice sustainability, Punjab, North-western Indo-Gangetic Plains (IGP), rice productivity, food security.

INTRODUCTION

Rice is the staple food crop for more than 70% of Indian people and is the main crop during rainy season in trans-Indo-Gangetic Plains (IGP), including Punjab (Prasad and Nagarajan, 2004). Currently, annual total planting area in Punjab under rice is 2.8 million hectares, comprising 6% of India's rice cultivated area. Punjab ranks first under Indian context with average unhusked rice productivity (6 t/ha) level which is at par with average productivity of China (FAOSTAT, 2009). About 85% of the total area in Punjab is planted with non-basmati type of varieties. Aromatic varieties of rice are generally grown in North Western part of Punjab, as the climate is very congenial for raising fine quality of basmati rice. Another important feature of rice is that it is grown following flood irrigation (Hira, 2009). The area, production, and productivity of rice in Punjab have increased by 6, 23 and 3.9 times, respectively for the last seven decades (Figure 1). The quantum jump has been accrued on account of the development of new genotypes since late 1960s coupled with the development of new production and protection practices, such as nutrient, water, pest, and agronomic management.

The development of irrigation infrastructure in Punjab had played a major role in improving the productivity of rice in Punjab. Presently, 12.6 lac tubewells are drafting water for rice cultivation in Punjab.

Punjab, constituting 1.5% geographical area of the country, has been contributing 40 to 50% of its production to the central pool for the last four decade. Further, over 95% of the food grains that are moved inter-state to food deficit areas through the public distribution system are the stocks procured from this state.

At present, the productivity enhancement warrants attention and efforts are being made to break its barrier using improved genotypes and following precision

*Corresponding author. E-mail: malajangulslan@rediffmail.com

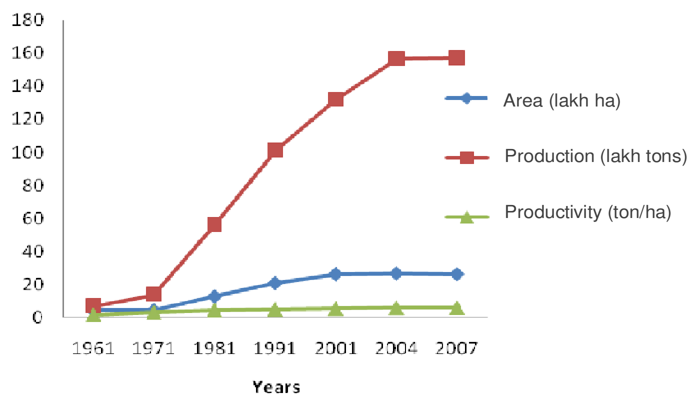

Figure 1. Time trend of rice cultivation and productivity.

management in increasing the input use efficiency. Rice demand in India will continue to increase as a result of burgeoning population pressure and increasing of urbanization area. It further gets complicated with the change in socio-economic and physical environment related to rice production in Punjab. Undoubtedly, rice was not the traditional crop of this state, and its high level of production led to overexploitation of natural resources such as soil and water. The complexities of problems would further increase, but simultaneously efforts are being made to counteract the noticed hardship by evolving new technological modules/capsules to address the propping up constraints.

CHALLENGES TO RICE SUSTAINABILITY

Shrinking land holding

During the last 50 years, arable land under rice in Punjab increased from 0.4 to 2.8 mha. There is no scope for horizontal expansion on account of static cultivated area (4.2 mha) for the last 4 decades. Therefore, most of the future increase in rice production must come for greater yield on existing crop land to avoid environmental degradation, the destruction of natural ecosystem, and loss of biodiversity. Scientifically, keeping in view the surface and underground water availability in the state, it has been perceived that water resource can sustain 1.6 mha of land under rice and 1.2 mha areas should be brought under other crops for sustaining rice productivity and maintaining the eco-balance under Punjab conditions (Hira, 2009).

Looming water crisis

Before partitioning, Punjab was known as land of five rivers, and there was plenty of water for irrigation. After partitioning, the major part of the canal irrigated area had gone to Pakistan. The hardworking peasantry continued to develop agriculture and with the favourable government policies, the network of irrigation infrastructure was created. Presently, 97% of area of this state is irrigated (71% by tubewell and 29% by canal). The scarcity of freshwater resources now threatens rice production in Punjab, mainly because of receding water table and increasing competition for freshwater resources from the urban and industrial sectors. Research revealed that puddled transplanted rice requires 3 to 4 times more water than other cereal crops, such as wheat, maize, and cotton (Gill et al., 2008). No doubt, it is a rainy season crop, but the extent of rainfall under Punjab condition is declining and its distribution is highly erratic in time and space (Kaur and Hundal, 2008). As a result, continuous cultivation of rice with underground water resulted in over-exploitation of the underground reservoir decline; it did not only affect the ecological condition of the state, but also the economical conditions impaired equally ultimately created panic over water crisis. All programmes now have been focused to: 'save water, save Punjab'. Farmers in this region have also started to realize it while installing deep tubewell. Every year, the water table is going down by 40 to 50 cm. As much as 11,145 tubewells have gone dry in central districts. Nearly, 6100 tubewells have been converted from ordinary to submersible ones. The water drawing efficiency of other tubewells has been affected up to 35%. Electric motors have been lowered by making brick wells, and ultimately, cost enhancement has increased immensely. So, rice production in this high productivity area of India is threatened due to depletion of underground water (Rodell et al., 2009; Hira, 2009). Estimates indicate that mean water-table depth, which was 22.8 m in 2006, would likely increase to 34.2 m in 2016 and 42.5 m in 2023.

Irrigated rice farmers will be forced to diversify their cropping system by growing aerobic rice, basmati rice, maize, and other less water requiring crops (Gill and Jat, 2006). Likewise, the quality of ground water is also deteriorating.

The groundwater quality map (Figure 2) shows that salt concentration has increased from the North Eastern to the South Western end. About 40% area of the state in the Southwest part has saline groundwater. By 2023, in the Central Zone of Punjab where water is of good quality, groundwater table is expected to sink to a depth of 41.2 m in Ludhiana, 44.5 m in Jalandhar, 46.7 m in Sangrur, 51.8 m in Moga, and 57.3 m in Patiala districts. Both Sangrur and Moga districts are very close to the Southwest zone where groundwater is more saline. In these districts, groundwater quality would deteriorate, because of a reverse flow mechanism. The soil-surface slope is in the direction of Northeast to Southwest and the direction of groundwater flow is the same.

For many centuries, groundwater had been flowing from the Northeast to the Southwest direction, with a gradient of 30 cm (1 foot)/km. Once the "reverse flow mechanism" starts, it would deteriorate groundwater

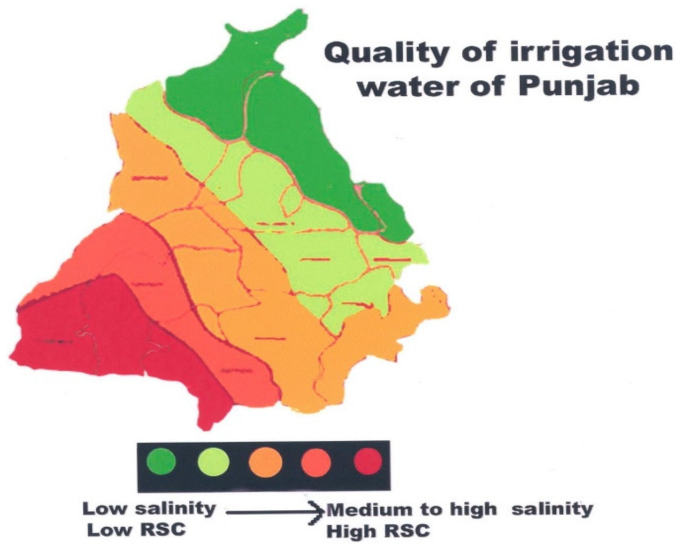

Figure 2. Map showing quality of irrigation water in Punjab.

quality of the Central Zone of Punjab with disastrous consequences. It was substantiated by the study conducted by the Punjab Agricultural University (PAU) in the NihalSinghwala block of Moga district. It was found that from 1997 to 2004 period, the percentage of water samples falling in the 'fit category' decreased from 51 to 28% and that of the 'unfit category' increased from 11 to 29% (Singh and Bishnoi, 2008). These observations suggest that if the water-table fall in the central districts continues, tubewell irrigation water quality may deteriorate. This is a looming problem that may happen in the near future.

Global climate change

In the frequency of natural disaster such as abrupt temperature change, incidence of erratic rainfall has increased partially, because of global climate change (Hundal and Kaur, 1996). During the last decade, sizeable variation in climatic parameters (temperature, rainfall, etc) has been noticed which not only affected the natural resources, but also influenced crop yields greatly, and as a result the crop yields are decreasing over time.

Climate change is real and manmade on account of over- exploitation and non-recycling of resources. Sharma and Mishra (2001), while studying the effect of simulated burning condition of crop residues, reported that complete burning of rice straw resulted in 100, 20.1, 19.8, and 80% losses of nitrogen (N), phosphorus (P), potassium (K), and sulphur (S), respectively.

The corresponding nutrient losses due to burning of wheat straw were 100, 22.2, 21.8, and 75%, respectively. Apart from the loss of such valuable constituents of soil fertility, burning also causes environmental pollution, fire hazards, besides the destruction of the natural fauna in the soil.

Increase in night temperature is greater than that in day-time temperature, considered crucial in climatic change (Mathauda et al., 2000). Rice grain yield decreased by 10% when night temperature increased by 1°C during the growing season (Sinha and Swaminathan, 1991; Peng et al., 2004). The higher maximum and minimum tem-perature results in decreasing spikelet sterility (Yoshida, 1981). The high minimum night time temperature affected rice productivity on account of reduced crop duration, increased respiration rates and changed photosynthate partitioning to grain. It also affected the survival and distribution of pest populations, hastened nutrient mineralization in soils, decreased fertilizer use efficiencies, and increased evapotranspiration (Aggarwal and Mall, 2002; Sinha and Swaminathan, 1991). A large proportion of grains remain empty when air temperature is higher than 35°C (Matsui et al., 2000; Mahajan et al., 2009a).

Recent studies, however, suggested that the effect of global warming would be largely negative for rice production, because of increased respiration and shortened vegetative and grain filling period. It is believed that climate change would affect the quality of crops; particularly, aromatic crops such as basmati rice.

Therefore, efforts are being made to develop cultivars having resilience to temperature and drought stress. The promotion of aerobic rice following conservation techniques will overcome the methane emission and nitrous oxide formulation, a common notion in trans-planted puddled rice.

Labour scarcity and increasing cost of production

Earlier farmers in Punjab used to take the help of migrated labour for transplanting rice. But now, on account of the development activities and industrialization, many states have provided employment opportunity for the local residents, and as a result the migration of labour working class has reduced, perceptibly affecting agriculture in Punjab.

During 2010, the transplanting charges of 1 ha/rice area varied from Rs. 3500 to 4500 as against the earlier years between Rs. 1300 and 1500 ha. Cost of production has increased immensely as a result of labour scarcity, lowering down tubewell bore, installation of more horsepower motors, shortage of electricity supply, dependence on electric generator sets, variation in rainfall (extent and distribution), and merely increase of 1% minimum support price against price escalation of inputs by 3.5%.

The growth rate of agriculture under Punjab conditions registered at 10% in 1980s has come down to mere 1.2%, and soil got fatigued and sick requiring more dose of fertilizers, pesticides, and other inputs to achieve the same level of productivity (Singh, 2009).

Multinutrient deficiency

Another challenge noticeable in rice growing area is the multi-nutrient deficiency, comprising major, secondary, and micronutrients that are propping up resulting in deterioration of soil health. Puddling results in the dispersion of soil aggregates and fine clay particles get fixed in pore space and encourage ponding of water. It affects oxidation and reduction conditions, thus governing the availability of nutrients. Moreover, there is interaction amongst the availability of plant nutrient present in excess. The soil of the state is now showing sign of fatigue, with depleting soil fertility and micronutrient deficiency of Zn and Fe (Nayyar et al., 2006). Fertilizer use efficiency in rice is only 30 to 35% which causes environmental and ecosystem deterioration (Yadvinder-Singh and Bijay-Singh, 2001). The losses of nitrogen are taking place due to ammonification, nitrous oxide formation, and leaching of nitrates. The runoff and leachate of nitrogen are causing eutrophication of water bodies leading to fish mortality. The high concentration of nitrate in drinking water reduces the oxygen in blood stream and causes blue baby syndrome in children and other diseases in human being. Balanced application of nutrients will certainly help to take care of soil health. Further, strengthening with integrated nutrient management will be highly conducive to improve edaphic factors.

Excessive use of fertilizer

Fertilizers need to be applied at the proper time and site with correct method, and if they are applied later than usual or at wrong sites, they may have harmful effect on crops. Punjab is currently India's largest consumer of N fertilizer, and between 1975 and 1988, average fertilizer N consumption increased from 56 to 188 kg N/ha/year (Yadvinder-Singh et al., 2007). Application of nitrogen increases the size of cell, merismatic activities and formation and function of protoplasm, which consequently increase crop growth (Verma and Saxena, 1995). Under high level of N fertilization, losses due to leaching, denitrification and NH_3 volatilization are much more compared to the rational use N application based on real N-time application using leaf colour chart and chlorophyll meter (SPAD) methods. There is need to create awareness among farmers to use the new methods to apply fertilizers. The customized fertilizers having major and micro nutrient may prove more useful for getting more response and to reduce cost of production.

Emergence of new weeds

Continuous cultivation of rice in rice-wheat system has led to the development of new biotype of weeds which were not controlled by the existing molecules of herbicides (butachlor group, etc). New biotypes and pests are appearing with the continuous cultivation of rice in the rice-wheat rotation. Problem of *Leptochloa chinensis* (*chini ghaas*) and *Ischameum rugosum* (*kanaki*), which were earlier hard to see in rice crop, can be seen anywhere in rice crop now (Mahajan and Timsina, 2010). Likewise, broad leaf weeds (*Gharilla*) have also started appearing in rice and cannot be killed with the common used herbicide (butachlor). Moreover, the weed flora under puddled and aerobic conditions is different to a great extent. Therefore, control measures are to be identified separately by following sequential spray schedule as compared to the pre-emergence application of the major group of herbicides so far. Another weed known as wild rice is also appearing in traditional areas where seeds are shattered in the standing paddy crop on account of early maturity; and it is not being controlled by the recommended herbicides, because its taxonomy and morphology is the same with that of rice.

Burning of rice residues

Punjab produces about 15 million tons of paddy straw. About 80% of the straw is burnt in the fields, particularly after combine harvesting. At the current prices, the cost of N, P_2O_5, and K_2O lost in the residues burnt comes to be Rs. 427 crores (Aulakh, 2004). Besides, nutrient loss, burning of rice straw also results in air pollution. It emits CO_2, CO, nitrous oxide, suphur oxide, and suspended matter in the air. The oxide of N and S is a potent source of acid rain, CO_2 and CO of global warming of carbon (C); it produces about 24 million tons of CO_2 in a short span of 15 to 20 days. Efforts are being made to develop the technology for recycling paddy straw. The C:N ratio of paddy straw is about 80:1 and to bring it into 20 to 30:1 takes enough time (around 20 weeks). Decomposition in incorporated field makes N availability less, and crop suffers from N stress. Using of crop residue following conservation agriculture is another viable option using second generation machinery. The results obtained till date amply advocate its beneficial effect on soil health and help to reduce the cost of production substantially. It also saves water, regulates soil temperature, suppresses weed flora, and above all, improves thermo-hydro regime which enables the wheat crop sown after rice to dissipate the effect of abrupt rise in temperature at the reproductive stage.

RESEARCH STRATEGIES FOR INCREASING RICE PRODUCTION IN PUNJAB

Improved rice cultivars

Germplasm collected worldwide is not much utilized by the conventional breeding approach due to low genetic diversity and their vulnerability to biotic and abiotic stress. Till date, no cultivars in the IGP for aerobic rice which can help to develop early vigour and use of water from the lower profile are available. The use of the cultivars having non-exacting root system needs to be encouraged. To overcome the change in climate, e.g. prevalence of high temperature at sowing/transplanting time and cloudy weather at inflorescence stage that affect crop growth and yield, improved cultivars are needed. Therefore, attention needs to be given to these issues through genetic modification techniques. The use of the cultivars which are more proficient to photosynthetic active radiation (PAR) at the initial stage may be encouraged. Shortly after emergence, the plant seedlings become fully autotrophic, manufacturing their own constituents from CO_2, water and mineral elements and transferring radiant energy into usable chemicals. In aerobic rice, there is problem of reduced sink size and high spikelet sterility which can be addressed through breeding programme. The situation is even worst in hybrid breeding programme due to limited magnitude of heterosis. It may be attributed to interaction of male sterility inducing cytoplasm and fertility restorer genes and is responsible for negative heterosis for spikelet fertility (Ramesh et al., 1999). The directly introduced Chinese hybrids as well as the hybrids developed by using Chinese females and locally developed male parents did not perform well. Hybrids developed by using the locally developed cytoplasmic male sterility (CMS) and restorer lines showed inconsistency in their performance due to the susceptibility of their parallel lines to bacterial blight, poor seed quality, and along with lodging susceptibility of the hybrids. Further investigations are still going on for evolving the rice hybrids.

Improving yield of basmati rice cultivars

Receding water table and increasing consumers' demand for high quality rice (basmati) warrant new directions in rice breeding programme. The added advantage to basmati rice is that their growing periods exactly coincides with the peak of rainy season and escape water shortage and weed menace. Rice varieties (aromatic) with high grain quality generally do not give high very yield; although, no genetic linkage between yield and quality has been found. The basmati rice grown in Northern part of the country in general and particularly, Punjab has great significance at global level. It is directly linked with the cultivation of photosensitive local cultivars well acclimatized with the climate. The lower temperature at the reproductive phase is the vital factor responsible for quality improvement. As living standard improves, the demand for high quality rice also increases (Anonymous, 2009). In 2000, less than 4% of rice area in Punjab was planted with high grain quality aromatic rice; presently, these are being grown in more than 15% rice area. When rice quality becomes the focus, yield improvement will receive less attention. The productivity improvement of aromatic rice enabled the evolvement of 10 rice varieties with high grain aromatic quality as well as production and protection package. On average, it has been realized that currently evolved cultivars, namely Punjab Basmati 2, Pusa Basmati 1121, Superbasmati, and Pusa Basmati 1 yields range from 25 to 40 q/ha, considered as fairly good yield levels.

Optimum use of pesticides

On an average, rice farmers in Punjab overuse pesticides by more than 30%. Over application of N fertilizer is partially responsible for the overuse of pesticides. In many cases, pest outbreaks were the result of overuse of pesticides, because of their effect on biodiversity. The study of Tiwana et al. (2009) revealed that Punjab consumed about 17% of pesticides used in India. The per hectare pesticide use is the highest in Punjab (923 g/ha) as compared to other agriculturally advanced states of India, like Haryana, Andhra Pradesh, Tamil Nadu, Karnataka and Gujrat. Although, the use of pesticides has helped to enhance economic gains through crop protection, they have had serious implications on human health and non-target plants and animals by accumulating in food and water. The recent recommended approaches explaining the use of chemicals based on economic threshold level for the control of different insect-pest do not only help to reduce the incidence level, but simultaneously prove cost effective and evade resistance problems. The economic thresholds for the control of stem borer in rice and basmati rice are 5 and 2%, respectively. Likewise, integrated pest management (IPM) is another viable approach to keep the incidence of insect-pests under check. Recently, to keep surveillance over insect pests and control by following insect specific method, kind, and dose specific of chemicals for making crop cultivation eco-friendly with minimum pesticide load is gaining importance and is a wise step towards optimum use of pesticides.

Matching of water availability with land use system

Total availability of water resources (canal water, rainfall and seepage) in Punjab was estimated to be 3.13 million ha m /year and water demand for irrigation purpose was found to be 4.33 million ha m /year. Thus, there is deficit of 1.2 million ha m /year of water. With the available water resources, Punjab can sustain only 1.6 m ha area under rice. Recent studies conducted at PAU revealed that wet seeded rice as well as aerobic rice culture is superior to traditional transplanted rice culture in terms of water use efficiency. There was a saving of about 290 mm of water under direct sown crop which was about 25.1% less than the water used by transplanted crop. Such type of agronomic management practice will certainly help to use the available water more rationally with high level of water productivity. Adoption of direct seeded basmati rice further accentuates water saving and needs to be encouraged at large scale by creating the marketing structure more emphatically. Results clearly advocate that the first fortnight of June, using 15 to 20 kg seed rate/ha at 2 to 3 cm soil depth and 20 to 25 cm row spacing gives productivity that varies from 6 to 8 t/ha. Irrigation water may be applied after 3 to 5 days when the ponded water is infiltrated into the soil. Likewise, sequential application of pendimethalin (1 kg/ha) as pre-emergence followed by post emergence application of bispyribac Na (25 g/ha) proved effective for satisfactory weed control (Mahajan et al., 2009b). The promotion of direct-seeded rice (DSR) is the appropriate option of crop diversification in Punjab for high yield realization and efficient use of resources. The impact of direct seeding of rice on long term productivity and sustainability of the system, however, requires careful evaluation within the context of production system. Varieties having characters of anaerobic germination, weed competitiveness, and efficient in Fe uptake from the soil are the key needs for direct seeding to be widely adopted in the near future.

Use of furrow irrigated raised bed (FIRB) technology and laser levelling

Nitrogen use efficiency is directly linked with water availability. The pre-requisite for uniform water availability is the levelling which can be accrued through the use of laser land leveler. The uniform application of water in furrow following FIRB planting system enhances water nutrient and herbicide use efficiency; nitrogen use efficiency was mainly attributed because of the accumulation of nutrients in the beds and reducing the leaching losses also on account of less ponded wet area (Kukal et al., 2008).

Potential agronomic advantages of beds include improved soil structure due to reduced compaction through controlled trafficking, reduced water logging, better surface drainage, improved fertilizer placement and feasibility of mechanical weed control , reduced irrigation time, and improved yields on fine-textured soils prone to water logging. Farmer and researcher trials in the IGP suggest irrigation water savings of 12 to 60% for direct seeded (DSRB) and transplanted rice on beds (TRB), with similar or lower yields for TRB when compared with puddle flooded transplanted rice (PTR), and usually slightly lower yields with DSRB (Balasubramanian et al., 2003). Rice-wheat systems on permanent beds have been intensively researched in Punjab, India and the results showed that there was no yield advantage of growing crops on beds as compared to flats, but there was little advantage in water savings (Humphreys et al., 2008; Kukal et al., 2008; Yadvinder-Singh et al., 2008, 2009). Another earlier study in the North West IGP also showed little effect of rice on beds on water productivity (typically around 0.30 to 0.35 g/kg) as the decline in water input was accompanied by a similar decline in yield (Sharma et al., 2002). With few exceptions (Maynard, 1991; Limon et al., 2000), the beds are heavily cultivated and reshaped or completely reformed each year, at considerable expense. But the acceptance of this technology by the rice-wheat farming system has been low owing to significant cost of making beds and their subsequent re-shaping on regular basis. Besides, bed-planter machine in North West IGP with large farm size requires tractor of higher (more than 45) horse power and custom hiring is still not a popular practice.

Adoption of practices without any distortion

Earlier farmers in Punjab used to take the help of migrated labour for transplanting rice. But now with the aid of the central government, the various state governments have initiated employment generation programmes, such as National Rural Employment Gurantee Act, which resulted in a sizeable reduction in the labour availability. Moreover, urbanization and industrialization have engaged large chunk of farm labourers. On account of labour scarcity, the farmers have dispensed very useful operations recommended by Punjab Agricultural University, which is affecting rice productivity. As a result, many rice farmers have over simplified crop management practices. Now, the farmers are applying herbicide by making hole in liquor bottle and sprinkling liquid formulation in the field, but the instruction is to mix in 150 kg sand/ha and spread uniformly 2 days after transplanting. These practices reduce the herbicide use efficiency and prove less productive. Secondly, on account of more labour cost, the farmers used to apply fertilizer by broadcasting and using of nitrogen in particular less splits as compared to recommended ones. For realizing high rice productivity, 33 hills/m^2 are required, but resource characterization survey revealed that plant population at cultivators' fields varied from 18 to 22 hills/m^2. In alkaline soils, 2 to 3 seedlings/hill are recommended because on account of high concentration of sodium, seedling mortality takes place, but they plant only one.

Integrated nutrient management

The continuous use of chemical fertilizer in different production system has created a void in the availability of major and micro plant nutrients and to achieve the same yield level, the quantity of plant nutrients needs to be enhanced. It is thus realized that to maintain soil fertility, use of fertilizer in combination with organic source of nutrition is required. The organic matter addition may be through crop residue management/green manure/-compost/farm yard manures, improve the physical condition of soil. The adoption of integrated nutrient management in rice-wheat system has a great potential to off-set the heavy requirements of chemical fertilizer, leading to maximum yield and sustainability of crop productivity over long term basis.

Amongst various organic manures, green manure (*in-situ*) helps to enhance organic matter content of soil, maintains and improves soil structure, reduces loss of nutrients, particularly N, provides a source of N for the succeeding crop and reduces soil erosion, thereby increasing the production of crops (Greenland et al., 1979). Likewise, green manure is inexpensive, ecofriendly alternative to mounting prices of fertilizer nitrogen and has become an efficient technology in economizing the agricultural production system, ensuring productive capacity of soil without causing environment problems (Bana and Pant, 2000). Green manures, particularly the legumes have relatively more N, low C:N ratio and behave almost like chemical nitrogenous fertilizer (Bhuiyan and Zaman, 1996).

Green manuring, particularly in rice is a well established practice, and saving of fertilizer N through green manure ranged from 30 to 100 kg N/ha and in most cases it was around 50 to 60 kg N/ha (Ladha et al., 1988), 45 to 60 kg N/ha (Sharma et al., 1985), 90 kg N/ha (Ghai et al., 1988), and 120 kg N/ha (Beri et al., 1989). Incorporation 45 days old, *Sesbania aculeate* and *Sesbania rostrata* accumulated 185 and 219 kg N/ha, respectively (Palaniappan et al., 1990). After two cycles of rice-wheat cropping, soil N decreased except in green manured plots fertilized with 120 kg N/ha (Tiwari et al., 1995).

Site specific nutrient management (SSNM)

SSNM is the application of need of nutrient based on the soil test. It is the approach which ensures the harvesting of potential yield, because to a great extent it helps to fulfill the 5 basic principles of soil management, essential for sustainable agriculture. (1) chemical nutrient removed by the crop must be replenished in the soil, (2) physical condition in the soil must be maintained which usually means that humus level must be constant or increase, (3) there must be no build up of pests and diseases, (4) there must be no increase in soil salinity or toxicity, and (5) soil erosion must be controlled. Gill (2006) reported that SSNM approach in hybrid rice PHB-71 along with balanced supply of nutrients in combination with micro nutrients enables the breaking of yield barrier from 13 to 17 t/ha, a remarkable increase in productivity of rice-wheat by 4 t/ha per annum which is mainly, because of paddy yield (10 t/ha). The yield contributing characters were improved with notable margin under SSNM. The results of SSNM experiment further advocated that this approach can only help to achieve the climatic yield potential of 18 t/ha/annum under Punjab conditions. The main micro nutrients applied were B, Cu, Mn, and Zn, while secondary nutrient applied was S to rice only. The corresponding rates of application were 5, 10, 20, and 25 kg/ha, respectively of micro nutrient and 40 kg/ha of S.

Strengthening of crop improvement programme

Pawjel Agricultural University is striving hard to develop new genotype of rice with expected productivity level of 10 t/ha. Till date, out of 30 improved cultivars released so far in Punjab State, PAU-201 cultivar fulfilled the hypothesis by giving 10 t/ha productivity. Among hybrid, PHB-71 gave almost 10 t/ha productivity. Unfortunately, both cultivars are not being grown, because PHB-71 is prone to lodging, while PAU-201 has become the victim of quality aspect. To maintain high pitch of 10 t/ha achieved in research programme, further attention should be given to the following in the coming days: (1) new varieties must be resilient to climate change, (2) cultivars must be tolerant to heat against spikelet sterility and (3), Direct seeded rice cultivars must be tolerant to drought stress during initial stages, and also must be tolerant to water logging during germination stage. In the past, most research focused on improving rice yield when water and nutrients were amply supplied (Timsina and Connor, 2001); but now, there is an urgent need to understand the physical mechanism coupled with crop management strategies to avail the full expression of yield potential. High yield with less nutrient and water requirement is the need of the hour which can only be possible through gene mutation, marker aided selection, and through the transformation of genetic engineering. Then, only the cultivars that evolve will be cost effective, have input use efficiency and will have compatibility with specific environment.

Integrated crop management

Various technologies for crop management have been developed in Punjab in the past for increasing rice productivity, from time of transplanting to harvesting. We believe that these will continue to play an important role in sustaining rice yield. Optimum time of transplanting rice (15 June to 5 July) has been standardized for maximum crop and water productivity (Mahajan et al., 2009). In case transplanting is delayed, then transplanting of 60 days old nursery should be done to compensate for the delay (Gill and Shahi, 1987). Close spacing of 15 × 15 cm was recommended rather than 20

× 15 cm spacing under late transplanting (Shahi and Khind, 1976). Application of N in 3 splits (basal, 21 DAT, 42 DAT) gave better productivity than 2 splits (Meelu and Gupta, 1980; Mahajan and Sekhon, 2010). Green manuring before paddy transplanting saved 50% N to rice (Bopari et al., 1992). To reduce the incidence of lodging in basmati rice, pruning of plants by 15 to 20 cm from top after 45 DAT can be done (Sardana et al., 2006). Alternate wetting and drying of paddy fields should follow irrigation scheduled to apply water 2 days after applying ponded water in the soil (Sandhu et al., 1980). Likewise, second and third split of nitrogen should be applied when water is not ponded and apply irrigation 3 days after application of nitrogen. In addition, synergy among fertilizer, water and pest management should be considered to maximize overall efficiency of the production system. New technology will be judged not only on the basis of yield and profitability, but also based on its short and long term impact on the environment. Sustainability of rice production system in Punjab can be maintained only when the natural resource base is protected and ecosystem services of the rice system are maximized.

Integrated pest and disease management

Rice production in Punjab faces many biotic stresses, which include bacterial blight, sheath blight, sheath rot, false smut, white backed plant hopper (WBPH), leaf folder and stem borer (Anonymous, 2009). Huge yield losses occur due to these biotic stresses every year. Infestation of leaf folder, bacterial blight false smut and sheath blight have become more severe in the recent years, because of breakdown in ecosystem stability caused by the heavy use of pesticides and the increase in air temperature due to global warming. Scientists in Punjab have already isolated many genes with disease and insect resistance from cultivated and wild species. Currently, more than two dozen genes conferring resistance to bacterial blight (BB) have been identified and designated as *Xa*1 to *Xa*30(t) (Cheema et al., 2008). These genes with resistances have been transferred into local varieties through transformation or backcrossing. Bacterial blight resistance genes *Xa5, Xa13* and *Xa21* have been pyramided in PR106 background (Singh et al., 2001). Likewise, BB resistance genes X*a 13* + *Xa21* and *sd1* for dwarfness were pyramided in tall basmati rice varieties. These genotypes are currently under testing. Bt-transgenic rice is a successful example for controlling stem borer although it has not been released officially for commercial production. At PAU, genetic transformation of basmati rice using synthetic *Cry1Ac* gene has been achieved. The genotypes carrying this gene have enhanced level of resistance to yellow stem borer (Gossal et al., 2001). The genetics of genes for resistance to whitebacked planthopper (WBPH) from five highly resistant stocks (Mudgo, MR1523, ARC11369, NCS2041 and MO1) have been worked out (Brar, 2002). Efforts are being made at PAU to identify and characterize new source of resistance against some diseases, including, sheath blight, brown spot (Goel et al., 2006), etc., for which, major genes are not identified. Accumulation of minor genes in the single genetic background seems to be an effective way for controlling these diseases. Resistance donors were identified against Punjab pathotype of *Xanthomonas oryzae* pv. *oryzae* and genetics of resistance have been worked out (Sidhu et al., 1979).

Rice varieties Lua Ngu, Nagane Tia, Nam Sagni, Nam Sakouy and Patong 32 each carried dominant allelic genes imparting resistance against bacterial blight. Single recessive genes that are also allelic confer resistance to Punjab isolate in DF_1, DV 29, DV 85, DV 86, DZ 78, BJ 1 and PI 231129. Dominant gene of Patong 32 and recessive gene(s) from RP 2151-173 -1-8 have been transferred to improved genetic background and resistant varieties with diverse genes for bacterial blight resistance have been released during different years (Bharaj et al., 2005). Since 1994, PAU has developed ten varieties of rice, namely, PR 111, PR 113, PR 114, PR 115, PR 116, PR 118, PAU 201, Punjab Basmati 2, PR 120, and Punjab Mehak 1. All these varieties, except Punjab Basmati 2, possess genetic resistance against bacterial blight pathogen for which no chemical control is feasible.

Two varieties namely, PR 108 (released during 1986) and PAU 201 (released during 2007) possess moderate level of resistance against WBPH. PR 108 also possesses resistance against backed plant hopper (BPH). For disease resistance, another strategy is to focus on quantitative resistance (mostly polygenic) that provides broad spectrum resistance against multiple pathogen races or different pathogens (Mew et al., 2004).

This can be combined with major resistant genes to achieve a higher degree of more stable resistance. The dynamics and severity of pest attack has shifted with the adoption and spread of rice-wheat crop rotation in Punjab during the last three decades. Excessive use of chemicals for pest control in agriculture is known to degrade the environ-ment. Integrated Pest Management (IPM) involves a proper choice and blend of compatible tactics (cultural, mechanical, biological and chemical), so that the components complement each other to keep the pest population at manageable levels.

The study reveals that a significant population of overwintering stem borer larvae in rice stubbles is killed when fields are disc ploughed 2 to 3 times. It has also been observed that if the rice crop is planted synchronously only during the recommended period of planting, chances of multiplying stem borer population are decreased to a greater extent. Work on mass trapping of yellow stem borer through pheromones has given some positive results to reduce incidence of pests. Studies have also shown that with the increase in nitrogen level, there is an increase in population of leaf folder and WBPH.

CONCLUSION

The new initiative such as integrated nutrient management, real time-N application, site specific nutrient management, evolution of high yielding varieties resistant to biotic and abiotic stresses, and strengthening of research to evolve varieties which are high nutrient responsive with high water use efficiency will prove as boon facts for sustaining the rice productivity over a longer period of time. Technology on direct seeded rice will further help to enhance water productivity, reduce labour cost and complete sowing operation in a stipulated time frame. Efforts are underway towards the development of improved variety by integrating germplasm, genomics resource, and molecular technology. The improved variety will have resistance to major diseases and insects; high efficiency in nutrient use including Fe and Zn; resistance to major abiotic stresses such as drought, salinity and abnormal temperature; high grain yield, and above all grain quality. It is anticipated that development of improved varieties will result in increased rice production with greatly reduced inputs in Punjab, thus providing livelihood and food security for India.

REFERENCES

Aggarwal PK, Mall RK (2002). Climate change and rice yields in diverse agro-environment of India. II. Effect of uncertainties in scenarios and crop models on impact assessment. Climate Change 52:331-343.

Anonymous (2009). Basmati rice prices rise on increased buying. *The Econ. Times*. 29 Aug 2009.

Aulakh KS (2004). Resource conservation and sustainability under Punjab conditions. *Proc National Symposium on Resource Conservation and Agricultural productivity*. Nov 2004. PAU, Ludhiana, India. pp. 22-25.

Bana OPS, Pant AK (2000). Green manuring for ecological sound crop production. Indian Farmers' Digest 33:19-20.

Balasubramanian V, Ladha JK, Gupta RK, Naresh RK, Mehla RS, Bijay-Singh, Yadvinder-Singh (2003). Technology options for rice in the rice–wheat system in South Asia. In: Ladha JK, Hill JE, Duxbury. (Eds.), ASA special publication. Madison, Wil; Am. Soc. Agron. 65:115-147.

Beri V, Meelu OP, Khind CS (1989) Biomass production N-accumulation, symbiotic effectiveness and mineralisation of green manure in relation to yield of wetland rice. Trop. Agric. 66:11-16.

Bharaj TS, Singh N, Kaur R, Kaur D, Singh K, Lore, JS (2005). Advances in breeding for bacterial blight resistance, superior grain quality and high yield potential in rice. 2005, Presented at: 5th International Rice Genetic Symposium and 3rd International Rice Functional Genomics Symposium held at Manila, Philippines from 19-23 Nov. p. 33.

Bhuiyan NI, Zaman SK (1996). Use of green manuring crops in rice field for sustainable production in Bangladesh agriculture. (In). Biological nitrogen fixation associated with rice production (Ed.) Rahman *et al.*, Dordrecht, Kluwer Academic Publishers, The Netherlands. pp. 51-64.

Bopari BS, Yadvinder-Singh, Sharma BD (1992) Effect of green manuring with Sesbania aculeate on physical properties of soil and on growth of wheat in rice-wheat and maize-wheat cropping systems in semi-arid region of India. Arid Soil Res. Rehabilat. 6:135-143.

Brar N (2002). *Inheritance of resistance to whitebacked planthopper, Sogatella furcifera* (Horvath) in rice, *Oryza sativa* L. 2002. Ph.D. Dissertation, Punjab Agricultural University, Ludhiana, Punjab, India.

Cheema KK, Grewal NK, Vikal Y, Das A, Sharma R, Lore JS, Bhatia D, Mahajan R, Gupta V, Singh K (2008). A novel bacterial blight resistance gene from *Oryza nivara*, mapped to 176kb region and transferred to *O. sativa* L. Genet. Res. 90:397-407.

FAOSTAT (2009). FAO statistical database. *www.fao.org*. Food and Agriculture Organization (FAO) of the United Nations, Rome,

Ghai SK, Rao DCN, Batra L (1988). Nitrogen contribution to wetland rice by green manuring with Sesbania spp. in an alkali soil. Biol. Fertility Soils 6:22-25.

Gill MS (2006). Sustaining high yield of rice-wheat system through site specific nutrient management in Punjab. Indian J. Fertilizer 2:45-50.

Gill MS, Jat ML (2006).Precision farming: Concept and realities in India. In: A*dvance in Agricultural Technology*. Punjab Agricultural Management and Extension Training Institute, Ludhiana. pp. 155-164.

Gill MS, Pal SS, Ahlawat, IPS (2008). Approaches for sustainability of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system in Indo-Gangetic plains of India – A review. Indian J. Agron. 53: 81-96.

Gill PS, Shahi WN (1987). Effect of nitrogen levels in relation to age of seedlings and time of transplanting on the growth, yield and milling characteristics of rice. Indian J. Agric. Sci. 57:630-634.

Goel RK, Bala R, Singh K (2006). Genetic characterization of resistance to brown leaf spot caused by *Drechslera oryza* in some wild rice lines. Indian J. Agric. Sci. 76:705-707.

Gossal SS, Gill R, Sidhu AS, Kaur Deepinder, Kaur Navraj, Dhaliwal HS, Christou P (2001). Transgenic basmati rice carrying genes for stem borer and bacterial blight resistance.In: Rice Research for Food Security and Poverty Alleviation 353-360 Eds. Peng S and Hardy B., International Rice Research Institute.

Greenland DJ, Rimmer D, Payna D (1979). Determination of structural stability class in English and Welsh soils using a water coherent test. J. Soil. Sci. 26:291-294.

Hira GS (2009) Water Management in Northern States and the Food Security of India. J. Crop. Improv. 23:136-157.

Hundal SS, Kaur P (1996) Climatic change and its impacts on crop productivity in Punjab, India, In: "*Climatic Variability and Agriculture*". Abrol, Y.P.et.al (Eds), Narosa Publishing House. New Delhi, India. pp 377-393.

Humphreys E, Roth CH (Eds.) (2008). In "Permanent Beds and Rice-Residue Management for Rice–Wheat systems in the Indo-Gangetic Plain". ACIAR ProceedingsNo. 127, Australian Centre for International Agricultural Research, Canberra, Australia.Available at http://www.aciar.gov.au/publication/term/18 (last accessed 17 Nov. 2008).

Kaur P, Hundal SS (2008). Impact of climate change on agriculture over Punjab. In : Prasada Rao GSL HV, Rao GG SN, Rao, Rao VUM, Ramakrishna YS (ed) *Climate Change and Agriculture over India.* Kerala Agricultural University. pp. 237-257.

Kukal SS, Humphreys E, Yadvinder-Singh, Balwinder-Singh, Yadav S, Amanpreet- Kaur, Thaman S, Timsina J, Dhillon SS, Brar NK, Prashar A, Smith DJ (2008). Permanent beds for rice–wheat in Punjab, India. Part 1: Crop performance.In "Permanent Beds and Rice-Residue Management for Rice–Wheat Systems in theIndo-Gangetic Plain". (E. Humphreys and C. H. Roth, Eds.), ACIAR Proceedings Australian Centre for International Agricultural Research, Canberra,Australia. 127:23–36. Available at http://www.aciar.gov.au/publication/term/18 (last accessed 17 Nov. 2008).

Ladha JK, Watanbe I, Saono S (1988). Nitrogen fixation by leguminous green manure and practices for its enhancement in tropical and lowland rice. In: Proc. Sympo. on Sustainable Agriculture; Green manuring in rice farming, 25-29 May, 1987. International Rice Research Institute, Philippines. pp.165-183.

Limon-Ortega, A, Sayre KD, Francis CA (2000). Wheat and Maize Yields in Response to Straw Management and Nitrogen under a Bed Planting System. Agron. J. 92:295-302.

Mahajan G.,Sekhon NK (2011) Yield and nitrogen use efficiency of indica rice varieties as influenced by timing of nitrogen fertilization. Indian J. Agric. Sci. 80:327-328.

Mahajan G, Timsina J (2011). Effect of nitrogen rates and weed control methods on weeds abundance and yield of direct-seeded rice. Arch.

Agron. Soil Sci. 57:239-250.
Mahajan G, Bharaj TS, Timsina J (2009a). Yield and water productivity of rice as affected by time of transplanting in Punjab. India. Agric. Water. Manag. 96:525-535.
Mahajan G, Chauhan BS, Johnson DE (2009b) Weed management in aerobic rice in northwestern Indo-Gangetic Plains. J. Crop Improv. 4:366-382.
Mahajan G, Sharma N, Bharaj TS (2009).Grain yield, water productivity and quality characteristics of basmati rice in response to cultivars and transplanting dates. Int. J. Plant Breed. 3:46-51.
Mew, TW, Leung H, Savary S, Cruz CMV, Leach JE (2004). Looking ahead in rice disease research and management. Crit. Rev. Plant Sci. 23:103-127.
Maynard M (1991) Permanent beds- their potential role in soil management for the future. Large Area. Farmer's Newslateer no. 137. Irrigation Research and Extension Committee, CSIRO Center for Irrigation, Griffth NSW. pp. 14-18.
Mathauda SS, Mavi HS, Bhangoo BS, Dhaliwal, BK (2000). Impact of projected climate change on rice production in Punjab (India). Trop. Ecol. 41:95-98.
Matsui T, Omasa K, Horie, T (2000). High temperature at flowering inhibits swelling of pollen grains, a driving force for thecae dehiscence in rice (*Oryza sativa* L.). Plant Prod. Sci. 3:430-434.
Meelu OP, Gupta, RK (1980). Time of fertilizer N application nitrogen in rice culture. Int. Rice Res. Newsl. 5:20-21.
Nayyar VK, Bansal RL, Manchanda JS, Khurana MPS (2006). Annual Report of AICRP of Micro- and Secondary nutrients and Pollutant Elements in Soils and Plants. Punjab Agricultural University, Ludhiana, India.
Palaniappan SP, Sidderworan K, Srinivasulu R (1990). Green manure evaluation for rice farming systems. International Symp. On Natural Resource management for sustainable Agriculture, 6-10 Feb, 1990, New Delhi. p. 220.
Peng S, Huang J, Sheehy JE, Laza RC, Visperas RM, Zhong X, Centeno CS, Khush,G.S., Cassman KG (2004). Rice yields decline with higher night temperature from global warming. In: Proc. Natl. Acad. Sci. 101:9971-9975.
Prasad R, Nagarajan S (2004). Rice–wheat cropping system – Food security and sustainability. Curr. Sci. 87: 1334-1335.
Ramesh MS, Ilyas M, Viraktamath BC, Vijaya Kumar CHM (1999). Physiological basis of heterosis for grain yield in rice. Indian. J. Genet. 5:411-415.
Rodell M, Velicigna I, Famiglietti JS (2009). Satellite-based estimates of groundwater depletion in India. Nature 460:999-1002.
Sandhu BS, Khera KL, Prihar SS, Singh B (1980) Irrigation needs and yield of rice on a sandy loam soil as affected by continuous and intermittent submergence. Indian J. Agric. Sci. 50:492-496.
Sardana V, Mahajan G, Sidhu MS (2006). Effect of foliage clipping on the grain yield of basmati rice. Oryza 43:247-48
Shahi HN, Gill, PS, Khind KS (1976) Effect of number of seedlings per hill and spacing on growth and yield of rice. Indian J. Agron. 21:392-395.
Sharma KN, Bhandari AL, Kapur, ML, Rana DS (1985). Influence of growing various crops in five different fixed rotation on the change in nitrate and total nitrogen content of soil. J. Agric. Sci. Cambridge. 104: 609-613.
Sharma PK, Mishra B (2001). Effect of burning rice and wheat crop residues: loss of N, P, K and S from soil and changes in the nutrient availability. J. Indian Soc. Soil Sci. 49:425-429.
Sharma, PK, Bhushan L, Ladha JK, Naresh RK, Gupta RK, Balasubramanian BV, Bouman BAM (2002). Crop-water relations in rice wheat cropping under different tillage systems and water-management practices in a marginally sodic, medium-textured soil. In "Water-wise Rice Production" (B. A. M. Bouman, H. Hengsdijk, B. Hardy, B. Bindraban, T. P. Toung, and J. K. Ladha, Eds.), International Rice Research Institute, Los Ban˜os, Philippines. pp. 223–235.
Sidhu GS (1979). Linkage relationships of some genes for disease and insect resistance and semidwarf stature in rice. Euphytica 28:228-32.
Singh B, Bishnoi SR (2006). Changes in quality of underground irrigation waters in Nihal Singh Wala block of Moga district of Punjab. J. Res. (PAU) 43:19-20.
Singh S, Sidhu JS, Huang N, Vikal Y, LiZ Brar DS, Dhaliwal S , Khush GS (2001). Pyramiding three bacterial blight resistance genes (*xa5, xa 13* and *Xa21*) using marker assisted selection into indica rice cultivar PR 106. Theor. Appl. Genet.102:1011-1015.
Sinha SK, Swaminathan MS (1991). Deforestation, climate change and sustainable nutrition security: A case study of India. Clim. Change. 19:201-209.
Timsina J, Connor DJ (2001) Productivity and management of rice–wheat cropping systems: issues and challenges. Field. Crops. Res. 69:93-132.
Tiwana NS, Jerath N, Singh G, Singh R (2009). Pesticide Pollution in Punjab: A Review. Asian J. Water, Environ. Pollut. 6:89-96.
Tiwari C, Singh Y, Singh-Dheer, Singh D (1995). Effect of Sesbania green manure and nitrogen fertilizer in rice-wheat cropping system. Indian J. Agric. Sci. 64:708-711.
Verma VS, Saxena KK (1995). Response of French-bean (*Phaseolus vulgaris*) to graded doses of nitrogen, phosphorus and potassium in silty loam soil of central Uttar Pradesh. Indian J. Agron. 40:67-71.
Yoshida S (1981) Fundamentals of rice crop science. International rice Research Institute (IRRI), Los Banos, Philippines. pp. 1-269.
Yadvinder-Singh, Bijay-Sigh (2001). Efficient management of primary nutrients in the rice-wheat system. J. Crop Prod. 4:23-86.
Yadvinder-Singh, Bijay-Sigh, Ladha JK, Singh JP, Choudhary OP (2007). Enhancing nitrogen use efficiency for sustainable rice-wheat production system in the Indo-Gangetic Plains of India. in 'Agriculture nitrogen use and its environmental implications', ed. By Y.P. Abrol, N. Raghuram and M.S. Sachdev., I.K. International Publishing House Pvt. Ltd, New Delhi. pp. 139-164.
Yadvinder-Singh, Brar N.K, Humphreys E. Bijay-Singh, Timsina J (2008). Yield and nitrogen use efficiency of permanent bed rice-wheat systems in northwest India: effect of N fertilization, mulching and crop establishment method. In "Permanent Beds and Rice-Residue Management for Rice-Wheat Systems in the Indo-Gangetic Plain". (E. Humphreys and C. H. Roth, Eds.), ACIAR Proceedings No. Australian Centre for International Agricultural Research, Canberra, Australia. 127:62-78. Available at http://www.aciar.gov.au/publication/term/18 (last accessed 17 Nov. 2008).
Yadvinder-Singh, Humphreys E, Kukal SS, Balwinder-Singh, Amanpreet-Kaur, Thaman S, Prashar A, Yadav S, Navneet-Kaur, Dhillon SS, Smith DJ, Timsina J (2009). Crop performance in a permanent raised bed rice-wheat cropping system in Punjab, India. Field Crops Res. 110:1-20.