Chapter 10

Cropping system approach to cope with climate change

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The continuing population pressure in the country will demand substantial increase in food, feed, fodder, fiber and fuel production over the next few decades to be able to maintain self sufficiency and also meet export requirement. Our population has already crossed one billion mark and is estimated to stabilize around 1.5 billion by the year 2030. The demand for food grains is estimated at 240 m t by the end of XI plan period. Keeping this in view, the government of India launched the National Food Security Mission to achieve the production of additional 10, 8 and 2 m t of rice, wheat and pulses, respectively. The task is quite challenging and the options available are very limited in view of plateauing trend of yield in high productive areas, decreasing and degrading land, water, labour and other inputs. Among the various possible approaches to achieve this target is to increase the productivity per unit time and area *i.e.,* by raising two or more crops per year through multiple, relay and intercropping both in irrigated and rainfed areas; and by utilizing the available resources more efficiently. With the availability of shorter duration varieties of different crops the scope for growing two or more crops in a year is continuously increasing. Hence, emphasis needs to be laid on identification of suitable cropping systems with higher and stable yields and/ or profit in different agro-ecological regions. Further, in response to commercialization of agriculture also, it is important to shift from routine food grain production system to newer crops/cropping systems depending upon the climatic conditions as well as agro-ecosystems under different rice-based production system in order to make agriculture an attractive, profitable and sustainable business.

The change in climate has been attributed to global warming and has many facets, including changes in long term trend in temperature and rainfall regimes as well as increasing year-to-year variability and a greater prevalence of extreme events. Agricultural systems will be affected by both short and long term changes in climate, and will have serious implications on rural livelihoods, particularly of the poor being the most vulnerable. The impact of climate change poses serious threats to productivity and sustainability of various rice-based cropping systems including rice-wheat cropping system, the backbone of food security of India. Despite some projected increase in photosynthesis caused by increased concentrations of carbon dioxide, increased temperature will have a far greater detrimental effect, resulting reduced crop productivity. Conservation agriculture involving continuous minimum mechanical soil disturbance, permanent organic soil cover and diversified crop rotations provides opportunities for mitigating greenhouse gas emission and climate change adaptation.

Rice and rice-based cropping systems

Rice (*Oryza sativa* L.) is the most important staple food crop in India that holds key to food security. Rice-based production systems provide livelihood for more than 50 million households. In India, rice is grown on more than 44 m ha under three major ecosystems: rainfed uplands (16%

area), irrigated medium lands (45%) and rainfed lowlands (39%), with a productivity of 0.87, 2.24 and 1.55 t ha^{-1}, respectively. The crop in *rabi*/summer is grown on nearly 3 m ha mostly with irrigation in the eastern and southern states, but the *kharif* crop is grown under a wide range of soil and climatic conditions throughout the country. Rice cultivation in eastern India is characterized by predominantly rainfed culture (70%), mono-cropping, low fertilizer use and traditional varieties. On the other hand under irrigated conditions, input intensive rice-based cropping systems involving cereals, pulses, oilseeds, tuber and fiber crops are practiced.

With the introduction of high yielding photo and thermo insensitive rice varieties of relatively shorter duration, there was remarkable changes in the cropping system concept (Sharma et al., 2004). A large number of crops are now being grown after rice under different ecologies based on soil and prevailing agro-climatic conditions in major rice growing states of the country. Out of the major cropping systems identified by the Project Directorate for Farming Systems Research, rice-based system occupies the largest area of about 28 m ha in India. Among the rice-based cropping systems, the major ones are rice-wheat (9.8 m ha), rice-rice (5.9 m ha), rice-fallow (4.4 m ha), rice-pulses (4.4 m ha), rice-vegetables (1.2 m ha), rice-groundnut (1.0 m ha), rice-mustard (0.5 m ha), rice-potato (0.5 m ha) and rice-sugarcane (0.4 m ha) (Yadav & Subba Rao, 2001). Preference of rice-based cropping systems in different parts is based on location advantages that include ecology, land topography, soil type, and availability of water and marketing facilities. For example, rice-wheat and rice-rice systems are practiced in irrigated ecology whereas rice-lathyrus, rice-gram or rice-blackgram/ greengram, etc. are practiced in rainfed uplands and lowlands.

Rainfed uplands

In India, 85% of the upland rice area is located in the states of Assam, Bihar, West Bengal, Odisha and eastern parts of Madhya Pradesh and Uttar Pradesh. The rainfall in this zone is in the range of 1000 to 2000 mm or more and temperature ranges from 25 to 41°C in July and from 6 to 25°C in January. Red laterite and lateritic soil such as mixed red and yellow, red sandy, red loam, lateritic and mixed red and brown hill soils account for about 55% of the total rice area in the east zone. Next in the order of occurrence is alluvial soil, which occupies about 27% of the total rice area. Rice is grown under rainfed condition in these uplands in monsoon season.

In rainfed uplands, shorter duration (90-105 days) rice varieties like Vandana, Kalinga III, Anjali, NDR 97, Annada are to be grown by sowing during the onset of monsoon, so that the field should be vacated early for the second crop (Saha et al., 2003). Crops like mustard, castor, linseed, safflower, blackgram, lentil, horsegram can be grown by taking advantage of residual soil moisture and late monsoon rains. The second crop should be sown as early as possible (within a week) after harvest of rice to get the advantage of residual soil moisture. Mulching by using rice straw also helps to conserve the soil moisture under such situations. In bunded uplands, where there is still possibility for giving at least one or two irrigation through harvested rain water, crops like sunflower, gram, tomato, etc. can be successfully grown after harvest of wet season rice. The short duration improved varieties of the above crops can give a good return under such situations. Intercropping of rice with short duration pulses like greengram, blackgram, pigeonpea or oilseeds like groundnut also shows a good prospect for improving productivity and farmers' income. Intercropping of upland rice with pigeon pea (4: 1 row ratio) recorded higher rice equivalent yield and net return over sole crop under Institute Village Linkage Programme in Cuttack district of Odisha (Anonymous, 2005). Rice-based inter cropping with pigeon pea, blackgram and groundnut recorded much higher (3.3-3.9 kg per ha-mm) rainwater use efficiency.

Irrigated medium lands

Under irrigated condition majority of rice is grown in wet season (June to October) but around 4 m ha is under dry season (November to May). The important cropping systems followed under irrigated medium land situations are rice-rice, rice-wheat, rice-winter maize, rice-groundnut, rice-sunflower, rice-potato, rice-mustard, rice-gram, rice-winter vegetables, etc. with 200% cropping intensity. There is still scope to introduce a third crop of short duration pulses like cowpea, greengram, blackgram or oilseed crops like sesame in areas where irrigation facilities are available to provide 1-2 life saving irrigation to the third crop. In West Bengal, rice-potato-sesame, rice-wheat-greengram, rice-wheat-jute are found to be remunerative. Rice-potato-sesame, rice-maize-cowpea, rice-sunflower-greengram, rice-groundnut-sesame are found to be promising in Odisha.

In Assam, Regional rainfed lowland rice research station, Gerua (a Research Station of CRRI, Cuttack) has standardized production technology for year round rice growing (rice-rice-rice cropping sequence with 300% cropping intensity) to meet household food security and year round employment generation for small and marginal farmers with land holding less than 1 ha. In Punjab, the cropping system with 300% intensity such as rice-potato-sunflower, rice-potato-winter maize and rice-toria-sunflower have been found to be more productive than conventional systems of 200% cropping intensity with rice-wheat or rice-winter maize. Early medium to medium duration (120-135 days) rice varieties like Naveen, Ratna, IR 36, Padmini, Khitish, Shatabdi, Tapaswini provides good scope to advance the sowing time of the second crop by late October to early November so that the third crop (70-90 days) can be accommodated during February-April.

Rainfed lowlands

Rainfed lowland rice is grown in around 13 m ha, mostly in eastern India, where soil moisture is available for longer period, rice varieties of 140 days duration, mostly photosensitive types are grown and harvested from mid November to mid December. The water depth varies in rainfed lowlands and it can be shallow up to 25 cm, and medium-deep waterlogged up to 50 cm. Deep-water rice is grown in areas where water depth is more than 50 cm up to 2 m, and around 4 m ha area is under cultivation in eastern India with an average productivity of 0.8 t ha^{-1}. Most of the deep water rice area in West Bengal, Assam, North-east Bihar, and coastal Odisha is now being under *boro* and dry season rice due to low productivity of deep water rice.

Farmers traditionally grow tall *indica* types, which are prone to lodging and are of low productivity. The varieties grown in these land situations are generally medium to long (130-180 days) duration depending upon the water depths in the fields where they are grown and should have tolerance to drought initially and to submergence at later stage; photosensitivity; moderate to high tillering abilities; tolerance to pests and diseases and elongation ability in semi-deep and deep situations. The ideal plant height for shallow lowlands is 110-130 cm, 130-150 cm for medium deep situations and > 150 cm for deep water areas.

Medium to long duration (140-155 days) rice varieties like Swarna, Vijeta, Surendra, Moti, Pooja, Pankaj, etc. are usually grown in rainfed shallow lowlands of eastern India. Short duration pulses like greengram, blackgram, etc. can be grown after rice harvest with residual soil moisture. There is a little scope to take a second crop in areas where soil moisture recedes fast during November onwards. Under such situation, crops like lathyrus, field pea, linseed, lentil, blackgram can be raised as relay/paira crop by sowing the second crop in the standing crop of rice 10-15 days before harvesting (Saha & Moharana, 2005). In certain areas of eastern India, crops like sunflower, groundnut, watermelon, okra, sweet potato can be raised with limited irrigations (2-3) by utilizing the harvested rainwater stored in small farm ponds.

Long duration (155-180 days) photosensitive rice varieties like Varshadhan, Gayatri, Savitri, Sarala, Panidhan, Durga, Tulsi, Kalashree, Sabita and Nalini are grown predominantly in intermediate deep and deep water rice ecology of east coast and lower Gangetic Plains of India. These areas are having potential to harvest rainwater during monsoon period (June-September) that can help to grow several winter vegetables like pumpkin, bitter gourd, okra, chilli, along with other crops like blackgram, greengram, sunflower, groundnut, watermelon, sesame, etc. during the dry season (January–early April). The salt affected coastal areas are generally rainfed and mono-cropped with rice. Land mostly remains fallow during the dry season due to soil salinity and unavailability of fresh water. However, rice and certain salt tolerant crops like sunflower, chilli, watermelon, sugar beet, cotton, etc. are grown in pockets depending on the availability of harvested rainwater, soil and climatic conditions (Singh et al., 2006). Pulses like blackgram, greengram, cowpea, etc. and groundnut is also grown in some areas having mild salinity.

Major sustainability issues in cropping systems

- In semi-arid ecosystem intensive water use in rice-wheat cropping system led to increased salinization in many areas. There are indications of yield declines where balanced nutrient application has not been made. Deficiency of micronutrients has been observed.
- The problem of depletion of underground water in semi-arid areas of Punjab and Haryana needs to be addressed through development of alternate cropping system under limited water supply.
- To reduce the use of purchased inputs by small farmers, green manure should be introduced in the rice-wheat, rice-rice system. Fifty percent of nitrogen requirement of rice could be substituted by growing *Sesbania* before transplanting rice.
- In the sub-humid ecosystem, reduction in wheat yield following rice is due to delayed wheat planting, low plant stand and poor nutrient management. Delayed wheat planting is associated with excess soil moisture at the time of rice harvest. Higher seed rate and nutrient can compensate wheat yield losses to some extent.

Management of rice-based cropping systems

The rice-based cropping systems will continue to be important cropping systems in India in the years to come. Therefore, there is a strong need to monitor these systems in terms of nutrient dynamics and to develop efficient integrated nutrient supply and management system in different regions using locally available resources like compost, farm yard manure, farm wastes, crop residues and green manures. There is also a need to monitor insect, disease and weed problems, water table and water harvesting techniques. Crop establishment of succeeding crops after rice and dry seeding methods of rice need greater attention. There is a need for the choice of genotypes and introduction of short duration, photoperiod insensitive varieties, the possibilities for crop intensification/diversification have to be studied. Thus, ample scope exists for improving the total land productivity through generation of appropriate production technologies for diverse agro-climatic situations.

Conservation agriculture

Conservation agriculture is characterized by three principles which are linked to each other, namely continuous minimum mechanical soil disturbance, permanent organic soil cover and diversified crop rotations in the case of annual crops or plant associations in case of perennial crops which provides opportunities for mitigating greenhouse gases (GHGs) emission and climate change adaptation. Recent research efforts have attempted to develop resource conserving technologies (RCTs), which are more resource efficient, use less inputs, improve production and income, and reduce GHGs emission compared to the conventional practices. Some of these technologies are being adopted by the farmers on large scale, which would help farmers in combating climate change to a considerable extent. Specific impacts of various RCTs on GHGs mitigation are briefly discussed below:

Zero tillage

Conventional land preparation practices for wheat after rice involves as many as 10-12 tractor passes. Changing to a zero-till system on 1 ha of land would save 98 liters of diesel and approximately 1 million liters of irrigation water besides reducing about a quarter tonne less emission of carbon dioxide (CO_2), the principal contributor to global warming. However, impact of zero tillage on methane (CH_4) and nitrous oxide (N_2O) emissions have showed contrasting results with lower, equal and higher compared to the conventional systems depending upon the soil type and water management. Zero tillage also allows rice-wheat farmers to sow wheat sooner after rice harvest, so the crop heads and fill the grain before the onset of pre-monsoon hot weather.

Laser aided land leveling

Laser leveling of uneven field reduces water use allowing crop to grow in water limited condition. It also reduces fuel consumption because of efficient use of tractor and reduces GHGs emission, particularly CO_2. Several other benefits such as operational efficiency, weed control efficiency, water use efficiency, nutrient use efficiency, crop productivity and economic returns and environmental benefits have also been reported due to laser aided land leveling compared to conventional practice of land leveling.

Direct drill seeding of rice

Direct drill seeding of rice (DSR) could be a potential option for reducing CH_4 emission. Methane is emitted from soil when it is continuously submerged as in the case of conventional puddle transplanted rice. The DSR crop does not require continuous soil submergence, thereby either reducing or totally eliminating CH_4 emission when it is grown as an aerobic crop. Moreover, deeper root growth of DSR crop provides better tolerance to water and heat stress. Besides the unpuddled soil in DSR does not crack with moisture stress unlike puddle soil which helps to increase yield significantly.

Crop diversification

Diversification is growing a range of crops suited to different sowing and harvesting times, assists in achieving sustainable productivity by allowing farmers to employ biological cycles to minimize inputs, maximize yields, conserve the resource base, reduce risk due to both environmental and economic factors. The RCTs such as bed planting and zero tillage expand the windows of crop diversification. The farmers of rice-wheat belt have taken the initiative to diversify their agriculture by including short duration crops such as potato, soybean, blackgram, greengram, cowpea, pea, mustard, and maize into different combinations. Such diversification would not only improve income, employment and soil health but also reduce water use and GHGs emission and more adaptability to heat and water stress.

Raised bed planting

In raised bed planting a part of soil surface always remains unsubmerged. Thus it not only reduces water use and improves drainage but also reduces methane emission. Crops on beds with residue retained on surface is less prone to lodging and more tolerant to water stress, thereby making it more adaptable to unfavourable climate.

Leaf colour chart

The most efficient management practice to minimize plant N uptake and minimize N loss is to synchronize supply with plant demand. The use of leaf colour chart (LCC) promotes a need-based N application to rice crop that saves N and increases N use efficiency. As a result there will be less accumulation of mineral forms of N (NH_4 and NO_3) within the crop root zone and hence less losses of N and N_2O emission. Besides, because of healthier plant growth due to timely application of N fertilizer, damages caused by insects were reported to have been reduced.

Integrated nutrient management

Food security and soil health are two important concerns in Indian agriculture. Integrated nutrient management (INM) in crop production, particularly in rice-based cropping systems, plays a crucial role in the pursuit of these two set missions. Integrated nutrient management is achieved through combined use of different sources of plant nutrients such as chemical fertilizers, organic manures, green manures, crop residues, bio-fertilizers, industrial wastes and soil conditioners depending upon their availability and suitability in a specific agro-ecological situation (Hegde & Dwivedi, 1992; Panda & Singh, 1998). It also includes scientific management of these sources of nutrients for securing optimum crop yield and soil fertility improvement. According to Roy & Ange (1991), the basic concept underlying integrated plant nutrient supply and management system (IPNS) is the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. Economic viability and ecological sustainability are also major considerations in INM. In a holistic approach, the INM practices are designed and adopted to increase the quantity and quality of crop produce, decrease nutrient losses, increase the efficiency of applied and native nutrients, improve soil health, economize on fertilizer use, protect the environment and minimize the energy consumption in agriculture.

Takkar et al. (1998) considered a conceptual framework of IPNS which includes four distinct integral components *viz.,* (i) on-site nutrient resource generation, (ii) mobilization of off-site nutrient resources, (iii) resource integration and (iv) resource management. On-site nutrient resource generation is mostly achieved through green manuring and recycling of crop residues. Mobilization of off-site nutrient resources includes three categories of sources of nutrients *viz.*, bio-organic wastes (FYM and compost), bio-organisms (bio-fertilizers) and mineral resources (synthetic and mineral fertilizers). Resource integration, the guiding principle of INM not only supplements the fertilizer use but also provides the benefits of positive interaction for various nutrient sources in restoring soil fertility. It also ensures balanced crop nutrition and synergetic interaction in a cropping system for sustainable agriculture. The nutrient resource management improves the nutrient use efficiency by checking nutrient losses from soil, optimizing nutrient resource combination and monitoring plant nutrient flows. It also addresses the soil related problems limiting crop growth such as soil acidity, salinity, alkalinity, soil compaction, etc. Ultimately, it imparts resilience against the soil degrading processes and promotes quality of the environment.

Because of several reasons including those of soil health care and high crop yield, it is necessary to supplement/complement chemical fertilizer application with the other components of INM which are mostly organic in nature. Results of research on INM in irrigated rice revealed that at N level of 60 kg ha^{-1}, combined application of urea and *dhaincha* green manure/ *Azolla*/ FYM at 1:1 ratio on N level basis, produced comparable grain yield to that of urea alone. However, at N level of 90 kg ha^{-1}, INM practices involving *dhaincha* green manure or *Azolla* dual crop were superior to the chemical source of N (Panda et al., 1991)

Conclusions

The overwhelming importance of rice and rice-based cropping systems for the food security of India requires a thorough assessment of the rice resource base and the impact of rice cultivation on the environment. The decline in soil and water quality in rice-based systems is a major global issue. The situation is going to be worse in the event of possible global warming, which has negative impact on yield and soil fertility. Therefore, the systems should be constantly monitored in terms of their natural resource base. Suitable quantitative models that incorporate the relevant bio-physical and socioeconomic interactions to permit quantitative assessment of rice cultivation in relation to the environment and natural resources need to be developed. An environmental impact assessment should include a social impact assessment, strategic environmental assessment, and life cycle analysis of the implementation of rice technologies. Holistic and eco-regional strategies to manage, preserve and improve the nutrient resource base and soil qualities in rice-based cropping systems have to be strengthened.

Climate change poses serious threats to productivity and sustainability of various cropping systems. Recent efforts have attempted to develop and deliver resource conservation technologies involving no- or minimum tillage with direct seeding, and bed planting with residue mulch, innovations in residue management to avoid straw burning, and crop diversification as alternatives to the conventional management practices for improving productivity and sustainability of important rice-based cropping systems. The wide scale adoption of any improved cropping system by the farming community depends mostly on socio-economic factors such as labour availability, credit requirement, cost of inputs, processing, marketability and price of produce, risk involved and social acceptability of the new system. Thus before designing a particular cropping system, care should be given on its economic feasibility. Emphasis should also be given for developing suitable rice-based farming system model by incorporating animal components into the system to enhance the overall economy and standard of living of poor farm community.

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